Technical Assessment Report

to support Section 19 Flood Investigation

Long Marston, Hertfordshire

Client:

Hertfordshire County Council

Prepared by:

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CONTRACT

This report describes work commissioned by Hertfordshire County Council following written instruction by their representative dated 13/05/2014.

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GLOSSARY OF TERMS

The following glossary provides definitions of some of the technical terms used within this document.

Annual Exceedance Probability (AEP	The Annual Exceedance Probability is the chance or probability of a particular event occurring annually and is usually expressed as a percentage; e.g. a 1% Annual Exceedance Probability has a 1% chance of happening in a year (statistically once in every 100 years) and can be referred to as $Q_{100.}$
Evapotranspiration	Evapotranspiration is the sum of evaporation and plant transpiration from the Earth's land and water surfaces to the atmosphere.
Field Capacity	Water in the soil is held by capillary action against the pull of gravity. The maximum amount of water which can be held in this way is the field capacity state of the soil. In the UK soils normally return to field capacity state in autumn and dry below this state in spring.
Flood and Water Management Act (FWMA) 2010	The FWMA came into effect in April 2010 and takes forward recommendations from the Pitt Review by placing new responsibilities on the Environment Agency, local authorities and other flood risk management authorities to manage the risks of flooding. The FWMA sets out clear definitions of flooding, and by designating Unitary and County Councils as Lead Local Flood Authorities (LLFAs). LLFAs are responsible for local flood risk management strategies, and each must develop, maintain, apply and monitor a strategy for flood risk management in their area (a “local flood risk management strategy”). The FWMA emphasises partnership arrangements and requires relevant bodies to cooperate. This includes local authorities, the Environment Agency, water companies, highways authorities, planners, developers, conservation groups, etc. Responsibilities for local flood risk management can be delegated by the LLFA by agreements formalised through memorandums of understanding.
Flood Estimation Handbook (FEH)	The Flood Estimation Handbook is a piece of software that gives guidance on rainfall and river flood frequency estimation across the UK by providing rainfall details, catchment descriptors and information relating to likelihood of flood events for a chosen watercourse catchment.
Hydrologically Effective Rainfall (HER)	The period between the return to field capacity and the loss of capacity in spring gives opportunity for rainfall to recharge groundwater and flow to rivers. The sum of rainfall less evaporation during this period is known as excess rainfall (Hydrologically Effective Rainfall). HER contributes directly to river and surface water flooding.
JFlow	JFlow is a 2D flood model which solves depth averaged fluid flow equations to model the movement of water over the ground. It was used for formulation of data for EA surface water flood mapping. The 2D model is capable of simulating overland flow and flood extents to a level of detail equal to the terrain model it is based on. 1D models are limited to estimating flood depths in the direction of flow of a channel, whereas 2D models estimate variable flood depths across the extent of a floodplain.
Lead Local Flood Authority (LLFA)	The Unitary Authority or County Council responsible for the implementation of the Flood and Water Management Act.
Main River	Main rivers are defined by DEFRA in England and are usually larger streams and rivers, but also include some smaller watercourses. A main river is defined as a watercourse marked as such on a main river map, and can include any structure or appliance for controlling or regulating the flow of water in, into or out of a main river. The Environment Agency's powers to carry out flood defence works apply to main rivers only.

Ordinary Watercourse	A watercourse that is not part of a main river and includes rivers, streams, ditches, drains, cuts, culverts, dikes, sluices, sewers (other than public sewers within the meaning of the Water Industry Act 1991) and passages, through which water flows. The Lead Local Flood Authority has responsibility for approving works that affect the flow of an ordinary watercourse under the terms of the Land Drainage Act 1991.
MORECS	The Met Office Rainfall and Evaporation Calculation System (MORECS) is *"the only nationwide service giving real-time assessments of rainfall, evaporation and soil moisture. Analysis covers different soil, crops and topography."*
Return period	An estimate of the likelihood of an event. For example a 1 in 100 year return period has a 1% likelihood of occurrence within any particular year.
Soil Moisture Deficit (SMD)	The amount by which the soil moisture content is below the field capacity state. It can also be defined as the amount of water which would have to be added to the soil in order to bring it back to field capacity.
SPRHOST	Standard Percentage Runoff (SPR) is the percentage of rainfall that contributes to the increase of surface runoff. Based on analysis of data from flood events, and adjusted for rainfall and catchment properties. Hydrology Of Soil Types (HOST) classifies the soils of the United Kingdom into 29 categories. These classes are based on a series of conceptual models that simulate the hydrological behaviours associated with the soils and it interprets soils physical properties and their effects on the development of soil water.
Revitalised Flood Hydrograph (ReFH)	Using the ReFH model, design flood hydrographs can be generated for a specified initial soil moisture content and a design rainfall event of the required return period. It allows estimation of hydrographs (i.e. flow variation over time) reacting to a rainfall event, and allows the flow and the reaction time to peak flow following a rainfall event for a given watercourse to be estimated. The method can be used to simulate observed events.

EXECUTIVE SUMMARY

As required under Section 19 of the Flood and Water Management Act 2010, Hertfordshire County Council as Lead Local Flood Authority on becoming aware of a flood in its area must, to an extent that it considers it necessary or appropriate to:

- Investigate the incident.
- Identify the Risk Management Authorities (RMAs) with relevant flood risk management functions.
- Establish the relevant functions have been exercised or if it is proposed to exercise them.
- Publish its findings in a Flood Investigation Report.
- Consult and inform the relevant RMAs of its findings.

This report has been commissioned to satisfy the first, third and fourth requirement listed above and provides a summary of the flood incident as well as identifying the current position of RMAs and recommendations for reduction in flood risk.

All known / recorded flood events that have affected Long Marston have been collated. Winter 2013/2014 has seen the most frequent and serious flood events and it is flooding during this period that has brought about the commissioning of this investigation. The focus of the report has therefore been flooding within the previous winter.

A detailed qualitative assessment of watercourses, drainage infrastructure, surface water flow routes, hydrology and canal / reservoir infrastructure has been undertaken and the findings are presented within this assessment. The following are considered the primary findings in relation to the causes of recent flooding in Long Marston:

- Winter 2013/2014 was one of the wettest on record; and heavy rainfall falling on already highly saturated ground with an elevated groundwater table has caused flood flows likely to have overwhelmed the capacity of the main and ordinary river channels affecting the site
- Similarly, rainfall onto highly saturated ground tending to drain directly toward the village is likely to have caused excessive direct surface runoff resulting in surface water flooding
- The existing river network capacity, and in particular the main culvert capacity, is likely to be insufficient to convey the rate / volume of floodwater evident during the recorded flood events.
- The effect of failure of the foul pumping station is likely to have caused surcharge of the upstream sewer network and exacerbated surface water flooding in areas where surface drainage cross connections discharge to the foul network.
- Inflows to the river catchment from Canal and River Trust (CRT) infrastructure (canal and reservoirs) have been assessed. It is considered that controlled or otherwise discharges from the CRT network had no direct effect on the Tring Bourne catchment and effect on adjacent catchments would have had insignificant effect on flooding at Long Marston

It is considered likely that none of the causes identified above are solely responsible for the frequency and extent of flooding experienced in Long Marston; flooding is likely to be caused by a combination of factors following periods of prolonged heavy rainfall.

A number of short term measures are proposed. These measures are not anticipated to fully alleviate the likelihood or magnitude of flooding, but will assist in managing the impact of future floods, until such times as more substantial measures are put in place.

Additionally, potential medium/long term flood alleviation options are considered. The rights and responsibilities of the relevant stakeholders for the delivery of each option is required to be resolved in order to determine which party is responsible to undertake potential works. It is recommended that meetings take place between the relevant stakeholders to assess the potential options and agree a preferred course of action, likely to include a requirement for further detailed analysis to inform any future capital works. The parties deemed responsible will then be required to implement the preferred solution along with obtaining appropriate permissions as required.

The flood management / resilience option(s) selected as being the most appropriate will require further technical assessment and validation, by means of hydraulic modelling or similar, as part of the outline and detailed design process, prior to implementation.

1 INTRODUCTION

1.1 Terms of Reference

This Technical Assessment Report to support a Section 19 Flood Investigation was commissioned by Hertfordshire County Council (HCC) to investigate an identified flooding problem at Long Marston, Hertfordshire.

An assessment will be made of the history and nature of flooding at the site, from which the likely sources of flooding will be identified and evaluated. The deliverables of the project will include the scoping of potential mitigation and resilience measures and the identification of potential options to reduce the risk and / or frequency of future flooding occurring at the site.

1.2 Statement of Authority

This report and assessment has been prepared and reviewed by qualified professional civil engineers with extensive experience in the water industry. McCloy Consulting Ltd. staff possess in excess of 40 years combined experience in the fields of flood risk, drainage, wastewater, and hydraulic modelling studies.

- Paul Singleton MSc BEng (Hons) MIEI – Environmental Engineer with 4 years professional experience in flood risk assessment, hydraulic modelling, and Sustainable Drainage design in the UK & Ireland.
- Kyle Somerville BEng (Hons) CEng MIEI – Senior Civil Engineer with 10 years experience specialising in flood modelling and flood risk assessment, surface water management, drainage design and SuDS.
- Anthony McCloy BEng CEng FIEI – Charted Civil Engineer and Director of McCloy Consulting with in excess of 15 years specialising in the water industry, with particular expertise in hydraulic modelling, flood risk assessment, surface water management and sustainable drainage design.

1.3 Approach to the Assessment

This Flood Investigation has been commissioned by HCC in their role as Lead Local Flood Authority (LLFA) under Section 19 of the Flood & Water Management Act (FWMA) 2010 which states that:

1. On becoming aware of a flood in its area, a lead local flood authority must, to the extent that it considers it necessary or appropriate, investigate
    a) which risk management authorities have relevant flood risk management functions, and
    b) whether each of those risk management authorities has exercised, or is proposing to exercise, those functions in response to the flood.
2. Where an authority carries out an investigation under subsection (1) it must
    a) publish the results of its investigation, and
    b) notify any relevant risk management authorities.

In addition to meeting statutory obligations, the primary aims of this investigation are to indicate actions that can be taken with immediate effect and recommend options for actions and schemes to manage the flood risk affecting Long Marston. HCC have been in regular contact with local community, with feedback and considerations collated and considered within the brief of this investigation.

All stakeholders who hold data relating to flooding events in the area have been consulted and information gathered from responses received is incorporated in the following assessment. For the purposes of this investigation the Risk Management Authorities are:

- Hertfordshire County Council as Lead Local Flood Authority (LLFA)
- Hertfordshire County Council as Highways Authority
- Buckinghamshire County Council as Highways Authority
- Buckinghamshire County Council as adjacent Lead Local Flood Authority (LLFA)
- Dacorum Borough Council as planning authority within the catchment
- Environment Agency (EA)
- Canal and River Trust (CRT)

- Thames Water.

Additional interested parties and other Stakeholders include:

- Hertfordshire Resilience Forum
- Hertfordshire Fire and Rescue
- Hertfordshire Constabulary
- Adjacent Landowners
- Local community
- Any affected businesses
- Tring Rural Parish Council.

Two walk over surveys of the site were conducted by McCloy Consulting Ltd. on 12th March 2014 and 10th September 2014; during the visits photographic surveys of the site and adjacent lands was undertaken. Site visit photographs are included in Appendix D.

In accordance with the requirements of the investigation the following activities will be undertaken as part of this assessment:

- Collation of available information on historical flood events.
- Research the conditions under which flooding occurs at the site.
- Investigation of drainage infrastructure asset records.
- Qualitative assessment and identification of contributing catchments and flow pathways, and factors contributing to flooding.
- Confirmation of the conditions under which flooding is likely to occur.
- Outline of potential works that could be carried out to reduce the probability or impact of flooding.

2 SITE INFORMATION

2.1 Site Details

Figure 2.1: Site Location

Area of Interest	Long Marston, Hertfordshire
County Authority	Hertfordshire County Council
District Authority	Dacorum Borough Council
OS Grid Reference	489811 215622

Location Plan:

2.2 Site Description & Geographical Scope

Long Marston is a village located in the west of Hertfordshire, approximately 8 km east of Aylesbury and 20 km north west of Hemel Hempstead.

The village is centred on the intersection of Station Road, Astrope Lane, Tring Road and Cheddington Lane. Long Marston is located within Tring Rural Parish Council area and the district of Dacorum Borough Council. The name of the village is likely to be derived from 'Marsh Farm', which is a reflection of its low lying location and 'propensity for flooding'[1].

The following figure presents the geographical scope (boundary shown in red) of this assessment which is centred on the village of Long Marston. Hereafter, the indicated geographical scope will be referred to as 'the site'. To appreciate the hydrological complexities of the site, a much wider area will be investigated, especially areas of higher ground surrounding the site.

Figure 2.2: Long Marston Flood Investigation Geographical Scope

Contains Ordnance Survey data © Crown copyright and database right 2014

2.3 Affecting Watercourses

An EA designated 'main river' (locally referred to and hereafter referred to as Tring Bourne) flows through Long Marston. The source of the Tring Bourne is west of Startop's End Farm near the junction of Watery Lane and Lower Icknield Road (B489). The low flows at the head of the stream are thought to be from groundwater or underground springs; the clay lined Startopsend Reservoir built in 1817 will affect ground water levels in this locality, however water levels in the reservoir do not vary rapidly so any percolation of water from the canal would be fairly constant.

It follows a route along the western side of Tring Road before entering a complex culvert and flowing to the south of Chapel Lane before flowing in a north westerly direction away from the village. The watercourse is culverted at regular intervals along both Tring Road and Chapel Lane at property entrances and the river appears to act as a roadside drain.

An ordinary watercourse flows along the eastern side of Tring Road, on the opposite side to Tring Bourne, before being shown to cross the road and follow the same path as the main river. This unnamed ordinary watercourse also acts as a roadside drain as it receives direct runoff from the road.

[1] http://www.hertfordshire-genealogy.co.uk/data/books/books-0/book0053-placenames.htm [accessed 20th May 2014]

Figure 2.3 and Figure 2.4 show the water features in the vicinity of the site that are considered potentially significant as part of this assessment.

Figure 2.3: Long Marston Affecting Watercourses

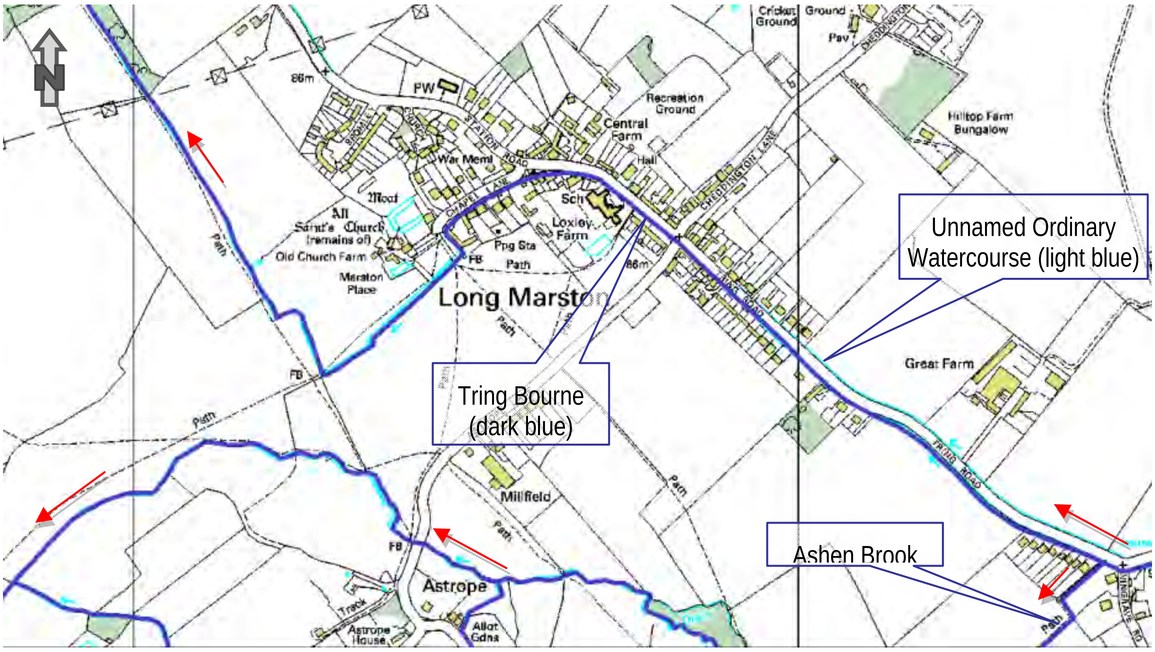
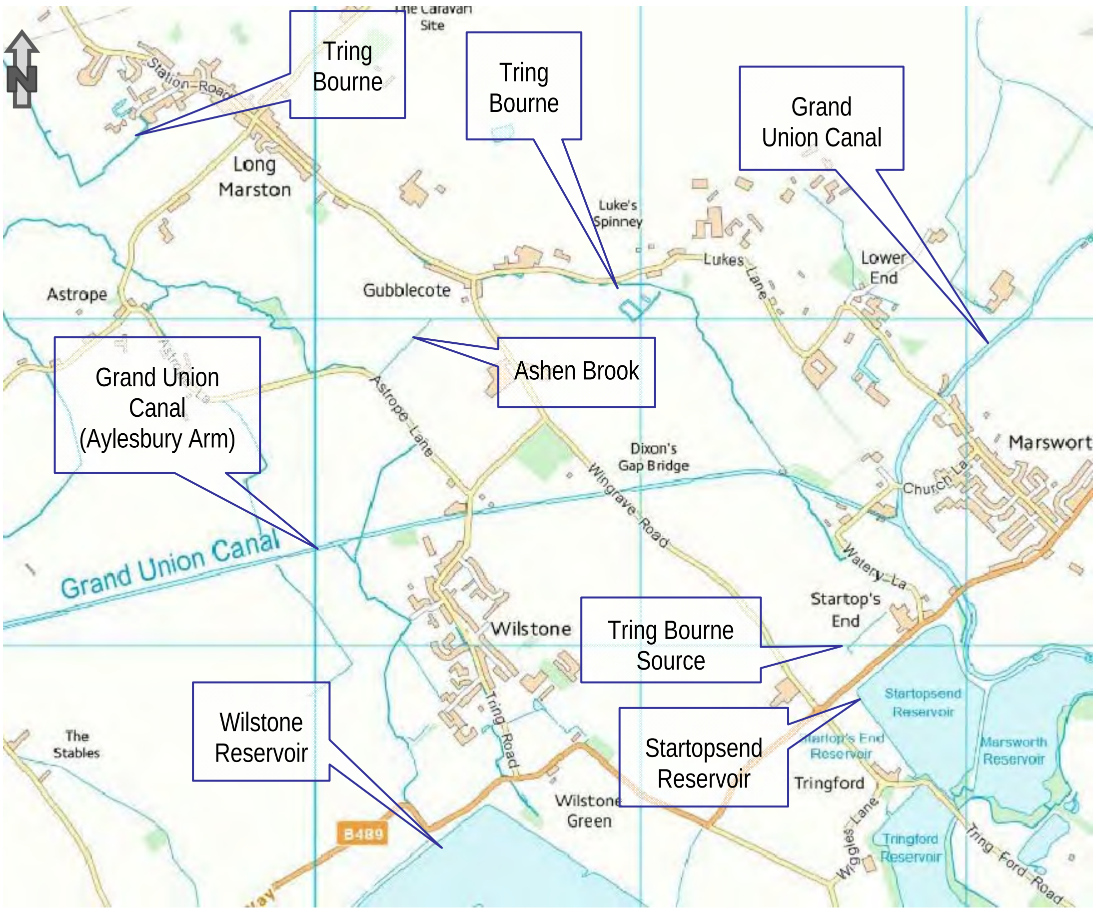


Figure 2.4: Long Marston Affecting Watercourses – Wider Catchment



3 BACKGROUND INFORMATION REVIEW

As part of the data collection phase, a number of available sources of information were investigated in order to build an understanding of the potential causes of flooding to the site.

The following review highlights the key findings of the anecdotal evidence collection exercise.

3.1 Internet / Media / Search

A number of sources relating to flooding at Long Marston, Hertfordshire were found during an initial internet / media search. Records of flooding in February 2014[2][3], January 2014[4] and December 2013[5] were established and these are referred to subsequently in this report.

3.2 Relevant Stakeholders

3.2.1 Hertfordshire County Council – Lead Local Flood Authority

HCC has collated and provided a range of information relating to the Flood Investigation at Long Marston. National surface water flood modelling data and mapping, carried out by the Environment Agency (EA) using JFlow, has been provided along with photos, reports and correspondence relating to the project. These will be referred to and used as a basis for the assessment throughout this report.

3.2.2 Hertfordshire County Council – Highway Authority

The Highways department of HCC has provided details relating to flooding in Long Marston in February 2014. Details of major and minor recorded flood events are included in Section 4.2 as part of the assessment of previous flood events at the site.

HCC has indicated that highways drainage is present at the site, however network or record drawing data is not readily available. HCC has confirmed that Long Marston is on an 18 month cycle for gully maintenance and indicates that there are no gullies on their 'vulnerable gully' list.

3.2.3 Long Marston, Wilstone, Puttenham and Astrope website

Flooding information for Long Marston and the surrounding area has been covered on longmarston.org[6], a local community website.

Information relating to flooding is summarised as follows:

- Significant flooding occurred in January and February 2014.
- Hertfordshire County Council as the LLFA were invited to a public meeting and has commissioned this Flood Investigation.
- A meeting was held between local residents and the Canal and Rivers Trust "following speculation of water being released from the local reservoirs, where they shared…technical data and information about their water management system. The CRT do not believe that they were responsible for the rapid flow of water that entered Long Marston via Tring Road, although the release from Wilstone reservoir via Gudgeon Brook is likely to have accounted for the flooding in Astrope."[7]
- In July 2009, the Parish Council made sandbags available in response to flooding.
- Historical flooding in 1978 is also referenced and it is stated that flooding occurred four times during that year.

[2] http://www.bucksherald.co.uk/news/more-news/updated-flooding-causes-chaos-in-the-vale-1-5862970 [accessed 22nd May 2014]
[3] http://www.hemeltoday.co.uk/news/local/overnight-rain-has-caused-severe-flooding-and-roads-have-been-closed-across-dacorum-1-5862939 [accessed 22nd May 2014]
[4] http://www.hemeltoday.co.uk/news/local/long-marston-villagers-say-fix-our-drains-or-we-will-be-flooded-time-and-time-again-1-5799086 [accessed 22nd May 2014]
[5] http://www.hemeltoday.co.uk/news/local/long-marston-villagers-say-fix-our-drains-or-we-will-be-flooded-time-and-time-again-1-5799086 [accessed 22nd May 2014]
[6] http://www.longmarston.org/index.php?s=flood [accessed 22nd May 2014]
[7] longmarston.org. (11 Mar 2014). Flooding in Long Marston, Astrope, Puttenham & Wilstone. Available from: http://www.longmarston.org/index.php?s=flood. [Accessed: 26/5/2014].

3.2.4 Local Residents

In addition to the internet based local information outlined previously, local residents have provided a summary of observations directly to Hertfordshire County Council for collation. A review of this data as well as an examination of information available through a local community forum[8],has been undertaken.

The primary points, relevant to the study area, raised by residents in disclosing information to the council and through the online forum are summarised as follows:

- Surface water discharges from Church View and Bromley developments may be contributing to flooding along Chapel Lane.
- During flood conditions, water filled the moat adjacent to All Saint's Church before overtopping and flooding nearby fields.
- High road levels at the south western end of Chapel Lane prevent surface water running away to low lying lands towards the main river (Tring Bourne) downstream.
- Chapel Lane, a public highway, has no formal surface water / highway drainage.
- An access footbridge across Tring Bourne to the south west of the village causes a restriction to flows leaving the area.
- A land drain was found in gravel access to cottages next to The Boot; flow in the land drain was forced up through gravel surface during flood events.

3.2.5 Hertfordshire Fire & Rescue Service

Hertfordshire Fire & Rescue Service has been consulted and provided information indicating that members of the emergency services attended calls relating to flooding once on the 6th February, three times on the 7th February and once on the 8th February. In total, there were fourteen calls relating to flooding over the three days.

3.2.6 Tring Rural Parish Council

Tring Rural Parish Council is the local authority for Tring Rural civil parish covering the villages of Long Marston, Puttenham and Wilstone, and the hamlets of Astrope, Gubblecote and Little Tring. HCC has provided correspondence received from Tring Rural Parish Council, dated 12th March 2014, in relation to flooding and drainage issues in the civil parish. The following points were included in this correspondence, and the conclusions listed below are those of Tring Parish Council.

- *'Extreme flooding occurred on 24th December 2013, 7th January 2014 and 7th February 2014 that badly affected the villages of Long Marston, Astrope, Puttenham and Wilstone.*
- *It is clear that a major contributor to the flooding on all occasions was the poorly maintained drains and culverts in and around these villages, many of which have collapsed or are completely blocked.*
- *Inadequate drains coupled with a sewerage system constrained by the local pumping station resulted in a dramatic rise in surface water levels, contaminated by sewage'.*

Details of damage to property and incidents where people were at risk are also outlined including:

- *'A child fell into an open flooded drain in Wilstone'.*
- *'An adult was rescued from a flooded ditch that became indistinguishable from the surface water torrent created on Chapel Lane in Long Marston'.*
- A commercial property in Long Marston had been subject to closures due to flooding of the ground flood and basement.
- At least two families remained unable to reside in their homes as of March 2014 and were living in temporary accommodation
- School grounds were flooded and had to close.
- Cars located in the centre of Long Marston have been written off due to flood damage
- Damage to listed buildings.

[8] http://www.forum.longmarston.org/ [accessed 27th May 2014]

3.2.7 Canal and River Trust

The Canal and River Trust (CRT) are responsible for the Grand Union Canal including the Wendover and Aylesbury Arms and the associated Wilstone, Tringford and Startopsend Reservoirs. At its closest point, the Aylesbury Arm of the Grand Union Canal is situated approximately 1.3 km south of the village.

The CRT website[9] states that the Grand Union Canal (from upstream to downstream of the reach adjacent to Long Marston) was closed from the 7th February to the 10th February 2014 with the following explanation:

> *"Due to excessively high water levels following recent heavy rainfall, the Grand Union Canal between Grove Lock 28 and Marsworth Lock 45 and the Aylesbury Arm, will be closed with immediate effect. This is in order to allow the running of flood water through locks.*
>
> *Water levels have started to subside following the slightly drier weather over the last couple of days. The closure of the Grand Union Canal has allowed us to move water north, into areas with less flooding, which has also improved the situation. The canal will therefore be opened at 1.30pm on Monday 10th February 2013. Canal & River Trust may still require to run water through locks but we can now do this with the navigation open."*

Extensive correspondence with CRT has been undertaken as part of this assessment. A thorough investigation of the reservoir and canal network in the vicinity of the site has been carried out. Further findings of this activity are included in Section 5.2 of this report.

3.3 Environment Agency

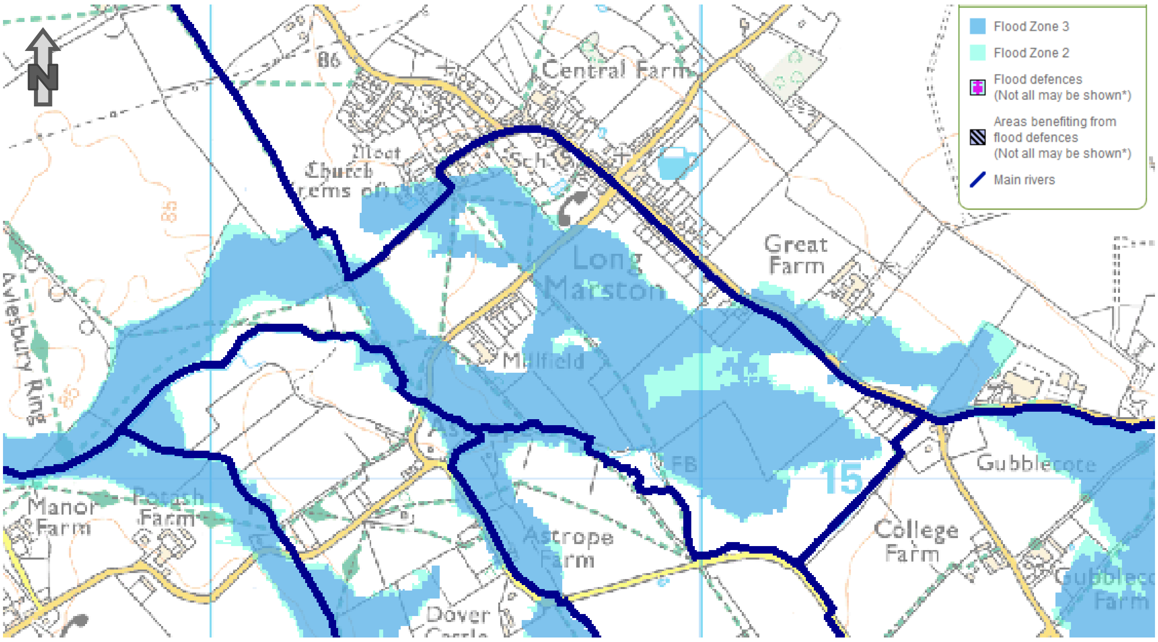
3.3.1 EA Flood Maps

Figure 3.1 shows the EA Flood Map for Planning (Rivers and Seas) for the Long Marston area. Coastal flooding is not applicable so the floodplain shown is fluvial primarily from Tring Bourne that flows through the village and another main river located to the south of Long Marston.

Lands in the vicinity of Long Marston are shown to be affected by fluvial flooding. The EA mapping indicates that properties are generally not predicted to be affected by flooding but surrounding lands would be inundated with floodwater during an extreme event.

Figure 3.2 is taken from EA 'Risk of Flooding from Surface Water' mapping, available online, and indicates that much of the village is at risk from surface water flooding. Much of the high risk areas coincide with Tring Bourne that flows through Long Marston with significant high risk areas noted at the western end of Chapel Lane.

Figure 3.1: Environment Agency Flood Map for Planning (Rivers and Seas)



[9] http://canalrivertrust.org.uk/notice/476/grand-union-canal-grove-lock-28-to-marsworth-lock-45-and-aylesbury-arm [accessed 27th May 2014]

Figure 3.2: Environment Agency Risk of Flooding from Surface Water

3.3.2 CCTV Culvert Survey

The EA commissioned a CCTV survey[10] of the main culvert on Tring Bourne that runs through the centre of Long Marston. The report, published in September 2010, gives a comprehensive assessment of the route of the culvert and ascertains the condition of the culvert lengths and headwalls.

The culvert consists primarily of 600 mm circular concrete pipe, brick inlet and outlet headwalls with nine manholes along its length. The inlet is situated to the south east of Ravens Court adjacent to Tring Road and the outlet is located to the south of the eastern extent of Chapel Lane. The culvert runs for a total of approximately 434 m and follows the general path of Tring Road, Station Road and Chapel Lane; a schematic of which is shown below.

A number of the primary findings of the CCTV culvert survey are summarised as follows:

- Eight of the ten pipe lengths are classified as Grade 5 for 'Service / Operational Defects', the lowest defect grade description, indicating that 'rehabilitation is urgent and short-term in order to prevent further damage'.
- Six of the ten pipe lengths are classed as Grade 4 or 5 for 'Structural Defects' indicating that 'rehabilitation procedure is urgent' and needs to be completed within 'one to two years' and 'in the short-term' respectively.
- The survey could not be completed between MH05 and MH06 due to obstruction within the culvert (grout obstruction at joint).

In general, the survey revealed that the Tring Bourne culvert through Long Marston is in very poor condition and in need of urgent repairs. No evidence or record of any subsequent rehabilitation work having been carried out to rehabilitate the service condition of the culvert has been established during the course of this assessment.

[10] Long Marston main river (Tring Bourne) CCTV culvert survey available via the community forum or from HCC

Figure 3.3: Tring Bourne main culvert route through Long Marston

3.3.3 EA Maintenance Regime

The Technical Advisor to the Asset Performance Team of the Environment Agency South East provided information in relation to maintenance of watercourses in the Long Marston area. The response received is summarised as follows:

- The Long Marston area has not been maintained by the EA in at least ten years, i.e. post 2004.
- The EA have no intention of carrying out maintenance in the area in the immediate future as there is no funding available for the area.
- Up to three years ago, the village and surrounding area was considered to be a low consequence system, i.e. the consequences of the effect that flooding would cause, would not outweigh the cost of maintaining the channels using public money.
- Funding was then allocated on a higher demand filtering down to the lower consequence systems if there was enough to go around - this was almost always the case for Long Marston where funding had not reached as far down as other locations.
- Under these circumstances the riparian owner of the watercourse would be responsible for reducing their own risk by carrying out maintenance to the channel as per the EA's 'Living on the Edge' document which, in short, states that the riparian owner is always responsible for maintenance, but the EA can assist if they see it as a good investment or can dramatically reduce the risk of flooding and use public money / resource to undertake maintenance to any main river watercourse.
- Three years ago the EA started to use a different type of classification where the number of houses possibly affected by flooding based on the critical infrastructure and the cost of maintenance are all calculated and an amount of money is issued based on the minimum need for the area and the identified need.
- This system is similar to before but more flexible as requests by the EA for funding is considered as opposed to not being provided without consideration.
- The EA has not been successful in securing funding for Long Marston in this or previous years so duty of maintaining the river channel falls to riparian owners if they feel there is a requirement and / or flood risk.

Maintenance recommendations are also provided as part of the EA response and these will be discussed later in this report.

3.4 Strategic Flood Risk Assessment

Long Marston is located within Dacorum Borough Council. The relevant SFRA is the "Dacorum Borough Council, St. Albans City & District Council, Three Rivers District Council and Watford Borough Council SFRA", summarised as follows.

In August 2007, Dacorum Borough Council, St. Albans City & District Council, Three Rivers District Council and Watford Borough Council published a Strategic Flood Risk Assessment[11] for the area covered by their respective jurisdictions. The purpose of the SFRA was to assess and map all forms of flood risk from groundwater, surface water, sewer and river sources, taking into account future climate change predictions, and use this as an evidence base to locate future development primarily in low flood risk areas.

The SFRA included a review of historical flooding, EA Flood Maps, past flood risk assessment reports and details of major flood defences and flow control structures. No modelled flood levels were included in the SFRA.

Present and predicted flood mapping for the area is similar to that shown in the EA flood mapping with no discernible difference between present day and future scenario extents. Historical flood mapping included in the SFRA records 'minor surface water' flood incidents (DM_SW9) in the centre of Long Marston and details of flooding in the village are recorded as detailed below:

"Long Marston has been flooded twice, most recently in May 2007. The exact flooding source and mechanism is not fully understood. However, the area had been subject to continuous medium to heavy rainfall for 48 hours prior to the flooding. An open drainage ditch runs through the village next to the main road. It forms part of a network of ditches and cannels which combine to form the Upper Thame. The flooding properties were located on the opposite side of the road to the drainage ditch however the ditch itself was not over topping and was not therefore the direct source of the flood water. It was thought that the flooding may have arisen from overland flow from the surrounding saturated farm land. Approximately 7 residential properties and the local pub were flooded.

Flooding of Long Marston also occurred in 2003 via the same mechanism, resulting in internal flooding to 15-20 residential properties."

3.5 Sewerage Infrastructure

Records of sewerage infrastructure held by the relevant sewerage undertaker (Thames Water) in the Long Marston area have been compiled and provided by Hertfordshire County Council for purposes of this investigation.

The records confirm that a foul-only network serves the village, draining to a sewage pumping station located 65 m south east of Chapel Lane. The draining sewer network comprises small diameter pipes (minimum 100 mm dia. / typically 150 mm dia. pipes). The network to the north and east of the village is located within the public road, while sewers serving Bromley drain to Chapel Lane via riparian wayleave across open-ground.

Records indicate that no separate surface water drainage network is located at the site.

No operational information has been made available in relation to the sewage pumping station in terms of capacity, pump duty or records of downtime. Anecdotal evidence made available by local residents suggests that the pumping station is undersized and does not have capacity for the inflow during a flood event. Given that a foul-only network would not be affected by surface water, such a scenario indicates that the network and/or pumping station receives significant additional flow due either to surface drainage cross connections (causing the network to effectively act as a combined sewer) or due to groundwater ingress into sewerage and pumping infrastructure.

11 http://www.dacorum.gov.uk/home/planning-development/planning-strategic-planning/evidence-base/strategic-flood-risk-assessment-stage-ii?redirected=true [accessed 28th May 2014]

3.6 British Geological Survey

3.6.1 Geology

Long Marston has been reviewed using British Geological Survey (BGS) [12] mapping. This indicates that areas to the north, east and west of the village are underlain by bedrock geology consisting of 'Gault Formation and Upper Greensand Formation (Undifferentiated) – Mudstone, Siltstone and Sandstone'. An intrusion of 'West Melbury Marly Chalk Formation' underlies areas to the south of the village.

BGS mapping shows that superficial deposits over the Mudstone, Siltstone and Sandstone formation are minimal with deposits of clay, silt, sand and gravel overlying the chalk bedrock to the south.

3.6.2 Groundwater

The British Geological Survey's Susceptibility to Groundwater Flooding information displays areas where geological conditions could allow groundwater flooding to occur, and where groundwater may come close to the ground surface. The BGS note that 'groundwater flooding often lasts longer than river flooding and can result in significant social and economic disruption.'

Figure 3.4 shows a section of the groundwater flooding mapping centred on Long Marston. The lightest blue areas indicate that susceptibility to groundwater flooding is low. Darker blue areas are designated as being at moderate risk of being affected by groundwater flooding. It can be seen that areas south and west of Tring Road / Chapel Lane are shown as moderate while lands to the north are considered to be of low susceptibility to groundwater flooding.

Figure 3.4: BGS Susceptibility to Groundwater Flooding map – Long Marston

BGS mapping extracted from FIND maps

[12] http://mapapps.bgs.ac.uk/geologyofbritain/home.html [accessed 28th May 2014]

4 HISTORICAL FLOOD EVENTS

4.1 Introduction

Long Marston is known to be adversely affected by flooding. Historical flooding information has been provided by Hertfordshire County Council Highways division, local information and online media coverage.

The following sections summarise the flooding information gathered to date.

4.2 Recorded Flood Events

The table below collates known and recorded flood events that have affected Long Marston. These records span from 1978 until current day.

Due to a recent increase in flood frequency (from winter 2013 onwards), focus has been placed on assessment of rainfall over the winter period of 2013/2014 during which three major flood events are known to have taken place. The focus on this period is also confirmed by the project brief provided by the Client.

It is noted that the tables below are a summary of all currently available records of flooding of Long Marston. It is not an exhaustive list and it is acknowledged that there may have been occasions that Long Marston has been affected by flooding that have not been recorded or made available for the purposes of this investigation.

Table 4.1: Long Marston Flood Events Summary

Date	Source	Summary
1978 (day unspecified)	longmarston.org	Village flooded 4 times, up to 3 feet in depth
2nd January 2003	HCC Scoping Document / longmarston.org / Tring Rural Parish Council	Widespread flooding, Marston Court under water
2003 (day unspecified)	SFRA	Flooding in Long Marston
1st May 2007	SFRA	Medium to heavy rainfall for 48 hours
24th December 2013	Tring Rural Parish Council	Flooding on 24/12/2013 and four times between Boxing Day and 07/01/14
7th January 2014	HCC Scoping Document / The Bucks Herald / Tring Rural Parish Council	Widespread flooding
7th February 2014	HCC Scoping Document / The Bucks Herald / Tring Rural Parish Council	Emergency services

4.2.1 Hertfordshire County Council Highways Reports

The following table presents information relating to flooding in Long Marston provided by Hertfordshire County Council Highway's contractor Ringway. It is noted that records received to date cover February 2014 only.

Table 4.2: Long Marston Flooding – Highways Records

Date - Time	Location	Summary
05/02/14 – 07:56	Chapel Lane, Long Marston	Road flooded at bend on Station Road
05/02/14 – 22:53	Astrope Lane, between Long Marston and Puttenham	Road flooded
07/02/14 – 08:44	Chapel Lane, Long Marston	Properties damaged by flooding, fire brigade in attendance
07/02/14 – 10:06	Tring Road, Long Marston	Stream overflowing and causing flooding of the road
07/02/14 – 11:41	Chapel Lane, Long Marston	Area of standing water of trafficked part of carriageway
14/02/14 – 10:29	Station Road, north of Long Marston	Road flooded

4.3 Recorded Flood Locations

In addition to highways areas, HCC are aware of seven properties and a shared private car parking area within Long Marston that have flooded:

- 1 nr. business near centre of Long Marston.
- 5 nr. properties on Station Road.
- 1 nr. property on Chapel Lane.
- Several properties near the junction of Astrope Lane and Station Road have had severe flooding to parking areas.

Figure 4.1 identifies three distinct areas that have been shown to be adversely affected by flooding and are centred on the following areas:

- 'Area 1' - Junction of Station Road and Chapel Lane
- 'Area 2' - Junction of Station Road, Cheddington Lane, Tring Road and Astrope Lane (main crossroads)
- 'Area 3' - Western end of Chapel Lane

Note that this list is not exhaustive and other areas of flooding may exist, however, the listed areas are those known to HCC. Therefore, these areas will form the focus of this assessment in terms of flooding locations within Long Marston. It is noted that the areas listed are consistent with EA surface water flood mapping.

In addition to the affected properties listed by HCC, Tring Rural Parish Council have commented that an additional property on Chapel Lane has flooded on several locations. Marsworth recreation field, located between Watery Lane and Grand Union Canal, is also reported to have flooded. The cause of the flooding of the recreation field was reported during a Marsworth Parish Council Meeting of 12th March 2014 to be a blocked drain at the south-east corner of the field causing water to flow onto the recreation field.

Figure 4.1: Long Marston – Historical Reported Flooding Areas

5 FLOOD MECHANISMS

The following section focus on a qualitative assessment of possible flood mechanisms identified as potentially impacting on the frequency, depth and duration of flooding at Long Marston, intended to inform future studies as may be required to determine any design of flood alleviation scheme or other activities that may be proposed. Future flood management and flood resilience options are outlined in Section 6.

5.1 Fluvial & Surface Water Flooding

It is initially perceived that the primary risk of flooding in Long Marston is the combined effect of Tring Bourne that flows through the village in combination with direct pluvial (surface water) flooding caused by rainfall running overland or surface water caused by culvert / drainage incapacity.

To appreciate the impact that a given rainfall event may have on a catchment, it is necessary to understand the localised rainfall patterns during, and prior to each of the reported flood incidents, as well as other catchment characteristics affecting rate of runoff such as catchment saturation and wetness.

The following sections present the catchments for both fluvial and pluvial flooding at various locations known to be affected by flooding and in particular assess catchment rainfall and wetness characteristics for the known flood events of interest in the scope of this project, i.e. the winter of 2013/2014 when flooding was most frequently reported and caused greatest disruption.

5.1.1 Site Topography

The topography of Long Marston is relatively flat with shallow gradients. Lands of this type allow water to travel and spread over a large area. In addition, the watercourses in the vicinity of the site are shallow and do not have high banks to contain water when inundated by significant flows.

Local topography is significant in terms of flood routing through the village. Analysis of the EA surface water flood maps, historical flood records and local height data indicates that the roads through and surrounding the village are generally subject to the greatest depth of water during a flood event and provide preferential flow paths for overland flooding. It was observed during the site visit that along Tring Road and Station Road, properties on both sides are elevated causing any pluvial runoff or out of bank flow to be channelled along the road towards the centre of the village. Localised depressions where floodwater from any source would tend to concentrate were noted at both major road junctions in the village, correlating with properties affected by historic flooding per previous Figure 4.1.

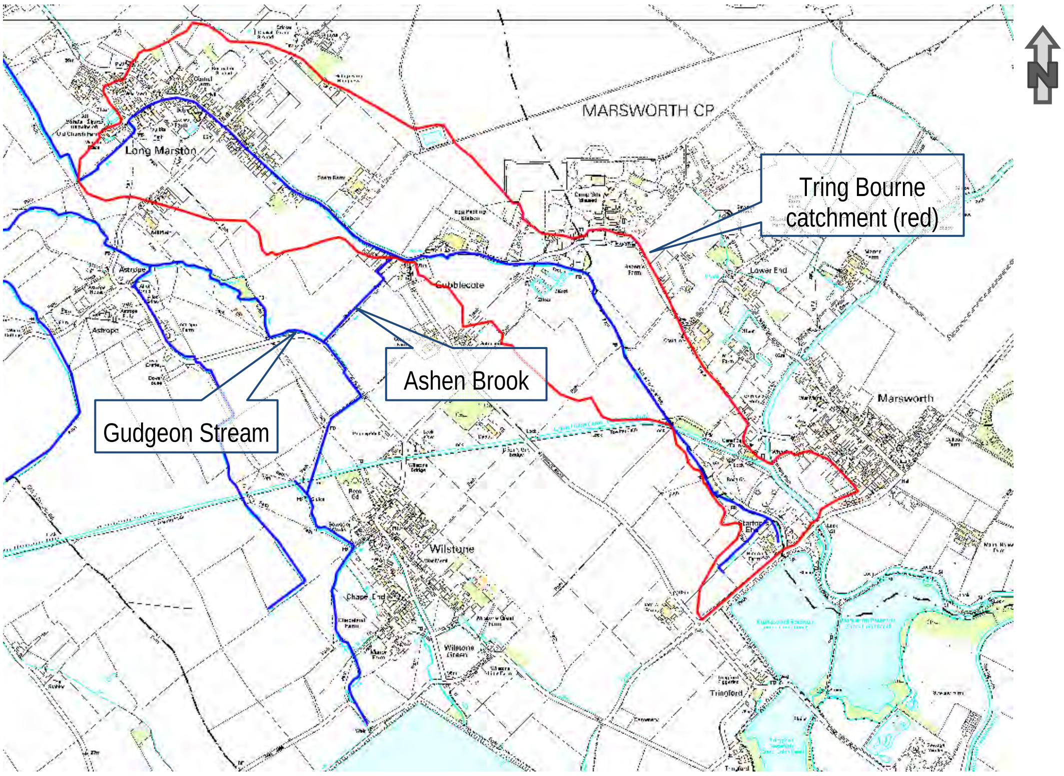
5.1.2 Fluvial (River) Catchment

The following Figure 5.1 shows the delineated catchment of Tring Bourne that flows through Long Marston. The catchment is approximately 148 hectares (ha) in area; catchment topography ranges in elevation from 102m ODN (Ordnance Datum Newlyn) in the south east to 84m ODN towards the north west resulting in an average gradient along its length from source to Long Marston of 1 in 178 (c. 0.5%).

The majority of the catchment consists of agricultural land and green space. The downstream extent of the catchment is dominated by the residential and commercial properties of the village and includes a section of extensive culverting. It is noted that as the watercourse flows alongside the road for the majority of its route adjacent to Tring Road it is subject to a large number of small, private crossings to allow access to properties.

It is noted that a sluice arrangement at Gubblecote causes a proportion of the flow to be directed to the south west along Ashen Brook shown in the map below. During the site visit, the approximate proportion of flow split or method of operation of the sluice could not be determined. The opening size of the sluice gate relative to the channel indicates that more flow would be passed to Ashen Brook than onto Tring Bourne along Tring Road.

Figure 5.1: Tring Bourne Catchment



5.1.3 Surface Water (Pluvial) Catchment & Highway Drainage

Surface water catchments draining towards the site have been determined based on a 2 m Digital Terrain Model (DTM) grid which formed the basis for EA JFlow modelling and provided by HCC. Land use outside the village limits within the catchments comprises recreational open space and agricultural lands with mixed livestock grazing and tillage, as well as impermeable highways.

Lands in Long Marston and its immediate hinterland lie at shallow surface gradients, with the catchment shedding generally from north-east to south-west. Lands south-east of Cheddington Lane / north-east of Tring Road locally drain at a steeper gradient toward Tring Road, with typical gradients of 1 in 26 (c. 4%).

The natural drainage path for any overland flow irrespective of its source from lands to the west is towards Tring Bourne to the east, and must pass through the site (Long Marston) in all instances.

Therefore, in the event of flooding to west of Long Marston due to runoff from saturated ground or local drainage system failure, surface water is likely to be directed towards and through the developed area on its natural path to the west. The pluvial catchments of two key locations, consisting of the primary areas affected by historical flooding and coinciding with localised depressions that would essentially form “pinch points” for overland flooding from any source, have been delineated and are presented below.

The pinch point locations identified are as follows:

- SW Catchment 1 – Junction of Station Road and Chapel Lane
- SW Catchment 2 – Village Crossroads (Junction of Station Road, Cheddington Lane, Tring Road and Astrope Lane)

It is noted that the third area noted as being at risk of flooding, the western end of Chapel Lane, is situated adjacent to the open channel of the main watercourse and is therefore not considered to be at risk from surface flooding only, i.e. flooding at that location is likely to be surface water in combination with fluvial influences.

As shown in Figure 5.2, the main crossroads in Long Marston (SW Catchment 2) has a significantly larger surface water catchment than that for Chapel Lane / Station Road (SW Catchment 1). Surface water catchments are included to demonstrate that overland flow has the potential to cause flooding directly without any contribution from fluvial or other sources.

Surface water from both catchments would tend to drain toward the watercourses on the site, flowing either directly into the channel or entering via an engineered drainage network (highway drains or sewer network). As outlined previously, there is no evidence of any surface water drainage infrastructure in the village, therefore the majority of runoff would tend to flow overland. Such a scenario would be exacerbated where the receiving watercourse was flowing full or in flood, or where the highway drainage network (where it exists) was rendered ineffective by lack of maintenance or surcharge caused by back water effects from downstream incapacity.

Specific to concerns in relation to runoff from highways; the estimated total area of highways within the Tring Bourne catchment area is approximately 2.7 hectares, with 1.5 hectares of this upstream of the flow split at Ashen Brook. The highway footprint represents less than 2% of the total catchment area. The majority of highway runoff would flow directly into the Tring Bourne or to other roadside drainage channels that flow into Tring Bourne (in locations where the watercourse is not culverted). While any impermeable surface would cause a greater response to rainfall than an equivalent unpaved surface and would contribute to flood events (particularly localised / low return period events),, runoff from highways is not considered significant in relation to the extreme flood events under particular consideration by this assessment. The flashy runoff from the highways would not be significant in the context of similarly effective high percentage runoff characteristics from the saturated clay catchment (refer to Section 5.1.6) coinciding with the observed flood events.

Figure 5.2: Long Marston Surface Water Catchments

5.1.4 Soil Properties

5.1.4.1 Runoff Indicators

A review of Wallingford Winter Rain Acceptance Potential (WRAP) class mapping indicates that Long Marston is situated in an area designated as Soil Type 4. This characterises the area as being generally impermeable with relatively low infiltration rates.

The Standard Percentage Runoff (SPR) is a standard parameter used in runoff and flood estimation, which represents the percentage of total rainfall likely to contribute to direct runoff. Values in the UK range from 2% (sand or chalk with slow response / low runoff) to a maximum of 60% for peat bog (rapid response / high runoff).

Review of the site in relation to HOST class mapping (Hydrology of Soil Types) indicates a Standard Percentage Runoff (SPR) in the site area of 45.6%. This value indicates that the general permeability of the catchment is relatively low and that the catchment is likely to have a naturally high response to rainfall events. It also indicates that natural drainage in the catchment will predominantly be via watercourses as opposed to direct infiltration to groundwater.

5.1.4.2 Geological Data

British Geological Survey (BGS) 'Geology of Britain'[13] viewer has records of a number of borehole scans within and in the vicinity of Long Marston, all from 1967.

In general, at that time there was approximately 0.3 – 0.6 m of top soil, firm chalky clay up to 2 m in depth and stiff grey silty clay between 2.5 m and 8 m in depth. Water table levels varied between 1 and 1.6 m below ground level.

Such ground conditions would exhibit characteristics that correlate with the predicted WRAP / SPR classification in terms of permeability and proportionate response to runoff.

5.1.4.3 MORECS Data

The Met Office Rainfall and Evaporation Calculation System (MORECS) gives real-time assessments of rainfall, evaporation and soil moisture and analysis covers different soil, crops and topography.

MORECS data can provide a range of parameters. Of particular interest as part of this investigation is the Soil Moisture Deficit (SMD) and Hydrologically Effective Rainfall (HER).

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

MORECS data comprising SMD and HER values have been obtained for Long Marston. The SMD of the ambient ground conditions is an important parameter when considering surface water flooding at the site. If the SMD is high then ground is dry and rainfall will infiltrate into the ground. When SMD values are low, the ground has reached its field capacity or saturation point and rainfall cannot infiltrate.

Figure 5.3 and Figure 5.4 graph SMD values which have been obtained from Met Office for discrete periods correlated with periods of high rainfall to inform the investigation of the conditions under which flooding in Long Marston has and is likely to occur.

5.1.5 Rainfall

5.1.5.1 Average Rainfall

Met Office mapped climate averages[14] indicate that Long Marston is situated in an area with a winter average rainfall of 150 – 200 mm which is 2nd lowest band of rainfall (of 9 bands) in the UK.

Online media reports[15] state that the southeast and central southern England received 439.2 mm of rainfall during winter (December, January, February) 2013/2014 breaking a previous record for winter rainfall that had stood since 1914/1915 and substantially above the average rainfall figure making 2013/2014 the wettest winter on record.

5.1.5.2 Rainfall Records

There are a number of rainfall data sources for the UK. The Met Office provides monthly rainfall averages and maximum / minimums as part of publically available information on their website.

Rainfall data, including records of daily rainfall depths, is available from Weather Underground through their website. Records for the previous three years have been obtained for the site and surrounding area via Weather Underground's online database Data was extracted for three weather stations within a 10 km radius of the site and these were compared with Met Office monthly totals for Heathrow and Oxford for corroboration.

Data from the gauged weather station at Dagnall (IENGLAND226)[16] has been established as being the most consistent with Met Office monthly records and is also considered to provide a reliable representation of rainfall depths experienced at Long Marston.

[13] http://mapapps.bgs.ac.uk/geologyofbritain/home.html [accessed 28th May 2014]
[14] http://www.metoffice.gov.uk/climate/uk/averages/ukmapavge.html [accessed 28th May 2014]
[15] http://www.bbc.co.uk/news/science-environment-26280219 [accessed 28th May 2014]
[16] http://www.wunderground.com/personal-weather-station/dashboard?ID=IENGLAND226 [accessed 18th April 2014]

These records form the basis of the charts included in the following pages as Figure 5.3 and Figure 5.4. Full records are included in Appendix C.

It is noted that across England, the winters of 2012/2013 and 2013/2014 have coincided with two extended periods of exceptional seasonal rainfall. The month of December 2013 was the 6th wettest on record.

A 'Monthly Water Situation Report' published by the EA states that:

> *"February 2014 has been another very wet month, the second consecutive month with more than 250% of the long term rainfall average. As catchments remain saturated, rivers and groundwater remain sensitive to further rainfall. River flows are among the highest ever recorded and groundwater levels have continued to rise causing groundwater flooding at a number of location across the South East Region."*

In addition, the report states that the region received approximately 64% of the long term average rainfall in the three months from December 2013 to February 2014 and that the wettest day across the region [in 2014] was the 6th February when almost 20% of the monthly rain fell.

It is clear that rainfall during January and February 2014 was extreme, unexpected and well above levels expected based on historical events.

5.1.6 Analysis

As a means of qualifying the response to rainfall within the catchment, five day cumulative rainfall (on a rolling basis) and Soil Moisture Deficit (SMD) data have been analysed and are presented graphically in the following section.

Figure 5.3 presents rainfall and SMD data for the winter of 2013/2014 with recorded flood events in December, January and February also shown. The data suggests that flooding tends to occur when the 5 day total rainfall depth is over 50 mm coinciding with SMD at or nearing zero.

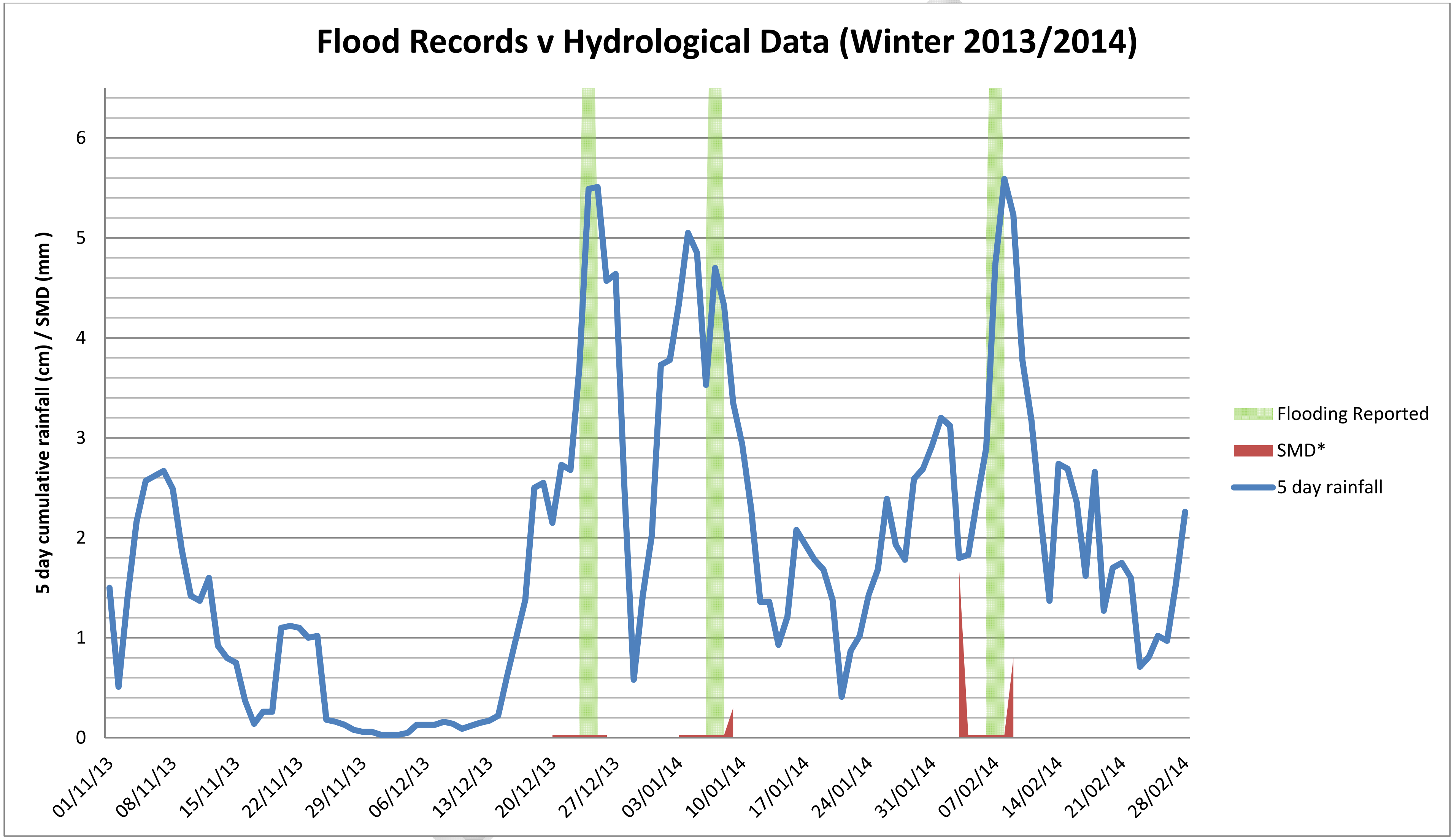
Figure 5.4 presents an investigation of two other instances during spring / summer 2012 when rainfall was found to be above the previously noted threshold value of 50 mm. There are no reports or records of flooding at the time of these extreme rainfall events and this is considered to be due to the relatively higher SMD levels.

The floods in the winter of 2013/2014 coincided with an extended period of exceptional seasonal rainfall. The month of December 2013 was the 6th wettest on record. In addition, a 'Monthly Water Situation Report' published by the EA demonstrates that February 2014 was a very wet month and that the wettest day across the region [in 2014] was the 6th of February which coincides with the major flood event in Long Marston. This prolonged period of exceptional wet weather would have increased the frequency and severity with which floods have been experienced with records of flooding a number of a number of occasions during winter 2013/2014. This extreme seasonal rainfall is considered to be the primary contributing factor to increased frequency of flooding in Long Marston.

It is evident that while flooding occurs as a result of high levels of rainfall, the antecedent wetness of the ground within the catchment has a significant effect on whether flooding occurs. Whenever the catchment has been subject to rainfall on preceding days, the ground becomes saturated and the majority of the rainfall incident on a catchment producing overland flow. The converse is true when rainfall occurs following dry spells of weather when the ground has capacity for inception losses (soakage of topsoil layer and infiltration where the soil has potential to infiltrate). The potential for high proportionate runoff due to poor rain acceptance potential correlates with previously indicated WRAP / HOST SPR values and soil / subsoil types observed on site investigation data.

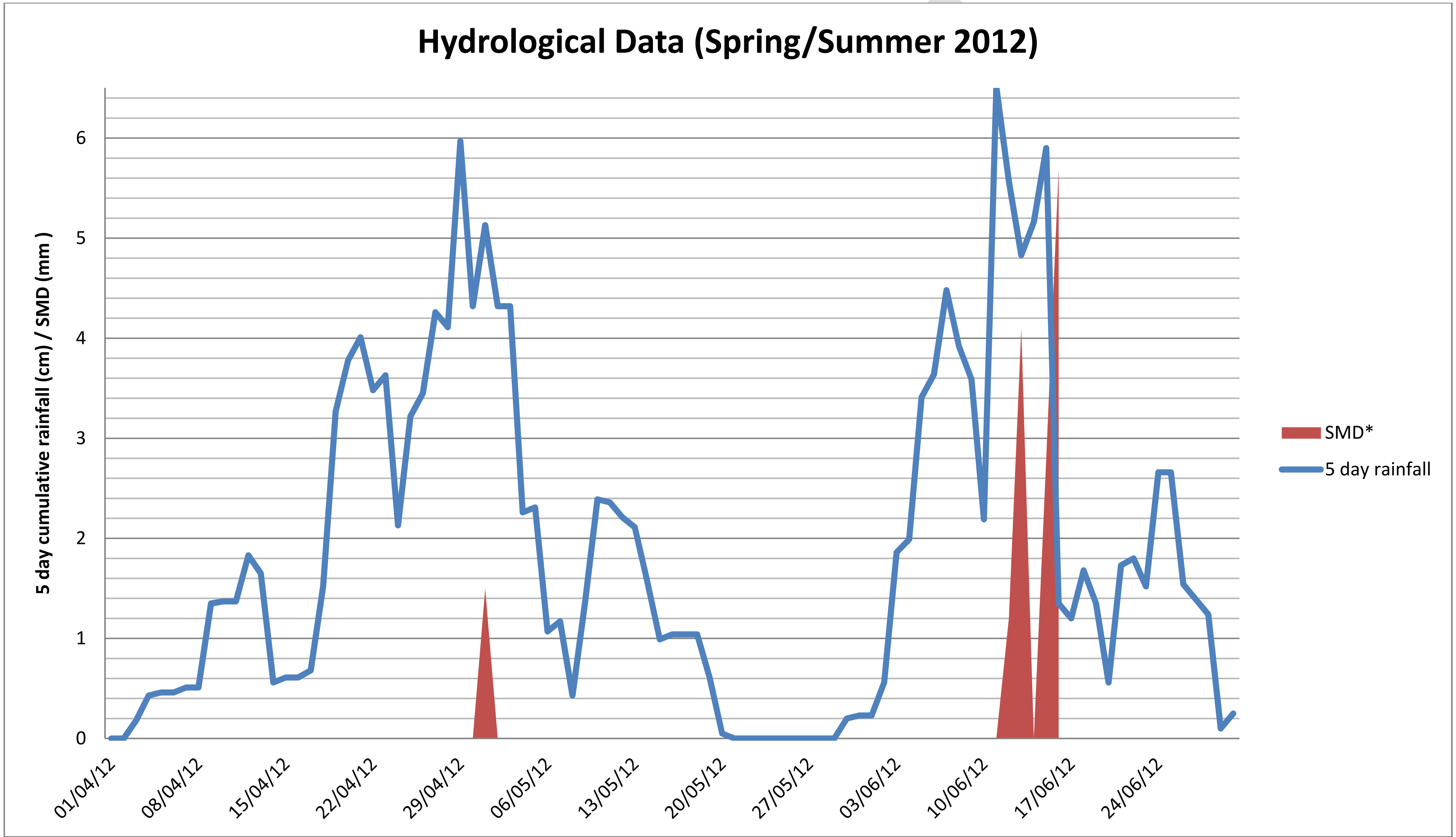
The river catchment contributing to the site is small with a high proportionate runoff particularly when the catchment is saturated, and is initially considered likely to react in a spate / flashy nature when the catchment is subject to heavy rainfall. A hydrological analysis to determine a typical time to peak flood in the village (following a rainfall event) has been undertaken, based on Flood Estimation Handbook (FEH) Revitalised Flood Hydrograph (ReFH) with catchment parameters adjusted to allow for the antecedent catchment wetness experienced in 2013 results in a time to peak of c. 2 hours. This estimate tallies with local residents reports that on the 7th February, heavy rainfall was observed at 2am and flooding commenced at approximately 4am.

Figure 5.3: Graph of Flood Records v Hydrological Data (Winter 2013/2014)



*SMD values obtained for discrete ranges coinciding with high rainfall events

Figure 5.4: Graph of Hydrological Data (Spring/Summer 2012)



*SMD values obtained for discrete ranges coinciding with high rainfall events

5.1.7 Fluvial / Surface Water Summary

The preceding qualitative analysis of fluvial and pluvial effects at Long Marston (exclusive of other factors considered subsequently in this assessment) indicates the following:

- The upstream contributing catchment of the main watercourse is likely to have a rapid "flashy" response to rainfall particularly during periods of saturated ground conditions across the catchment.
- A review of surface topography indicates that the site is located in an area where water will tend to accumulate as it passes from high ground in the north and east to low ground in the west. Typically shallow gradients cause a larger areal extent of flooding (as surface flows will tend to spread); however Tring Road, Station Road and Chapel Lane in particular form preferential flow routes for overland flooding. Localised depressions along those routes (corresponding to the locations of historic flooding) are the most significantly affected areas.

Fluvial and surface water flooding is considered a significant flood hazard at the site in its own right and is likely have to have been a significant contributing factor to flooding in the village on the occasions under consideration.

Additional information obtained indicates that a number of artificial factors have potential to significantly exacerbate fluvial / surface water flooding and is considered subsequently in this assessment. In the absence of a quantitative assessment it cannot be determined whether fluvial / surface water flooding would have caused flooding irrespective of those additional factors. It is noted that the complex nature of the watercourse network and additional factors such as culvert condition and local drainage arrangements means that undertaking hydraulic modelling in an attempt to replicate a known event is infeasible at this stage.

5.2 Tring Reservoirs and Canal Infrastructure

Tring Reservoirs are four reservoirs in the Tring/Marsworth areas that encompass Wilstone Reservoir, Tringford Reservoir, Marsworth Reservoir and Startopsend Reservoir. HCC staff and the local online community forum have indicated that local residents are concerned that the local canal and reservoir infrastructure may have exacerbated flooding in Long Marston in February 2014 and on other occasions. As assessment of the Tring Reservoirs and canals included a site walkover survey of the canals, reservoirs and associated overflows and watercourses in the locality, a site meeting with a representative of the Canal and River Trust (CRT) and an independent assessment of information provided by CRT.

The CRT has provided information on the operation philosophy of the reservoirs and canals in the affecting area and their status in the days before and after the flooding event of 7th February 2014. The effect of the canals and reservoirs on the hydrological characteristics of the catchment has been assessed to determine if there is any evidence that the flood risk at Long Marston, or elsewhere, can be affected by the operation of the canals and associated infrastructure. A simplified schematic plan of the operation of the canal and reservoir system is presented in Figure 5.5.

5.2.1 Canal and Reservoir Operation

The Tring Reservoirs provide the main source of water for maintaining water levels in the canals for safe operation of boating. Locks are used to maintain different water levels in the canals to allow for navigation of boats on rising or falling topography. Each operation of a lock involves the movement of approximately 140,000 to 250,000 litres of water from the higher level to the lower level. On the Aylesbury Arm canal water is passed from the local high point at Marsworth Pound towards Aylesbury in a general westwards direction. Tring Reservoirs receive flow from numerous springs.

The operation of the canal and reservoir infrastructure is shown in Figure 5.5; numbers in **red bold** refer to features shown and annotated on this figure. The operational philosophy of the canals and reservoirs when the reservoirs have capacity is:

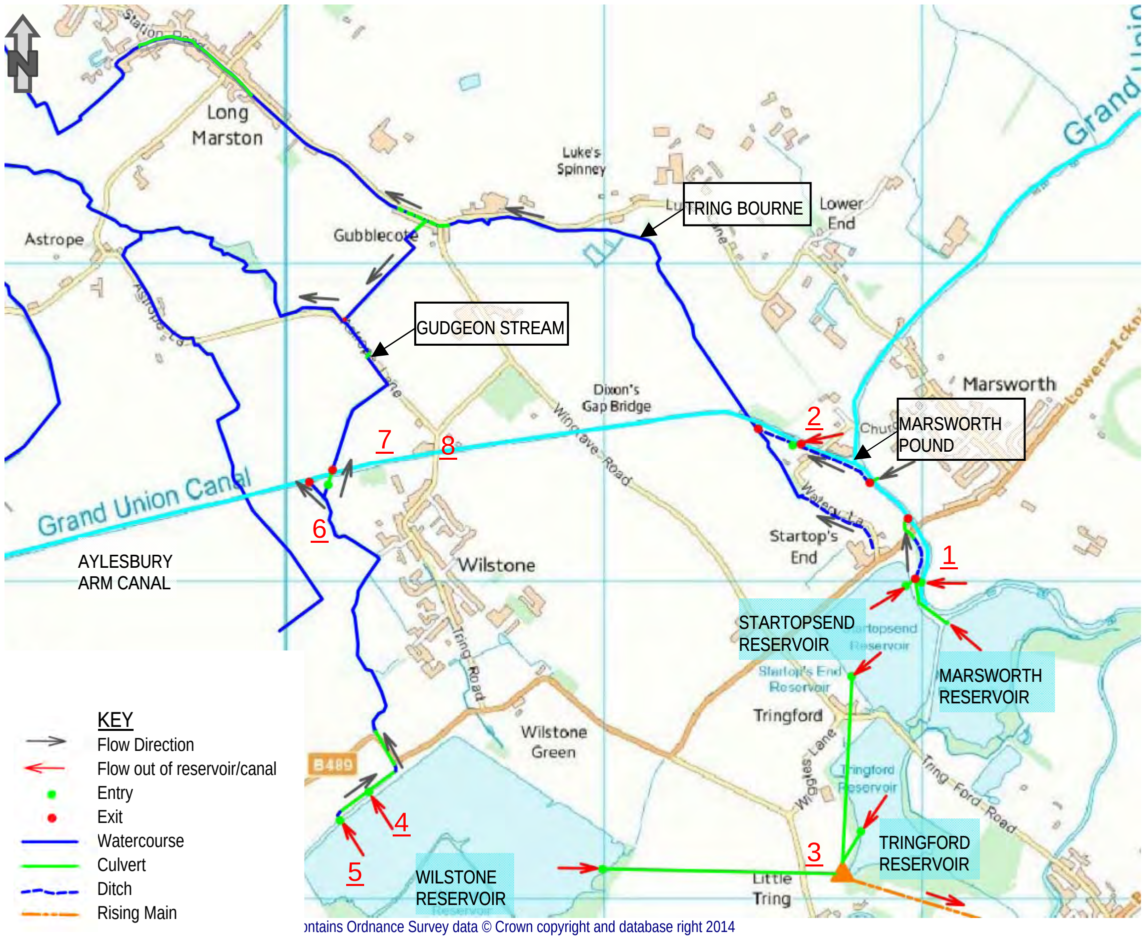
- The Aylesbury Arm of the Grand Union Canal is located partially within the Tring Bourne and Gudgeon Stream catchments. Approximately 850m of the Grand Union Canal and Aylesbury Arm are located within the Tring Bourne catchment and 1150m of Aylesbury Arm canal is located in Gudgeon Stream catchment. Water from the canal and reservoir system in normal conditions only enters either catchment at one location via a high level 225mm diameter overflow pipe (**2**) from the canal west of Water Lane Bridge on Aylesbury Arm canal to a canal-side ditch near the head of the Tring Bourne. Note that this overflow was not identified during a walkover survey as it may have been hidden by permanent narrow-boat moorings.

- Overflows from Marsworth Reservoir and Tringford Reservoir discharge into Startopsend Reservoir, which is the lowest lying of the four reservoirs. Tringford Reservoir is supplied by water via natural groundwater springs and streams.
- Startopsend Reservoir conveys flow to the Startops Feeder stream (1) via a gauging pit. Startops Feeder flows into the Grand Union Canal via a culvert near Marsworth Pound west of Lower Icknield Way Bridge and Marsworth Lock No. 39. Startops Feeder also receives flow from both Marsworth Reservoir via a culvert and from Grand Union Canal via an overflow pipe. This overflow pipe into the feeder stream essentially acts as a flows bypass channel for Lock No. 39.
- Deep culverts from Startopsend Reservoir and Tringford Reservoir convey flow to Tringford Pumping Station (3), which then pumps water to Tring Summit, the highest point in the local canal system, when required.
- Flow can only enter Aylesbury Arm canal at two points within the locality of Long Marston and the Tring Bourne catchment; through the lock gates and over the top beam of Aylesbury Arm Lock No.1 and by diverting flows from Gudgeon Stream.
- CRT take water from Gudgeon Stream to supply Aylesbury Arm canal. Two sluice gates (6) act to apportion flows between continuing under the canal via a syphonic culvert or into the canal. It is worth noting that during a site visit in September 2014 all of the flow in Gudgeon Stream was flowing into the canal largely due to the presence of silt affecting the relatively shallow depth of flow rather than the settings on the sluice gates or apron structure. The two sluice gates are configured such that during higher flows with a greater depth a higher percentage of flow would continue downstream in Gudgeon Stream than be diverted into the canal.
- The reservoirs act as a buffer to localised flooding during heavy rainfall and prolonged wet periods as they store water for releasing to a canal, and effectively reduce the catchment area of natural watercourses.

When the reservoirs are at, or nearing, storage capacity:

- Excess water from Startopsend, Marsworth and Tringford Reservoirs can be released via the sluice controlled feed to Startops Feeder and/or via Tringford Pumping Station. The receiving waterbody for both flows is the Grand Union Canal at two different locations; near Marsworth Pound and Tring Summit respectively.
- Excess water from Wilstone Reservoir can be released via a culvert to Tringford Pumping Station, an overspill weir (5) and/or a siphon (4). The overspill weir and siphon convey flows into Gudgeon Stream, effectively becoming the head of the stream.

Figure 5.5: Tring Reservoirs Schematic



ontains Ordnance Survey data © Crown copyright and database right 2014

The primary points findings of the role the canals and reservoirs have on the catchment are:

- After a prolonged period of wet weather the Tring Reservoirs were nearing storage capacity in January 2014. Tringford and Marsworth reservoirs were both overflowing into Startopsend Reservoir intermittently from November 2013 through to August 2014. As a result of this Startopsend Reservoir was filling to levels in January/February 2014 that CRT try to avoid, i.e. 600mm below top water level.
- Wilstone Reservoir was supplying water to Aylesbury Arm canal via the syphon and Gudgeon Stream for a prolonged period in 2013 until 14th January 2014 when the overflow weir began to operate and the manually controlled syphon operation was halted. Spill over the overflow weir in Wilstone Reservoir continued until mid-June 2014. The depth of flow over the weir on 15th February was 220mm resulting in a flow of approximately 475 litres per second to Gudgeon Stream. Warnings from HCC Resilience Team were issued in mid-January 2014[17] to forewarn residents that CRT had reported to them that the reservoirs were nearing capacity and that flooding of the Astrope Lane and Watery Lane areas could be expected. The depth of flow over the weir in Wilstone Reservoir remained high for several months with levels recorded on 24th March of 170mm above weir level and on 9th May 100mm above weir level.
- Startopsend Reservoir sluice gate was opened further to increase flow to Startops Feeder stream several hours after reports of flooding in Long Marston at 13:00 on 7th February 2014. Note that this feeder stream flows into Grand Union Canal. This action was undertaken by CRT in response to the flooding event to free up capacity in the Tring Reservoirs so that more rainfall and water could be held within the reservoirs and canals. CRT has provided data logger information for a gauging station at this location to prove the timings of the increased flow from the reservoir.

[17] http://swhertslibdems.org.uk/en/article/2014/758938/flooding-risk-wilstone-puttenham-and-long-marston

- Water level traces for Lock 1 on the Aylesbury Arm (Marsworth Pound) have been provided by CRT and are included in Appendix A. The trace demonstrates that on 7th February 2014 the recorded levels in Marsworth Pound were 164mm above normal baseline levels. This level corresponds to a top water level in the canal that is below the general canal threshold level of 250/300mm and therefore it is suspected that no over-spilling of the canals occurred.
- CRT undertook a photographic survey on 18th February 2014 when the water level of Marsworth Pound was recorded to be approximately 160mm above baseline levels i.e. almost identical to levels recorded on 7th February 2014. Results of this photographic survey are included in Appendix A and show that flow over the top beam in Lock No. 1 top was contained within the canal. This adds credence to the belief that the Aylesbury Arm canal did not overspill between Lock No. 1 and Lock No. 8 (8) near Wilstone as within this stretch of canal there are no additional inflows into the canal.
- A walkover inspection survey of the Aylesbury Arm of the Grand Union Canal undertaken to inform this assessment indicates that the canal bank levels are generally approximately 250 to 300mm higher than normal water level in the canal. Tide marks are visible on some vegetation and canal walls indicating a top water level during historic high water level events; there were no signs of previous overtopping of the canal such as signs of bank erosion or vegetation erosion.
- A low lying section of canal bank was noted during the walkover survey, the location of which is shown on Figure 5.5 demarcated as location 7. This location corresponds with an area identified as a possible breach of the canal by residents' investigations. Any overspill from the canal in this section would flow into Gudgeon Stream; given the course of this watercourse, lack of channel capacity and localised flooding upstream of Long Marston, it is very unlikely that if a breach of the canal were to occur at this location that flood waters would affect Long Marston. Although this section of bank was visited 7 months after the flooding events of February 2014, there were no signs of past erosion such as ruts, channels or bare earth in the bank and surrounding field areas as would normally be expected from a high volume or high velocity flow a caused by a large water body overtopping. There were signs of erosion of the bank forming a shallow pool in the bank but no signs that that top of bank was breached.

The canals and Tring Reservoirs have different effects on the hydrology of the area depending on whether there is storage capacity within the reservoirs and the requirement to supply water to the canals. The canals' water supply requirement is highest during the boating season which peaks in the summer months. During autumn and winter months the CRT operational philosophy is to recharge the reservoirs to normal water levels to provide a reservoir of water for the next boating season. During the recharging stage the loss of water from the reservoir is controlled to maintain operational canal water depths. When the reservoirs are full they essentially become a natural part of the catchment and overspill weirs will convey flows to natural watercourses, such as Wilstone Reservoir flows navigate to Gudgeon Stream.

The key discharge that has the most potential to affect flooding in Long Marston could be the overspill weir and siphon flows from Wilstone Reservoir. This flow discharges to the head of Gudgeon Stream upstream of where flow is divided between a culvert to Aylesbury Arm canal with the remainder of flows continuing along the watercourse under the canal and towards Astrope and west of Long Marston. Tring Bourne is connected to Gudgeon Stream via Ashen Brook as shown in Figure 2.4 and Figure 5.6. There is anecdotal evidence of flooding of fields adjacent to Gudgeon Stream south of the canal, and at Astrope Lane where Gudgeon Stream flows under the highway in a culvert; this flooding due to a lack of capacity in the channel would have significantly reduced channel flows before reaching the environs of Long Marston. This flow is therefore not perceived to be a contributing factor to flooding in Long Marston. The capacity of the Gudgeon Stream and its tributaries of roadside ditches would have been reduced by excessive siltation and growth of vegetation as a result of historically low levels of groundwater and resultant stream flows. The siltation at the Gudgeon Stream sluice gates, where flow is split, was observed to be causing all of the flow to be diverted into Aylesbury Arm canal during a site visit in September 2014; this may be a historic problem and may have exacerbated siltation and vegetation growth downstream due to a lack of base-flow therefore reducing channel capacity further.

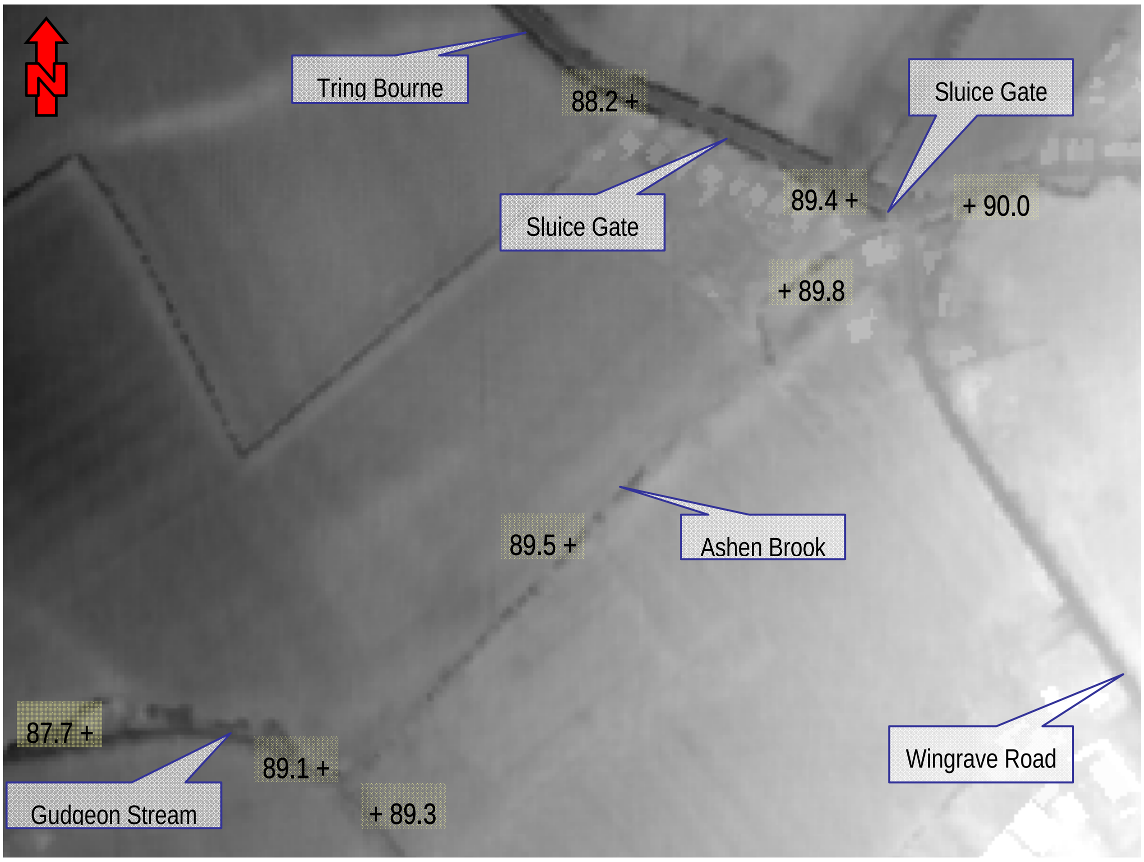
While it is noted that channels / culverts downstream of the Wilstone Reservoir overspill outlet including Gudgeon Stream are in poor serviceable condition (highly silted), the effect of that condition would serve to cause flooding upstream (south) of the canal regardless of capacity of the outlet and syphonic culvert feeding Gudgeon Stream; therefore it would not be perceived to be a contributing factor to the particular instance of flooding in Long Marston under consideration.

An assessment has been undertaken using 2m DTM to determine whether high water levels in the Stream could impact water levels and therefore flow in the Tring Bourne. There is approximately 700mm of fall in the stream bed level between the head of Ashen Brook and Gudgeon Stream. Anecdotal evidence of flooding on sections of Astrope Lane would indicate that water depths in Gudgeon Stream may have been approximately 600 to 700mm deep at the junction with Ashen Brook. This would result in an estimated top water level of 89.8m AOD which is the same level as the stream bed near the flow split with Tring Bourne. Based on the available information flows from Gudgeon Stream could not normally flow eastwards along Ashen Brook and into Tring Bourne.

The Tring Bourne bed level at the sluice gate where flows are divided between Ashen Brook and Tring Bourne is approximately 90.0m AOD, 900mm above the stream bed at the streams' confluence. Based on anecdotal flood depths, evidence gathered during a walkover survey of Ashen Brook and utilisation of a 2m DTM survey, it is concluded that flood depths in Gudgeon Stream would have no effect on the proportion of flows diverted to Tring Bourne of Ashen Brook. This flow split is likely to be dependent on conditions local to the sluice gate and not 400m downstream. Note that there is uncertainty of the conclusion due to the complexity of the interaction between the watercourses. To remove any uncertainty a detailed topographical survey, a flow survey in the three affected streams and hydraulic modelling of the catchments and watercourses would be required which is outside the scope of this assessment.

Figure 5.6 shows a representation of ground levels with low levels labelled indicating the bed level of a stream or ditch.

Figure 5.6: DTM Level Map, Gubblecote



(Darker areas indicate low lying areas, lighter areas are higher levels. Ground level labels indicate lowest points i.e. stream bed, metres above Ordnance Datum)

Gudgeon Stream flows in a northerly direction and under Astrope Lane road via a culvert. There are anecdotal reports of run-off from Astrope Lane flowing into Long Marston, therefore an assessment has been undertaken to determine if high flows from Gudgeon Stream could flow into Long Marston. Figure 5.7 shows the lowest levels of streams and ditches in the Astrope Lane area. The figure demonstrates that the bed level of Gudgeon Stream is a minimum of 1.2 metres lower than the lowest point in the roadside ditch of Astrope Lane near Long Marston, therefore flows from Gudgeon Stream would not flow into Long Marston via this route.

Figure 5.7: DTM Level Map, Astrope & Long Marston

(Darker areas indicate low lying areas, lighter areas are higher levels. Ground level labels indicate lowest points i.e. stream bed, metres above Ordnance Datum, except where stated)

In summary there is no evidence that Grand Union Canal or Aylesbury Arm Canal has overspilled in areas where outflows would enter the Tring Bourne catchment, and therefore is not considered to have had a direct impact on flooding in Long Marston. Excess water overspilling from Wilstone Reservoir did cause flooding of farmland and highway flooding along Astrope Lane; it is worth noting that this is not a controlled release. The overspill weir is used to maintain safe top water levels in the reservoir. It is similarly worth noting that Wilstone Reservoir weir continued to convey flow to Gudgeon Stream until mid-June 2014 without further reported flooding incidents.

Canal and River Trust data is included in Appendix A.

5.3 Tring Bourne Culverts

5.3.1 Main Culvert Incapacity

In relation to the extensive culvert on the Tring Bourne starting at Ravens Court adjacent to Tring Road and discharging at the eastern end of Chapel Lane, any incapacity in the would cause surcharging of the system and potential for overland routing of floodwater in excess of the culvert capacity from the inlet and/or manhole covers along the route.

A hydrological assessment using ReFH (as detailed in Section 5.1.6) has been undertaken to estimate flows within Tring Bourne that is culverted through Long Marston. In order to give a level of qualification to the main Tring Bourne culvert capacity, a coarse hydraulic assessment has also been carried out and indicates that for a Q_{100} event, the calculated flow is approximately four times larger than a conservative assessment of the peak capacity of the culvert.

It is noted that the hydraulic assessment for the culvert assumes pipe-full conditions only, excludes inlet / bend losses and does not allow the potentially significant effect of loss of serviceable capacity through siltation or partial blockage; as such capacity estimates are likely to be unrealistically favourable. It is therefore considered likely that the culvert is significantly and is likely to be a **significant contributing factor** to flooding.

Out of channel flow, potentially arising at the culvert inlet (east of Ravens Court development) and via unsealed manhole covers along the culvert route, would tend to follow the preferential flow path formed by Tring Road and Chapel Lane, with concentrated flooding at localised depressions along that route.

5.3.2 Main Culvert Blockage

A review of the CCTV Survey commissioned by the EA and carried out on the main Tring Bourne culvert through Long Marston has indicated that the serviceable condition of the pipes is generally poor. The survey carried out in 2010, recommended urgent and short-term rehabilitation works. Ingress of grout at joints and tree roots are the most common forms of blockage identified by the survey causing both service and structural defects.

Any blockage within the culvert would lead to a loss in capacity within the culvert and cause in increase in the volume and rate at which water surcharges the system and forms overland flow. In addition, there is a trash screen comprising a narrow bar screen to the inlet to the culvert at Ravens Court; the observed condition suggests that the screen is prone to blockage (based on degree of litter present) which would serve to significantly increase the likelihood of blockage.

It is noted that the CCTV survey was carried out almost four years ago and the internal condition of the culvert is likely to have deteriorated. No evidence of culvert improvements or rehabilitation works has been found as part of this assessment and anecdotal reports suggest that the culvert has been observed to surcharge from manholes leading to flooding in the village.

The effect of blockage of the culvert in terms of flood routing and locations is as per Section 5.3.1. Where it was established that the culvert capacity was further reduced by a significant blockage, this would be likely to be a **significant contributing factor** to flooding.

5.3.3 Minor Culverts

Tring Bourne and parallel unnamed ordinary watercourse are culverted over short distances to provide private access to properties on Tring Road and Chapel Lane. Culvert opening sizes vary, however on occasion of site inspections a significant number appear to have impaired capacity based on the observed available headroom to the culvert soffit and depth of silt deposited.

The effect of blockage of such culverts would be to cause a backing up effect until water overtopped the access (driveway) or flooded onto the adjacent road. Dependant on the road topography, overland flooding would either return to the channel downstream of the culvert or continue overland on the preferential flow route formed by the road.

Based on observed conditions it is considered that the number, size, and condition of culverts is likely to be a contributing factor to flooding.

5.4 Local Surface Drainage Network

Based on information made available to date, there is no surface water drainage network in the village. HCC highways drainage is understood to be located in Tring Road and Station Road; however no record information is available with which to make an informed assessment.

All surface water would tend to drain ultimately to the main or ordinary watercourse in the village, either by running directly into the channel or by collection in a highway drain. In all areas west of Ravens Court (off Tring Road), i.e. western Tring Road and Station Road, surface water would be *entirely reliant* on collection by the highway and any other informal drainage network for discharge to the culverted Tring Bourne.

The local drainage network (or lack of) would primarily have potential to affect flooding by the following means:

- Direct flooding due to rainfall in areas where no surface drainage exists, in particular at lands to the rear of Tring Road.
- Indirect flooding due to main Tring Bourne culvert surcharge being released at gullies and manholes.
- Exacerbated fluvial / pluvial flooding where overland flooding from rivers onto roads cannot return to the culvert due to the lack of a drainage network.

It is considered that the effect of the drainage network (or lack of) is likely to be a contributing factor to flooding.

5.5 Local Foul Drainage Network

It is considered likely (given reported incapacity at the pumping station south east of Chapel Lane) that surface water cross connections exist on the foul sewer at property level, so providing a degree of surface drainage for low probability rainfall. Such connections would cause the foul network to operate as a combined network. No relief (by combined overflow or similar) would be installed on the network, hence the system would be highly susceptible to surcharge, correlating with residents reporting problems with toilet flushing during previous flood events as noted by HCC during scoping.

Potential for groundwater ingress to the foul sewer network would have potential to cause a similar or effect in combination with surface water. Historically, borehole records for the vicinity from 1967 indicate that water table levels varied between 1.0 and 1.6 m below ground level (i.e. shallow groundwater at depths likely to affect a sewer); while it is widely reported that groundwater levels were high over the winter of 2013/2014 due to high levels of rainfall across the south east of England. An analysis of British Geological Society groundwater levels at Stonor Park[18] (c 30 km south) indicates that groundwater levels in 2013 / 2014 represent a 12-year high.

All water in the drainage network, including that in exceedance of the designed foul flow would be required to be pumped. Reports of failure of the pumping station around the time of recent flooding would correlate with the anticipated effect of surface water or groundwater flow in the foul network overwhelming the capacity of the pumps.

While not likely to pose a significant risk of flooding in its own right, the foul drainage network would primarily have potential to affect flooding by the following means:

- Surcharge / backing up of floodwater into low lying properties along the sewer route.
- Lack of capacity when operating as a combined system would cause localised flooding to any area relying on surface discharge to the foul sewer.
- Causing flood waters to become contaminated with foul sewage, representing a hazard to health and the environment.

It is considered that the effect of the foul network as it presently exists is likely to be a contributing factor to flooding in localised low lying properties in the vicinity of Chapel Lane.

5.6 Watercourse Maintenance

As summarised in Section 3.3.3, the watercourses in Long Marston and surrounding area have not been subject to any statutory agency maintenance in the past ten years.

A lack of watercourse maintenance is considered likely to have contributed to an increase in flood risk to the village. Significant build up of silt, debris and growth of channel and bankside vegetation will lead to a decrease in the capacity of the channel and therefore increase the potential for overland flooding from the watercourses.

5.7 Groundwater Flooding

As noted in Section 3.6.2, much of the village is denoted by BGS data as being at moderate susceptibility of groundwater flooding. As identified in Section 5.5, groundwater levels were likely to be elevated (locally near ground level) during the recent flood events; however, as recent flood events were of relatively short duration they are not characteristic of flooding arising directly from groundwater.

5.8 Summary of Findings

The following are the key findings of the previously presented fluvial / pluvial analysis and other flooding mechanisms that have been determined as part of this assessment:

- Winter 2013/2014 was one of the wettest on record for the region; and heavy (while not extreme) rainfall falling on already highly saturated ground with an elevated groundwater table has caused flood flows likely to have overwhelmed the capacity of the main and ordinary river channels affecting the site, causing overland flooding into Tring Road, Station Road and Chapel Lane. Tring Road and Station Road forms a preferential flow route through the village.

[18] British Geological Society. (2014). Groundwater Levels - Stonor Park. Available from: http://www.bgs.ac.uk/research/groundwater/datainfo/levels/sites/StonorPark.html. [Accessed: 18/6/2014]

- Similarly, rainfall onto highly saturated ground tending to drain directly toward the village is likely to have caused direct surface water flooding on lands to the rear of properties on Tring Road and would exacerbate fluvial flooding in the same vicinity.
- The existing river network capacity, and in particular the main culvert capacity, is likely to be insufficient to convey the rate / volume of floodwater caused by recent events, a situation exacerbated by the lack of maintenance. The significant effect of lack of culvert capacity (due to culvert size and serviceability) is likely to have caused a significant effect in terms of causing out of channel flooding at its inlet, causing direct flooding due to surcharge of manholes, and causing the failure of surface drainage networks (where present) to cater for direct runoff to due to surcharge / incapacity in the system.
- Inflows to the river catchment from CRT infrastructure (canal and reservoirs) are discounted in terms of causing or significantly contributing to flooding in Long Marston.
- The effect of failure of the foul pumping station is likely to have caused surcharge of the upstream sewer network and exacerbated surface water flooding in areas where surface drainage cross connections discharge to the foul network. Failure of the pumping station would feasibly have caused direct flooding of low lying properties on Chapel Lane in the immediate vicinity of the plant.

Primary flood mechanisms and flood routing is considered at the three main areas previously affected by flooding noted as follows, whereby each is a localised depression on the main flow route through the village:

'Area 1' - Junction of Station Road and Chapel Lane

- Overland flooding from Tring Bourne (emerging from culvert manholes and flooding from the open channel upstream) and surface water flooding draining from lands north/west would accumulate in this area where highway drainage reliant on discharge to the main culvert failed.
- Water would accumulate until overtopping a localised high point on Chapel Lane to the south-west.

'Area 2' - Junction of Station Road, Cheddington Lane, Tring Road and Astrope Lane

- Overland flooding from Tring Bourne (emerging from the culvert inlet to the south-east at Ravens Court) would tend to accumulate in this vicinity.
- Direct runoff from lands west of Tring Road would in the absence of any surface drainage network tend to accumulate to the rear of properties facing onto Tring Road and would be impounded locally by built structures before overtopping onto Tring Road.
- Flooding would accumulate until reaching an overtopping level before flowing north-west onto Station Road toward Chapel Lane.

'Area 3' - Western end of Chapel Lane

- Out of bank floodwater from the Tring Bourne channel would accumulate at the west of Chapel Lane and would be prevented from returning to the watercourse to the south by a locally raised road level. Water would tend to spread toward properties to the north.
- Low lying surface water connections to the sewerage network would tend to back up due to downstream surcharge, and cause surface flooding in this vicinity.

6 FUTURE FLOOD MANAGEMENT AND FLOOD RESILIENCE

6.1 Short Term Options

A number of actions are available that may serve to reduce the risk and the impact of flooding in Long Marston. These will not resolve flooding issues in the long term but would lessen the damage and inconvenience caused by flooding during more frequent (and less extreme) rainfall events.

Potential short term solutions include the following:

- Target improved public awareness of obligations in relation to riparian maintenance of watercourses and culverts to applicable properties and occupants adjacent to main and ordinary rivers.
- Increase riparian maintenance of the Tring Bourne channel.
- Regular maintenance (clearing of debris, removal of large objects etc.) of the trash screen at the inlet of the main Tring Bourne culvert would reduce the risk of flooding from inlet blockage.
- Undertake maintenance of the main culvert on Tring Bourne (to include localised structural / serviceability repairs informed by CCTV condition survey) and improved frequency of jetting to clear blockages and silt deposits.
- Increase riparian maintenance of the Gudgeon Stream, including the sluice gate apron area and syphonic culvert under the canal. Syphonic culverts are by their nature prone to siltation and blockage due to settlement of silt and debris, particularly while operating under limited head or flow. Excessive siltation at the sluice gates apron may be causing more flow to be diverted to the canal than continue along Gudgeon Stream where anecdotal evidence suggests historically more flows were present in Gudgeon Stream. Maintaining a base-flow in the Gudgeon Stream may reduce siltation and debris build-up, this reducing the risk of flooding at Astrope Lane; this option however would not alleviate the particular flood risk in Long Marston.
- Target improved public awareness of property level protection options and advocate property level preparedness including registration for the EA flood warning service.
- Improve preparedness for flooding by implementing a community flood plan, with subsequent actions such as assembling stocks of sandbags, formalising arrangement of distribution of sandbags and warning schemes, and improved coordination with emergency services.

Roles and responsibilities relevant to any party proposing to undertake any short term improvement are to be defined within the main Section 19 Flood Investigation of which this technical assessment is a component.

6.2 Medium / Long Term Options

A number of options to alleviate flooding in whole or part that may be feasibly available have been identified and are considered subsequently in this section. Options are considered separately under "capital works schemes" and "maintenance schemes".

It is highlighted that all options would be required to be technically assessed and approved by the relevant responsible authority prior to further development through outline and detailed design stages. A number of data sources exist, including existing Environment Agency surface flooding model data, which may be used to validate detailed surface modelling of the catchment and inform future detailed design. Additional consultancy studies utilising Integrated Catchment Modelling, whereby the effects of pluvial, fluvial, and culverted drainage networks can be incorporated may be appropriate where sufficient potential benefit was perceived in terms of informing future capital works.

Further work required for validation has been identified for each of the individual options. Alleviation or amelioration measures may be considered individually or in combination dependent upon the anticipated effectiveness of each following detailed assessment.

6.2.1 Capital Works

A number of potential capital works options are presented in the following sections. It is recommended that any capital works solution be subject to hydraulic modelling or similar as part of a detailed quantified assessment to ascertain existing flow routes and 'pinch points' along the system, suitability of present watercourse and drainage systems, and merit of any flood alleviation or amelioration measures. Scoping of any detailed quantified analysis or modelling exercise should be informed by the findings of this assessment; due to the complexity of the identified mechanisms it is anticipated that Integrated Catchment Modelling may be appropriate.

6.2.1.1 Main Tring Bourne Culvert Upgrade / Replacement Works

This assessment has demonstrated that the main Tring Bourne culvert running through Long Marston is in a general state of disrepair and is likely to be significantly under capacity relative to the present design standard for flood protection for new structures. When surcharging of the culvert occurs, the resultant overland flooding poses a significant risk to flooding of local properties and highways.

Capital works to improve the present serviceable condition of the culvert are likely to provide a degree of benefit; however given the initially perceived scale of incapacity, it is likely that an upgrade of the structure to comply with present day design standards would be required in order to realise significant benefit. Works to the culvert would improve its capacity and thus reduce the volume of water escaping the culvert during a flood event.

Any works to upgrade or replace the main culvert would be dependent upon:

- Further works to ascertain the nature of local surface water drainage discharges to the culvert.
- Further works to undertake a quantitative hydrological and hydraulic analysis by means of modelling of the culvert to ascertain a better estimate of existing capacity and demonstrate the effect of any potential improvement proposed. Such an assessment would be required to consider the potentially detrimental effect of routing floodwater more rapidly to the downstream culvert extent on Chapel Lane.
- Further works to determine the feasibility of such a scheme, dependant on engineering constraints (e.g. structural cover to culverts, proximity to existing utilities, buildability, land take, agreement with Environment Agency).
- A cost analysis to measure the of the capital cost versus anticipated benefit.

Any such scheme would be subject to the following limitations in terms of alleviating flood risk in Long Marston:

- Direct surface water flooding of properties east of Tring Road would be initially considered unlikely to be fully alleviated by such works, subject to further investigation.
- The scheme would be required to demonstrate that it did not cause a significant adverse flooding effect elsewhere, notably downstream.

6.2.1.2 Tring Bourne Diversion(s)

Re-routing or diverting Tring Bourne away from (and around) Long Marston would have potential to significantly reduce or remove the volume and rate of water that would otherwise be channelled by existing topography and drainage networks through the village.

The head of Tring Bourne watercourse is adjacent to Startop's End Farm near Lower Icknield Road and flows in a north westerly direction. At Gubblecote, 800 m south east of the site, a bifurcation (sluice) is used to divide flows, with pass forward flow distributed between Tring Bourne through Long Marston, and Ashen Brook flowing south west towards Astrope Lane. The bifurcation sluice was investigated during a site inspection; however the nature of operation could not be observed and is not known by the EA who maintain water control devices on 'main rivers'.

Flows diverted from Tring Bourne to Gudgeon Stream via Astrope Lane could be increased to reduce the flood risk and severity at Long Marston; provided that it could be demonstrated that this action would not significantly increase flood risk elsewhere. A remotely controlled sluice gate could operate to apportion flows to whichever stream had capacity. The emergency overspill flow from Wilstone Reservoir will have an impact on the capacity of Gudgeon Stream, therefore any system installed to change the current division of flow between watercourses should take into account of the overspill flows, possibly by remote sensing.

It is initially considered likely that potential exists to either:

- Increase the proportion of flow directed to Ashen Brook (thus removing water from the catchment affecting Long Marston entirely); or
- Construct a new diversion channel to the west of Long Marston village, returning to the existing Tring Bourne channel south-west of Chapel Lane.

Any works to divert the watercourse within its present catchment or divert water from the catchment would be dependent upon the following:

- Further works to undertake a quantitative hydrological and hydraulic analysis by means of modelling of the fluvial network to demonstrate the effect of any potential improvement proposed. Such an assessment would be required to consider the potentially detrimental effect of routing floodwater into another catchment or diverting floodwater to areas west of the village not presently at risk.

- Further works to determine the feasibility of such a scheme, dependant on engineering constraints (e.g. availability of lands and landowner agreements).
- Analysis of the cost versus anticipated benefit.

Any such scheme would be subject to the following limitations in terms of alleviating flood risk in Long Marston:

- Any bifurcation should have clarity as to the mode of operation and responsibility for operation, in terms of control of diverted flows.
- Direct surface water flooding of properties east of Tring Road would be initially considered unlikely to be fully alleviated by such works.
- Direct surface water flooding discharging to the Tring Bourne downstream of any bifurcation may ultimately cause a residual flood flow exceeding the capacity of existing infrastructure.
- The scheme would be required to demonstrate that it did not cause a significant adverse flooding effect elsewhere.
- The Tring Reservoirs were at capacity from mid-January 2014 to June 2014. Wilstone Reservoir emergency overflow was discharging throughout this period to maintain safe top water levels. The overflow level is currently not adjustable therefore flow into Gudgeon Stream cannot currently be controlled or stopped once the overflow is in operation. This means that the capacity for Gudgeon Stream to receive more flow from Tring Bourne via Ashen Brook is restricted by the outflow from Wilstone Reservoir when the reservoir is full.

6.2.1.3 Surface Water Interception – Tring Road & Station Road

The assessment has demonstrated that a significant flood mechanism exists for direct surface water runoff from lands east of (behind) Tring Road and Station Road to flow directly onto lands and property adjacent to Tring Road and Station Road correlating with recent flooding of properties in these areas. Information made available indicates that no surface water drainage network exists to the rear of properties along Tring Road and Station Road, hence floodwater is reliant on property-level drainage (including potential cross connections to the foul sewer) or would be impounded behind Tring Road and Station Road or the built development before overtopping onto the carriageway or entering the main or ordinary rivers running parallel.

Potential exists for management (interception / collection) of runoff west of Tring Road and Station Road upslope of existing properties, with the water collected and diverted via a new hard engineered or landscaped drain, potentially to include attenuation, to discharge to Tring Bourne flowing along Tring Road / Chapel Lane.

Any works would be dependent upon the following:

- Further works to undertake a quantitative hydrological and hydraulic analysis by means of modelling of the surface water flooding west of Tring Road and Station Road to demonstrate the effect of any potential improvement proposed.
- Further works to determine the feasibility of such a scheme, dependant on engineering constraints (e.g. availability of lands and landowner agreements).
- Analysis of the cost versus anticipated benefit.

Any such scheme would be subject to the following limitations in terms of alleviating flood risk in Long Marston:

- The scheme would have no beneficial / potentially adverse effect to properties in the vicinity of Chapel Lane.
- The scheme is likely to be reliant on adequate capacity for discharge in the Tring Bourne culvert downstream.

6.2.1.4 Sewerage Infrastructure Improvements

The assessment has identified that for developed areas other than highways, no separate surface drainage network exists and that the foul network, either through unintended operation as a combined sewer or due to groundwater ingress, may cause a direct flood risk to localised properties adjacent to the pumping station and properties connected to the lowest lying reaches of sewer, and an indirect effect to areas reliant on drainage of surface water to the foul network.

Highways drainage within the Long Marston area and Tring Bourne catchment generally at present relies on runoff discharging directly to adjacent ditches / ordinary watercourses and/or the Tring Bourne channel itself.

Potential exists to improve surface water drainage in the vicinity by means of providing a new surface water network (incorporating SuDS) or storm separation scheme. Additionally (where feasible) dedicated highway drainage could potentially be installed/improved in tandem with sewerage improvements. Highway drainage would need to be attenuated using storage, or disposed off via an alternative pathway i.e. not to existing watercourses but via sustainable drainage methods such as infiltration.

Any such scheme would be dependent on the following:

- Further works to determine the nature, extent, and anticipated performance of existing highways drainage in the village; to investigate the degree of surface water cross connections into the foul drainage network and determine the potential for a storm separation scheme; and to investigate the significance of hydraulic leakage into the foul sewerage network and sewage pumping plant by raised groundwater levels (by infiltration survey / flow monitoring) and determine the potential for remedial works to suit.
- Further works to design a scheme depending on the outcome of the above.
- Analysis of the cost versus anticipated benefit.

Any such scheme would be subject to the following limitations in terms of alleviating flood risk in Long Marston:

- Any surface drainage scheme is likely to be reliant on adequate capacity for discharge water collected in a surface network into the Tring Bourne culvert or channel downstream.

6.2.1.5 Modifications to Road Levels - South of Chapel Lane

Chapel Lane is the present natural flow path from the centre of the village towards the open watercourse to the west. As outlined previously, road levels at the western extent of Chapel Lane are higher than lands to the east and north leading to localised impounding and flooding of properties in these areas rather than continuation of flow away from the village.

Slight re-grading (lowering) of road levels in this area to provide a preferential flow path from Chapel Lane to lower lying lands to the west would potentially allow surface water to escape with greater expediency than at present.

Any works would be dependent upon the following:

- Further works to obtain detailed topographic data and undertake a detailed design of the scheme.
- Further works to determine the feasibility of such a scheme, dependant on engineering constraints (e.g. landowner agreement where works affected lands outside the public road and verge).
- Analysis of the cost versus anticipated benefit.

Any such scheme would be subject to the following limitations in terms of alleviating flood risk in Long Marston:

- Direct surface water flooding of properties east of Tring Road would initially be considered unlikely to be fully alleviated by such works.
- The scheme would initially be anticipated to reduce the flood hazard, however is unlikely to alleviate flood risk to a level equivalent to present day flood protection standards.

6.2.1.6 Land Management – East of Tring Road and Station Road

The surface water catchments draining to Tring Road and Station Road are relatively limited, occupying an undeveloped area of 25 ha and comprising approximately 15 individual plots of land. Land use is understood to be generally agricultural based on site observations and orthophotography, and typically comprises livestock grazing and tillage with additional green recreational space.

While land use and management is not considered a particular contributing factor to flood risk at the site or in the vicinity of Tring Road, it is acknowledged that there is substantial evidence that local flooding can be affected by changes in (rural) land management and management practices[19]. Evidence[20] published suggests that variability in proportionate runoff from grass fields can vary by up to c. 60% when comparing grass fields underlain by good soil structure versus poor (compacted) soil structure.

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

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

Potential exists to develop a land management framework on plots draining to Tring Road that would encourage improvement of soil structures (therefore improving infiltration and reducing runoff reaction to rainfall events) and/or encourage vegetation types that may encourage evapo-transpiration.

Any works would be dependent on further studies to ascertain the potential benefits available, and would be subject to landowner agreement.

Any such scheme would be limited insofar as that it would have limited potential to alleviate flooding in areas of Long Marston other than Tring Road, and quantification of predicted benefits may not be realistically achievable.

6.2.2 Maintenance Works

6.2.2.1 Local Watercourses

As discussed previously in this report, Long Marston watercourses are not actively maintained by the EA and build up of debris is likely to contribute to flooding in the village and surrounding area, particularly during extreme rainfall events.

Correspondence received from the EA included guidance on riparian owners' responsibilities in relation to maintenance of watercourses including 'main rivers,' detailing measures that could improve the capacity and conveyance potential of rivers and streams.

The EA have not specified the responsible party for undertaking maintenance work in their stead and therefore, the rights and responsibilities for watercourse maintenance as part of flood alleviation measures should be finalised as part of the Section 19 Flood Investigation process.

The following measures are intended to inform any future maintenance programme for watercourses:

- Maintenance should consist of removal of any items within the channel that can impede its flow including (small) trees, excess vegetation etc.
- River banks should be due adequate attention which would normally consist of removal of brambles, bushes and stiff vegetation; these reduce flow capacity and can encourage collection of debris increasing the risk of blockages. Grass and nettles do not always need removing as they will lay flat during high flows.
- Weed growth should to be removed from the centre of the channel as this will impede the flow and increase water levels up stream. Hand picking is best, but cutting off under the water level is acceptable if it is done on an annual basis.
- Maintenance using a machine requires a consent for the work to be undertaken; and the EA should be contacted directly for guidance if it is unclear when a consent is needed to undertake maintenance.
- Light maintenance needs a small consent for which assistance is also available through the relevant parties.

Further information can be found within the EA's guidance document for riparian owners; 'Living on the Edge – A Guide to Your Rights and Responsibilities of Riverside Ownership'[21]. Further work would be required to establish the scope and extent of any future maintenance regime and assess the cost benefit relative to its anticipated effect.

6.2.3 Property Level Protection

Formalised engineered property-level protection such as demountable barriers, flood gates etc. may be feasible to provide short and long term benefit either as a standalone option or to mitigate residual risk in conjunction with other capital or maintenance works.

Property level protection should be specified to suit the worst historic flood event and flood level, incorporating a suitable degree of freeboard, or should be informed by any detailed analysis undertaken to qualify the effect of any other capital works.

Where property level protection was proposed, the following should be established:

- A cost / benefit analysis of the proposed protection measures.
- Responsibility for supply / installation.
- Responsibility for maintenance.
- Responsibility for use in the event of flooding, and liability for misuse.

[21] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/297423/LIT_7114_c70612.pdf [accessed 13th June 2014]

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

This technical report was prepared to investigate flooding experienced in the village of Long Marston and determine the conditions under which flooding is likely to occur, qualify the mechanism of flooding, and outline remedial measures, including short term maintenance actions, to reduce both the risk and impact of flooding. The scope of the study does not include for exhaustive hydraulic modelling, prolonged investigative surveys or extensive liaison with third parties; this report aims to advise the Section 19 Flood Investigation and to provide guidance on whether further investigation is needed and how this could be undertaken.

Through analysis of stakeholder data, rainfall patterns and catchment wetness data in correlation with reported incidents of flooding, it has been established that the primary mechanism of flooding has been due to a rapid response to intense rainfall within the catchment combined with highly saturated soils within the upstream catchment due to antecedent weather conditions. Fluvial flooding arising is likely to have acted in combination with direct surface water flooding from lands upslope draining directly toward the village.

The effect of the extensive culvert on the Tring Bourne is considered highly significant and is likely to be significantly under capacity relative to present day design standards, due to its conveyance capacity and poor serviceable condition.

Other contributing factors that have attributed to or compounded fluvial / surface water flooding have been identified as follows:

- The number, size, and condition of access culverts on Tring Bourne and parallel ordinary watercourse.
- Lack of an effective surface drainage system.
- Lack of maintenance of the watercourses and culverts affecting the site.
- Potential surface water cross connections to the foul sewerage network.
- Potential infiltration of groundwater to the foul sewerage network.

Note that the effect of discharges from upstream reservoirs and canal overtopping have been assessed and are not considered to be an adverse contributing factor to the flood events under investigation. Groundwater, while a consideration in terms of catchment saturation and effect on runoff, is not considered significant as a direct source of flooding for the events under investigation.

7.2 Recommendations

Several potential management and resilience options, of which a number should be subject to further assessment and validation prior to implementation, have been presented as part of this investigation to remove and reduce the risk and / or impact of flooding in Long Marston.

It is noted that the authority or persons responsible for undertaking further investigation or implementing options varies depending on the nature of the work proposed to be undertaken.

As part of the process of selecting the preferred option(s) it is recommended that further discussions are held between the relevant Risk Management Authorities and stakeholders in order to identify priorities and future actions to be taken.

It is recommended that the short term options listed in Section 6.1 are undertaken as a minimum. It is recommended that HCC make all affected residents aware of their riparian ownership responsibilities and where riparian ownership is not readily known, HCC as local authority may wish to consider establishing an interim system to have key reaches of watercourses inspected and maintained until ownership is determined.

In addition to the short term options, it is recommended that feasibility studies are undertaken for the following options that are detailed further in Section 6.2 to ensure that the flood risk reduction benefits of such proposals are thoroughly investigated before capital is secured for any remedial works. The following measures are listed in order of initially perceived priority based on a high level assessment of the option providing flood risk reduction and the likely cost benefit of such option:

1. Maintenance Works to Watercourses feasibility study; a review should be undertaken in relation to the eligibility for allocation of funding for EA maintenance of the main river (Tring Bourne) given the established consequence of flooding. Additionally, EA should be approached to ascertain whether consent is needed to remove excess silt and debris from specific stream beds where required in order that riparian owners can undertake to satisfy their responsibilities (applicable to both ordinary watercourses and main rivers).

2. Property Level Protection investigation; flood risk assessments for all of the properties affected by flooding could be undertaken to determine the extent of flood resistant measures that could be retro-fitted to properties to reduce the potential for internal property flooding.
3. Tring Bourne culvert upgrade/ replacement works feasibility study; considerable liaison and communication would be needed with landowners and the EA to confirm that the scheme would be beneficial to reduce flooding risk and would not cause significant flooding elsewhere. Scheme would need EA agreement and consent for undertaking construction works.
4. Tring Bourne diversion feasibility study; considerable liaison and communication would be needed with landowners and the EA to confirm that the scheme would be beneficial to reduce flooding risk and would not cause significant flooding elsewhere. The landowners of the proposed diversion route would need to be in agreement with the proposals. The scheme would need EA agreement and consent for undertaking construction works. The scheme would similarly be dependent on establishing the nature of interaction between Tring Bourne and Gudgeon Stream via Ashen Brook, including determination of the mode of operation and interaction with spills from Wilstone Reservoir.
5. Surface Water Interception (Tring Road & Station Road) feasibility study; a study is needed including preparing a detailed hydraulic model to accurately replicate surface water flows and to model storm water attenuation options. Study could be combined with the option below, modifications to Road Levels south of Chapel Lane.
6. Modifications to Road Levels (South of Chapel Lane) feasibility study; an investigation is needed, including obtaining detailed topographical information, to ascertain whether minor ground level and road re-grading works could reduce the flood risk for properties on Chapel Lane. The scheme would require HCC Highways department approval.
7. Sewerage Infrastructure Improvements feasibility study; additional consultation with Thames Water would be required to ascertain the extent of the flood risk, if any, associated with the operation of the sewage pumping station and the condition of sewers. A hydraulic model would need to be prepared accompanied with infiltration (soakaway) tests to determine if highway drainage could be disposed off via other means.
8. Land Management (East of Tring Road and Station Road) feasibility study; this option is largely dependent on landowner/tenant agreement to change the land use of their fields, coupled with a hydrological study to determine if changes would serve to sufficiently reduce flood risk to provide benefit.

APPENDIX A

Canal and River Trust Data

Investigation into the Long Marston Flooding 7th Feb 2014

Photographs taken 18th Feb showing similar conditions in the Marsworth Pound as to that on 7th February and the top end of the Aylesbury Arm.

Marsworth Pound/ Aylesbury Arm Lock 1

8:00 18/2/14

Aylesbury Arm Lock 2

Aylesbury Arm Looking Towards Lock 4

Wilstone Outflow 15/2/14

Wilstone Outflow 15/2/14

Wilstone Reservoir Overflow Weir 15/02/14

Wilstone Reservoir Overflow Weir Spillway 15/02/14

Startops Reservoir Outflow Sluice Gearing Discharges to Startops Feeder

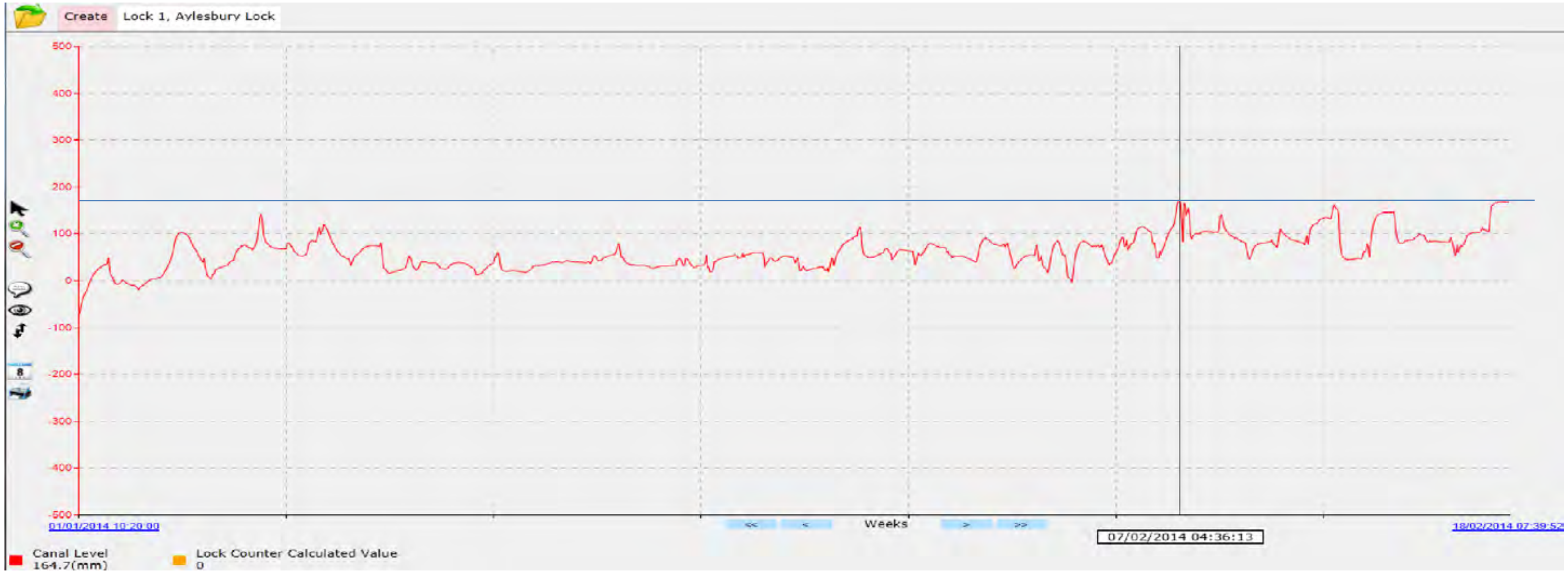
Startops (and Marsworth) Reservoir gravity outflow into Startops Feeder

Wilstone Reservoir Syphon Outlet Chamber Looking Downstream

Wilstone Syphon Pipe

Wilstone Reservoir Overflow Weir

Data logger from Marsworth Pound showing water levels near Aylesbury Arm Canal Lock 1



APPENDIX B

Local Residents' Observations

MAP 1 - LONG MARSTON & ASTROPE

1. Surface water discharges from Church View and Bromley developments need to be identified to assess impact on water levels at Long Marston Brook in Chapel Lane.

   Are there any piped discharges to the unmarked ditch (green on map) or moat? Does the unmarked ditch have an outfall?

1A. During flood conditions water overflowed unmarked ditch to fill moat. Water in the moat then overflowed to fields.

2. High road level at the bottom of Chapel Lane (area marked red) prevents surface water running away to low lying meadow/orchard. **(area marked orange)**

Note: Chapel Lane, a public highway, has no surface water/highway drainage.

3. Access/footway bridge crossing has a concrete invert/base causing a flow restriction.

4. 225/300mm diam. open jointed land drain found in gravel access to cottages next to The Boot (Old Public House). Flow in land drain forced up through the gravel surface. Land drain thought to be connected to surface water culvert.

5. Surface water drain taking flow from land above houses runs into culvert. Diameter to be established

6. Drains and ditches overwhelmed by volume of water produced by Wilstone Reservoir overspill.

7. Surface water from Gubblecote flows down towards Astrope unobstructed by overspill flow.

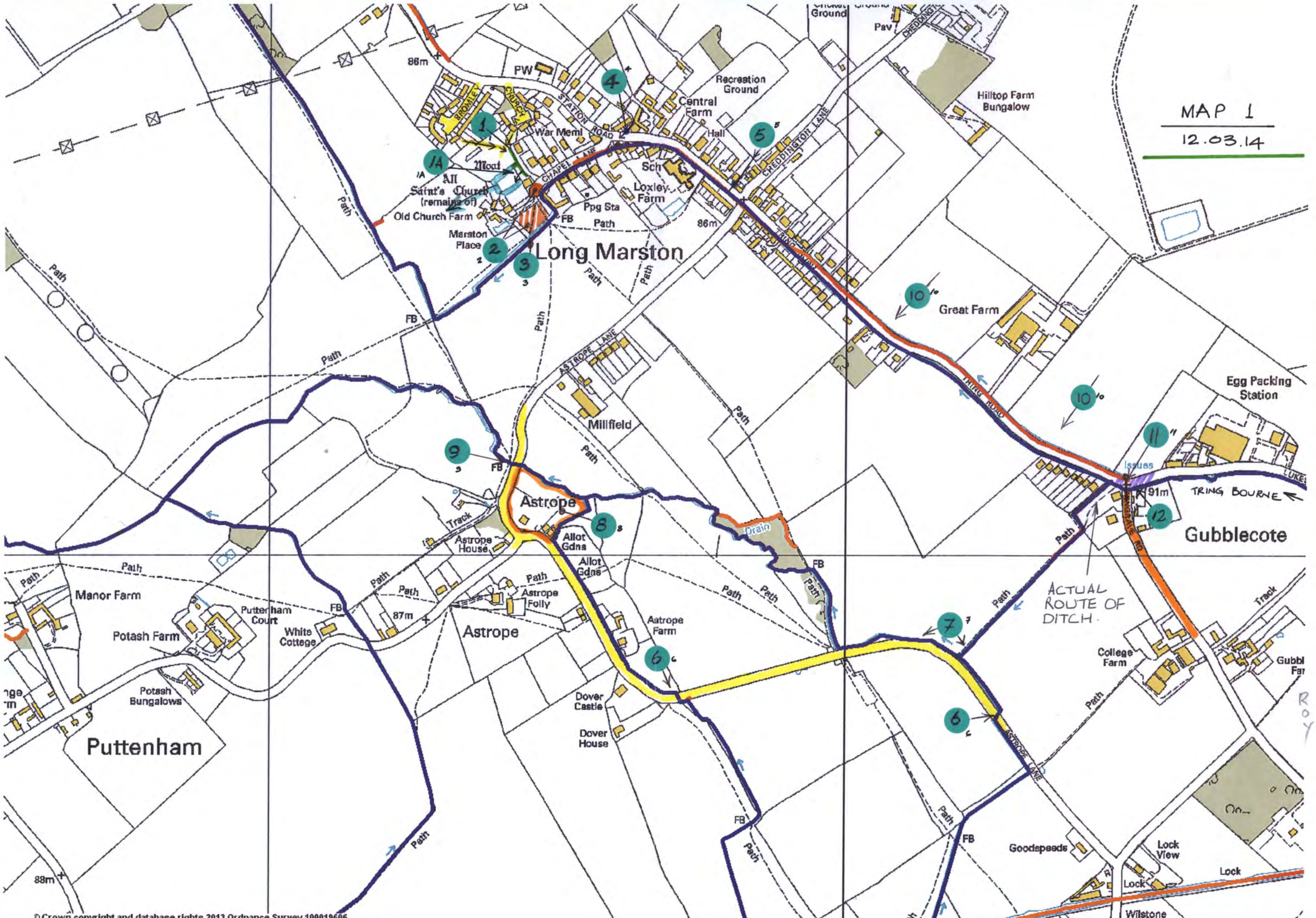
8. Properties surrounded by flood water caused by Reservoir overspill.

9. Footbridge washed away by flood water.

10. Run off from agricultural land enters ditch..

11. Highway drain serving Wingrave Rd discharges into ditch

12. Observations of flow regime during flood conditions at road junction yet to be established. **(purple area)**


MAP 1
12.03.14
Long Marston
Astrope
Gubblecote
Puttenham
Recreation Ground
Central Farm
Hilltop Farm Bungalow
War Meml
Sch
Loxley Farm
Ppg Sta
All Saint's Church (remains of)
Moat
Old Church Farm
Marston Place
Great Farm
Egg Packing Station
Millfield
Astrope House
Allot Gdns
Astrope Folly
Astrope Farm
Dover Castle
Dover House
Manor Farm
Potash Farm
Puttenham Court
White Cottage
Potash Bungalows
College Farm
Goodspeeds
Lock View
Lock
Wilstone Bridge
TRING BOURNE
ACTUAL ROUTE OF DITCH
Issues
Drain
STATION ROAD
CHAPEL LANE
CHEDDINGTON LANE
TRING ROAD
ASTROPE LANE
Path
FB
Track
86m
87m
88m
91m
ROY

APPENDIX C

Hydrological Data

RAINFALL DATA

The following tables list the daily and 5 day cumulative rainfall figures for winter 2013/2014 which are used as the basis for the hydrological assessment section of this assessment.

The daily rainfall data is sourced from Dagnall (IENGLAND226) through Weather Underground.

Rainfall Records - Winter 2013/2014

Table D.1: Rainfall Records - Winter 2013/2014

Date	Rainfall Depth (cm)	Cumulative Previous 5-day rainfall (cm)	Date	Rainfall Depth (cm)	Cumulative Previous 5-day rainfall (cm)
01/10/2013	0	-	31/12/2013	0.66	2.03
02/10/2013	0.41	-	01/01/2014	2.13	3.73
03/10/2013	0.2	-	02/01/2014	0.05	3.78
04/10/2013	0.13	-	03/01/2014	0.61	4.34
05/10/2013	0	0.74	04/01/2014	1.6	5.05
06/10/2013	0.03	0.77	05/01/2014	0.46	4.85
07/10/2013	0	0.36	06/01/2014	0.81	3.53
08/10/2013	0.03	0.19	07/01/2014	1.22	4.7
09/10/2013	0.03	0.09	08/01/2014	0.23	4.32
10/10/2013	0.03	0.12	09/01/2014	0.63	3.35
11/10/2013	0.28	0.37	10/01/2014	0.05	2.94
12/10/2013	0.51	0.88	11/01/2014	0.15	2.28
13/10/2013	1.45	2.3	12/01/2014	0.3	1.36
14/10/2013	0.43	2.7	13/01/2014	0.23	1.36
15/10/2013	0	2.67	14/01/2014	0.2	0.93
16/10/2013	0.48	2.87	15/01/2014	0.33	1.21
17/10/2013	0	2.36	16/01/2014	1.02	2.08
18/10/2013	0.03	0.94	17/01/2014	0.15	1.93
19/10/2013	0.18	0.69	18/01/2014	0.08	1.78
20/10/2013	1.55	2.24	19/01/2014	0.1	1.68
21/10/2013	0.28	2.04	20/01/2014	0.03	1.38
22/10/2013	0.56	2.6	21/01/2014	0.05	0.41
23/10/2013	0.51	3.08	22/01/2014	0.61	0.87
24/10/2013	0.03	2.93	23/01/2014	0.23	1.02

Table D.1: Rainfall Records - Winter 2013/2014

Date	Rainfall Depth (cm)	Cumulative Previous 5-day rainfall (cm)	Date	Rainfall Depth (cm)	Cumulative Previous 5-day rainfall (cm)
25/10/2013	0.36	1.74	24/01/2014	0.51	1.43
26/10/2013	0.18	1.64	25/01/2014	0.28	1.68
27/10/2013	0.66	1.74	26/01/2014	0.76	2.39
28/10/2013	0.99	2.22	27/01/2014	0.15	1.93
29/10/2013	0	2.19	28/01/2014	0.08	1.78
30/10/2013	0	1.83	29/01/2014	1.32	2.59
31/10/2013	0.1	1.75	30/01/2014	0.38	2.69
01/11/2013	0.41	1.5	31/01/2014	0.99	2.92
02/11/2013	0	0.51	01/02/2014	0.43	3.2
03/11/2013	0.89	1.4	02/02/2014	0	3.12
04/11/2013	0.76	2.16	03/02/2014	0	1.8
05/11/2013	0.51	2.57	04/02/2014	0.41	1.83
06/11/2013	0.46	2.62	05/02/2014	1.55	2.39
07/11/2013	0.05	2.67	06/02/2014	0.94	2.9
08/11/2013	0.71	2.49	07/02/2014	1.83	4.73
09/11/2013	0.15	1.88	08/02/2014	0.86	5.59
10/11/2013	0.05	1.42	09/02/2014	0.05	5.23
11/11/2013	0.41	1.37	10/02/2014	0.1	3.78
12/11/2013	0.28	1.6	11/02/2014	0.33	3.17
13/11/2013	0.03	0.92	12/02/2014	0.89	2.23
14/11/2013	0.03	0.8	13/02/2014	0	1.37
15/11/2013	0	0.75	14/02/2014	1.42	2.74
16/11/2013	0.03	0.37	15/02/2014	0.05	2.69
17/11/2013	0.05	0.14	16/02/2014	0	2.36
18/11/2013	0.15	0.26	17/02/2014	0.15	1.62
19/11/2013	0.03	0.26	18/02/2014	1.04	2.66
20/11/2013	0.84	1.1	19/02/2014	0.03	1.27
21/11/2013	0.05	1.12	20/02/2014	0.48	1.7
22/11/2013	0.03	1.1	21/02/2014	0.05	1.75

Table D.1: Rainfall Records - Winter 2013/2014

Date	Rainfall Depth (cm)	Cumulative Previous 5-day rainfall (cm)	Date	Rainfall Depth (cm)	Cumulative Previous 5-day rainfall (cm)
23/11/2013	0.05	1	22/02/2014	0	1.6
24/11/2013	0.05	1.02	23/02/2014	0.15	0.71
25/11/2013	0	0.18	24/02/2014	0.13	0.81
26/11/2013	0.03	0.16	25/02/2014	0.69	1.02
27/11/2013	0	0.13	26/02/2014	0	0.97
28/11/2013	0	0.08	27/02/2014	0.58	1.55
29/11/2013	0.03	0.06	28/02/2014	0.86	2.26
30/11/2013	0	0.06	01/03/2014	0	2.13
01/12/2013	0	0.03	02/03/2014	1.24	2.68
02/12/2013	0	0.03	03/03/2014	0.18	2.86
03/12/2013	0	0.03	04/03/2014	0.03	2.31
04/12/2013	0.05	0.05	05/03/2014	0	1.45
05/12/2013	0.08	0.13	06/03/2014	0	1.45
06/12/2013	0	0.13	07/03/2014	0	0.21
07/12/2013	0	0.13	08/03/2014	0	0.03
08/12/2013	0.03	0.16	09/03/2014	0	0
09/12/2013	0.03	0.14	10/03/2014	0	0
10/12/2013	0.03	0.09	11/03/2014	0	0
11/12/2013	0.03	0.12	12/03/2014	0	0
12/12/2013	0.03	0.15	13/03/2014	0.03	0.03
13/12/2013	0.05	0.17	14/03/2014	0.03	0.06
14/12/2013	0.08	0.22	15/03/2014	0	0.06
15/12/2013	0.43	0.62	16/03/2014	0	0.06
16/12/2013	0.41	1	17/03/2014	0.03	0.09
17/12/2013	0.41	1.38	18/03/2014	0	0.06
18/12/2013	1.17	2.5	19/03/2014	0	0.03
19/12/2013	0.13	2.55	20/03/2014	0.33	0.36
20/12/2013	0.03	2.15	21/03/2014	0.13	0.49
21/12/2013	0.99	2.73	22/03/2014	0.15	0.61

Table D.1: Rainfall Records - Winter 2013/2014

Date	Rainfall Depth (cm)	Cumulative Previous 5-day rainfall (cm)	Date	Rainfall Depth (cm)	Cumulative Previous 5-day rainfall (cm)
22/12/2013	0.36	2.68	23/03/2014	0.03	0.64
23/12/2013	2.21	3.72	24/03/2014	0	0.64
24/12/2013	1.9	5.49	25/03/2014	0.63	0.94
25/12/2013	0.05	5.51	26/03/2014	0.15	0.96
26/12/2013	0.05	4.57	27/03/2014	0.15	0.96
27/12/2013	0.43	4.64	28/03/2014	0.03	0.96
28/12/2013	0	2.43	29/03/2014	0	0.96
29/12/2013	0.05	0.58	30/03/2014	0	0.33
30/12/2013	0.89	1.42	31/03/2014	0	0.18

APPENDIX D

Site Visit Photographs

Photo 1: View of Chapel Lane / Station Road junction	**Photo 2: View east along Chapel Lane**
	
Photo 3: View of main crossroads in Long Marston	**Photo 4: View of Tring Bourne along Tring Road**
	
Photo 5: View of main Tring Bourne culvert inlet	**Photo 6: View of downstream extent of Tring Bourne – west of Long Marston**
	

Photo7: Sluice gate on Tring Bourne	Photo 8: Sluice gate on Tring Bourne
	
Photo 9: Canal showing tide level	Photo 10: Gauging pit (Startops Feeder)
	
Photo 11: Low bank level canal	Photo 12: View immediately adjacent to low bank area (possible canal overspill breach location)
	

McCloy Consulting
Water Engineering Solutions

Location Plan for Photographs