BRAGBURY LANE

Bragbury End

Technical Assessment Report to support

Section 19 Flood Investigation

Project No: **0469**
Date: **October 2014**

Reviewed By: **Tom Butler**
Approved By: **Neil Harding**

NHTB Consultancy Ltd, Unit 1 St George's Works, Delamare Road, Cheshunt, Herts., EN8 9AP

01992 633271
www.nhtb.co.uk info@nhtb.co.uk

DOCUMENT CONTROL:

Project Number:	0469
Project Name:	0469 - Herts CC ERP-INV-05 Flood Investigations
Client:	Hertfordshire County Council

Revision	Originated	Checked	Approved
Draft	Name  Date 23-09-2014	Name  Date 23-09-2014	Name  Date 23-09-2014
Final	Name  Date 28-10-2014	Name  Date 28-10-2014	Name  Date 28-10-2014
1	Name  Date 05-12-2014	Name  Date 05-12-2014	Name  Date 05-12-2014
	Name Date	Name Date	Name Date
	Name Date	Name Date	Name Date

CONTENTS

1 INTRODUCTION

1.1 TERMS OF REFERENCE

This Technical Assessment Report to support Section 19 Flood Investigation was commissioned by Hertfordshire County Council (HCC) to investigate flooding at Bragbury Lane, Bragbury End, Hertfordshire (the site). The report contains a summary of an investigation into the flooding to identify the areas affected, the flooding mechanism(s), the relevant Risk Management Authorities (RMAs) and it also includes potential mitigation measures.

1.2 THE INVESTIGATING CONSULTANT

The study was conducted by NHTB Consultancy Limited. The team consisted of a team of professional civil engineers with extensive drainage experience and personal knowledge of the Hertfordshire area.

1.3 FLOOD & WATER MANAGEMENT ACT 2010 - DUTY TO INVESTIGATE

The study described in this report was commissioned by Hertfordshire County Council (HCC) in their role as the Lead Local Flood Authority (LLFA), as defined in the Flood & Water Management Act 2010. The Act requires, as specified in Section 19, that the LLFA investigate a flood when they are aware of the event and to the extent it considers appropriate and relevant. Specifically it must investigate which Risk Management Authorities (RMAs) have functions and whether they have exercised, or propose to exercise, those functions in response to the flood. Where an investigation under the Act is conducted the LLFA must publish the results of its investigation and inform relevant RMAs.

2 DETAILS OF THE SITE

2.1 SITE LOCATION

The area affected by flooding is shown in Figure 1 below. The area includes 6 residential properties on Bragbury Lane plus one commercial property located a short distance to the north in Bragbury Close.

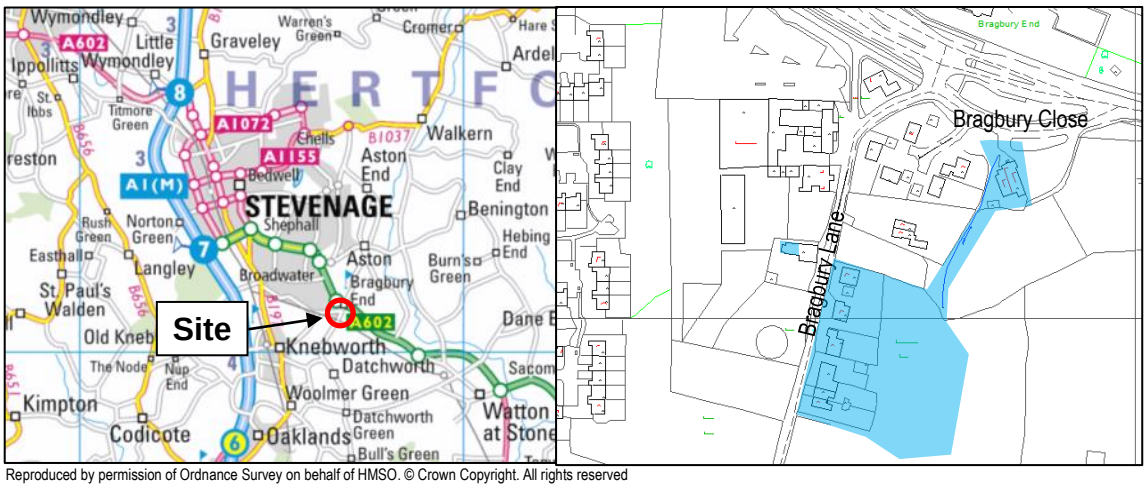


Figure 1: Site Location

2.2 SITE DESCRIPTION

The site is located to the south east of the principal town of Stevenage, adjacent to the A602. Bragbury Lane is a single lane country road connecting Bragbury End to the village of Datchworth to the south east. Bragbury Close is located at the end of Bragbury Lane just prior to the junction with the A602.

The affected area of Bragbury Lane sits in a small depression and the ground slopes away from the road towards the area to the rear of the properties. This area is a flood storage area constructed as part of the Hertford Road development to attenuate surface water runoff into the River Beane. The local residents refer to it as a water meadow. The affected property in Bragbury Close also sits in a small hollow and is adjacent to a small watercourse that originates at the rear of Bragbury Lane.

3 FLOODING EVENT IMPACTS – 7 February 2014

3.1 INTRODUCTION

The storm event of 7 February 2014 occurred in the early hours of the morning. There had been a prolonged period of exceptionally wet weather in the months preceding the storm and the ground was saturated when the storm commenced. The quotation below is from the Meteorological Office and is their assessment of the unusually wet winter rainfall conditions between December 2013 and February 2014.

"Around 6 major storms hit through this period, separated by intervals of 2 to 3 days. The sequence of storms followed an earlier stormy period from mid-December 2013 to early January 2014. Taken individually, the first two storms were notable but not exceptional for the winter period. However, the later storms from early to mid-February were much more severe. Overall, the period from mid-December 2013 to mid-February 2014 saw at least 12 major winter storms, and, when considered overall, this was the stormiest period of weather the UK has experienced for at least 20 years."

The rainfall was unable to infiltrate into the ground and significant surface water runoff resulted. The procedure adopted for this study to assess the impact of the flooding was to conduct interviews with those affected directly by the flooding and to identify and record where the flood water came from and went to, the flooding mechanism.

3.2 FLOODING MECHANISM

3.2.1 Areas affected by flooding

There were two discreet areas affected by the flooding as illustrated in Figure 2 below. The first of these included a row of six residential properties on Bragbury Lane. The second location involved one commercial property in Bragbury Close.

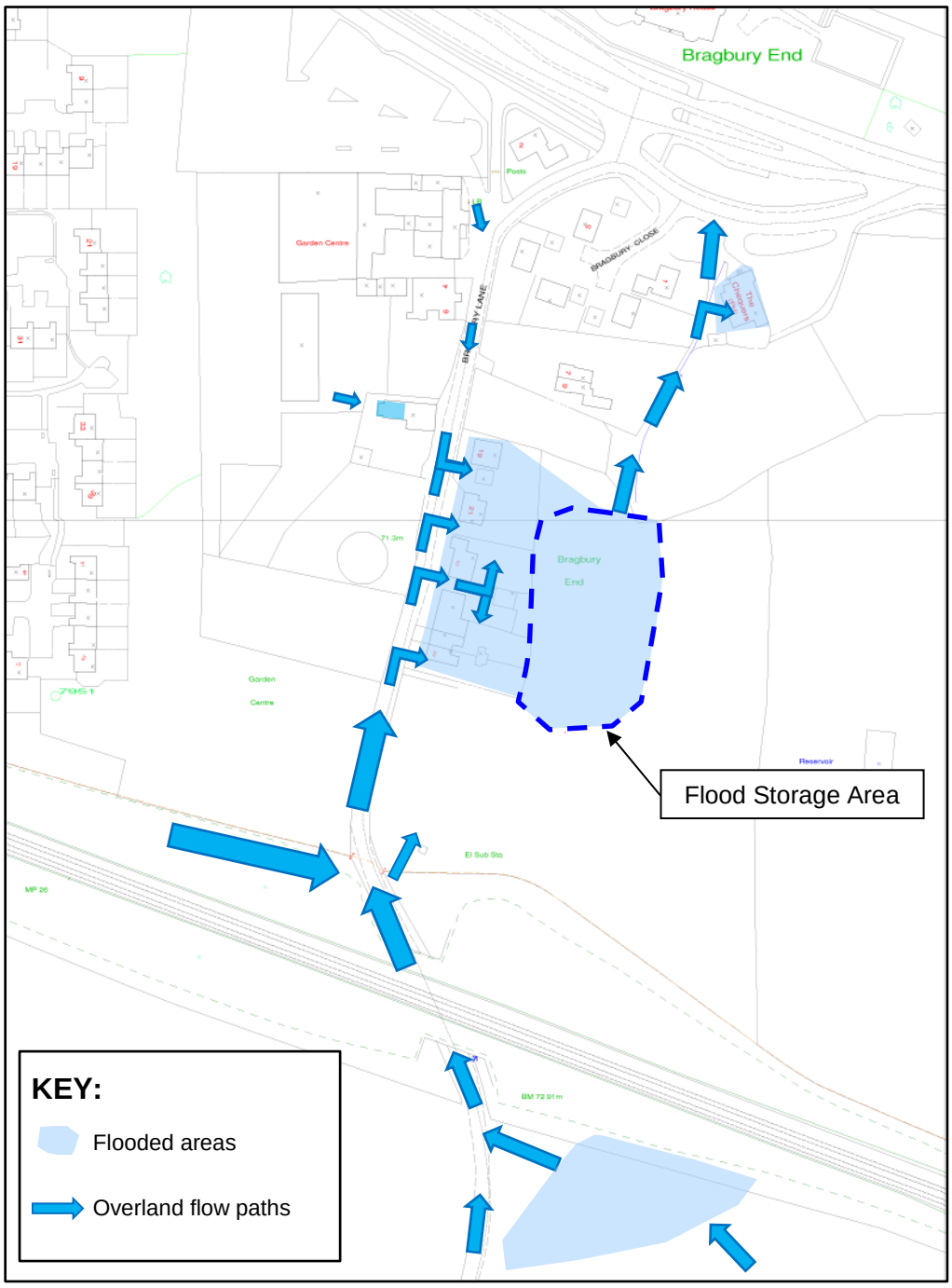


Figure 2: Flooding Mechanism - Overland Flow Paths

3.2.2 Overland Flow Paths

3.2.2.1 Bragbury Lane

There were two distinct flooding issues in Bragbury Lane.

Bragbury Lane - west

The first area affected involved a single residential dwelling on the western side of the road and was the result of local runoff from higher ground behind the property. Surface water runoff followed the local ground slope from the development site (former gardening centre) and flowed into the property.

Bragbury Lane - east

The flooding of these properties was the result of two principal flow paths off the contributory catchment as illustrated in Figure 3 below. It is unclear whether floodwater from the large field system in the south west part of the catchment spilled over onto Bragbury Lane upstream of the railway tunnel. There is evidence that substantial and prolonged flow emerged from the downstream side of the railway embankment in this general location. This extensive flow could potentially have been the result of runoff from the fields passing through the railway embankment onto lower ground the other side and then onto the road surface. Flow that came through the railway tunnel and that from the railway western embankment combined at a point just downstream of the railway tunnel and then flowed along the road surface towards the six properties to the east of Bragbury Lane. These properties are situated at the lowest point of the road, which then rises towards the A602 to the north. The floodwater flowed off the road and into the front gardens of the six residential properties. Floodwater affected the front gardens of all six properties and caused damage to the gardens. The floodwater was of sufficient depth to enter some of the properties through airbricks or over the front door threshold as summarised in Table 1 below. The water also entered garages from the front and in some properties it spilled over interconnecting doors into the rear of the property. Outside the dwellings the water migrated around the building from the front into the rear garden flowing down the garden towards the lower level area across the rear of all six properties. This area is a flood storage area built as part of the Hertford Road development as a balancing pond to restrict the rate of surface water runoff from the new development into the River Beane. Its operation is described in Section 5.3.2.1. The water meadow filled and eventually overtopped the low height bund across its downstream end. The overspill water entered a small natural watercourse located immediately downstream of the bund. This watercourse flows into Bragbury Close where it enters a culvert under the A602.

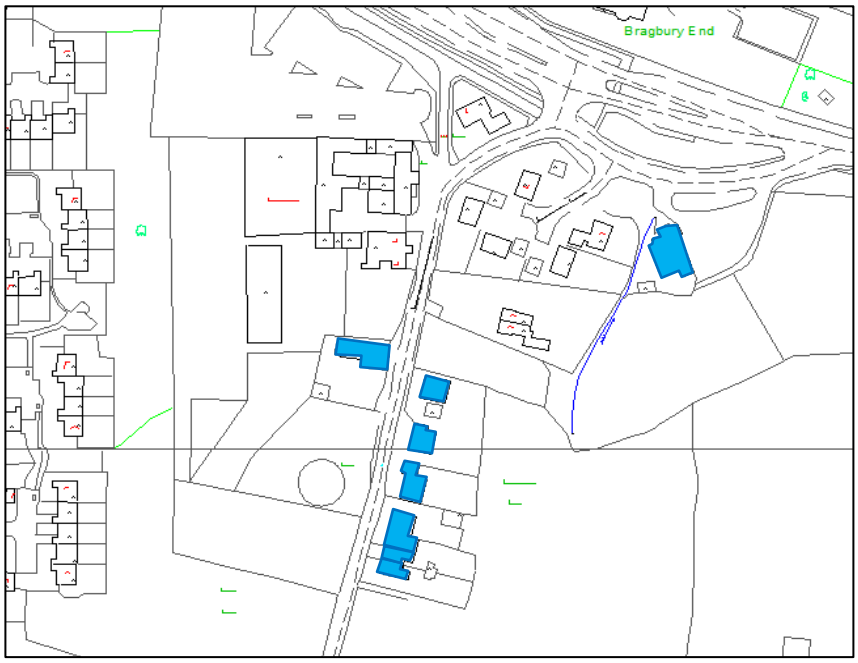


Figure 3: Flooded Properties

Property	Internal Flooding	External Flooding
Bragbury Close	Yes (through rear door)	Yes
Bragbury Lane - west	Yes	Yes
Bragbury Lane - east	Yes (through front door)	Yes
Bragbury Lane - east	Yes (through front door)	Yes
Bragbury Lane - east	Yes (through garage and into utility room)	Yes
Bragbury Lane - east	Yes (through front door)	Yes
Bragbury Lane - east	Yes (through airbricks)	Yes
Bragbury Lane - east	No	Yes

Table 1: Flood Event Impact Summary

3.2.2.2 Bragbury Close

The overflow of water from the water meadow to the east of Bragbury Lane that entered the open watercourse in the rear of Bragbury Close could not be contained in the open channel and it spilled out onto the adjacent surface. The water flowed the short distance to the rear of the building where it entered the property over the rear door threshold. Once in the building the water filled most of the ground floor areas including the toilets and administration offices at the rear of the building.

3.3 RELEVANT STAKEHOLDER ENGAGEMENT

3.3.1 Local Residents and Businesses.

Occupants of each property in the areas affected by the flooding were interviewed as part of this study. The interviews were conducted in person with the resident/occupant wherever possible or over the telephone, by email or by the interviewee completing a questionnaire and returning it through the post. The information gathered from the interview process included the following:

- Details of the flooding mechanism; where the water came from and where it went
- How the property was affected by the flooding including the depth of water inside and outside the property
- The impact of the flooding; damages and other tangible and indirect effects
- Photographic records
- Correspondence records

The interview information was recorded onto a standard questionnaire copies of which are located in Appendix A together with copies of correspondence sent and received by the interviewees plus photographic images they provided during the interview process. The properties affected by flooding are shown in Figure 3 above. Interviews were conducted at properties in Bragbury Lane and one in Bragbury Close (attempts were made to contact the occupants of the residential property to the west of Bragbury Lane but without success):

3.3.2 Hertfordshire County Council as Lead Local Flood Authority
Local residents in Bragbury Lane contacted the LLFA and this study has subsequently been commissioned.

3.3.3 Hertfordshire County Council as Highway Authority (Highway Drainage)
Residents of Bragbury Lane contacted Hertfordshire County Council in their capacity as the Highway Authority to arrange for the road drainage gullies in Bragbury Lane to be cleaned. Copies of their correspondence are located in Appendix A.

3.3.4 Thames Water (Surface Water Sewers)
None of those affected by the flooding contacted Thames Water in connection with the flooding. NHTB Consultancy contacted Thames Water directly to ascertain what surface water drainage assets they have in the vicinity of the area affected by flooding and what plans they have to investigate the condition and performance of those assets and any planned actions they have identified. Thames Water responded to the enquiry and provided updates to their enquiries at weekly intervals. At the time of writing this report they had not been able to conclude their investigations. It is probable that Thames Water are responsible for the flood storage area and the large storage pipe system to which it discharges.

3.3.5 Stevenage Borough Council (Ordinary Watercourses)
Discussions were held with the local authority from whom it was understood that, historically, the water meadow was maintained by the local authority on behalf of Thames Water. They were unaware whether any maintenance had been undertaken since 2001. To their knowledge no maintenance had been conducted on the small open watercourse to the rear of Bragbury Close other than what the property had performed themselves. They had no plans for works following the flooding of February 2014.

3.4 FLOOD DAMAGE COSTS
The nature of the flooding had different effects on each affected property; some experienced internal flooding of varying depth and consequence whilst others suffered external flooding only.
As part of the interview process with those affected by the flooding details were obtained of the financial implications of the flooding damage and these included those costs incurred by the resident/occupier and other costs that were the subject of an insurance settlement, or pending, insurance claim.
There was a significant range of damage costs disclosed during the interviews. A summary of the damages is shown in Table 2 below.

Location	Insurance Claim Costs	Personal Costs
Bragbury Close	Undisclosed	N/A
Bragbury Lane	0	£400
Bragbury Lane	£8080.77	£200
Bragbury Lane	£2200	0
Bragbury Lane	0	0
Bragbury Lane	0	£200
Bragbury Lane	0	£400
Bragbury Lane	Undisclosed	Undisclosed

Table 2: Flood Damages - Costs Summary

The damage caused by the flooding to four properties in Bragbury Lane was minimal, only just entering inside the houses over the front or internal garage door threshold and being constrained to small areas of the ground floor. The residents chose not to submit insurance claims and instead paid for the replacement of small items of furniture and carpeting at their own expense. Insurance claims were made from two properties where the flooding damage was more extensive. The insurance claim/damage costs for the commercial property in Bragbury Close were not disclosed but it is expected that the overall impact to the business would have been several thousands of pounds including the loss of income over two days of commercial trading.

4 HISTORICAL FLOOD EVENTS

4.1 INTRODUCTION

During the flood survey interviews, several of the residents of Bragbury Lane referred to one other significant flooding event that affected the same group of residential properties. They were unsure of the exact dates of flooding but a few referred to an event they considered more severe in terms of its impact than the event in February 2014. On that occasion, the Fire and Rescue Service attended and assisted with pumping water.

4.2 FLOOD HISTORY

Some of the residents recalled that there had been at least one previous serious flooding incident and several lesser incidents when floodwater affected the gardens but did not enter the properties. Flooding of the front gardens in Bragbury Lane has happened on many occasions and was reported by many of the residents to be a regular occurrence although no specific dates were provided. One resident confirmed that the front porch of his property flooded internally on 24 December 2013 for this reason. Two other residents mentioned a major flooding event of several years previous when a fire engine attended the site to pump floodwater. Unfortunately, neither of the residents could remember the exact date of the flood event. One resident reported a flooding event on 13 October 2014, when the front garden and garage were affected by surface water runoff from the housing development site on the opposite side of Bragbury Lane. The flooding mechanism for this more recent event is different to that of the event in February 2014. Although this report is specifically for the event of February 2014 the more recent event is recorded here because the measures required to prevent a re-occurrence should not be overlooked and there is an opportunity to include such measures within the scope of potential mitigation measures described later in this report. The Stevenage Borough Council Strategic Flood Risk Assessment (SFRA) produced in 2009 did not record any historical flooding of the area under consideration.

5 CATCHMENT CHARACTERISTICS & EXISTING SURFACE WATER DRAINAGE INFRASTRUCTURE

5.1 INTRODUCTION

The catchment that drains to the area where flooding occurred measures approximately 192ha. The catchment is shown in Figure 4 below and consists of

three principal areas that each generate and contribute surface water runoff to the flooding:

- Farmland to the south
- Highway (Bragbury Lane)
- Residential urban area to the west

The surface water drainage arrangements are quite complicated and involve connection between the different systems under particular flow conditions. The nature, location, condition and operation of the surface water drainage systems are described in the following sections.

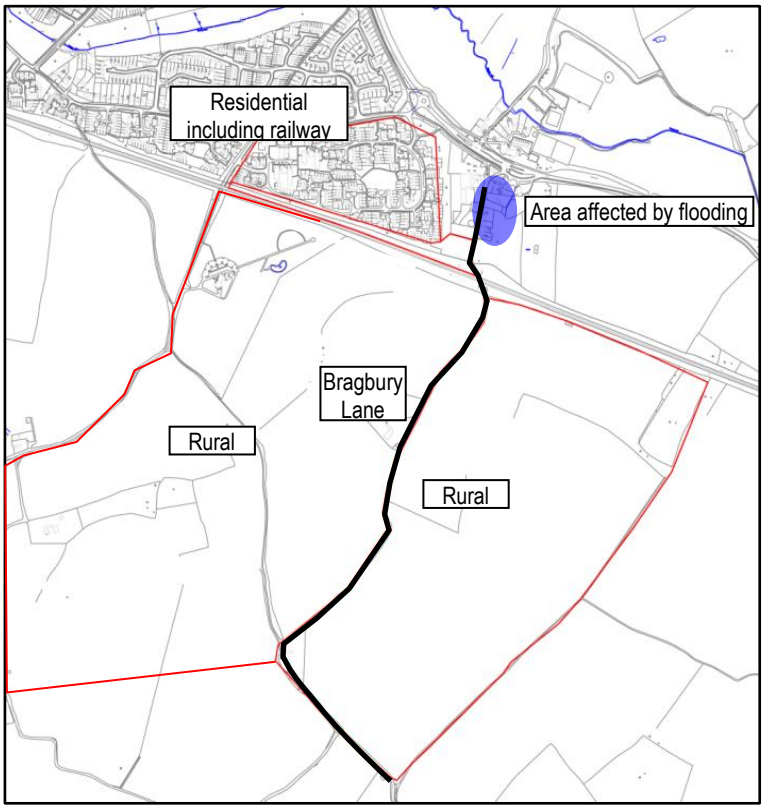


Figure 4: - Catchment Boundary

5.2 TOPOGRAPHY & GEOLOGY

5.2.1 The catchment is relatively steeply sloping from a high point to the south of approximately 120m elevation to the lowest point in Bragbury Lane at the northern boundary of the catchment, where flooding occurs, at an elevation of approximately 70m.

The land south of the railway is primarily arable farmland plus a small sector of the eastern extremity of the Knebworth development. The railway line effectively bisects the catchment in a west to east alignment and 'funnels' surface water runoff from most of the arable land in the south eastern part of the catchment through a road tunnel under the elevated tracks. The largely arable farmland and area to the east of Knebworth that forms the south western sector of the catchment, south of the railway, slopes from a high point of 94m towards the railway.

To the north and west of the railway the catchment contains residential development of outer Stevenage known as the Hertford Road development. This area falls from a high point at its western boundary of approximately 80m to the low point in Bragbury Lane.
Bragbury Lane slopes from the highest, southern, catchment boundary down wards in a northerly direction, under the railway to a low point alongside the properties that experienced flooding before rising slightly at the northern boundary of the catchment.

5.2.2 A topographical survey was conducted on the principal elements of the catchment including those areas where major sources of surface water runoff resulted in overland flow and where flooding was experienced. This survey was conducted by NHTB Consultancy and utilised precision Total Station survey techniques supplemented by GPS measurements where appropriate. The survey data was used to identify and measure overland flow paths that were used subsequently in the hydrological analyses (refer to Chapter 6 below) and surface depressions where surface water runoff collected, either causing flooding of properties or where runoff was held before the locations affected by flooding.

5.2.3 The geology of the catchment is a combination of Glacial Sand and Gravel deposits and Chalk as shown in Figure 5 below. This would imply that the catchment is relatively free draining with high permeability. This issue is explored in Section 6.2.2 below where it is postulated, based on experience of surface water runoff under extreme conditions in other parts of Hertfordshire, that runoff is influenced significantly by factors other than soil type.

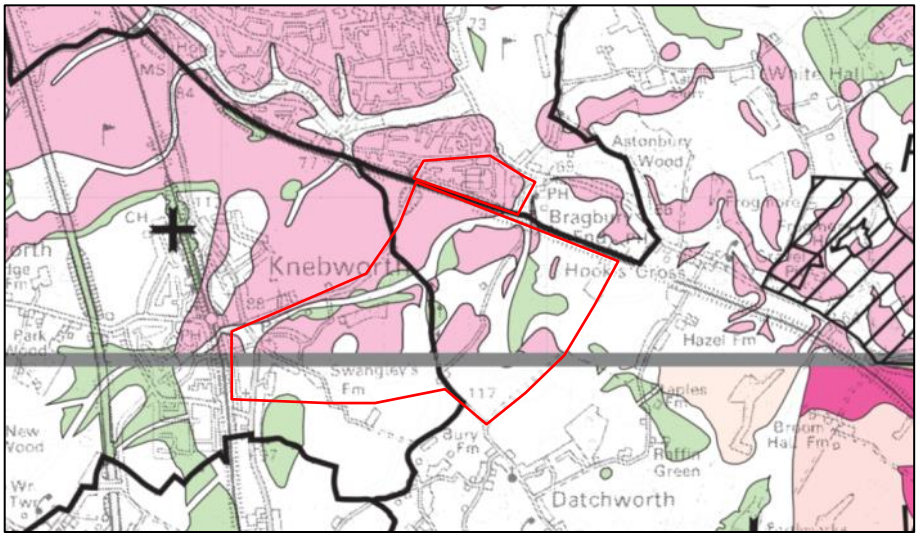


Figure 5: - Geology

Key:
- Catchment boundary
- Chalk bedrock
- Glacial sand and gravel deposits

5.3 LAND USE AND SURFACE WATER DRAINAGE ARRANGEMENTS

There are three principal surface water drainage systems within the catchment consisting of both natural and man-made. Different bodies are responsible for each system. The different systems are shown in Figures 6.1 and 6.2 below.

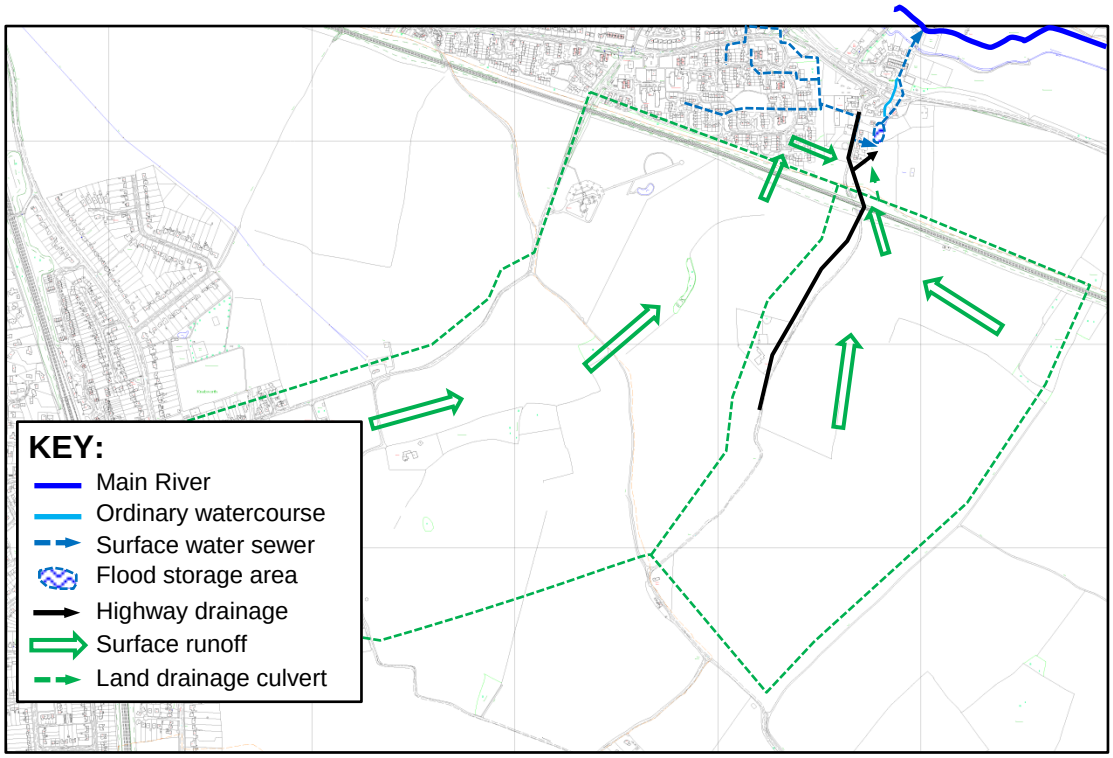


Figure 6.1: Surface Water Drainage Systems

Figure 6.2: Highway Drainage System

5.3.1 Highway Drainage (Hertfordshire County Council as the Highway Authority)

There is a highway drainage system serving the lower section of Bragbury Lane. A survey of the system was conducted as part of this study. There are a few isolated road gullies evident in the road; one outside the properties affected by flooding; two double gullies between the flooded properties and the railway tunnel and a few single gullies on the higher section of Bragbury Lane to the south of the railway. The location and principal details of the highway drainage system is shown in Figure 6.2 above.

Both double gullies were clear and discharged across the open area towards the flood storage area (water meadow) to the rear of Bragbury Lane. A resident of Bragbury Lane keeps the double gullies clear of surface debris. There are road gullies evident in the upper (southern) part of Bragbury Lane where it passes through farmland and these generally contain copious quantities of silt.

The highway drainage pipework runs along Bragbury Lane in a northerly direction but it was not possible to confirm where it outfalls. The pipework is 225mm diameter where it is visible. It is presumed that the outfall is into the flood storage area (water meadow). There is a single manhole chamber visible in Bragbury Lane just to the north of the railway tunnel. The chamber is heavily silted and it is not possible to confirm pipework details. No flow is possible in the highway drainage system at this location.

There is a second manhole chamber located to the north of the railway line to the west of Bragbury Lane. It contains a 225mm diameter pipe aligned parallel to the railway and flowing from the west to the east. The pipe is completely blocked with silt. It is most probable that this pipe connects to the highway drain in Bragbury Lane. It is possible that this pipe receives flow from the land drainage network to the south west of the catchment described in section 5.3.3.1 below.

At some time in the past a small gap was cut through the raised edging to the road on the eastern side of the carriageway at a location just north of the railway tunnel. This ‘notch’ assists in conveying water off the road surface and towards the flood storage area but has limited size and is not at an ideal location to intercept the maximum quantity of surface flow.

Under normal conditions surface water runoff from farmland immediately adjacent to the road and from the railway embankment to the west of Bragbury Lane flows onto the road surface. Surface flows are conveyed along the road following the topography in a northerly direction and under the railway. In extreme storm conditions there can be a significant rate of surface water runoff from the farmland and railway embankment onto the road surface at a point just north of the railway tunnel. There are three road drainage gullies (one double plus a single) between this point and the location of flooding in Bragbury Lane. The surface water runoff from the agricultural land is exacerbated by issues with the land drainage system serving the fields (see Section 5.3.3.1 below).

All of the highway drainage system should be cleaned and an internal CCTV inspection carried out to ascertain any structural defects and hydraulic restrictions.

As stated in section 4 above a flooding event occurred in October 2014 as a result of surface water runoff from the re-development of the former garden centre site to the north west of Bragbury Lane. Water flowed from the site and onto Bragbury Lane then into the front garden of a property in Bragbury Lane (east side) and into the garage. It is probable that the surface water was either unable to enter the road gullies within the new development and/or there were large areas of exposed soil without grass cover or buildings with formal surface water drainage, to slow the rate of runoff of the rainfall. It is of note that there are no gullies on Bragbury Lane from the entrance to the new development, in a southerly direction, until the first one outside 23/25 Bragbury Lane. This is a large expanse of road without any formal drainage arrangements. The flood water was observed by the resident of the affected property as it flowed along the road before entering the property where the edge of the road surface is lower and then falls towards the property.

5.3.2 Surface Water Sewerage (Thames Water)

5.3.2.1 There is a surface water sewerage system within the catchment. It extends from the Hertford Road development to the west of Bragbury Lane, crosses Bragbury Lane to the south of the residential properties and discharges into the water meadow at the rear of the properties that were flooded. It is understood that the water meadow is a flood storage area constructed as part of the Hertford Road development built in the 1970's, and adopted with the associated sewers by Thames Water. The flood storage area discharges into a surface water sewer that passes to the east of the Chequers public house, across the A602 and eventually discharges into the River Beane.
The purpose of the flood storage area is to act as a flow attenuation feature that controls the rate of discharge of surface water from the development site into the receiving watercourse system. It incorporates a flow control at its outlet that restricts the maximum rate of discharge with the surplus runoff being stored temporarily in the 'water meadow' upstream. The flood storage area was formed by the construction of a low embankment across the natural valley in the area behind Bragbury Lane. An outlet pipe with associated flow control structure was formed in the embankment.

5.3.2.2 The surface water sewer downstream of the flood storage area is oversized and forms an on-line storage tank. The tank sewer is 1200mm by 600mm (rectangular) in profile. It extends from behind the commercial property in Bragbury Close to the development on the opposite side of the A602. The discharge from the tank sewer is regulated by a smaller diameter throttle pipe (450mm diameter) at the end of the tank sewer. The surface water sewer continues through the development before ultimately discharging into the River Beane.

5.3.2.3 An attempt was made to ascertain the operation and maintenance regime for the surface water sewerage system, including the flood storage area, with Thames Water but their response with supporting details was still awaited at the time of finalising this report. Discussions were held with the former Drainage Services Manager of Stevenage Borough Council (who is now a manager in the HCC Highways Department). This officer recollected how the flood storage area and surface water sewers in the Bragbury Lane area were routinely inspected and cleaned by the council on behalf of Thames Water

under contract (Sewerage Management Contract, subsequently the Sewerage Operations Contract) up until the contract was terminated by Thames Water in 2001. He was unaware of what maintenance had been conducted.

5.3.3 Land Drainage

5.3.3.1 Field Drainage (area south of the railway)

The higher part of the catchment consists of a large arable field system, split roughly in half by Bragbury Lane, that slopes in a northerly direction towards the railway.

The field to the east of Bragbury Lane has a natural valley profile aligned towards a natural low spot adjacent to the railway approximately 25m to the east of the tunnel under the railway. There is a small (225mm diameter) land drainage culvert under the railway at this point that emerges to the north of the railway into the area adjacent to the flood storage area (water meadow). This culvert was evident only at its downstream end, the upstream end being totally overgrown with vegetation. Historical aerial photographs (Bing maps) show what appears to be an inlet structure, probably a headwall feature, at the upstream location. There was a small amount of seepage evident at the outlet of the culvert in dry conditions that might signify that the culvert intercepts ground water or surface water from the railway embankment in the vicinity of where the culvert passes beneath it. The area surrounding the outlet of the culvert had been scoured by the passage of flow and it was clear that the culvert had, at some point in the past, conveyed a reasonable rate of discharge. There is a manhole within the Network rail land on the north east side of the bridge. The manhole is full of debris and it is unclear what drainage pipework, if any, connects to this chamber.

There is very little level difference between the inlet to the culvert and Bragbury Lane a few metres to the west. It is highly probably that surface water runoff from the adjacent field would collect upstream of the inlet to the culvert forming a pond. The topography is such that only a small pond would form before it overflowed westwards onto Bragbury Lane and through the railway tunnel. The culvert is the responsibility of Network Rail.

The image below shows the lower part of Bragbury Lane prior to construction of the railway and, specifically, it includes a probable ditch from Bragbury Lane towards where the balancing pond is now located. It is probable that this ditch was used to convey surface water runoff from Bragbury Lane into the receiving natural watercourse system.

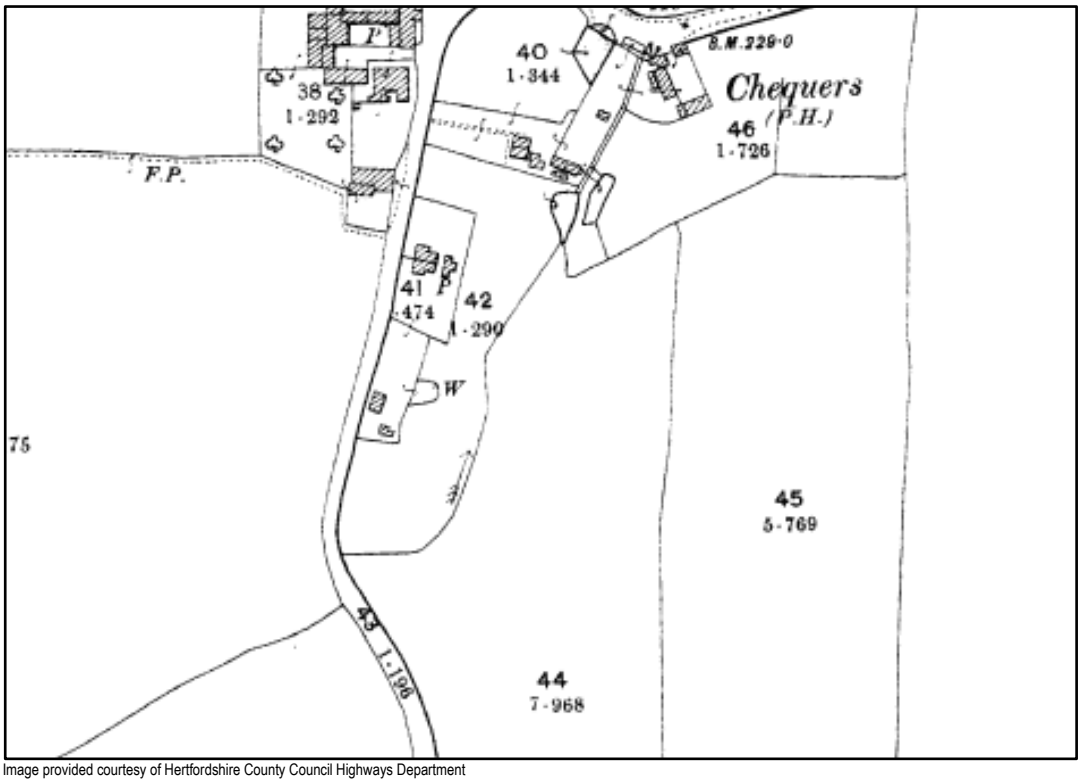


Image provided courtesy of Hertfordshire County Council Highways Department

Figure 6.2a: Historical Map showing Land Drainage Prior to Construction of the Railway

The field system to the west of Bragbury Lane extends as far as the outskirts of Knebworth. There is a defined natural valley profile to this area with the downstream end of the valley meeting the railway at a distance of approximately 200m to the west of the railway tunnel on Bragbury Lane. There is a small ridge of higher ground between Bragbury Lane and the valley bottom. The ridge is approximately 1m in height. No culvert under the railway was evident during the site survey conducted as part of this investigation but it is possible that a culvert exists in a similar manner to that found on the opposite side of Bragbury Lane. There are at least two large depressions along the natural valley in the filed system where surface water would be expected to collect plus another where the valley meets the railway. If this area were to overflow flood water would be conveyed onto Bragbury Lane and then into the tunnel under the railway. If there is a culvert present under the railway it is the responsibility of Network Rail.

5.3.3.2 Ordinary watercourses (Stevenage Borough Council)

There is one short length of ordinary watercourse within the catchment. It is identified in Figure 6 and is located downstream of the flood storage area flowing towards the A602 to the north where it converges with the surface water sewerage system before finally converging with the River Beane. The watercourse appears to follow the natural valley of the catchment that would once have extended from the watershed to the south through where the railway bisected it, through the flood storage area, across the A602 and into the River Beane. Construction of the railway and flood storage area with associated surface water sewerage system effectively isolated this last remnant of the watercourse. The head of the watercourse is situated immediately downstream of the flood storage area embankment and

receives surface water runoff and ground water from the small surrounding area and flows the short distance into the rear garden of the commercial property in Bragbury Close before entering into a large brick culvert to the side of the public house. This culvert was heavily silted when inspected as part of this study. The culvert converges with the Thames Water surface water sewerage system to the front (north) of The commercial property. The watercourse is relatively small in dimensions measuring approximately 1.5m at its widest (upstream end) and less than 1m in depth, with no visible flow and standing water of approximately 300mm depth. The width of the channel diminishes where it passes through the rear garden of the commercial property and this reduced width, plus general lack of gradient of the invert and siltation of the outlet culvert, restrict its flow conveyance capabilities, particularly in storm flow conditions. During the flood event of February 2014 water escaped from the watercourse and flooded an adjacent commercial property.

5.3.3.3 Main rivers (Environment Agency)

All surface water runoff from the catchment ultimately drains into the River Beane that is located to the north of the catchment. This watercourse is classified as a main river and therefore falls within the overall administration of the Environment Agency's land drainage powers. There is a single point of discharge from the catchment to the river via a surface water sewer maintained by Thames Water.

6 HYDROLOGICAL ASSESSMENT

6.1 INTRODUCTION

As part of this investigation, an assessment was made of the rainfall conditions that precipitated the flooding. The assessment took into consideration the conditions prior to the flooding and including the catchment conditions and antecedent rainfall in the period leading up to the storm that caused the flooding. Other contributory factors that may have influenced the flood event were also investigated and are described below. The investigation sought to confirm the flooding mechanism and to quantify the various factors that combined to cause the flooding putting each into relative perspective and scale with the others. The second part of this chapter describes the results of a hydrologic assessment that examined how the catchment and components of the surface water drainage systems would respond to a range of statistical design storms under a range of antecedent conditions. The final part of this chapter makes reference to other recent flood risk assessments that have been conducted and how they compare to this investigation.

6.2 ASSESSMENT OF 7 FEBRUARY 2014 STORM EVENT

6.2.1 Rainfall data

Details of rainfall recorded at three permanent rain gauge sites maintained by the Environment Agency were obtained by the LLFA for this investigation. The gauges were located at the following sites shown geographically in Figure 7 below:

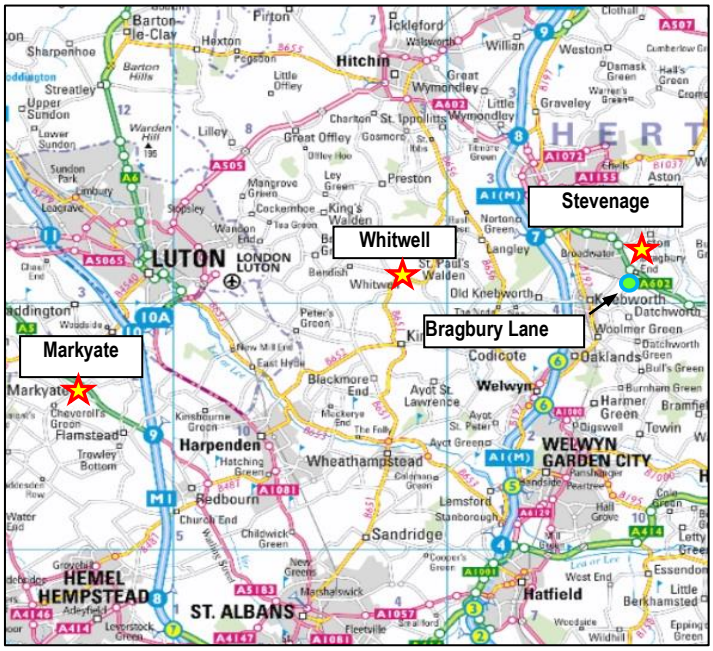


Figure 7: Rain gauge locations

The measurements of rainfall were recorded as a total depth of rainfall over each successive 15 minute interval.

A brief summary of the rain recorded by the rain gauges is presented below in Table 3.

	Stevenage TBR	Whitwell STW TBR	Markyate STW TBR
Date/time	**Depth of Rain (mm)**	**Depth of Rain (mm)**	**Depth of Rain (mm)**
07/02/2014 00:15:00	0	0.1	0.2
07/02/2014 00:30:00	0	0.3	0.8
07/02/2014 00:45:00	0.2	0.7	1
07/02/2014 01:00:00	0.2	0.5	1
07/02/2014 01:15:00	0.2	0.5	0.4
07/02/2014 01:30:00	0.4	0.6	0.4
07/02/2014 01:45:00	0.4	0.3	0.2
07/02/2014 02:00:00	0.2	0.6	0.4
07/02/2014 02:15:00	0.4	1.3	1
07/02/2014 02:30:00	0.8	1.3	1.2
07/02/2014 02:45:00	1.2	1.9	1
07/02/2014 03:00:00	1.4	1.9	2.2
07/02/2014 03:15:00	2	1.9	1.6
07/02/2014 03:30:00	1.4	1.7	1.2
07/02/2014 03:45:00	3	1.5	1.2
07/02/2014 04:00:00	3.2	1.6	0.8
07/02/2014 04:15:00	1.8	0.9	0.8
07/02/2014 04:30:00	1.2	0.5	0.6
07/02/2014 04:45:00	0.8	0.7	0.4
07/02/2014 05:00:00	0.4	0.1	0
07/02/2014 05:15:00	0.4	0.1	0.2
	19.6mm	19mm	16.6mm

"Contains Environment Agency information © Environment Agency and database right"

Table 3: Rainfall Summary (7 February 2014)

From examination of the data above the following details are evident:

(i) The storm commenced just after midnight on 6 February and continued for approximately 5 hours

(ii) 19.6mm of rain was recorded at the Stevenage rain guage (the nearest to Bragbury Lane) located approximately 1km to the north of Bragbury Lane in the Stevenage Golf Club

(iii) The storm was reasonably consistent in character as it moved across the catchment from west to east (Markyate to Stevenage) with approximately 15% variation in total depth of rainfall recorded between the three gauges. The maximum depth of rainfall recorded by the rain gauges was at Stevenage

(iv) The rainfall intensity peaked at 3.2mm in the fifteen minute time period from 04:00am. This equates to an average intensity of 12.8mm/hr. The average intensity for the storm event as a whole was 4.4mm/hr (19.6mm over 4:30 hours)

The depth of rainfall recorded in Stevenage does not represent rainfall of unusually high intensity nor significant quantity. As an illustration the data in

Table 4 below shows the average equivalent depths and intensities for design storms of a similar duration and increasing severity compared to the event of 7 February 2014. The rainfall characteristics compare very favourably with those of a theoretical storm of 1 in 1 year return probability.

Storm Return Period	Storm Duration	Average Rainfall Intensity	Rainfall Depth
7 February 2014	**270 mins**	**4.4 mm/hr**	**19.6mm**
1 in 1 year	270 mins	4.3 mm/hr	19.35mm
1 in 5 years	270 mins	6.6 mm/hr	29.7mm
1 in 10 years	270 mins	7.7 mm/hr	34.7mm
1 in 50 years	270 mins	11.0 mm/hr	49.5mm
1 in 100 years	270 mins	12.8 mm/hr	57.6mm

Table 4: Illustrative Design Rainfall Characteristics

Under normal conditions, a storm of 1 in 1 year return period would not be expected to create flooding conditions as witnessed on 7 February 2014 in Bragbury Lane. Other contributory factors to the flooding are discussed below.

6.2.2 Catchment antecedent conditions

The period leading up to the flooding event was unusually wet and the ground was reported by the local residents as being saturated with small surface puddles evident in the arable fields south of the railway. An assessment of the rainfall recorded over the preceding 28 days is reported in Table 5 below.

The data in Table 5 shows that there was almost 101mm of rain over the 26 days prior to the flooding event on 7 February 2014. This is considerably greater than the average that would be expected. The standard average annual rainfall (SAAR) for this part of the UK is 600mm which equates to a monthly average (January) of 60mm. The average rainfall data for January is shown in Figure 8 below. The amount recorded is typically 70% greater than the average and, more importantly there was 16.8 mm recorded in the 48 hours before the flood event. This rainfall would have resulted in the soil being saturated and the removal of any soil moisture deficit (SMD). Despite the basic soil type for this area being based on glacial deposits of sands and gravels plus chalk, the prolonged period of rainfall in the weeks leading up to the storm event means the soil structure would have been unable to absorb the intense rainfall that occurred on 7 February 2014. The quantity of rainfall also resulted in the formation of puddles on the surface in small surface depressions. These two factors in combination would have created conditions conducive to a very high percentage runoff that in turn would have resulted in most of the rainfall that fell converting into surface water runoff. The typical percentage runoff that would be expected from a permeable surface from a theoretical design storm is approximately 35% (wetted). In comparison, the runoff from an impervious surface would be in the range of 95% (wetted).

	Stevenage TBR	Whitwell STW TBR	Markyate STW TBR
Date/time	**Depth of Rain (mm)**	**Depth of Rain (mm)**	**Depth of Rain (mm)**
11/01/2014	1	0.8	1.4
12/01/2014	2.4	2.9	3
13/01/2014	4.2	2.7	3.6
14/01/2014	1.4	1.8	2
15/01/2014	3.4	3.3	4
16/01/2014	8.2	10	4.6
17/01/2014	1	1.4	2
18/01/2014	2.4	1.7	1.2
19/01/2014	0.4	0.2	1.4
20/01/2014	0	0	0.2
21/01/2014	0.2	0.7	0.2
22/01/2014	6.2	8.2	6.4
23/01/2014	3.4	3.2	2.8
24/01/2014	4.4	5	5.6
25/01/2014	3.4	2.8	3.2
26/01/2014	5.8	7	8.2
27/01/2014	0.8	0.6	1.6
28/01/2014	2.4	3	1.4
29/01/2014	7.6	8.7	10
30/01/2014	4.2	3.3	2.6
31/01/2014	8.2	8.3	10
01/02/2014	5.8	7.4	6
02/02/2014	0	0	0
03/02/2014	0	0	0
04/02/2014	1.6	2.3	3.4
05/02/2014	8.2	9	13.8
06/02/2014	8.6	9.5	10
	100.9mm	**110.6mm**	**108.6mm**

"Contains Environment Agency information © Environment Agency and database right"

Table 5: Antecedent Rainfall Summary

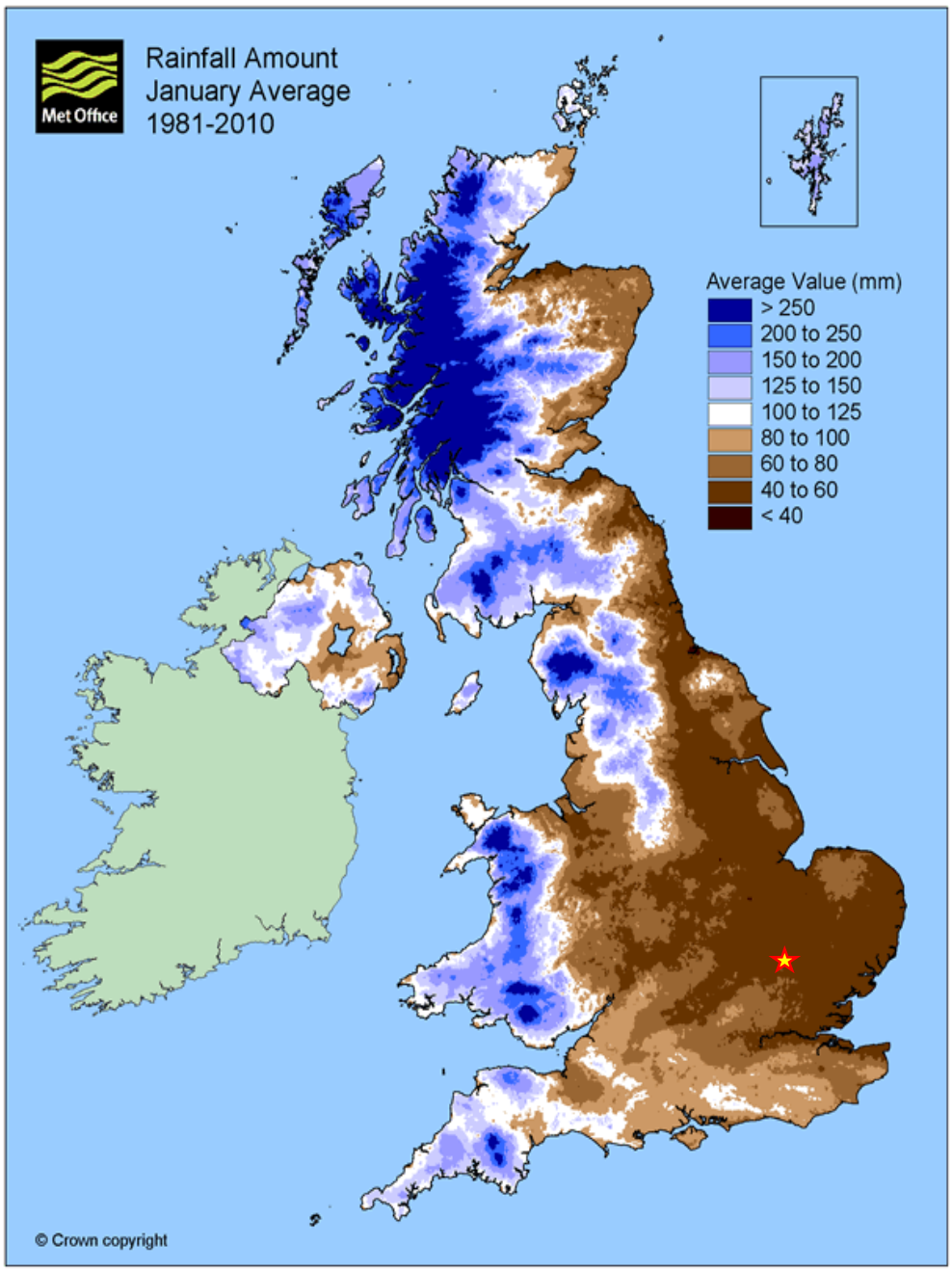


Figure 8: Average Monthly Rainfall Depth for January

6.2.3 Runoff assessment

A hydrological assessment was undertaken of the 7 February 2014 storm event to investigate how the catchment runoff converted into overland flows from the 3 principal catchment areas (refer to Figure 4), namely the farmland and Bragbury Lane, railway embankment and residential sector. The analyses are included in Appendix B. The analyses included certain assumptions as summarised below:

Hydrological analysis assumptions:

(i) The catchment was saturated before and during the storm event
(ii) The highway drainage system provided negligible capacity and impact on drainage of runoff from Bragbury Lane - on the basis of the survey conducted in October 2014
(iii) The rainfall intensity profile during the storm was assumed to be an equivalent average intensity
(iv) The flood storage area outlet screen was unobstructed allowing free passage of flow
(v) The throttle in the outlet chamber to the flood storage area was fully opened (300mm diameter)
(vi) The surface water sewer storage pipework between the flood storage area and the residential development to the north of the A602 was empty before the storm, unobstructed by silt or debris and the outlet throttle was also unobstructed.

The analyses show that there was an excess of surface water runoff that could not be contained within the natural surface hollows in the large fields system south of the railway and a peak discharge onto Bragbury Lane with a calculated depth across the full road width leading towards the flooded properties of 138mm.

The total runoff from the Hertford Road development amounted to 1188m^3. The flood storage area and the storage pipes in the surface water sewer system immediately downstream could accommodate all of this volume but with the additional inflow from the runoff flowing down Bragbury Lane and through the flooded properties into the flood storage area there was an excess of 11000m^3 of flood water that was conveyed over the embankment to the flood storage area, into the small watercourse downstream and then some of that volume (not calculated) flooded out of the stream and into the commercial property in Bragbury Close.

6.2.4 Assessment of Existing Drainage Infrastructure

Highway Drainage

The existing highway drainage infrastructure is representative of that which is found in edge of town / rural areas. The gullies can become blocked easily by debris blown from the farmland to the south, straw from farm vehicles and by leaves off nearby trees and bushes. The effect of these conditions is that surface water runoff from the road, and any from adjacent ground (see below) will be conveyed along the road surface, being unable to enter the highway drainage pipes below ground. The fall along Bragbury Lane will convey flows to the lowest point in the road outside the properties to the east of Bragbury Lane. Normally highway drainage is designed for storm conditions that are less severe than the exceptional weather that occurred over the winter of 2013-14. The highway drainage system would not have been able to accommodate all of the surface water runoff from the extreme conditions experienced, even if each component part was operating to its optimum performance. As an illustration, the theoretical capacity of the

highway drainage system, based on a 225mm diameter pipe at a gradient representative of the lower section of Bragbury Lane (typically 1 in 100), is 52 l/s. The typical rate of surface water flow on Bragbury Lane is calculated as 843 l/s (Refer to Appendix B). The highway drainage system is able to convey approximately 5% of the storm runoff from the February 2014 event and the remaining flow would remain on the road surface.

Land Drainage Network - culvert under railway
The entrance to the culvert is completely blocked and prevents passage of flow towards the flood storage area to the north of the railway. The inside of the culvert is probably partially or completely blocked. As a consequence surface water runoff from the large field south of the railway will pond in the low point in the field at the upstream end of the culvert and eventually spill onto Bragbury Lane when water level rises sufficiently.

Land Drainage Network - railway embankment west of Bragbury Lane
There is an extensive area of railway embankment that sheds water onto adjacent ground alongside the Hertford Road development. There is an area of grassed open space within the development at the south eastern corner and this probably generates surface water runoff that merges with that from the railway embankment. All the runoff flows onto Bragbury Lane where it is conveyed northwards towards the properties that flood. Photographic evidence from the flood-affected residents showed water continuing to flow from this location after the storm had abated and water had ceased to flow down Bragbury Lane from the fields to the south as illustrated in Figure 9 below.

Photograph courtesy of resident of Bragbury Lane

Figure 9: Surface Water Runoff from the Railway Embankment (in distance) and adjacent Permeable Open Space - in foreground (west of Bragbury Lane)

Land Drainage Network - open watercourse to the rear of Bragbury Close
This ditch at its upstream end is heavily silted and overgrown by encroaching vegetation. The section of ditch where it emerges into Bragbury Close is reasonably well maintained but the entrance into the brick arched culvert is heavily silted. The loss of ditch profile because of the silt reduced the flow capacity of the ditch and would have caused storm flows to spill out of the ditch and towards Bragbury Close, flooding a commercial property in the process.

Surface Water Sewerage System - Flood Storage Area
The flood storage area is heavily overgrown with extensive weeds. These were probably not present at the time of the flooding event but there is likely to have been considerable quantity of dead weeds that would have been conveyed by the flood water towards the small trash screen over the outlet to the storage area. The invert of the storage area is silted which has reduced the volume available for storage of flood water. The small embankment across the valley forming the water retaining barrier was well maintained but is low in height compared to the crest of the chamber that houses the flow control device set into the embankment. Inside the control chamber is a dividing wall that rises from the invert to a crest, weir, level that is marginally lower than the crest of the embankment. The weir was presumably designed to allow excess water from extreme storm events to flow over the dividing wall, and hence by-pass the flow control in the wall, and to be conveyed uncontrolled into the downstream surface water storage pipes. The relatively small size of the outlet pipe into the control chamber from the storage area, and the small trash screen that protects it from blockage, limit how much water can be conveyed into the chamber and therefore the water level in the storage area is governed more by the pipe and trash screen from the storage area than by the flow control and overflow weir.

Surface Water Sewerage System
There is no evidence that the surface water sewerage system serving the Hertford Road development has any significant flooding problems. The system was designed to discharge into the flood storage area (see above) where the outlet controls would limit the maximum rate of discharge into the surface water sewerage system downstream and ultimately the River Beane beyond. The oversized storage pipes in the surface water sewerage system downstream of the flood storage area did not appear to flood during the event in February 2014. Thames Water were contacted as part of this investigation but at the time of writing a formal response was still awaited.

6.3 IMPACT OF EXTREME STORM EVENTS

6.3.1 Rainfall criteria and catchment antecedent conditions

A simplified method of hydrological assessment was conducted as part of this investigation to ascertain the impact of design storms of increasing severity and the likely flooding and consequential damages that they would induce. In making the assessment, certain assumptions and simplifications were made as summarised below:

(i) The assessment was conducted on the basis of deriving the total volume of surface water runoff within separate principal sectors of the catchment, removing volumes that would be accommodated in any large surface depressions then calculation of the depth of flow in principal overland flow paths to derive depths of flow and the properties that would be expected to flood. Flood damages were calculated on the basis of typical higher-end insurance and privately funded repair costs obtained from the flooding interview data

(ii) Rainfall data and runoff volumes were derived from standard data profiles and processed by the 'FLOOD2' analysis software (Copyright Hertsmere Borough Council)

(iii) The duration of each design storm was set at 270 minutes to be equivalent to the flood event of 7 February 2014

(iv) The catchment was saturated prior to the storm and all rainfall was converted into surface water runoff

(v) The flood storage area and surface water sewers plus storage pipes were empty and clear at the commencement of the storm

(vi) No surface water runoff was conveyed by the highway drainage system and all runoff remained on the road surface based on the findings of the survey of the highway drainage.

6.3.2 Predicted flooding impact

Details of the hydrological analyses are contained in Appendix C. A general summary is provided below.

Four different scenarios were analysed using two design storm return periods; 1 in 10 year event and 1 in 100 year event. Each was analysed with a dry and a wet catchment before the storm. The following summary Table 6 shows the calculated depth of flood water on Bragbury Lane in the section north of the railway tunnel leading towards the residential properties. The reported flood depths outside the flooded properties on the eastern side of Bragbury Lane in the February event ranged from 400mm to just sufficient to rise over the front door threshold at most others (150mm). The following figures support those accounts and are indicative of the expected flood depths to be expected for more extreme storm events.

Storm	Depth of flow on Bragbury Lane
1 in 10 year dry catchment	150mm
1 in 10 year wet catchment	200mm
1 in 100 year dry catchment	215mm
1 in 100 year wet catchment	275mm
7 February 2014	**138mm**

Table 6: Summary of Design Storm Hydrological Analyses

6.3.3 Predicted Damage Costs

The predicted depths of flood water for the 1 in 10 year and 1 in 100 year design storm conditions are all greater than that of the 7 February 2014 event and as a result it is to be expected that there would be a greater likelihood of more water entering inside properties. In the February 2014 event flooding entered 5 properties on Bragbury Lane and one in Bragbury Close. Of these two in Bragbury Lane and the single property in Bragbury Close suffered significant damages as a consequence. The other three suffered from minimal water damage as the quantity of water was small. For more extreme storm conditions it is projected that the internal flooding would be deeper with all 5 properties in Bragbury Lane and the one in Bragbury Close having water throughout the ground floor with considerable damage to fixtures and fittings, plaster and electrical wiring. The value of the insurance claim made for one property in Bragbury Lane as a result of the February event (£8080) is reasonably consistent with the average value of claims (£10,000) made for smaller residential properties where internal flooding greater than 25mm has occurred throughout the ground floor affecting typically the kitchen, lounge and dining room. It is typical for the value of damage costs to rise only marginally with increase in flood depths above 25-50mm as most furniture, kitchen floor units, carpets and plaster are generally affected by the initial shallow depth of flooding and no further damage (replacement costs) is incurred by an increase in depth of water. There may be some exceptions to this general presumption however if high value electrical goods (televisions, audio equipment etc.) are affected as the flood water increases in depth. On this basis the damage costs for a 1 in 100 year event are considered to be at least 10% greater than those for a 1 in 10 year event.

Damage costs for the commercial property in Bragbury Close are more difficult to estimate because of the lack of factual evidence of historic claims and loss of trade etc. To derive an estimate of predicted damages the rate per residential property is suggested as a starting point with the overall cost being calculated pro rata to the respective floor space area of the two properties with an extra allowance being made for other stock and equipment close to ground level that would be expected to be damaged or destroyed in a flood. The property in Bragbury Close is typically double that of a typical residential property in Bragbury Lane and has a large quantity of stock and equipment at ground level. In our judgement the typical damage

costs for this property should be equivalent to 300% of those for a typical residential property.

In consideration of these factors we consider that the typical costs of damages for each residential property are as shown below in Table 7.

Property Type	Predicted Damage Costs	
	1 in 10 years	1 in 100 years
Residential (Bragbury Lane)	£10,000 / property	£11,000 / property
Commercial (Bragbury Close)	£30,000 / property	£33,000 / property

Table 7: Summary of Predicted Design Storm Flood Damages

6.4 FLOOD RISK ASSESSMENTS

6.4.1 Environment Agency Surface Water Maps

The results of the analysis undertaken by the Environment Agency are illustrated below in Figure 10. They show a reasonable correlation with the surface water runoff witnessed by local residents on 7 February 2014. The map does not show how surface water from adjacent fields in the southern part of the catchment would stay on Bragbury Lane and conveyed to where the houses flooded and this was the key mechanism that resulted in the flooding to properties. The map indicates that surface water runoff from the large field system to the south-west of the catchment would flow onto Bragbury Lane south of the railway tunnel. Overland flow at this location was not witnessed by those interviewed as part of this investigation; it might have occurred but because the storm took place in darkness and the residents were occupied with clearing up after the flooding no observations were made in this area. The map does show the presence of 3 large natural surface storage ponds in low spots along the flow path in this area and there is evidence of their existence in aerial photographs.

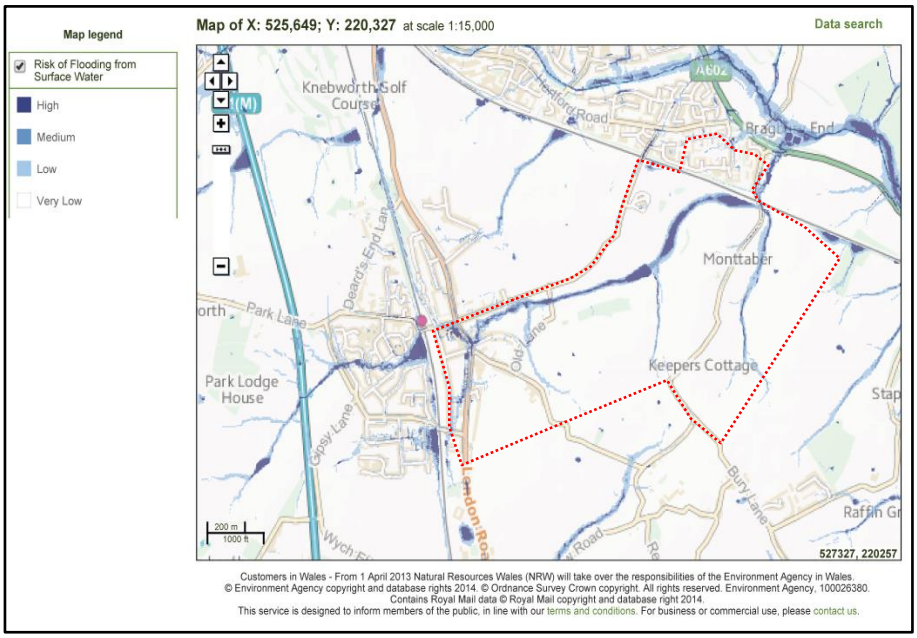


Figure 10: Environment Agency Surface Water Maps

6.4.2 Stevenage Borough Council SFRA

A Strategic Flood Risk Assessment was produced in 2008 for the administrative catchment of Stevenage Borough Council. The SFRA included a record of historic surface water flooding. There was no record in the SFRA of any flooding in Bragbury Lane as shown in Figure 11 below. Reference was made in the SFRA to a number of surface water flood storage reservoirs (ponds) within Stevenage, as shown in Figure 12 below, including one at Bragbury Lane. This is the drainage feature described above in earlier sections of this report and which is understood to be the responsibility of Thames Water.

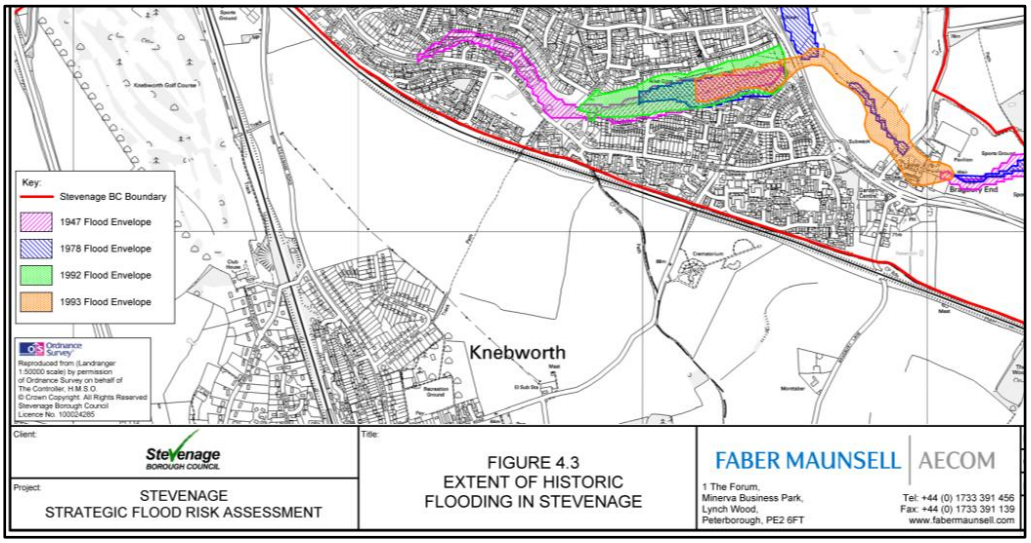


Figure 11: Stevenage Borough Council SFRA - Extract showing historical flooding

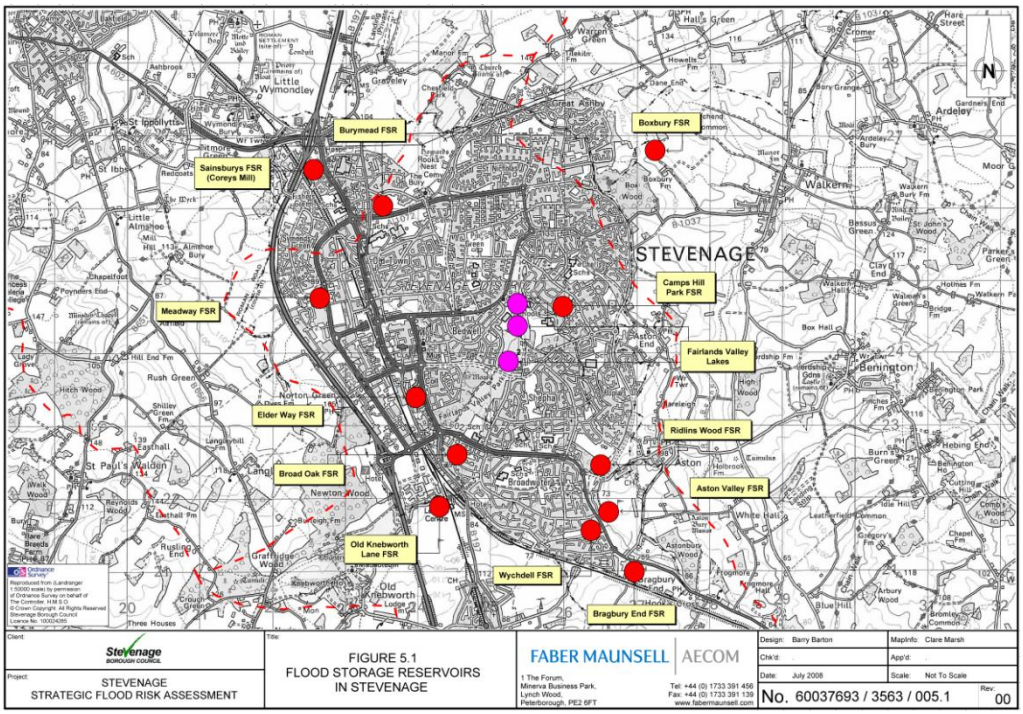


Figure 12: Stevenage Borough Council SFRA - Extract showing location of flood storage areas (reservoirs)

7 FLOOD MITIGATION AND RESILIENCE OPTIONS

7.1 INTRODUCTION

There is considerable scope to provide mitigation to reduce flooding. There are various surface water drainage arrangements already in existence and these all have scope to be improved, either by regular planned inspection and maintenance and/or by improvement to increase their hydraulic performance. This section provides a brief overview of the various options available. They can be implemented individually or in combination. There are five different options described. A description is provided of the relative merits and issues associated with each option. Approximate budget cost estimates are provided for the construction of the options. Further detailed assessment will be required to establish accurate cost estimates if any is to be progressed further. A drawing of the proposed mitigation options is located in Appendix D.

7.2 MAINTENANCE ENHANCEMENTS

7.2.1 Locate, survey and clean highway drainage system

The existing highway drainage system is ineffective and offers little protection against flooding. It is recommended that the entire system is cleaned using high pressure jetting and a CCTV survey conducted to establish any serious structural defects that are inhibiting optimum hydraulic performance. A programme of routine inspection and reactive maintenance of gullies should be introduced. These actions should be implemented by Hertfordshire County Council Highways Department.

7.2.2 Clear the flood storage area of undergrowth and silt

The existing flood storage area is heavily overgrown with weeds and the central flow channel is heavily silted. The inlet headwall(s) from the surface water sewer system serving the Hertford Road development and those for the highway drainage system in Bragbury Lane were not found during the course of this investigation and these should be located, cleaned and a programme of regular inspection and cleaning implemented. This will require action by Thames Water for the surface water sewerage system assets and Hertfordshire County Council Highways Department for the highway drainage system.

7.2.3 Locate, clean and survey the land drainage culvert(s) under the railway

A survey should be conducted to locate the inlet to the culvert under the railway to the east of the railway tunnel. The entrance arrangements should be cleared to facilitate an unrestricted passage of surface water runoff from the adjacent field into the culvert, perhaps involving localised re-profiling of the adjacent ground surface to facilitate this. The culvert outlet should be cleared in a similar manner to enable emerging flow to be conveyed into the flood storage area. The culvert should be cleaned by high pressure jetting and then surveyed to ensure it is in a good structural condition and any significant defects repaired as necessary. A routine programme of inspection and clearance of the inlet and outlet of the culvert should be implemented by the respective landowners.

It is considered probable that there is another land drainage culvert under the railway to the west of the railway tunnel. A survey should be undertaken to locate it and where it discharges to (potentially the manhole chamber at the northern portal to the railway tunnel in the railway embankment might be a part of a land drainage system). It should be cleaned and an internal inspection conducted with any repairs of serious structural defects being implemented as necessary. A routine programme of inspection and clearance of the inlet and outlet of the culvert should be implemented by the respective landowners.

7.3 MITIGATION OPTIONS

The various mitigation options are summarised in the following Tables 8.1 to 8.5 on the following pages.

Ref:	Description
1.1	**Improvements to Highway Drainage - Surface Water Collection** It may be possible to introduce improvements to increase the removal of surface water from the road surface and to convey it in pipes below ground to a suitable outfall. Modern standards for highways that are to be considered for adoption by the highway authority would be a logical starting point as the basis for the criteria the drainage should meet. Wherever possible we advise that additional road gullies are installed to increase drainage from the road surface and also to allow for the probable blockage of some gullies during extreme storm events. Gullies should be added from the junction with the new development at the north western end of Bragbury Lane down as far as the railway tunnel. There are two outlets from the existing highway drainage between the railway tunnel and the flooded properties in Bragbury Lane. The outlets should be cleared and the outlets improved to enable an unrestricted discharge into the flood storage area. The cost estimate assumes existing pipes are retained after cleaning and no replacement with larger capacity pipes is required.
	Advantages: Improved collection and disposal of surface water from the road surface Reduced likelihood of blockage to gullies
	Issues: Increased maintenance liability No benefit to Bragbury Close commercial property
	Budget Cost Estimate: £150,000

Table 8.1: Mitigation Option 1.1 - Improvements to Highway Drainage Surface Water Collection

Ref:	Description
1.2	**Improvements to Highway Drainage - Modify Carriageway Surface Profile and Edge Details** A major factor in the cause of the flooding was the conveyance of surface water along the carriageway surface of Bragbury Lane towards the properties that suffered from flooding. The rate and quantity of flow in extreme conditions is well above those that highway drainage is conventionally designed to cater for. The opportunity exists to convey water off the road surface and direct it towards the flood storage area thus avoiding it passing along the road and through the properties before ultimately entering the flood storage area. The proposal involves the provision of a two lowered sections of roadside verge (currently a raised section of earth beside the road with small bushes on top) each of approximately 10m in length on the east side of Bragbury Lane as shown on the drawing. The ground beside the road leading across to the flood storage area from each should be profiled to form a swale. To supplement the swale detail the proposal includes the construction of 2 raised speed tables on Bragbury Lane, one located at the northern end of each swale. These two features will act as barriers to surface water flow on the road surface and will cause it to be conveyed off the road and into the swales and then to the flood storage pond. The raised table nearest to the railway tunnel should capture most runoff and the second will ensure any flow that passes over the first table in exceptional storm conditions is also captured and directed to the flood storage pond.
	Advantages: Improved dispersal of water off the road surface into the flood storage area. Traffic calming
	Issues: Increased maintenance liability
	Budget Cost Estimate: £50,000

Table 8.2: Mitigation Option 1.2 - Improvements to Highway Drainage, Modify Carriageway Surface Profile and Edge Details

Ref:	Description
2	**Expand and improve the flood storage area** The flood storage area can be re-profiled by careful excavation to increase its capacity. The storage volume can be further increased by raising and extending the existing bund. The bund can be extended from its western end in a southerly direction along the rear boundary of the houses on the eastern side of Bragbury Lane and alongside the southern boundary of the southernmost house. This will assist in holding and attenuating the surface runoff from upstream. Emergency overflow arrangements should be incorporated and the embankment protected against overtopping. The trash screen over the outlet pipe from the storage area should be replaced with one designed to modern standards with a larger surface area of screen and to be accessible to remove debris if it becomes blocked. The design, operation and maintenance of the flow control and emergency overflow arrangements should be analysed and optimum hydraulic performance of the flood storage area achieved.
	Advantages: Increased storage capacity and flood risk benefit to the commercial property in Bragbury Close.
	Issues: Increased maintenance liability No benefit to properties in Bragbury Lane unless implemented with Option 1.2
	Budget Cost Estimate: £50,000

Table 8.3: Mitigation Option 2 - Improvements to the Existing Flood Storage Area

Ref:	Description
3	**Improvements to Land Drainage Arrangements by Provision of Attenuation Storage Features** Provide three raised embankments around the natural low point 'hollows' in the fields to the south of the railway and incorporate features to limit the passage of flow out of them. Embankments located as below: 1. A short low height embankment along the east side of Bragbury Lane just south of the railway to contain excessive surface water runoff from the adjacent field that drains to the existing culvert in the corner of that field under the railway until it is able to drain naturally through the culvert. 2. A short low height embankment along the west side of Bragbury Lane just south of the railway to contain excessive surface water runoff from the adjacent field. 3. A raised embankment around the existing hollow in the field system to the east of Knebworth between Old Lane and Watton Road. Incorporate a feature to artificially narrow the existing channel at the embankment (e.g. revetment) to restrict the rate of discharge of surface water.
	Advantages: Improved flood risk protection by attenuation of surface water runoff from a major part of the catchment Minimal maintenance liabilities
	Issues: Requires consent from the local landowners Maintenance liability for the flow controls Potential damages for loss of crops
	Budget Cost Estimate: £25,000

Table 8.4: Mitigation Option 3 - Improvements to Land Drainage by Provision of Attenuation Storage Features

Ref:	Description
4	**Flood Protection Measures to Individual Properties** Emergency protection measures are recommended to be fitted to each of the flood entry points at the properties that have been subject to flooding in Bragbury Lane and The Chequers public house. Ideally these should be automated devices that are activated by the presence of approaching flood water, alternatively they can be fittings that require installation by the residents in advance of anticipated severe storm conditions. Grants are currently available from the local authority under certain conditions. The grant scheme is known as…. *Local Government "Flooding Recovery: Repair and Renew Grant Scheme"* Advice can be found at the following web site: *www.gov.uk/government/publications/flooding-recovery-households-and-businesses-applying-for-the-repair-and-renew-grant-scheme/flooding-recovery-households-and-businesses-applying-for-the-repair-and-renew-grant-scheme* Construct a raised defence wall alongside the open watercourse at the rear and beside the commercial property in Bragbury Close to prevent water escaping from the watercourse.
	Advantages: Protection to the inside of the properties
	Issues: Requires consent from the local landowners Dependence upon sufficient grant and/or top-up contribution from property owners Owner intervention required to install non-automatic flood barriers No protection to the gardens and driveways
	Budget Cost Estimate: £0 - £10,000

Table 8.5: Mitigation Option 4 - Flood Protection Measures to Individual Properties

7.4 BENEFIT:COST ASSESSMENT OF MITIGATION OPTIONS

The nature of the flood mechanism and disparity between the mitigation options in terms of the benefits they bring to different properties makes any direct correlation between the costs of mitigation and the value of benefits derived difficult. As an illustration of the mitigation measures that will achieve a significant, but not the maximum reduction in risk of flooding, comparisons of costs and benefits are presented below in Table 9. The costs and benefits are approximate and accurate figures should be developed as part of detailed development of options.

Mitigation Option	Costs	Properties Benefitted	Benefit Value			
			1 in 10 yr	Benefit: Cost	1 in 100 yr	Benefit: Cost
1.2	£50,000	Bragbury Lane (6 No.)	£60,000	1.2	£66,000	1.32
2	£50,000	Bragbury Close (1 No.)	£30,000	0.6	£33,000	0.66
1.2 & 2	£100,000	Bragbury Lane (6 No.) Bragbury Close (1 No.)	£90,000	0.9	£99,000	0.99

Table 9: Benefit : Cost Comparison for Selected Mitigation Measures

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

8.1.1 A total of 7 properties experienced internal flooding from surface water runoff during the storm event of 7 February 2014:

Commercial property in Bragbury Close
6 properties in Bragbury Lane

One additional property experienced external flooding:

Bragbury Lane

8.1.2 The flooding was the result of excessive surface water runoff from a combination of rural and residential urbanised catchment. The surface water runoff resulted from an intense rainfall event over a period of approximately 4.5 hours onto ground that was saturated from a period of prolonged rainfall over 4 weeks prior to the flood.

8.1.3 The natural topography of the catchment funnelled surface water runoff towards the location where flooding occurred. Surface water runoff from an extensive and relatively steeply sloping rural catchment was conveyed onto the surface of Bragbury Lane and towards the properties in Bragbury Lane that flooded. Flood water was then conveyed into a flood storage area behind the flooded properties. The flood storage area overflowed and this water then flooded a commercial property a short distance downstream from the storage pond.

8.1.4 The property to the west of Bragbury Lane was flooded inside the front porch as a result of excessive surface water runoff from higher adjacent ground which was the site of a former garden centre being re-developed at the time of the flooding event.

8.1.5 There are various existing surface water drainage systems present in the catchment:

- Highway drainage - responsibility of Hertfordshire County Council in its role as the Highway Authority
- Surface water sewerage including a flood storage area (pond) designed as a balancing pond to attenuate the runoff from the Hertford Road housing development in the 1970's - responsibility of Thames Water
- Land drainage - culvert under the railway - responsibility of Network Rail

Each of these drainage systems is in need of cleaning; some of the highway drainage gullies are blocked and some of the pipework is silted; the land drainage culvert under the railway is blocked and a suspected second land drainage culvert under the railway was not located; the flood storage area was overgrown and heavily silted.
Elements of each of the drainage systems have limited capacity:

The spacing of highway drainage gullies could be improved; the trash screen over the outlet of the flood storage area is very small and is also not easily accessible for the removal of trapped debris; the land drainage culvert under the railway is very small for the size of the catchment that it serves.

8.1.6 Flooding is predicted to occur for storm events of a return period of once in 10 years on a dry catchment or of once 1 in 1 year on a saturated catchment.

8.1.7 There is scope for introduction of mitigation measures to improve the current drainage systems and to reduce the risk of flooding from surface water runoff.

8.2 RECOMMENDATIONS

8.2.1 Arrange for a programme of detailed investigation and cleaning of all of the existing drainage systems by the responsible Risk Management Authorities:

Highway Drainage:	Hertfordshire County Council as the Highway Authority
Surface water sewers and flood storage area:	Thames Water
Land drainage culvert(s) under the railway:	Network Rail

8.2.2 Develop and implement a programme of planned inspection and maintenance for the existing drainage systems to ensure they operate at their optimum performance.

8.2.3 In addition to the investigation and maintenance measures stated above implement a series of mitigation measures to reduce the risk of flooding from surface water runoff for severe storm events and, at the same time, improve drainage arrangements for less severe rainfall conditions. The optimum combination of mitigation measures should include all of the following:

Option 1.1	Improvements to Highway Drainage Surface Water Collection (HCC)
Option 1.2	Improvements to Highway Drainage, Modify Carriageway Surface Profile and Edge Details (HCC)
Option 2	Improvements to the Existing Flood Storage Area (Thames Water)
Option 3	Improvements to Land Drainage by Provision of Attenuation Storage Features (Land owners)
Option 4	Flood Protection Measures to Individual Properties (Property owners - potentially with assistance/contribution from RMAs)

8.2.4 Of these options there are two that are recommended to be progressed in tandem as a priority. Option 1.2 and Option 4 will provide the most significant part of the potential benefit to the majority of affected properties. Protection measures to affected properties (Option 4) has the potential opportunity of

grant from Stevenage Borough Council through the central government scheme and, if the flood barriers are installed, will avoid internal flooding until such time as other mitigation measures are implemented to reduce the overall risk of flooding. Option 1.2 will ensure that any surface water runoff on Bragbury Lane avoids coming into contact with properties and is routed directly into the flood storage area. The protection measures to the property to the west of Bragbury Lane would not benefit from the impact of Option 1.2, its protection will be solely dependent upon installation of a flood barrier to the property.

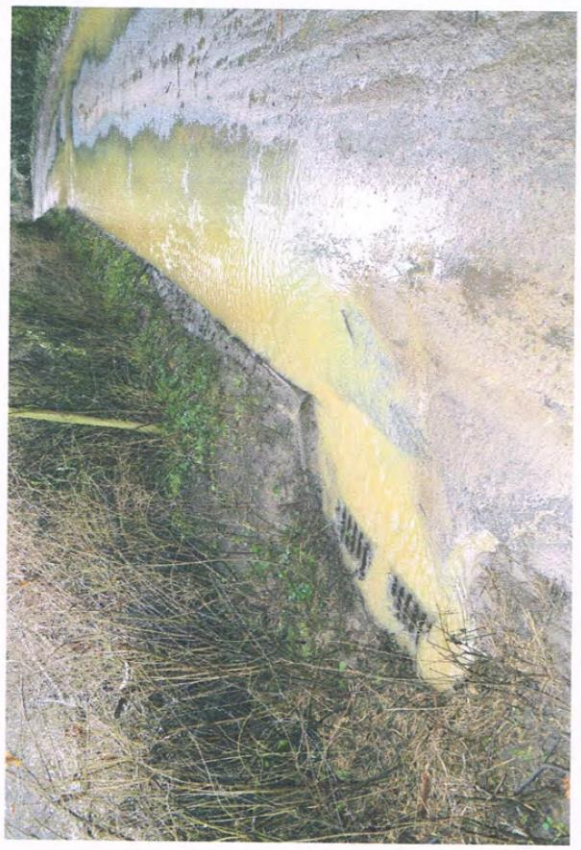
8.2.5 The proposals to improve the flood storage area will reduce further the flood risk to the commercial property in Bragbury Close.

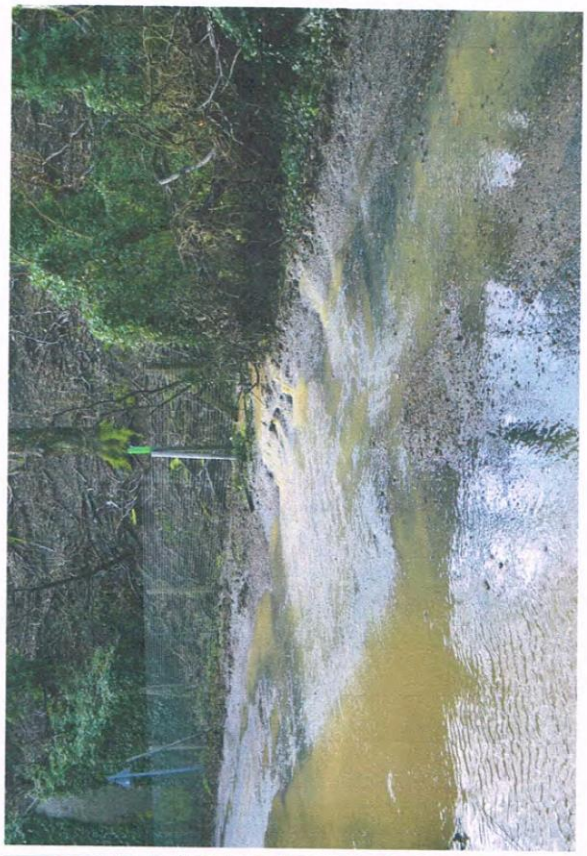
8.2.6 Options 1.1 and 3 would provide additional flood risk protection by removing as much runoff from the surface of Bragbury Lane as possible (Option 1.1) and by attenuating surface water runoff in the upper catchment that would in turn reduce the impact of flows on the drainage systems in the lower catchment.

APPENDIX A

Flood Event Images

[redacted]





APPENDIX B

Runoff Assessment of the storm of 7 February 2014

Saturated Catchment

NOTE: USE 1 IN 1 YEAR DESIGN STORM IN FLOOD2 (RAINFALL FIGURES CORRELATE CLOSELY TO A 1 IN 1 YEAR DESIGN STORM). STORM DURATION = 270 MINUTES

Catchment	Description	Area (ha)	Tc (mins)	Peak Discharge	Flow Channel		Depth of flow on Bragbury Lane (m)	Total Volume of Runoff (m3)	In-catchment Storage (m3)		NET Volume of Runoff	Receptor For Runoff	SW Storage Pipes and Flood Storage Area	FLOOD WATER CONVEYED PAST THE FSA THEN ONTO THE CHEQUERS
				(assumes all contributory area is effectively impermeable due to saturation and runoff is equivalent to 5l/s/ha)			(using Manning formula)	(Ave rainfall intensity from a 1 in 1 year storm of 270 min duration. Input Tc = 54mins into FLOOD2. Ave i = 4.4mm/hr)					Pipes = 144m3 & FSA = 3000m3	
1	Hertford Rd housing development	6	25	386	750mm dia SW sewer connecting to the FSA	Pipe capacity = 780l/s		1188	144	Storage pipes	1044	Flood Storage Area & storage pipes		
				Figure above is from FLOOD using "c5" figure as 100% imp)										
2	Fields (SE)	60.5	90 (but use 60 mins in FLOOD2)	302.5 Figure above and below is area times 5l/s/ha	Bragbury Lane	W= 5m, Gradient = 1 in 73		11979	625		11354	Flood Storage Area & storage pipes		
3	Fields (SW)	108	120 (but use 72min in FLOOD2)	540	Bragbury Lane	W= 5m, Gradient = 1 in 73		21384	7440	pond 1 adj railway	1694	Flood Storage Area & storage pipes		
									7000	pond 2 250m u/s from railway				
				0.8425			0.1375		5250	pond 3 800m u/s from railway				
									19690	TOTAL	14092		3144	10948

Approximate discharge rate (assuming 400 minute duration to end of major runoff event) i.e. 270min storm plus 130min period to end of principal runoff 'surge'

456 l/s

http://www.calctool.org/CALC/eng/civil/manning

Slope of Road	300	0.00333333	Channel Width	Flow Depth	CSA	Wetted Perimeter	Slope (240mm over 72m = 1 in 300)	Q	
			5	0.05	0.25	5.1	0.003333		m3/s
			5	0.1	0.5	5.2	0.003333	0.5	m3/s
			5	0.125	0.625	5.25	0.003333	0.728	m3/s
			5	0.1375	0.6875	5.275	0.003333	0.85	m3/s
			5	0.15	0.75	5.3	0.003333	0.98	m3/s
			5	0.175	0.875	5.35	0.003333	1.26	m3/s
			5	0.2	1	5.4	0.003333	1.56	m3/s

Manning coefficient for Bragbury Lane road surface = 0.012

APPENDIX C

Runoff Assessment of Design Storms

1 in 10 year Dry Catchment

NOTE: USE 1 IN 10 YEAR DESIGN STORM IN FLOOD2

Catchment	Description	Area (ha)	Adjusted Area	Tc (mins)	Peak Discharge	Flow Channel		Depth of flow on Bragbury Lane in front of Flooded Houses (m)	Total Volume of Runoff (m3)	In-catchment Storage (m3)		NET Volume of Runoff	Receptor For Runoff	SW Storage Pipes and Flood Storage Area	FLOOD WATER CONVEYED OVER THE FSA THEN ONTO THE CHEQUERS
			(assumes 40% imp +60% perm@10% imp equiv)		(assumes rural contributory area is equivalent to 10% of total area as 100% impermeable)			(using Manning formula)	(Ave rainfall intensity from a 1 in 10 year storm of 270 min duration. Input Tc = 54mins into FLOOD2. Ave i = 7.8mm/hr)					Pipes = 144m3 & FSA = 3000m3	
1	Hertford Rd housing development	6	2.76	25	333	750mm dia SW sewer connecting to the FSA	Pipe capacity = 780l/s		2106	144	Storage pipes	1962	Flood Storage Area & storage pipes		
2	Fields (SE)	60.5	6.05	90 (but use 60 mins in FLOOD2)	403	Bragbury Lane	W= 5m, Gradient = 1 in 73		21235.5	625		20610.5	Flood Storage Area & storage pipes		
3	Fields (SW)	108	10.8	120 (but use 72min in FLOOD2)	627	Bragbury Lane	W= 5m, Gradient = 1 in 73		37908	7440	pond 1 adj railway	18218	Flood Storage Area & storage pipes		
										7000	pond 2 250m u/s from railway				
		54			1.03			150mm		5250	pond 3 600m u/s from railway				
		54								19690	TOTAL	40790.5		3144	37646.5

Approximate discharge rate (assuming 400 minute duration to end of major runoff event) 1569 l/s — i.e. 270min storm plus 130min period to end of principal runoff 'surge'

Slope of Road 300 0.00333333

http://www.calctool.org/CALC/eng/civil/manning

Channel Width	Flow Depth	CSA	Wetted Perimeter	Slope (240mm over 72m = 1 in 300)	Q	
5	0.05	0.25	5.1	0.003333		m3/s
5	0.1	0.5	5.2	0.003333	0.5	m3/s
5	0.125	0.625	5.25	0.003333	0.728	m3/s
5	0.1375	0.6875	5.275	0.003333	0.85	m3/s
5	0.15	0.75	5.3	0.003333	0.98	m3/s
5	0.175	0.875	5.35	0.003333	1.26	m3/s
5	0.2	1	5.4	0.003333	1.56	m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s

1 in 10 year Saturated Catchment

NOTE: USE 1 IN 10 YEAR DESIGN STORM IN FLOOD2

Catchment	Description	Area (ha)	Adjusted Area	Tc (mins)	Peak Discharge	Flow Channel		Depth of flow on Bragbury Lane in front of Flooded Houses (m)	Total Volume of Runoff (m3)	In-catchment Storage (m3)		NET Volume of Runoff	Receptor For Runoff	SW Storage Pipes and Flood Storage Area	FLOOD WATER CONVEYED OVER THE FSA THEN ONTO THE CHEQUERS
			(assumes 40% imp +60% perm@100% imp equiv)		(assumes all contributory area is effectively impermeable due to saturation and runoff is equivalent to 9l/s/ha) 1 in 10 year runoff is approx 90% greater			(using Manning formula)	(Ave rainfall intensity from a 1 in 10 year storm of 270 min duration. Input Tc = 54mins into FLOOD2. Ave i = 7.8mm/hr)					Pipes = 144m3 & FSA = 3000m3	
1	Hertford Rd housing development	6	6	25	723	750mm dia SW sewer connecting to the FSA	Pipe capacity = 780l/s		2106	144	Storage pipes	1962	Flood Storage Area & storage pipes		
2	Fields (SE)	60.5	60.5	90 (but use 60 mins in FLOOD2)	544.5	Bragbury Lane	W= 5m, Gradient = 1 in 73		21235.5	625		20610.5	Flood Storage Area & storage pipes		
3	Fields (SW)	108	108	120 (but use 72min in FLOOD2)	972	Bragbury Lane	W= 5m, Gradient = 1 in 73		37908	7440	pond 1 adj railway	18218	Flood Storage Area & storage pipes		
										7000	pond 2 250m u/s from railway				
		54			1.5165			200mm		5250	pond 3 600m u/s from railway				
		54								19690	TOTAL	40790.5		3144	37646.5

Approximate discharge rate (assuming 400 minute duration to end of major runoff event) — i.e. 270min storm plus 130min period to end of principal runoff 'surge'

1569 l/s

http://www.calctool.org/CALC/eng/civil/manning

Slope of Road 300 0.003333

Channel Width	Flow Depth	CSA	Wetted Perimeter	Slope (240mm over 72m = 1 in 300)	Q	
5	0.05	0.25	5.1	0.003333		m3/s
5	0.1	0.5	5.2	0.003333	0.5	m3/s
5	0.125	0.625	5.25	0.003333	0.728	m3/s
5	0.1375	0.6875	5.275	0.003333	0.85	m3/s
5	0.15	0.75	5.3	0.003333	0.98	m3/s
5	0.175	0.875	5.35	0.003333	1.26	m3/s
5	0.2	1	5.4	0.003333	1.56	m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s

1 in 100 year Dry Catchment

NOTE: USE 1 IN 100 YEAR DESIGN STORM IN FLOOD2

Catchment	Description	Area (ha)	Adjusted Area	Tc (mins)	Peak Discharge	Flow Channel		Depth of flow on Bragbury Lane in front of Flooded Houses (m)	Total Volume of Runoff (m3)	In-catchment Storage (m3)		NET Volume of Runoff	Receptor For Runoff	SW Storage Pipes and Flood Storage Area	FLOOD WATER CONVEYED OVER THE FSA THEN ONTO THE CHEQUERS
			(assumes 40% imp +60% perm@10% imp equiv)		(assumes rural contributory area is equivalent to 10% of total area as 100% impermeable)			(using Manning formula)	(Ave rainfall intensity from a 1 in 10 year storm of 270 min duration. Input Tc = 54mins into FLOOD2. Ave i = 13.0mm/hr)					Pipes = 144m3 & FSA = 3000m3	
1	Hertford Rd housing development	6	2.76	25	557	750mm dia SW sewer connecting to the FSA	Pipe capacity = 780l/s		3510	144	Storage pipes	3366	Flood Storage Area & storage pipes		
2	Fields (SE)	60.5	6.05	90 (but use 60 mins in FLOOD2)	680	Bragbury Lane	W= 5m, Gradient = 1 in 73		35392.5	625		34767.5	Flood Storage Area & storage pipes		
3	Fields (SW)	108	10.8	120 (but use 72min in FLOOD2)	1062	Bragbury Lane	W= 5m, Gradient = 1 in 73		63180	7440	pond 1 adj railway	43490	Flood Storage Area & storage pipes		
										7000	pond 2 250m u/s from railway				
		54			1.742			215mm		5250	pond 3 600m u/s from railway				
		54								19690	TOTAL	81623.5		3144	78479.5

Approximate discharge rate (assuming 400 minute duration to end of major runoff event) — i.e. 270min storm plus 130min period to end of principal runoff 'surge'

3270 l/s

Slope of Road 300 0.00333333

http://www.calctool.org/CALC/eng/civil/manning

Channel Width	Flow Depth	CSA	Wetted Perimeter	Slope (240mm over 72m = 1 in 300)	Q	
5	0.05	0.25	5.1	0.003333		m3/s
5	0.1	0.5	5.2	0.003333	0.5	m3/s
5	0.125	0.625	5.25	0.003333	0.728	m3/s
5	0.1375	0.6875	5.275	0.003333	0.85	m3/s
5	0.15	0.75	5.3	0.003333	0.98	m3/s
5	0.175	0.875	5.35	0.003333	1.26	m3/s
5	0.2	1	5.4	0.003333	1.56	m3/s
5	0.215	1.075	5.43	0.003333	1.76	m3/s
5	0.225	1.125	5.45	0.003333	1.89	m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s

1 in 100 year Saturated Catchment

NOTE: USE 1 IN 100 YEAR DESIGN STORM IN FLOOD2

Catchment	Description	Area (ha)	Adjusted Area (assumes 40% imp +60% perm@100% imp equiv)	Tc (mins)	Peak Discharge (assumes all contributory area is effectively impermeable due to saturation and runoff is equivalent to 15.7l/s/ha) 1 in 10 year runoff is approx 317% greater than a 1 in 1 year so 5l/s/ha is increased to 15.7l/s/ha)	Flow Channel		Depth of flow on Bragbury Lane in front of Flooded Houses (m) (using Mann formula)	Total Volume of Runoff (m3) (Ave rainfall intensity from a 1 in 10 year storm of 270 min duration. Input Tc = 54mins into FLOOD2. Ave i = 13.0mm/hr)	In-catchment Storage (m3)		NET Volume of Runoff	Receptor For Runoff	SW Storage Pipes and Flood Storage Area Pipes = 144m3 & FSA = 3000m3	FLOOD WATER CONVEYED OVER THE FSA THEN ONTO THE CHEQUERS
1	Hertford Rd housing development	6	6	25	1212	750mm dia SW sewer connecting to the FSA	Pipe capacity = 780l/s		3510	144	Storage pipes	3366	Flood Storage Area & storage pipes		
2	Fields (SE)	60.5	60.5	90 (but use 60 mins in FLOOD2)	949.85	Bragbury Lane	W = 5m, Gradient = 1 in 73		35392.5	625		34767.5	Flood Storage Area & storage pipes		
3	Fields (SW)	108	108	120 (but use 72min in FLOOD2)	1695.6	Bragbury Lane	W = 5m, Gradient = 1 in 73		63180	7440	pond 1 adj railway	43490	Flood Storage Area & storage pipes		
										7000	pond 2 250m u/s from railway				
		54			2.64545			275mm		5250	pond 3 600m u/s from railway				
		54								19690	TOTAL	81623.5		3144	78479.5

Approximate discharge rate (assuming 400 minute duration to end of major runoff event) i.e. 270min storm plus 130min period to end of principal runoff 'surge'

3270 l/s

http://www.calctool.org/CALC/eng/civil/manning

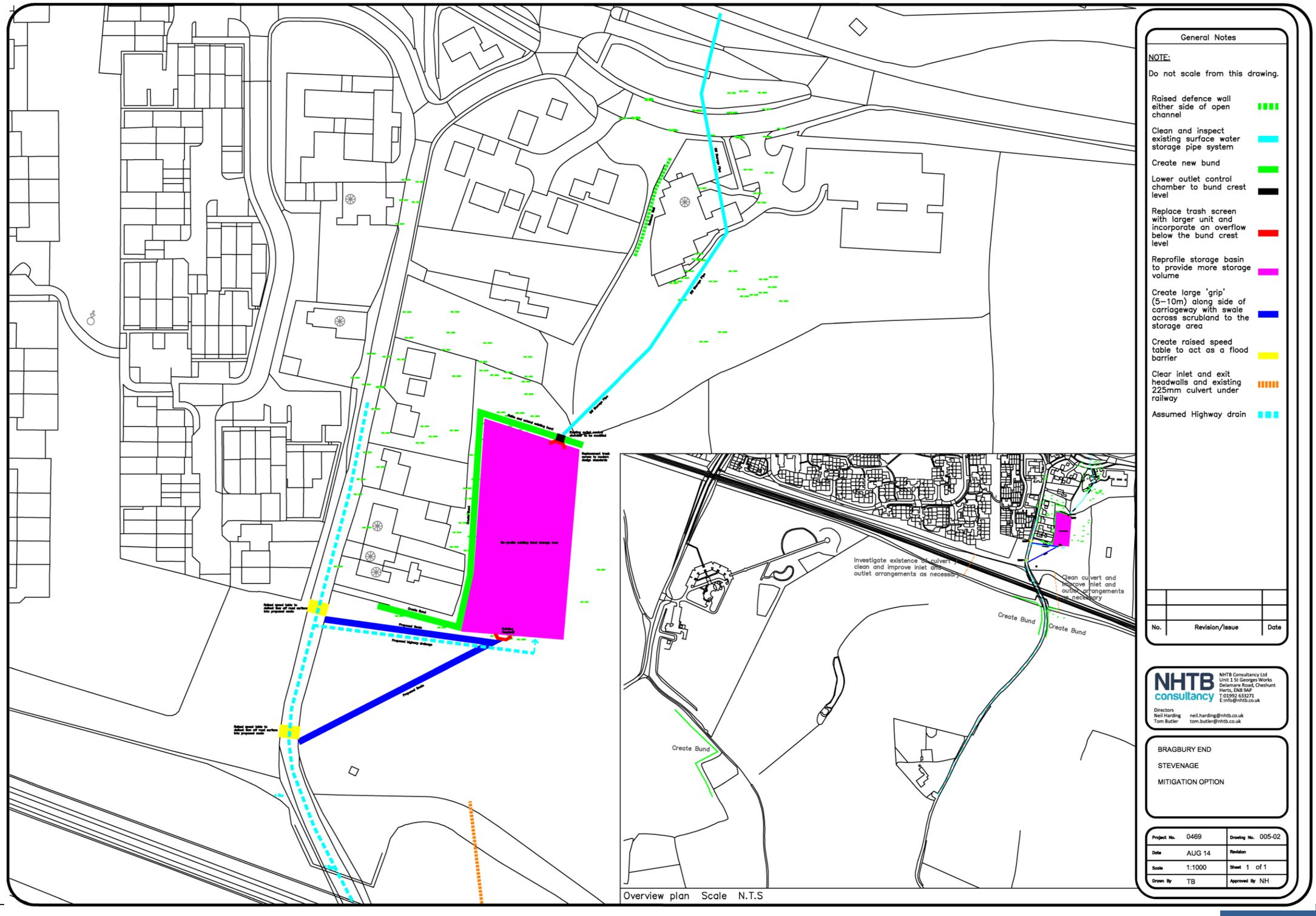
Slope of Road 300 0.00333333

15.7

Channel Width	Flow Depth	CSA	Wetted Perimeter	Slope (240mm over 72m = 1 in 300)	Q	
5	0.05	0.25	5.1	0.003333		m3/s
5	0.1	0.5	5.2	0.003333	0.5	m3/s
5	0.125	0.625	5.25	0.003333	0.728	m3/s
5	0.1375	0.6875	5.275	0.003333	0.85	m3/s
5	0.15	0.75	5.3	0.003333	0.98	m3/s
5	0.175	0.875	5.35	0.003333	1.26	m3/s
5	0.2	1	5.4	0.003333	1.56	m3/s
5	0.215	1.075	5.43	0.003333	1.76	m3/s
5	0.225	1.125	5.45	0.003333	1.89	m3/s
5	0.25	1.25	5.5	0.003333	2.24	m3/s
5	0.275	1.375	5.55	0.003333	2.61	m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s
5	0.1	0.5	5.2	0.003333		m3/s

APPENDIX D

Proposed Mitigation Measures



General Notes

NOTE:

Do not scale from this drawing.

- Raised defence wall either side of open channel
- Clean and inspect existing surface water storage pipe system
- Create new bund
- Lower outlet control chamber to bund crest level
- Replace trash screen with larger unit and incorporate an overflow below the bund crest level
- Reprofile storage basin to provide more storage volume
- Create large 'grip' (5–10m) along side of carriageway with swale across scrubland to the storage area
- Create raised speed table to act as a flood barrier
- Clear inlet and exit headwalls and existing 225mm culvert under railway
- Assumed Highway drain

No.	Revision/Issue	Date

NHTB consultancy

NHTB Consultancy Ltd
Unit 1 St Georges Works
Delamare Road, Cheshunt
Herts, EN8 9AP
T:01992 633271
E:info@nhtb.co.uk

Directors
Neil Harding neil.harding@nhtb.co.uk
Tom Butler tom.butler@nhtb.co.uk

BRAGBURY END

STEVENAGE

MITIGATION OPTION

Project No.	0469	Drawing No.	005-02
Date	AUG 14	Revision	
Scale	1:1000	Sheet	1 of 1
Drawn By	TB	Approved By	NH