ORCHARD WAY / BROOM GROVE

Knebworth

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 04-12-2014	Name  Date 04-12-2014	Name  Date 04-12-2014
	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 Orchard Way and Broom Grove, Knebworth, 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 5 residential properties in Orchard Way and 15 residential properties in Broom Grove.

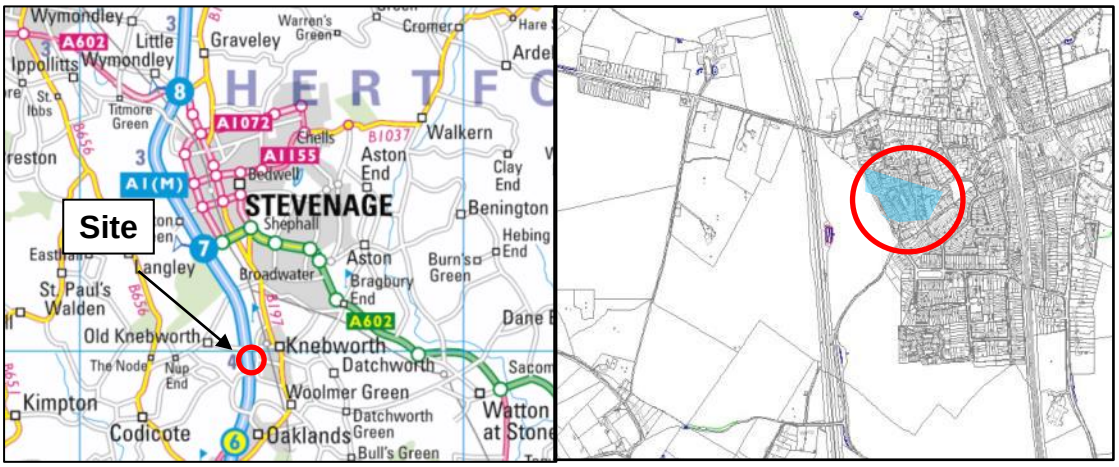


Figure 1: Site Location

2.2 SITE DESCRIPTION

The site is located to the western edge of Knebworth immediately to the east of Gypsy Lane.

The affected areas include part of Orchard Way and also Broom Grove. These areas are situated at the lower end of a natural valley that falls from the A1(M) to the west across a large arable field towards Gypsy 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

The flooding occurred within the flow path of the natural valley runoff, as shown by the direction arrows in Figure 2 below. Refer to Table 1 below for details of the flooded properties.

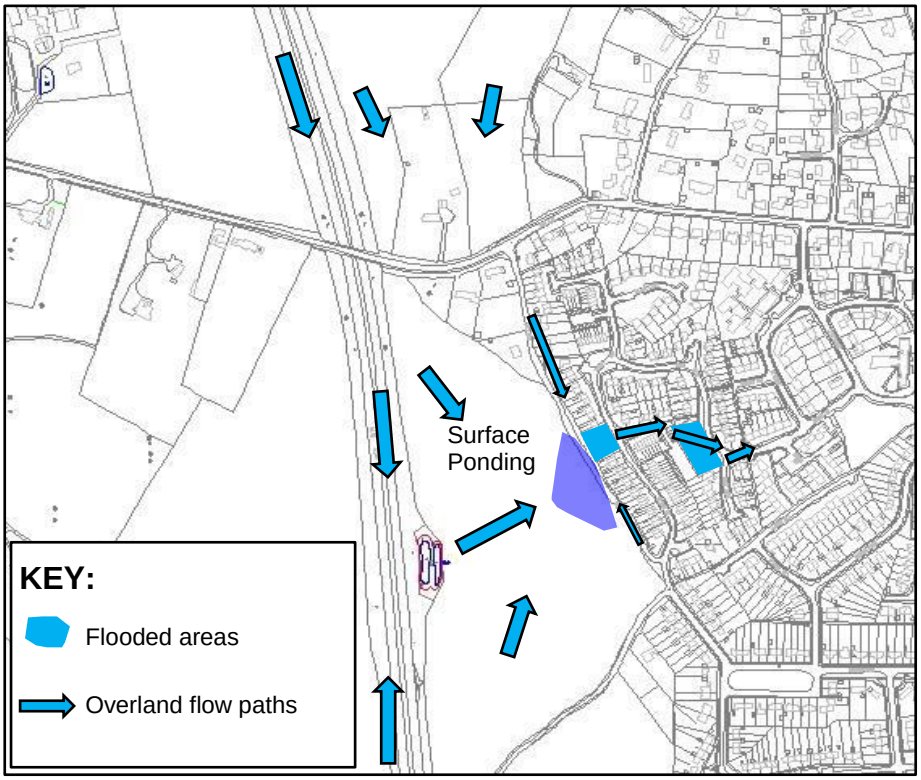


Figure 2: Flooding Mechanism - Overland Flow Paths

3.2.2 Overland Flow Paths

3.2.2.1 Orchard Way

A total of five properties were flooded, four internally.

Water flowed off the adjacent large field between the A1(M) and Gypsy Lane ponding in the field immediately adjacent to Gypsy Lane before overflowing onto the lane and into the rear gardens of the affected properties in Orchard Way. Flood waters built up against the rear of properties before entering properties through rear doors. The flood water migrated around the sides of the houses and across front gardens and onto Orchard Way then flowed down the natural slope towards the turning into the garages at the rear of Broom Grove where it ponded.

Broom Grove

A total of fifteen properties were flooded of which fourteen flooded internally.

The flooding of these properties was the result of flood water from Orchard Way flowing into the rear gardens of properties in Broom Grove. The presence of garden fences and other restrictions to surface flow caused the flood water to accumulate against the rear of the properties until it entered through their rear doors and exited through the front doors and through a limited number of small gaps between some of the properties. Water then flowed down the natural valley in Broom Grove collecting and ponding on the surface at the junction with Gibbons Way where it resulted in flooding of the garden to another property.

The flow path is illustrated in Figure 2 above. The flows were effectively funnelled to the bottom of the natural valley of the catchment.

The flows in the catchment originated from two principal sources:

Rural runoff from large fields,
Runoff from the A1(M) that was suspected of overflowing from a surface water runoff attenuation pond.
This pond was not particularly large and had little effect in mitigating the flows.

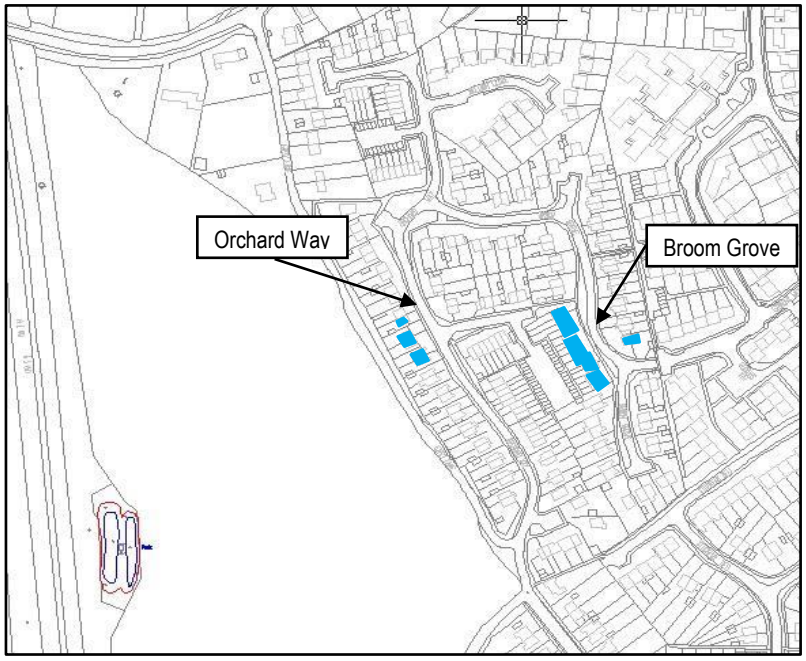


Figure 3: Flooded Properties

Property	Internal Flooding	External Flooding
Orchard Way	Yes (Through rear door)	Yes
Orchard Way	Yes (Through rear door)	Yes
Orchard Way	Yes (Through rear door)	Yes
Orchard Way	Yes (Through rear door)	Yes
Orchard Way	No	Yes
Broom Grove	Yes (Through rear door)	Yes
Broom Grove	Yes (Through rear door)	Yes
Broom Grove	Yes (Through rear door)	Yes
Broom Grove	Yes (Through rear door)	Yes
Broom Grove	Yes (Through rear door)	Yes
Broom Grove	Yes (Through rear door)	Yes
Broom Grove	Yes (Through rear door)	Yes
Broom Grove	Yes (Through rear door)	Yes
Broom Grove	Yes (Through rear door)	Yes
Broom Grove	Yes (Through rear door)	Yes
Broom Grove	Yes (Through rear door)	Yes
Broom Grove	Yes (Through rear door)	Yes
Broom Grove	Yes (Through rear door)	Yes
Broom Grove	Yes (Through rear door)	Yes
Broom Grove	No	Yes

Table 1: Flood Event Impact Summary

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. The properties affected by flooding are shown in Figure 3 above. Interviews were not conducted at all affected properties and the flooding impact details provided in Table 1 above for those properties where no survey was conducted have been interpolated from properties on either side and/or from details supplied by other

residents who were affected by the same flood event. Of the twenty properties affected by flooding, surveys were completed with ten of them. Several attempts were made to contact the others but without success. One property in Orchard Way was still unoccupied after the flooding event in February 2014.

Subsequent to the interview process further flooding events occurred. None of these storm events resulted in internal flooding but significant flooding to rear gardens in Broom Grove and the lower part of Orchard Way was reported (the event of 8 August was witnessed by NHTB Consultancy) as summarised below.

Date of Storm	Storm Duration	Areas Affected
8 August 2014	30 minutes	Road surface in the upper and lower ends of Orchard Way, rear gardens of Broom Grove and lower end of Broom Grove road surface at junction with Gibbons Way
19 September 2014	1 hour	Road surface at the lower end of Orchard Way and rear gardens of Broom Grove
13 October 2014	30 minutes	Road surface at the lower end of Orchard Way and rear gardens of Broom Grove

Table 2: Subsequent Flooding Events after February 2014

The investigations and interviews focussed on the flooding event of 7 February 2014 but from the events observed above it is clear that lesser flooding events occur on a relatively frequent basis. These 'near miss' events do not result in flooding inside properties but gardens are affected and can result in unquantified damages including restricted use of gardens, loss of plants or garden furniture, induced stress from the anticipation of flooding and potentially many other tangible and intangible factors.

3.3.2 Hertfordshire County Council as Lead Local Flood Authority
Local residents in Orchard Way and Broom Grove contacted the LLFA and this study has subsequently been commissioned.

3.3.3 Highway Drainage

3.3.3.1 Hertfordshire County Council as Highway Authority (Highway Drainage)
Residents of Orchard Way and Broom Grove contacted the highways authority to request drain clearance. Details of the highway drainage system are shown I Figure 4.1 below.

3.3.3.2 Highways Agency as Highway Authority for the A1(M) (Highway Drainage)
Engineers who manage the operation and maintenance of the highway drainage for the section of the A1(M) adjacent to the flood affected area on behalf of the Highways Agency, Amey, were contacted by NHTB Consultancy as part of this investigation. They confirmed that there is a surface water runoff attenuation pond present to the east of the A1(M) at the top of the natural valley that crosses from west to east across the large field towards Gypsy Lane/Orchard Way/Broom Grove. The pond feature is visible in Figures 1, 2 and 3 above and Figure 4.2 below. The pond consists of two parallel shallow wetted ponds with a larger

combined area above them that fills during storm events. The pond operates by infiltrating water into the ground below. The engineers could not confirm whether the pond overflowed during the flood event of 7 February 2014.

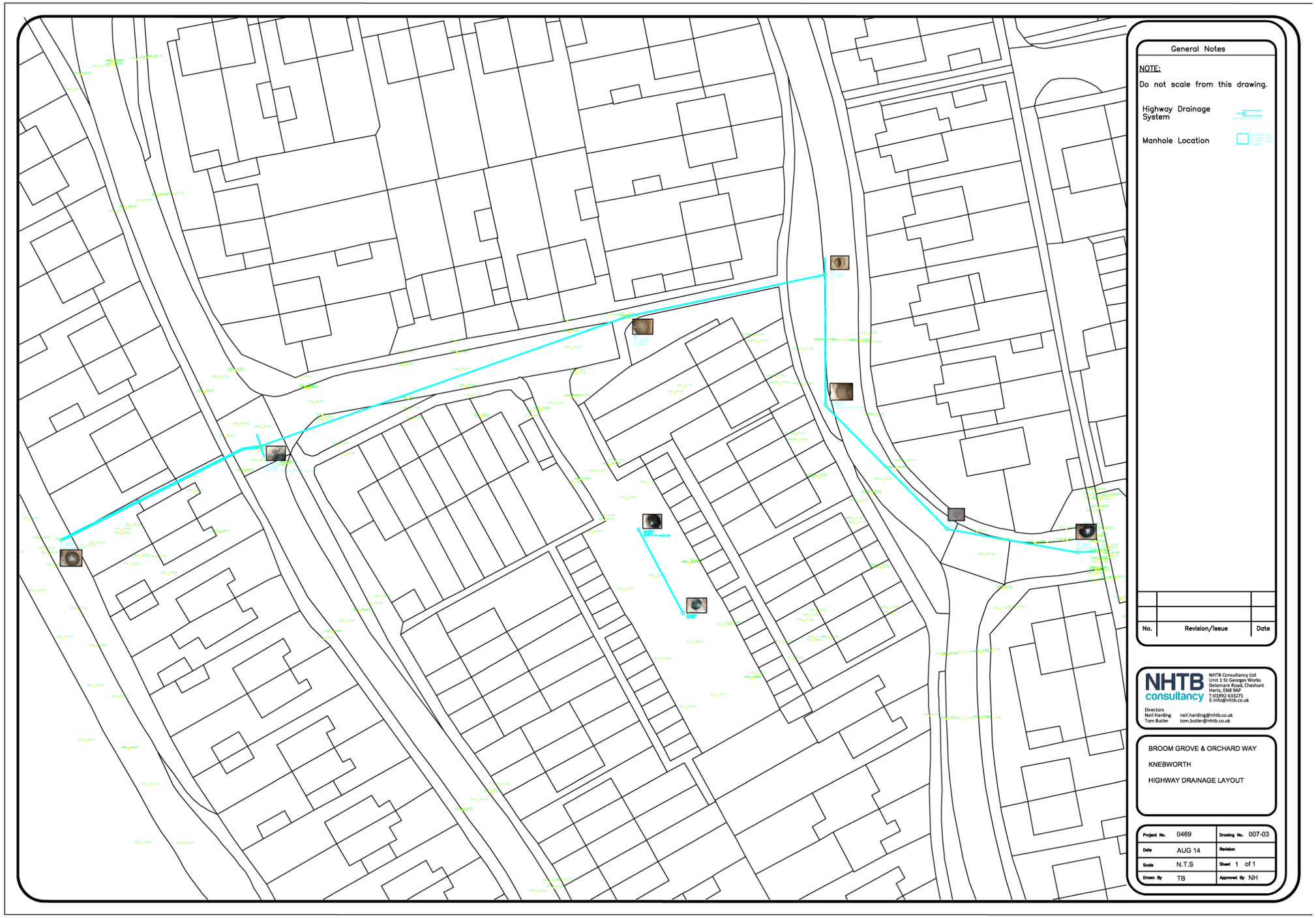


Figure 4.1: Highway Drainage (Hertfordshire County Council)

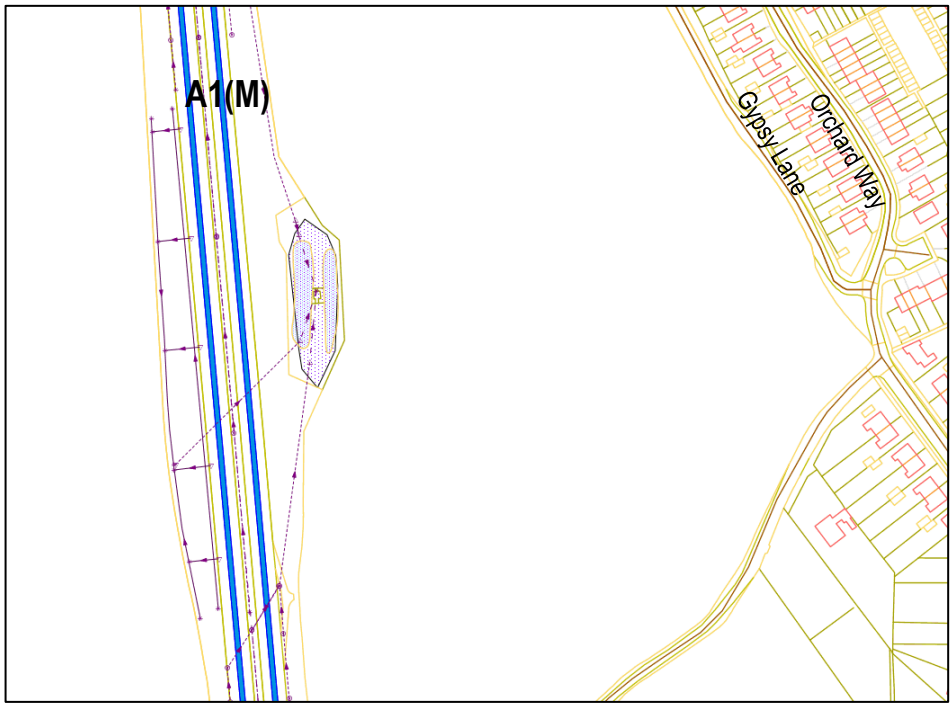


Figure 4.2: A1(M) Highway Drainage (Highways Agency)

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 has not contacted Thames Water as there are no surface water or foul sewers which contributed to the runoff from the catchment.

3.3.5 North Hertfordshire District Council (Ordinary Watercourses)
There are no ordinary watercourses in the vicinity of the site, nor within the catchment which could have any effect on the flow regime from the catchment, or to the flooded area from other directions.

3.3.6 Environment Agency (Main River Watercourses)
There are no Main Rivers within the catchment area, therefore there is no risk from, or correlation to, Main River levels and flooding in this catchment.

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 3 below.

Location	Insurance Claim Costs	Personal Costs
Orchard Way	£2000	£0
Orchard Way	£1000	£9000
Orchard Way	£2000	£5000
Orchard Way	£35000	£2500
Orchard Way	£0	£0
Broom Grove	£0	£11000
Broom Grove	£10800	£0
Broom Grove	£43000	£0
Broom Grove	£21000	£4000
Broom Grove	Not available	Not available
Broom Grove	Not available	Not available
Broom Grove	Not available	Not available
Broom Grove	Not available	Not available
Broom Grove	Not available	Not available
Broom Grove	Not available	Not available
Broom Grove	Not available	Not available
Broom Grove	Not available	Not available
Broom Grove	Not available	Not available
Broom Grove	Not available	Not available
Broom Grove	Not available	Not available
Broom Grove	Not available	Not available
Broom Grove	Not available	Not available
Broom Grove	Not available	Not available
Broom Grove	Not available	Not available
Broom Grove	Not available	Not available

Table 3: Flood Damages - Costs Summary

The damage caused by the internal flooding to four properties in Orchard Way affected all of the ground floor rooms. One of those properties was still unoccupied at the time of the investigation whilst undergoing refurbishment. The damage costs incurred were available from all of the five properties. Typical costs amounted to approximately £14,000 per flooded (internal) property and included works to replace kitchen furniture and fittings plus carpets, plastering, furniture and fittings in the lounge and dining room and hallway.

In Broom Grove less information about the costs of flood damage was obtained from the residents, primarily due to the lower success rate at making contact. The surveys showed that the physical damage to each property was generally very similar, all but one property experienced internal flooding of the entire ground floor and required complete replacement of all fittings and furniture with a significantly higher value insurance claim. The value of the damage to properties varied more widely however with higher costs for properties where fittings and contents with a greater value than at other properties were destroyed by the flood water.
Generally, some residents chose not to submit insurance claims and instead paid for the replacement of flood damaged items and repairs their own expense.

4 HISTORICAL FLOOD EVENTS

4.1 INTRODUCTION

During the flood survey interviews, the residents of Orchard Way and Broom Grove recalled that there was regular ponding of surface water runoff at the lower end of Orchard Way and Broom Grove. Surface water ponding in the large field beside Gypsy Lane had also occurred on several occasions previously.

4.2 FLOOD HISTORY

One resident from Orchard Way recollected that a surface water drain was constructed through his neighbour's property from a roadside ditch alongside Gypsy Lane to the rear into the highway drainage system in Orchard Way to the front shortly after the houses in Orchard Way were constructed and following flooding of Gypsy Lane. Two other residents in Orchard Way recalled that flooding had occurred previously in 1978 and 1987 and that the flooding only affected the external areas of their properties. A long-term resident of Broom Grove recorded in correspondence to Hertfordshire County Council after the February 2014 event that there had been a serious flooding event approximately 20 years previously.

4.2.1 North Hertfordshire District Council - Strategic Flood Risk Assessment (SFRA)

The SFRA produced in 2008 makes no mention of any historic flooding in the part of Knebworth studied in this investigation. The fact that there is no reference to any historical flooding is not conclusive evidence that flooding has not occurred, merely that the SFRA process did not discover any data.

5 CATCHMENT CHARACTERISTICS & EXISTING SURFACE WATER DRAINAGE INFRASTRUCTURE

5.1 INTRODUCTION

The catchment that drains to the area where flooding occurred measures approximately 29 ha. The catchment is shown in Figure 5 below and constitutes the only contributing area to the surface water flooding:

- Arable farmland to the west of the site

There is no surface water sewerage infrastructure, or areas of hardstanding, to contribute to the runoff

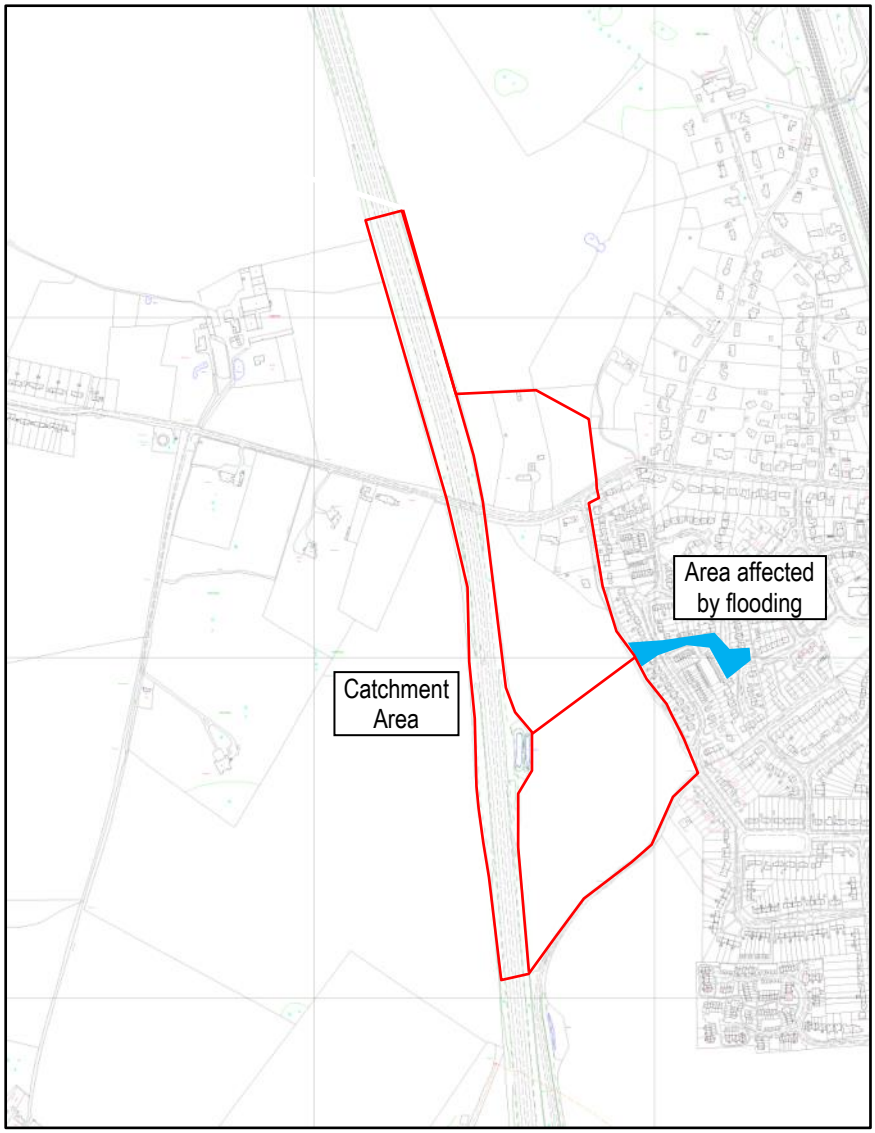


Figure 5: Catchment Boundary

5.2 TOPOGRAPHY & GEOLOGY

5.2.1 The catchment is a relatively steeply sloping catchment, from a high point to the west at approximately 122m elevation to the lowest point in Broom Grove at the eastern boundary of the catchment, at an elevation of approximately 101m.
The land west of Gypsy Lane is almost entirely arable farmland. The western catchment boundary is formed by the A1(M). There is arable land to the north plus a section of Park Lane. Runoff from the entire catchment is funnelled into the field at the rear of Orchard Way.

5.2.2 A topographical survey was conducted of 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 upstream of 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 6 below. This would imply that the catchment is relatively free draining with high permeability. This presumption is explored further in Chapter 6 below.

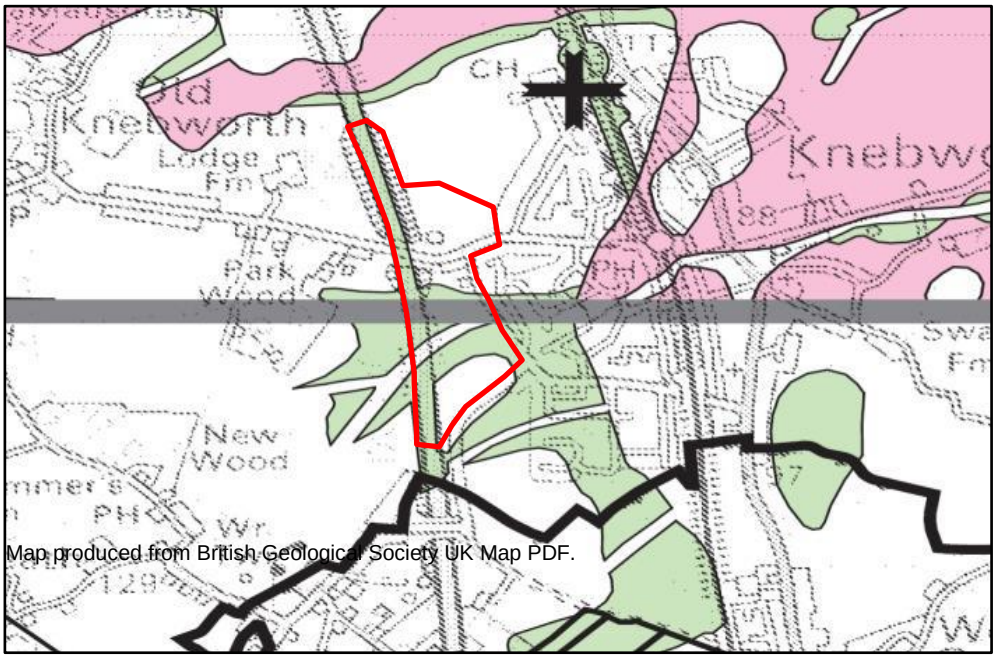


Figure 6: - Geology

Key:
- Catchment boundary
- Chalk bedrock
- Sand and gravel deposits

5.3 LAND USE AND SURFACE WATER DRAINAGE ARRANGEMENTS

There are two principal surface water drainage systems within the catchment comprising mostly natural and a small area of man-made. Different bodies are responsible for each system. The different systems are shown in Figure 7 below.

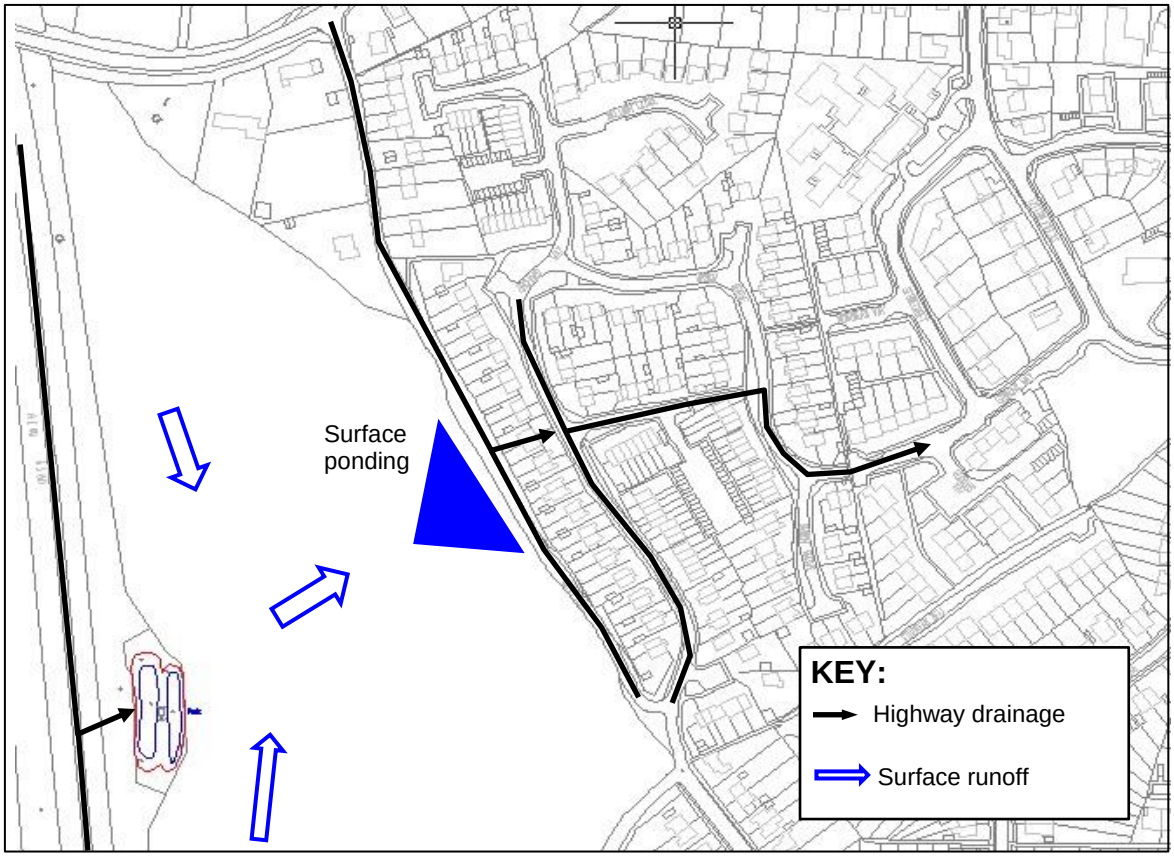


Figure 7: Surface Water Drainage Systems

5.3.1 Highway Drainage

5.3.1.1 A1(M)

All the surface water runoff from a section of the A1(M) over a length of approximately 1000m drains to the attenuation storage pond alongside the road in the field to the west of Gypsy Lane. The pond discharges by infiltration of water into the chalk strata below. The pond was observed from outside the boundary fence as part of this investigation by NHTB Consultancy and it was noted that the invert was heavily overgrown and silted with standing water present. It is highly probable that the pond did not operate at its optimum during the storm event in February 2014 because of the silt and vegetation.

5.3.1.2 Estate Drainage

There is a highway drainage system serving Gypsy Lane, Orchard Way and Broom Grove. A survey of this system was conducted as part of this investigation in October.

There is only a single point of entry into the highway drainage system in Gypsy Lane, via the chamber in the invert of the ditch alongside the road at its lowest point behind Orchard Way. The entry to this chamber was almost entirely obstructed by silt. There are a few isolated road gullies evident in Orchard Way and Broom Grove and appeared generally clear during our surveys on site, except for some silt in the bases. Highway drainage system manholes were also inspected and significant quantities of silt were identified in many. The silt will

severely restrict the hydraulic capacity of the pipes. It had been proposed by the residents that the drainage was blocked and would have made some difference to the flooding. The gullies were unlikely to have significantly affected the performance of the highway drainage system. The gullies assist in conveying water off the road surface and towards the highway drainage system. The gullies would not be expected to cater for the surface flow in extreme storm conditions (refer to Section 6.2.4 below).

5.3.2 Surface water sewerage (Thames Water)

5.3.2.1 There is no surface water sewerage network in either Gypsy Lane, Orchard Way or Broom Grove.

5.3.3 Land Drainage

5.3.3.1 Field Drainage (Farmer)

The catchment to the west consists of ploughed fields. The fields effectively form a natural valley profile aligned towards a natural low spot adjacent to the rear of Orchard Way. The catchment is relatively steep with an average gradient of approximately 1:25. This would result in a relatively short time of concentration of runoff, especially considering the existing ground conditions at the time of this event.

5.3.3.2 Ordinary watercourses (North Hertfordshire District Council)

There are no Ordinary Watercourses within the catchment or that could affect the flooding.

All surface water runoff from the catchment ultimately drains into the River Beane several kilometres to the east of the catchment. The watercourse is classified as a Main River and therefore falls within the overall administration of the Environment Agency's land drainage powers.

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 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 Lead Local Flood Authority for this investigation. The gauges were located at the following sites shown geographically in Figure 8 below:

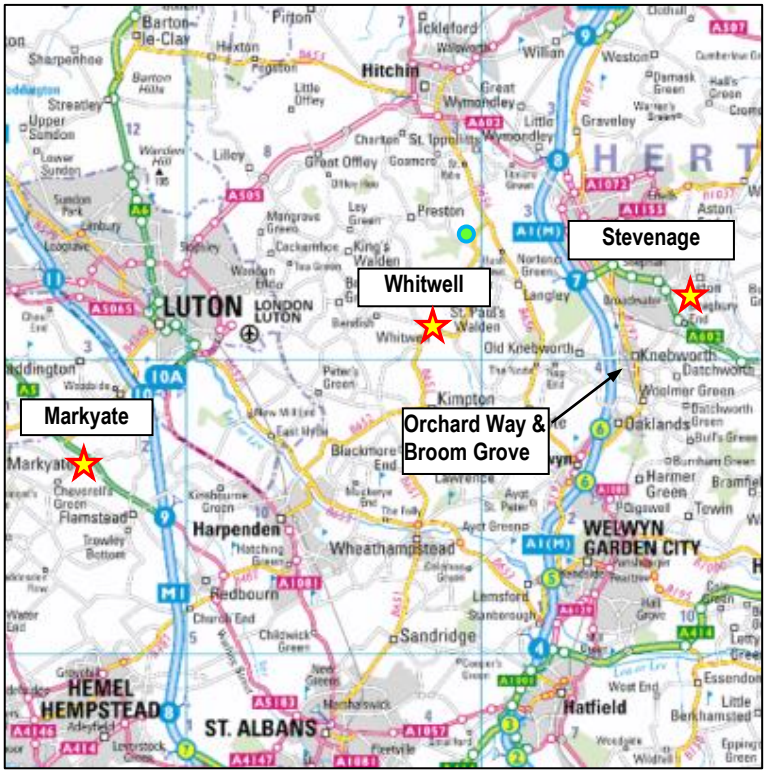


Figure 8: Rain gauge locations

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 4.

	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

Table 4: 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 four and a half hours

(ii) 19.6mm of rain was recorded at the Stevenage rain gauge (the nearest to the investigation site).

(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 in Stevenage at 3.2 mm in the 15 minute time period from 03:45am until 04:00am. This equates to an average intensity of 12.8mm/hr. The average intensity for the storm event as a whole was 4.2mm/hr (19.6mm over 4:30 hours).

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

data in Table 5 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***	***4.2 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 5: 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 Knebworth. 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 an area of ponding in the adjacent field beside Gypsy Lane. An assessment of the rainfall recorded over the preceding 28 days is reported in Table 6 below.

	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**

Table 6: Antecedent Rainfall Summary

The data above in Table 6 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 9 below. The amount recorded is typically 85% 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). The quantity of rainfall also resulted in the formation of ponding 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).

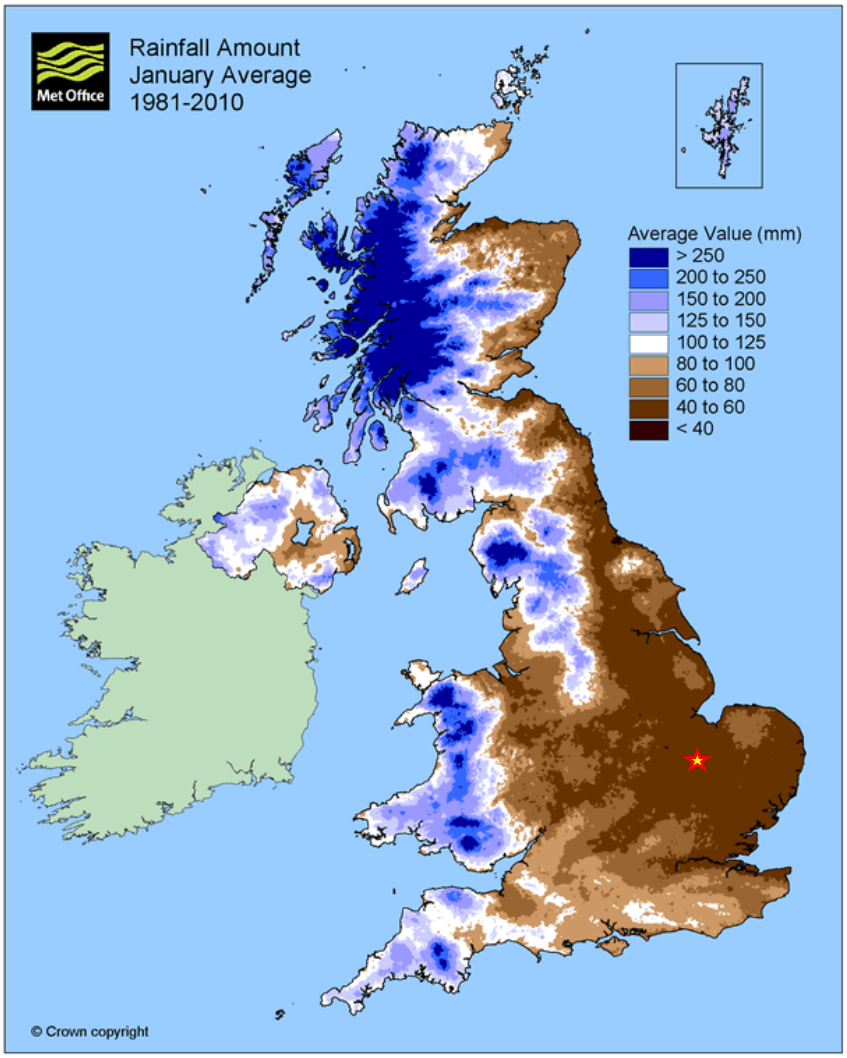


Figure 9: Average Monthly Rainfall Depth for January

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 three catchment areas (refer to Figure 5), namely the farmland to the north, farmland to the south and area of residential development. The analyses are included in Appendix A. The analyses included certain assumptions as summarised below:

(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 - based on findings from the survey conducted in October 2014.

(iii) The rainfall intensity profile during the storm was assumed to be an equivalent average intensity.

The analyses show that there was an excess of surface water runoff that could not be contained within the natural surface hollow in the large field in the catchment, and a peak discharge across Gypsy Lane and into Orchard Way with a calculated depth of 110mm.

The total runoff from the event amounted to 5,742m^3.

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 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 Orchard Way will convey flows to the natural low point in the road to the rear of Broom Grove where there are two gullies. Normally highway drainage is designed for storm conditions that are less severe than the exceptional weather that occurred over the winter of 2013-14. We would not expect the drainage system to 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 150mm diameter pipe at a gradient representative of the lower section of the catchment in the vicinity of Orchard Way and the garages behind Broom Grove (typically 1 in 27), is 34l/s. The typical rate of surface water flow on Orchard Way resulting from runoff from the large rural catchment upstream is calculated as 855l/s for the February 2014 event (Refer to Appendix A). The highway drainage system is able to convey approximately 4% of the storm runoff from the February 2014 event and the remaining flow would remain on the road surface.

The drainage of the A1(M) will result in all surface water runoff, either through French Drains alongside the carriageways or over the surface in intense rainfall conditions, towards the low point in the road adjacent to the storage pond. The pond should be able to accommodate runoff from minor storm events but it is highly likely that under extreme rainfall conditions more water than the pond can accommodate and infiltrate into the ground would overspill the pond onto the adjacent field where it would be conveyed towards Gypsy Lane. The storage pond has a reduced capacity due to the accumulation of silt and vegetation. Given the saturated nature of the ground immediately prior to the storm of 7 February it is highly probable that the pond was partially, or even completely filled with runoff from earlier rainfall. There are no eyewitness accounts of water flowing out of the pond on the morning of 7 February because the storm occurred during the hours of darkness. The images below in Figure 10 do, however, show a stream of flow from the direction of the pond (located in the tree line at the rear of the field in the distance). This point is discussed further in section 6.3 below.

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) 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 B. 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.

6.3.2.1 Overland Flow Path Water Depth

The following summary Table 7.1 shows the calculated depth of flood water in the flow path off the large field adjacent to Gypsy Lane. The following figures support eye witness accounts and photographic evidence (see Figure 10 below) and are indicative of the expected flood depths to be expected for more extreme storm events.

Storm	**Depth of flow across flow path**
1 in 10 year dry catchment	160mm
1 in 10 year wet catchment	160mm
1 in 100 year dry catchment	215mm
1 in 100 year wet catchment	215mm
7 February 2014	**110mm**

Table 7.1: Summary of Design Storm Hydrological Analyses

6.3.2.2 An assessment was made of the expected runoff from the A1(M) into the storage pond to ascertain whether there is any likelihood of overspill from that pond contributing towards flood water in Gypsy Lane/Orchard Way/Broom Grove. The figures in Table 7.2 below show how the increasing volumes of runoff from storms of increasing severity exceed the maximum available capacity of the pond and also how a saturated drainage system in combination with a full pond from prior

rainfall affects the quantity of overspill from the pond. It has been assumed in the analyses that all inflow into the pond that infiltrates into the ground does not remerge onto the ground surface of the adjacent field that slopes away towards Gypsy Lane. It has also been assumed that there is effectively no infiltration during the storm due to the short storm duration. In any future detailed analysis these assumptions should be taken into consideration. From the figures it can be seen that the pond provided sufficient capacity to accommodate all the runoff from storm events of no greater severity than a 1 in 10 year design storm (with a dry antecedent condition). It can be observed that the total runoff from the A1(M), if it overspills from the storage pond, contributes approximately 40% additional flow to that from the natural catchment. If the A1(M) pond overspills the resultant water would increase the potential flood risk to Orchard Way and Broom Grove.

Storm	Available Volume of Storage in the Pond	Total Runoff from A1(M)	Total Natural Catchment Runoff
1 in 10 year dry catchment	3600m^3	3054m^3	7125m^3
1 in 10 year wet catchment	0m^3	3054m^3	7125m^3
1 in 100 year dry catchment	3600m^3	5090m^3	11876m^3
1 in 100 year wet catchment	0m^3	5090m^3	11876m^3
7 February 2014	**0m^3**	**1722m^3**	**4019m^3**

Table 7.2: Summary of Design Storm Hydrological Analyses for the A1(M) Storage Pond

Figure 10: Images of runoff from field adjacent to Gypsy Lane during storm of 7 February 2014
(Images courtesy of resident of Orchard Way)

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 four properties in Orchard Way and fifteen in Broom Grove. For more extreme storm conditions it is projected that the internal flooding would be deeper and would cause internal flooding to additional properties in Orchard Way (one, possibly two properties) with an increase in depth of flooding to those that were flooded internally in February. The average value of insurance claims and privately funded repairs/purchases made by those for which data is available is £20,000. This value reflects the greater damage and repair costs associated with the greater depth of flood water that affected the entire ground floor of properties in Broom Grove. 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.
In consideration of these factors we consider that the typical costs of damages for each residential property are as shown below in Table 8.

Property Type	**Predicted Damage Costs**	
	1 in 10 years	**1 in 100 years**
Residential (Orchard Way & Broom Grove)	£20,000 / property	£22,000 / property

Table 8: 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 11. They show a reasonable correlation with the surface water runoff witnessed by local residents on 7 February 2014. The map indicates that surface water runoff from the catchment would flow eastwards to the low point behind Orchard Way. The map also indicates the passage of surface water runoff, with surface ponding, to the west of the A1(M). There was no evidence uncovered during this investigation to confirm that this flow path operated during the flooding event in February. It is possible that any surface runoff, if it occurred as would be expected on a saturated catchment, was intercepted by the A1(M) attenuating the flow. The A1(M) is on an elevated embankment that is located across the natural valley at this point. It could be possible for some flow to pass beneath the road via the highway drainage system and into the storage pond but this would be dependent upon the condition and capacity of the drainage system. The road embankment forms a barrier to excess surface water runoff from the field system and a large pond of water would be expected to be evident on the upstream side of the embankment in severe storm conditions. The analyses conducted as part of this investigation have not included any catchment to the west of the A1(M) but the potential for this area to contribute towards the overall catchment draining to the western perimeter of Knebworth should be studied in detail as part of any future assessment and design of potential mitigation measures.

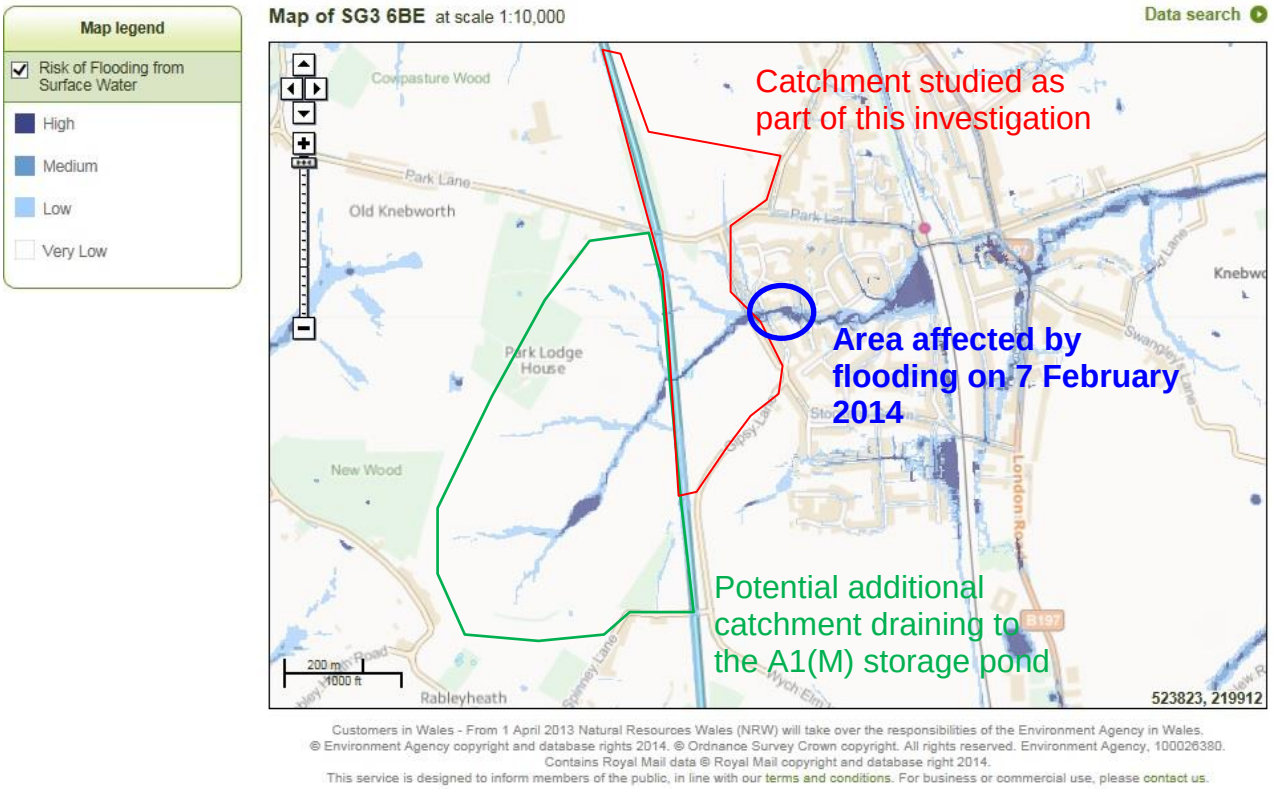


Figure 11: Environment Agency Surface Water Maps

7 FLOOD MITIGATION AND RESILIENCE OPTIONS

7.1 INTRODUCTION

There is suitable scope to provide mitigation to reduce flooding. The highway drainage has potential scope to be improved, either by regular planned inspection and maintenance and/or by improvement to increase the hydraulic performance. This section provides a brief overview of the various options available, they can be implemented individually or in combination. A description is provided of the relative merits and issues associated with each option. 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 C.

7.2 MAINTENANCE ENHANCEMENTS

7.2.1 Locate, survey and clean highway drainage system

There are two discrete highway drainage systems; that operated by Hertfordshire County Council and that by Amey on behalf of the Highways Agency for the A1(M). It has been assumed that the existing highway drainage systems each have limited capacity and offer limited protection against flooding based on the results of the survey conducted as part of this investigation. The following measures should be instigated:

(i) It is recommended that both systems are cleaned using high pressure jetting, and a CCTV survey conducted to establish any serious structural defects that are inhibiting optimum hydraulic performance.
(ii) The storage pond for the A1(M) should be investigated and an assessment made of its operational performance made including any overspill arrangements.
(iii) A programme of routine inspection and reactive maintenance of gullies and French Drains should be introduced.
(iv) These actions should be implemented by Hertfordshire County Council Highways Department and the Highways Agency.

7.3 MITIGATION OPTIONS

The various mitigation options are summarised in the following Tables 9.1 to 9.6 on the following pages.

Ref:	Description
1	**Improvements to Highway Drainage - Surface Water Collection** There is suitable scope to improve the surface water collection and disposal capacity for runoff from the carriageway surface. 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. We recommend that additional gullies are installed at a greater density required in the design standards to allow for the inevitable blockage of some gullies during extreme storm events. Increase the pipework capacity
	Advantages: Improved collection and disposal of surface water from the road surface Reduced likelihood of blockage to gullies
	Issues: Increased maintenance liability
	Budget Cost Estimate: £150,000

Table 9.1: Mitigation Option 1 - Improvements to Highway Drainage Surface Water Collection

Ref:	Description
2	**Improvements to Highway Drainage - Modify Carriageway Surface Profile and Edge Details** Reprofile the footpath and grassed verge at the lower end of Orchard Way to form a dedicated surface flow path to convey excessive surface water runoff from Orchard Way directly onto the road surface of Broom Grove. Raise the kerbs along Broom Grove to the connection with Gibbons Way. Remove the raised barrier between Broom Grove and Gibbons Way and replace with bollards. Raise the kerb edgings to the southern side of Gibbons Way alongside the green area as far as the turning into the rear service road (to protect adjacent properties from flooding off the road) Create a flow path from the end of the service road at the rear of Gibbons Way (southern side) onto the adjacent public open space Form a scalloped swale feature in the open space to accommodate surface runoff. Include a connection from the swale to the highway drainage system in Lytton Fields/Hornbeam Spring.
	Advantages: Significantly reduce risk of flooding to properties in Broom Grove.
	Issues: Does nothing to reduce risk of flooding to properties in Orchard Way
	Budget Cost Estimate: £175,000

Table 9.2: Mitigation Option 2 - Improvements to Highway Drainage, Modify Carriageway Surface Profile and Edge Details

Ref:	Description
3	**Improvements to Highway Drainage - Install flood wall, additional drainage and increase capacity of existing connection to Orchard Way from Gypsy Lane** Construct a dwarf wall along the rear of Orchard Way on the downstream side of Gypsy Lane to prevent overland flow off Gypsy Lane entering rear gardens. Improve the roadside ditch and catch-pit chamber arrangement beside Gypsy Lane to include more inlets for flow to the highway drainage system Provide additional capacity to the highway drain from the catch-pit in Gypsy Lane to the highway drainage system in Orchard Way.
	Advantages: Significantly reduce risk of flooding to properties in Orchard Way.
	Issues: Increased maintenance liabilities Requires consent from private landowner in Orchard Way to work on their property to increase the drainage capacity
	Budget Cost Estimate: £40,000

Table 9.3: Mitigation Option 3 - Improvements to Highway Drainage (Gypsy Lane to Orchard Way)

Ref:	Description
4	**Improvements to Highway Drainage - Improve the infiltration and storage capabilities of the existing storage pond serving the A1(M)** Raise the ground level around the pond and re-profile the inner area/extend the pond to provide additional storage capacity Increase the infiltration capacity by provision of additional infiltration zone contact area(s)
	Advantages: Significantly reduce risk of flooding to properties in Orchard Way and Broom Grove.
	Issues: Increased maintenance liabilities
	Budget Cost Estimate: £20,000

Table 9.4: Mitigation Option 4 - Improvements to Highway Drainage - A1(M)

Ref:	Description
5	**Improvements to Land Drainage Arrangements by Provision of Attenuation Storage Features** Provide a raised embankment in the field to the rear of Orchard Way alongside Gypsy Lane with a restricted outlet to drain into the highway ditch alongside Gypsy Lane.
	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 outlet arrangements Potential damages for loss of crops Embankment is likely to be large to contain sufficient runoff unless constructed in combination with other mitigation options.
	Budget Cost Estimate: £35,000

Table 9.5: Mitigation Option 5 – Improvements to Land Drainage by Provision of Attenuation Storage Features

Ref:	Description
6	**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 Orchard Way and Broom Grove. 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. In addition, remove flow barriers at sides of properties and replace with flow sensitive alternatives (i.e. large wooden gates/fencing replaced with iron gates / open slatted fencing or raised fencing) to reduce backup effect / blockage. 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*
	Advantages: Protection to the inside of the properties.
	Issues: Requires consent from the local landowners Dependence upon sufficient grant and/or top-up or possible contribution from property owners Owner intervention required to install non-automatic flood barriers No protection to the gardens and driveways
	Budget Cost Estimate: £0 - £75,000

Table 9.6: Mitigation Option 6 - 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 10. The costs and benefits are approximate and accurate figures should be developed as part of detailed development of options. The approximate benefit value has been taken for this exercise as £20,000 per property. This takes into account the fact that the actual costs incurred from many affected properties in the flood event were not obtained but it is understood that the nature of the damage incurred was considerable. It is likely, therefore that the average cost (benefit) to each property would be greater than that revealed during this study.

Mitigation Option	Costs	Properties Benefitted	Benefit Value			
			1 in 10 yr	Benefit: Cost	1 in 100 yr	Benefit: Cost
2	£175,000	Broom Grove (15 No.)	£300,000	1 : 1.71	£330,000	1 : 1.89
3	£40,000	Orchard Way (5 No.)	£100,000	1 : 2.50	£110,000	1 : 2.75
2+3	£215,000	Broom Grove (15 No.) Orchard Way (5 No.)	£400,000	1 : 1.86	£440,000	1 : 2.05

Table 10: Benefit : Cost Comparison for Selected Mitigation Measures

8 CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

8.1.1 A total of 20 properties were affected by the storm event of 7 February 2014 in Orchard Way and Broom Grove. The majority were flooded internally.

8.1.2 The flooding was the result of excessive surface water runoff from a primarily rural 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 through the rear gardens of properties in Orchard Way, onto the road surface at the front and down to the rear gardens of Broom Grove where the flood water built up in level before entering several properties.

8.1.4 Flooding was exacerbated by the poor performance of the highway drainage system in the area. The estate road highway drainage includes gullies that are inadequate in number and performance due to blockages and the storage pond to the A1(M) has a relatively low theoretical performance.

8.1.5 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.

8.1.6 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.

8.1.7 Multiple mitigation measures will need to be implemented to achieve the optimum reduction in risk of flooding from surface water.

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 and the Highways Agency as the Highway Authorities

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 **Improvements to Highway Drainage Surface Water Collection**
Option 2 **Improvements to Highway Drainage, Modify Carriageway Surface Profile and Edge Details**
Option 3 **Improvements to Highway Drainage (Gypsy Lane to Orchard Way)**
Option 4 **Improvements to Highway Drainage - A1(M)**
Option 5 **Improvements to Land Drainage by Provision of Attenuation Storage Features**
Option 6 **Flood Protection Measures to Individual Properties**

8.2.4 Of these options there are three that are recommended to be progressed in tandem as a priority. Option 2, Option 3 and Option 6 will provide the most significant part of the potential benefit to the affected properties. Protection measures to affected properties (Option 6) has the potential opportunity of grant from North Hertfordshire District Council through the central government scheme. If the flood barriers are initially installed in Option 6, it will avoid internal flooding until such time as other mitigation measures are implemented to reduce the overall risk of flooding.

The combination of Options 2 and 3 will effectively convey flood water past the affected properties and into a purpose built swale in the public open space. The designated flow path between Orchard Way and Broom Grove will provide significant benefit to properties in Broom Grove.

Option 5 offers significant benefits but will also require the implementation of Option 3 to avoid flooding from runoff along Gypsy lane.

Option 4 should be investigated further as it is possible that there is a larger catchment draining towards Gypsy Lane with surface water runoff from that catchment being intercepted by the existing storage pond alongside the A1(M).

APPENDIX A

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 off Field onto Gypsy Lane (mm)	Total Volume of Runoff (m3)	In-catchment Storage (m3)	NET Volume of Runoff	Receptor For Runoff
				Figure below from FLOOD using "c5" figure as 100% imp)			(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)		NOTE:-Assumed A1 Pond full at time of storm from antecedent conditions, so actual net volume=total runoff volume	
1	A1	8.7	15	754	Orchard Way/Broom Grove	W=4.6m, Gradient = 1 in 25		1722.6	3600	-1877.4	Gypsy Lane/Orchard Close / Broom Grove
				Figure below is area times 5l/s/h							
2	Field (E)	10.2	35	51	Orchard Way/Broom Grove	W=4.6m, Gradient = 1 in 25		2019.6	456	1563.6	Gypsy Lane/Orchard Close / Broom Grove
3	Field (N)	10.1	35	50.5	Gypsy Lane	W=4.6m, Gradient = 1 in 25		1999.8		1999.8	Gypsy Lane/Orchard Close / Broom Grove
				0.8555			110mm			5286	TOTAL Volume Runoff

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

Slope of Ground	25	0.04	Channel Width	Flow Depth	CSA	Wetted Perimeter	Slope (3000mm over 84m = 1 in 30)	Q	
			4.6	0.05	0.23	4.7	0.04	0.25	m3/s
			4.6	0.06	0.276	4.72	0.04	0.33	m3/s
			4.6	0.07	0.322	4.74	0.04	0.43	m3/s
			4.6	0.08	0.368	4.76	0.04	0.53	m3/s
			4.6	0.09	0.414	4.78	0.04	0.65	m3/s
			4.6	0.1	0.46	4.8	0.04	0.77	m3/s
			4.6	0.11	0.506	4.82	0.04	0.9	m3/s
			4.6	0.12	0.552	4.84	0.04	1.04	m3/s
			4.6	0.13	0.598	4.86	0.04	1.18	m3/s
			4.6	0.14	0.644	4.88	0.04	1.33	m3/s
			4.6	0.15	0.69	4.9	0.04	1.49	m3/s

APPENDIX B

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 A1 @100% Imp, Fields at 100%perm @10% Imp	Tc (mins)	Peak Discharge (assumes rural contributory area is equivalent to 10% of total area as 100% impermeable)	Flow Channel		Depth of flow off Field onto Gypsy Lane (mm) (using Manning 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 = 7.8mm/hr)	In-catchment Storage (m3)	NET Volume of Runoff	Receptor For Runoff
1	A1	8.7	8.7	15	1438	Orchard Way/Broom Grove	W=4.6m, Gradient = 1 in 25		3053.7	3600	-546.3	Gypsy Lane/Orchard Close / Broom Grove
2	Field (E)	10.2	1.02	35	91	Orchard Way/Broom Grove	W=4.6m, Gradient = 1 in 25		3580.2	648	3580.2	Gypsy Lane/Orchard Close / Broom Grove
2	Field (N)	10.1	1.01	35	90	Gypsy Lane	W=4.6m, Gradient = 1 in 25		3545.1		3545.1	Gypsy Lane/Orchard Close / Broom Grove
					1.619			160mm			10179	TOTAL Volume Runoff

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

Slope of Ground	25	0.04	Channel Width	Flow Depth	CSA	Wetted Perimeter	Slope (3000mm over 84m = 1 in 30)	Q	
			4.6	0.05	0.23	4.7	0.04	0.25	m3/s
			4.6	0.06	0.276	4.72	0.04	0.33	m3/s
			4.6	0.07	0.322	4.74	0.04	0.43	m3/s
			4.6	0.08	0.368	4.76	0.04	0.53	m3/s
			4.6	0.09	0.414	4.78	0.04	0.65	m3/s
			4.6	0.1	0.46	4.8	0.04	0.77	m3/s
			4.6	0.11	0.506	4.82	0.04	0.9	m3/s
			4.6	0.12	0.552	4.84	0.04	1.04	m3/s
			4.6	0.13	0.598	4.86	0.04	1.18	m3/s
			4.6	0.14	0.644	4.88	0.04	1.33	m3/s
			4.6	0.15	0.69	4.9	0.04	1.49	m3/s
			4.6	0.16	0.736	4.92	0.04	1.66	m3/s
			4.6	0.165	0.759	4.93	0.04	1.74	m3/s
			4.6	0.17	0.782	4.94	0.04	1.83	m3/s

1 in 10 year Saturated Catchment

NOTE: USE 1 IN 10 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 9l/s/ha) 1 in 10 year runoff is approx 90% greater than a 1 in 1 year so 5l/s/ha is increased to 9l/s/ha)	Flow Channel		Depth of flow off Field onto Gypsy Lane (mm) (using Manning 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 = 7.8mm/hr)	In-catchment Storage (m3)	NET Volume of Runoff	Receptor For Runoff
1	A1	8.7	8.7	15	1438	Orchard Way/Broom Grove	W=4.6m, Gradient = 1 in 25		3053.7	3600	-546.3	Gypsy Lane/Orchard Close / Broom Grove
2	Field (E)	10.2	10.2	35	91.8	Orchard Way/Broom Grove	W=4.6m, Gradient = 1 in 25		3580.2	648	3580.2	Gypsy Lane/Orchard Close / Broom Grove
2	Field (N)	10.1	10.1	35	90.9	Gypsy Lane			3545.1		3545.1	Gypsy Lane/Orchard Close / Broom Grove
					1.6207			160mm			10179	TOTAL Volume Runoff

Slope of Ground 25 0.04

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

Channel Width	Flow Depth	CSA	Wetted Perimeter	Slope (3000mm over 84m = 1 in 30)	Q	
4.6	0.05	0.23	4.7	0.04	0.25	m3/s
4.6	0.06	0.276	4.72	0.04	0.33	m3/s
4.6	0.07	0.322	4.74	0.04	0.43	m3/s
4.6	0.08	0.368	4.76	0.04	0.53	m3/s
4.6	0.09	0.414	4.78	0.04	0.65	m3/s
4.6	0.1	0.46	4.8	0.04	0.77	m3/s
4.6	0.11	0.506	4.82	0.04	0.9	m3/s
4.6	0.12	0.552	4.84	0.04	1.04	m3/s
4.6	0.13	0.598	4.86	0.04	1.18	m3/s
4.6	0.14	0.644	4.88	0.04	1.33	m3/s
4.6	0.15	0.69	4.9	0.04	1.49	m3/s
4.6	0.16	0.736	4.92	0.04	1.66	m3/s
4.6	0.165	0.759	4.93	0.04	1.74	m3/s
4.6	0.17	0.782	4.94	0.04	1.83	m3/s

1 in 100 year Dry Catchment

NOTE: USE 1 IN 100 YEAR DESIGN STORM IN FLOOD2

Catchment	Description	Area (ha)	Adjusted Area (assumes 40% imp +60% perm@10% imp equiv)	Tc (mins)	Peak Discharge (assumes rural contributory area is equivalent to 10% of total area as 100% impermeable)	Flow Channel		Depth of flow off Field onto Gypsy Lane (mm) (using Manning 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
1	A1	8.7	8.7	15	2378	Orchard Way/Broom Grove	W=4.6m, Gradient = 1 in 25		5089.5	3600	1489.5	Gypsy Lane/Orchard Close / Broom Grove
2	Field (E)	10.2	1.02	35	160	Orchard Way/Broom Grove	W=4.6m, Gradient = 1 in 25		5967	648	5967	Gypsy Lane/Orchard Close / Broom Grove
2	Field (N)	10.1	1.01	35	158	Orchard Way/Broom Grove	W=4.6m, Gradient = 1 in 25		5908.5		5908.5	Gypsy Lane/Orchard Close / Broom Grove
					2.696			215mm			16965	TOTAL Volume Runoff

Slope of Ground 25 0.04

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

Channel Width	Flow Depth	CSA	Wetted Perimeter	Slope (3000mm over 84m = 1 in 30)	Q	
4.6	0.05	0.23	4.7	0.04	0.25	m3/s
4.6	0.06	0.276	4.72	0.04	0.33	m3/s
4.6	0.07	0.322	4.74	0.04	0.43	m3/s
4.6	0.08	0.368	4.76	0.04	0.53	m3/s
4.6	0.09	0.414	4.78	0.04	0.65	m3/s
4.6	0.1	0.46	4.8	0.04	0.77	m3/s
4.6	0.11	0.506	4.82	0.04	0.9	m3/s
4.6	0.12	0.552	4.84	0.04	1.04	m3/s
4.6	0.13	0.598	4.86	0.04	1.18	m3/s
4.6	0.14	0.644	4.88	0.04	1.33	m3/s
4.6	0.15	0.69	4.9	0.04	1.49	m3/s
4.6	0.16	0.736	4.92	0.04	1.66	m3/s
4.6	0.165	0.759	4.93	0.04	1.74	m3/s
4.6	0.2	0.92	5	0.04	2.39	m3/s
4.6	0.215	0.989	5.03	0.04	2.67	m3/s
4.6	0.24	1.104	5.08	1.04	3.19	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 off Field onto Gypsy Lane (mm) (using Manning 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
1	A1	8.7	8.7	15	2378	Orchard Way/Broom Grove	W=4.6m, Gradient = 1 in 25		5089.5	3600	1489.5	Gypsy Lane/Orchard Close / Broom Grove
2	Field (E)	10.2	10.2	35	160.14	Orchard Way/Broom Grove	W=4.6m, Gradient = 1 in 25		5967	648	5967	Gypsy Lane/Orchard Close / Broom Grove
2	Field (N)	10.1	10.1	35	158.57	Orchard Way/Broom Grove	W=4.6m, Gradient = 1 in 25		5908.5		5908.5	Gypsy Lane/Orchard Close / Broom Grove
					2.69671			215mm			16965	TOTAL Volume Runoff

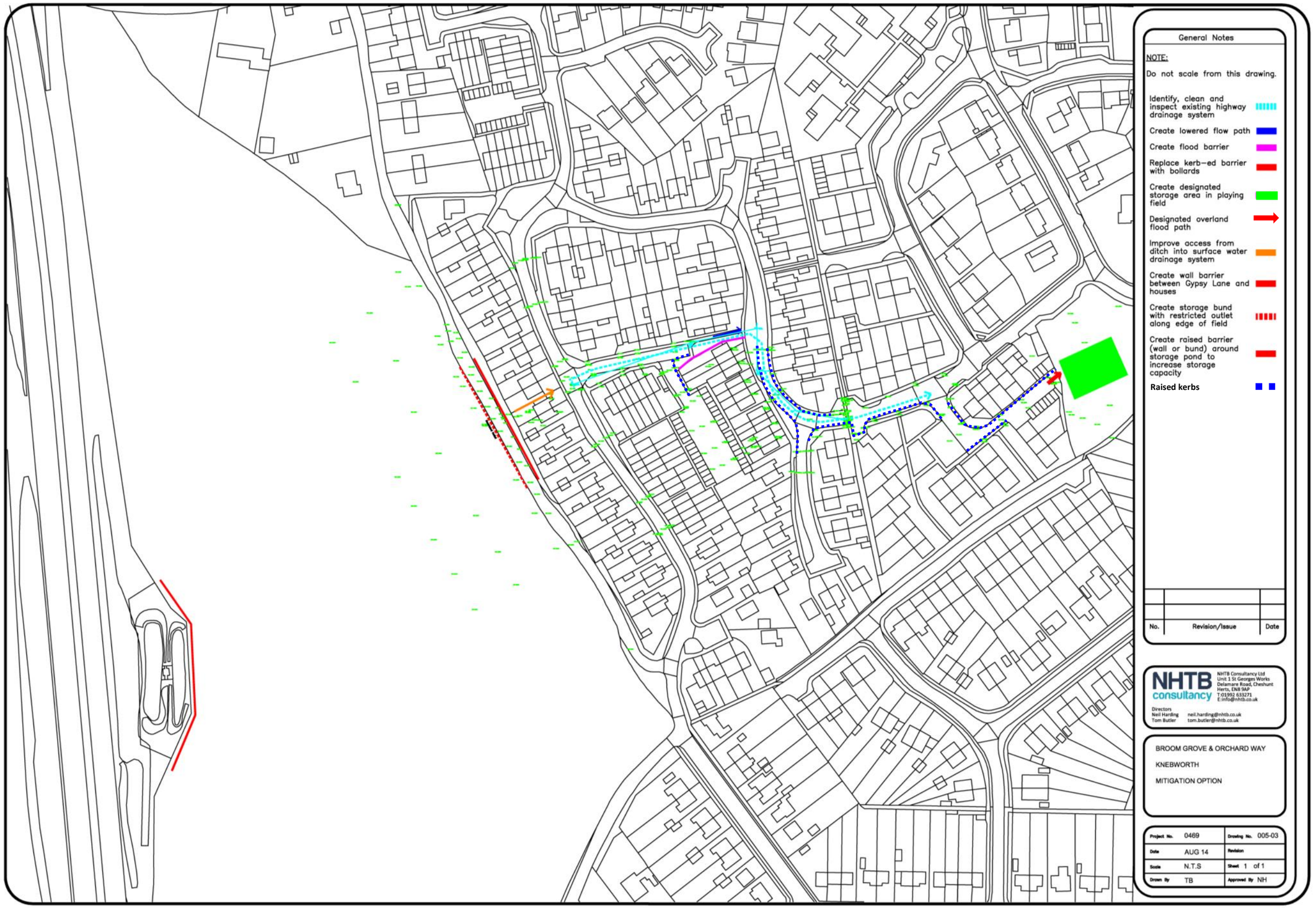
Slope of Ground 25 0.04

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

Channel Width	Flow Depth	CSA	Wetted Perimeter	Slope (3000mm over 84m = 1 in 30)	Q	
4.6	0.05	0.23	4.7	0.04	0.25	m3/s
4.6	0.06	0.276	4.72	0.04	0.33	m3/s
4.6	0.07	0.322	4.74	0.04	0.43	m3/s
4.6	0.08	0.368	4.76	0.04	0.53	m3/s
4.6	0.09	0.414	4.78	0.04	0.65	m3/s
4.6	0.1	0.46	4.8	0.04	0.77	m3/s
4.6	0.11	0.506	4.82	0.04	0.9	m3/s
4.6	0.12	0.552	4.84	0.04	1.04	m3/s
4.6	0.13	0.598	4.86	0.04	1.18	m3/s
4.6	0.14	0.644	4.88	0.04	1.33	m3/s
4.6	0.15	0.69	4.9	0.04	1.49	m3/s
4.6	0.16	0.736	4.92	0.04	1.66	m3/s
4.6	0.165	0.759	4.93	0.04	1.74	m3/s
4.6	0.2	0.92	5	0.04	2.39	m3/s
4.6	0.215	0.989	5.03	0.04	2.67	m3/s
4.6	0.24	1.104	5.08	1.04	3.19	m3/s

APPENDIX C

Proposed Mitigation Measures


General Notes
NOTE:
Do not scale from this drawing.
Identify, clean and inspect existing highway drainage system
Create lowered flow path
Create flood barrier
Replace kerb-ed barrier with bollards
Create designated storage area in playing field
Designated overland flood path
Improve access from ditch into surface water drainage system
Create wall barrier between Gypsy Lane and houses
Create storage bund with restricted outlet along edge of field
Create raised barrier (wall or bund) around storage pond to increase storage capacity
Raised kerbs
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
BROOM GROVE & ORCHARD WAY
KNEBWORTH
MITIGATION OPTION
Project No. 0469
Drawing No. 005-03
Date AUG 14
Revision
Scale N.T.S
Sheet 1 of 1
Drawn By TB
Approved By NH