BETTER SOLUTIONS, INTELLIGENTLY ENGINEERED

ENVIRONMENT

HB (South Caldecotte) Limited
South Caldecotte
Milton Keynes
Flood Risk Assessment

www.bwbconsulting.com

BWB

ENVIRONMENT

HB (South Caldecotte) Limited
South Caldecotte
Milton Keynes
Flood Risk Assessment

Birmingham
Livery Place, 35 Livery Street, Colmore Business District, Birmingham, B3 2PB
T: [redacted]

Cambridge
14-16 High Street, Histon, Cambridge
CB24 9JD
T: [redacted]

Leeds
Whitehall Waterfront, 2 Riverside Way, Leeds
LS1 4EH
T: [redacted]

London
11 Borough High Street
London, SE1 9SE
T: [redacted]

Manchester
4th Floor Carvers Warehouse, 77 Dale Street
Manchester, M1 2HG
T: [redacted]

Market Harborough
12a Woodcock House, Compass Point Market Harborough, Leicestershire, LE16 9HW
T: [redacted]

Nottingham
Waterfront House, Station Street, Nottingham NG2 3DQ
T: [redacted]

July 2019

DOCUMENT ISSUE RECORD

Document Number:	SCD-BWB-ZZ-XX-RP-YE-0003_FRA
BWB Reference:	NTS-2682_FRA

Revision	Date of Issue	Status	Author:	Checked:	Approved:
P01	30/11/18	S2	Natalie James BSc (Hons) [redacted]	Robin Green BSc (Hons) [redacted]	Heather Griffiths BSc (Hons) [redacted]
P02	18/12/18	S2	Natalie James BSc (Hons) [redacted]	Robin Green BSc (Hons) [redacted]	Heather Griffiths BSc (Hons) [redacted]
P03	02/07/19	S2	Robin Green BSc (Hons) [redacted]	Lauren Towle BSc (Hons) [redacted]	Robin Green BSc (Hons) [redacted]
P04	04/07/19	S2	Robin Green BSc (Hons) [redacted]	Lauren Towle BSc (Hons) [redacted]	Robin Green BSc (Hons) [redacted]

Notice

All comments and proposals contained in this report, including any conclusions, are based on information available to BWB Consulting during investigations. The conclusions drawn by BWB Consulting could therefore differ if the information is found to be inaccurate or misleading. BWB Consulting accepts no liability should this be the case, nor if additional information exists or becomes available with respect to this scheme.

Except as otherwise requested by the client, BWB Consulting is not obliged to and disclaims any obligation to update the report for events taking place after: -

(i) The date on which this assessment was undertaken, and
(ii) The date on which the final report is delivered

BWB Consulting makes no representation whatsoever concerning the legal significance of its findings or the legal matters referred to in the following report.

All Environment Agency mapping data used under special license. Data is current as of December 2018 and is subject to change.

The information presented, and conclusions drawn, are based on statistical data and are for guidance purposes only. The study provides no guarantee against flooding of the study site or elsewhere, nor of the absolute accuracy of water levels, flow rates and associated probabilities.

This document has been prepared for the sole use of the Client in accordance with the terms of the appointment under which it was produced. BWB Consulting Limited accepts no responsibility for any use of or reliance on the contents of this document by any third party. No part of this document shall be copied or reproduced in any form without the prior written permission of BWB

EXECUTIVE SUMMARY

This Flood Risk Assessment (FRA) has been prepared in accordance with the requirements set out in the National Planning Policy Framework (NPPF) and the associated Planning Practice Guidance. The FRA has been produced on behalf of HB (South Caldecotte) Limited in respect of a planning application for a proposed development of Distribution buildings (B8), with ancillary offices (B1 (a)), car and HGV parking areas, a new primary access off Brickhill Street, with earthworks, drainage and attenuation features and other associated infrastructure, in South Caldecotte, Milton Keynes (approximate grid reference: SP892341).

This report demonstrates that the proposed development is at an acceptable level of flood risk, subject to the recommended flood mitigation strategies being implemented.

The site is shown to be located entirely within Flood Zone 1, but site-specific hydraulic modelling has shown that two ordinary watercourses present on the site pose a flood risk. Interactions of the watercourses with the downstream River Ouzel, surface water runoff from the upstream hillside, and underlying groundwater also pose a potential flood risk to the site.

It is proposed to intercept and divert the ordinary watercourses around the development. The strategy will also include features to intercept and divert the overland flood flows entering the site. The site will be reprofiled to raise the development above the floodplain, thereby mitigating the flood risk from fluvial, surface water, and groundwater sources. Floodplain lost to the development will be compensated for within the watercourse corridors on the site.

Finished floor levels are to be set a minimum of 300mm above the adjacent 1 in 100-year+35% River Ouzel flood level, or at a level above the 1 in 100-year+65% flood level, whichever is greatest.

Additionally, ground levels surrounding the proposed buildings should be profiled to encourage pluvial runoff and overland flows away from the built development and towards the nearest drainage point.

To mitigate the risk of the culverts becoming blocked and watercourses' condition degrading, it is recommended that these are regularly inspected and maintained where necessary.

Surface water runoff from the development will be controlled appropriately and discharged to the local watercourse at a rate of 2l/s/ha, as required by the Bedford IDB. Attenuated storage will be provided within the elevated development, outside of the floodplain.

In compliance with the requirements of National Planning Policy Framework, and subject to the mitigation measures proposed, the development could proceed without being subject to significant flood risk. Moreover, the development will not increase flood risk to the wider catchment area as a result of suitable management of surface water runoff discharging from the site.

BWB

CONTENTS

FIGURES

TABLES

APPENDICES

1. INTRODUCTION

1.1 This Flood Risk Assessment (FRA) has been prepared in accordance with the requirements set out in the National Planning Policy Framework (NPPF) and the associated Planning Practice Guidance. The FRA has been produced on behalf of HB (South Caldecotte) Limited in respect of a planning application for a proposed development of Distribution buildings (B8), with ancillary offices (B1 (a)), car and HGV parking areas, a new primary access off Brickhill Street, with earthworks, drainage and attenuation features and other associated infrastructure, in South Caldecotte, Milton Keynes.

1.2 This FRA is intended to support a planning application and as such the level of detail included is commensurate and subject to the nature of the proposals at the planning stage. Summary information is included as **Table 1.1**.

Table 1.1: Site Summary

Site Name	South Caldecotte
Location	Milton Keynes
NGR (approx.)	489255, 234320
Application Site Area (ha)	c. 58
Development Type	Distribution and Office Use
Flood Zone Classification	Flood Zone 1
NPPF Vulnerability	Less Vulnerable
Environment Agency Office	East Anglia
Lead Local Flood Authority	Milton Keynes Council
Local Planning Authority	Milton Keynes Council

Sources of Data

i. Topographical Survey by Stafsurv, reference [Dwg No. 9439a]
ii. OS Explorer Series mapping
iii. Environment Agency consultation and model information
iv. A site-specific hydraulic flood model developed by BWB Consulting
v. Buckingham & River Ouzel Internal Drainage Board Consultation
vi. Milton Keynes Council Strategic Flood Risk Assessment
vii. Milton Keynes Council Preliminary Flood Risk Assessment
viii. Anglian Water Sewer Records

ix. British Geological Survey Drift & Geology Maps

Existing Site

1.3 The site is located approximately 7.7km south-east of Milton Keynes, in an area known as Caldecotte. The site is bound to the north by the Woburn Sands to Bletchley railway line, to the east by Brickhill Street and to the west by the A5. The site's location is illustrated within **Figure 1.1**.

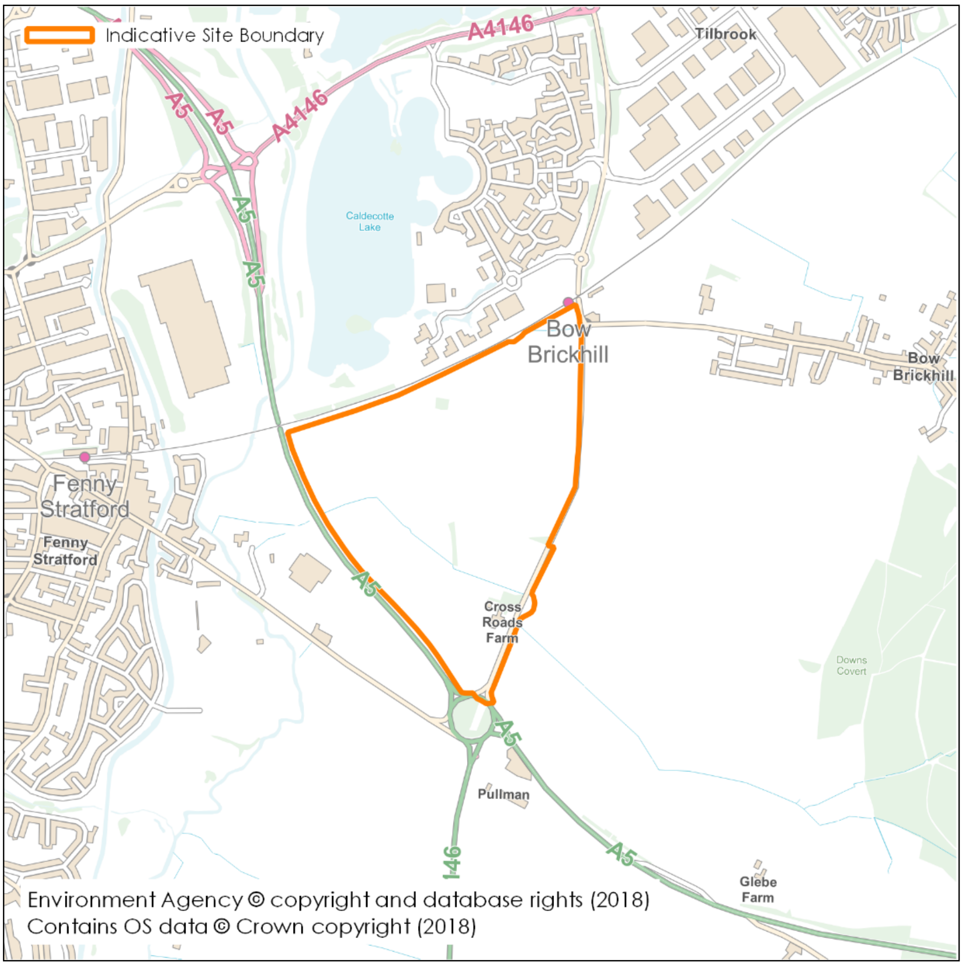


Figure 1.1: Site Location

1.4 The site is largely greenfield and is understood to be used as farmland (arable and pasture). Some minor development (Cross Roads Farm) is present in the south of the site next to Brickhill Street.

1.5 The majority of the site falls westwards, towards the River Ouzel. The north-western corner of the site forms the lowest point, ground levels here are in the region of 65.63m Above Ordnance Datum (AOD). Ground levels are highest in the centre of the eastern site boundary, in the region of 77m AOD.

1.6 The River Ouzel is located to the west of the site on the opposite side of the A5. The river flows past the site in a northerly direction.

1.7 Caldecotte Lake is located to the north of the site, on the opposite side of the embanked railway line. There are known hydraulic interactions between the River Ouzel and Caldecotte Lake.

1.8 The site, and immediate upstream hillside, are crossed by a network of minor ditches which are understood to be associated with land drainage. Two ordinary watercourses are also shown to cross the site.

1.9 An unnamed ordinary watercourse draining the 'Blackwood' hillside to the south east enters the site via a culvert under Brickhill Street. For the purpose of this assessment, it will be referred to as the 'Brickhill Brook'. The watercourse flows through the site in a north-westerly direction picking up outfalls from the ditch network. The watercourse passes beneath the A5 and outfalls to the River Ouzel approximately 360m downstream of the site. A stretch of this watercourse is understood to fall within the control of the Bedford Group of Internal Drainage Boards. A site visit undertaken by BWB Consulting in May 2018 identified the watercourse to be well vegetated, and heavily overgrown.

1.10 A second ordinary watercourse draining the hillside around Bow Brickhill to the north east enters the site via a second culvert beneath Brickhill Street, in the very north of the site. This flows for a short stretch within the site ownership before entering network rail land ownership. For the purpose of this assessment, it will be referred to as the 'Railway Brook'. The watercourse has been observed to flow in a south-westerly direction along the toe of the railway embankment, just to the north of the site ownership. The watercourse passes beneath the A5 before outfalling to the River Ouzel. Due to access restrictions, information and observations on this watercourse is limited.

1.11 A schematic plan of the observed channel network within the vicinity of the site is illustrated within **Figure 1.2**.

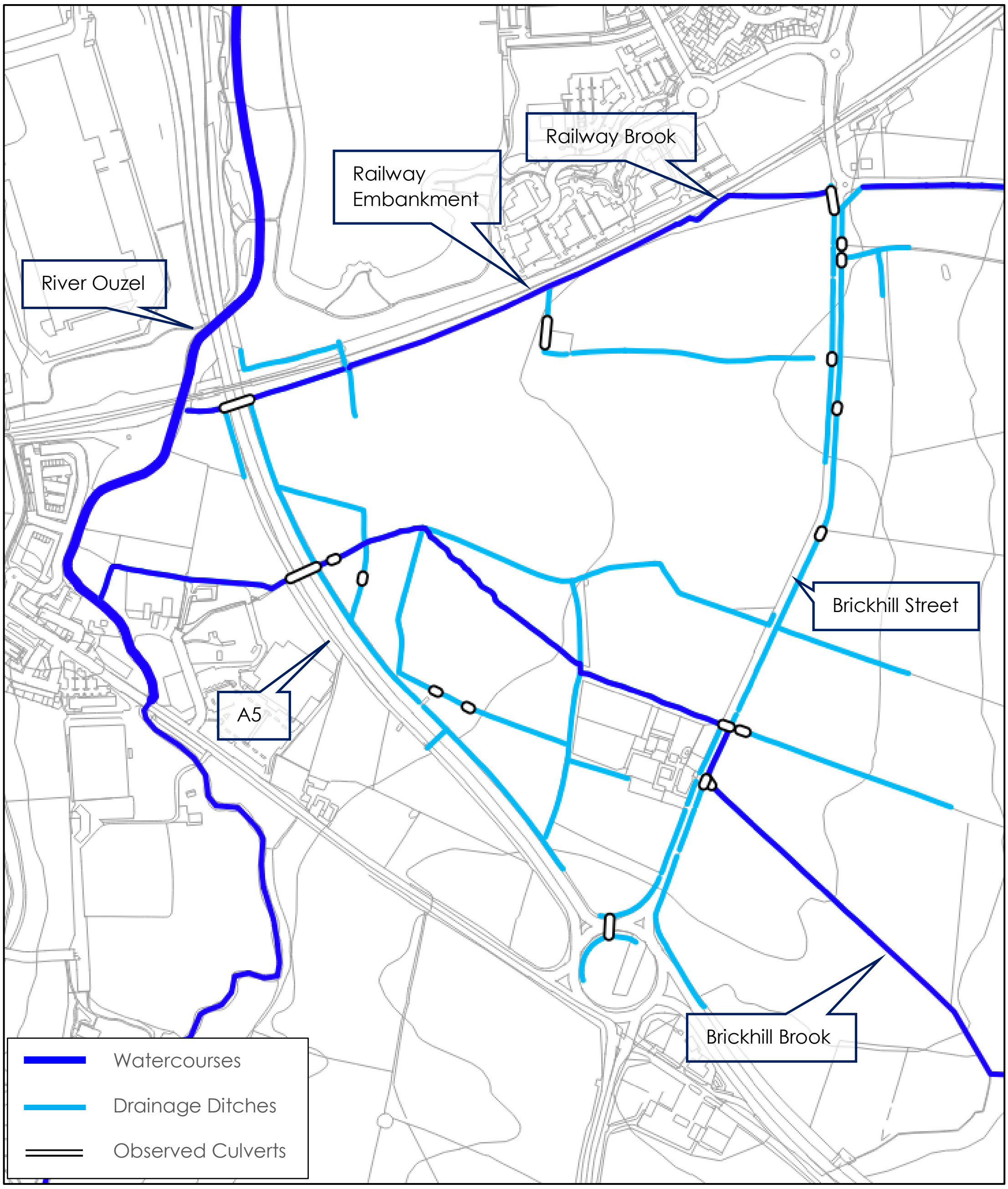


Figure 1.2: Observed Watercourse/Ditch Connectivity

Proposed Development

1.12 The development is understood to comprise up to 227,000 m² of storage and distribution buildings (B8), with ancillary offices (B1 (a)), car and HGV parking areas, a new primary access off Brickhill Street, with earthworks, drainage and attenuation features and other

1.13 The main entrance would be off Brickhill Street and incorporates highway improvements to enable this. This would provide an all-movement and all-vehicle and pedestrian access. A pedestrian access footpath would remain across the site.

1.14 An illustrative masterplan is presented as **Appendix 2**.

2. FLOOD RISK PLANNING POLICY

National Planning Policy Framework

2.1 The NPPF[1] sets out the Government's national policies on different aspects of land use planning in England in relation to flood risk. Planning Practice Guidance is also available online[2].

2.2 The Planning Practice Guidance sets out the vulnerability to flooding of different land uses. It encourages development to be located in areas of lower flood risk where possible and stresses the importance of preventing increases in flood risk off site to the wider catchment area.

2.3 The Planning Practice Guidance also states that alternative sources of flooding, other than fluvial (river flooding), should also be considered when preparing a Flood Risk Assessment.

2.4 The Planning Practice Guidance includes a series of tables that define Flood Zones (Table 1), the flood risk vulnerability classification of development land uses (Table 2) and 'compatibility' of development within the defined Flood Zones (Table 3).

2.5 This Flood Risk Assessment is written in accordance with the NPPF and the Planning Practice Guidance.

Flood Map for Planning

2.6 With particular reference to planning and development, the Flood Map for Planning produced by the Environment Agency identifies Flood Zones in accordance with Table 1 of the Planning Practice Guidance.

2.7 Flood Zone 1 (Low Probability) is defined as land having less than a 1 in 1000 annual probability of river or sea flooding (<0.1% Annual Exceedance Probability).

2.8 Flood Zone 2 (Medium Probability) is defined as land having between a 1 in 100 and 1 in 1000 annual probability of river flooding (1% - 0.1% AEP); or between a 1 in 200 and 1 in 1000 annual probability of sea flooding (0.5% - 0.1% AEP).

2.9 Flood Zone 3a (High Probability) is defined as land having a 1 in 100 or greater annual probability of river flooding (>1% AEP); or land having a 1 in 200 or greater annual probability of flooding from the sea (>0.5% AEP). This is represented by "Flood Zone 3" on the Flood Map for Planning.

2.10 Flood Zone 3b (The Functional Floodplain) is defined as land where water has to flow or be stored in times of flood. This is not identified or separately distinguished from Zone 3a on the Flood Map for Planning.

[1] Revised National Planning Policy Framework, Ministry of Housing, Communities & Local Government, July 2018
[2] Planning Practice Guidance: https://www.gov.uk/government/collections/planning-practice-guidance

2.11 The site is shown to be located entirely within Flood Zone 1, as shown in **Figure 2.1**.

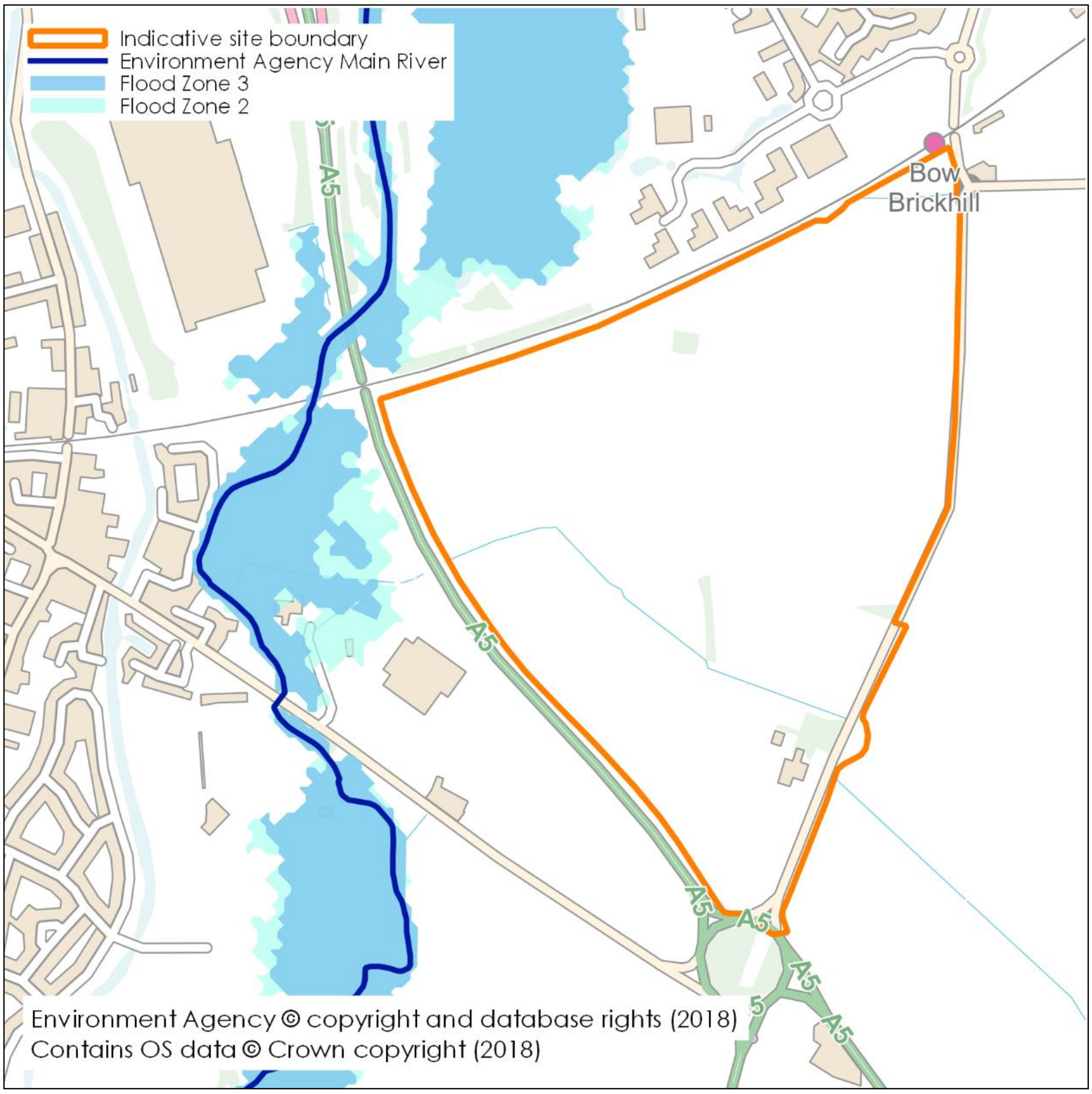


Figure 2.1: Flood Map for Planning

The Design Flood

2.12 The Planning Practice Guidance identifies that new developments should be designed to provide adequate flood risk management, mitigation, and resilience against the 'design flood' for their lifetime.

2.13 This is a flood event of a given annual flood probability, which is generally taken as fluvial (river) flooding likely to occur with a 1% annual probability (a 1 in 100 chance each year), or tidal flooding with a 0.5% annual probability (1 in 200 chance each year), against which the suitability of a proposed development is assessed and mitigation measures, if any, are designed.

Climate Change

2.14 Predicted future change in peak river flows caused by climate change are provided by the Environment Agency[3], with a range of projections applied to regionalised 'river basin districts'. The River Ouzel catchment falls within the Anglian river basin district. **Table 2.1** identifies the relevant peak river flow allowances from this river basin district.

Table 2.1: Peak River Flow Allowance for the Anglian River Basin District

Allowance Category	Total potential change anticipated for the '2020s' (2015 to 2039)	Total potential change anticipated for the '2050s' (2040 to 2069)	Total potential change anticipated for the '2080s' (2070 to 2115)
Upper End	25%	35%	65%
Higher Central	15%	20%	35%
Central	10%	15%	25%

2.15 When determining the appropriate allowance for use in a Flood Risk Assessment the Flood Zone classification, flood risk vulnerability and the anticipated lifespan of the development should be considered. **Table 2.2** provides a matrix summarising the Environment Agency's guidance on determining the appropriate allowances.

Table 2.2: Application of the Appropriate Climate Change Allowance

Flood Zone	Essential Infrastructure	Highly Vulnerable	More Vulnerable	Less Vulnerable	Water Compatible
1	Use the central allowance				Use none of the allowances
2	Use the higher central and upper end to assess a range of allowances	Use the higher central and upper end to assess a range of allowances	Use the central and higher central to assess a range of allowances	Use the central allowance	Use none of the allowances
3a	Use the upper end allowance	Development should not be permitted	Use the higher central and upper end to assess a range of allowances	Use the central and higher central to assess a range of allowances	Use the central allowance
3b	Use the upper end allowance	Development should not be permitted	Development should not be permitted	Development should not be permitted	Use the central allowance
*If development is considered appropriate when not in accordance with Flood Zone vulnerability categories, then it would be appropriate to use the upper end allowance.					

[3] Environment Agency, Flood risk assessments: climate change allowances: https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances#table-1

2.16 The proposed development is for commercial/distribution use (less vulnerable) with an anticipated lifespan of over 60 years, therefore the total potential change for the '2080s' will be adopted. Technically the site is located entirely within Flood Zone 1. However, given the proximity of the ordinary watercourses to the development, it is considered prudent to follow a precautionary approach. Therefore, for the purposes of this hydraulic modelling exercise it is proposed to assess the higher central and upper allowances.

2.17 Therefore, to ensure the development is designed adequately for its lifetime an allowance of 35% will be applied to the design flood to be used to set mitigation levels and inform the flood management strategy, and a 65% allowance will be used to assess the resilience of the strategy.

Strategic Flood Risk Assessment

2.18 A Strategic Flood Risk Assessment (SFRA) is a study carried out by one or more local planning authorities to assess the risk to an area from flooding from all sources, now and in the future.

2.19 The Milton Keynes Council Level 1 SFRA[4] has been reviewed in the production of this FRA. The SFRA provides information specific to the site location in the form of fluvial, surface water and groundwater flood risk mapping, as well as records of historical flooding. Information from the Level 1 SFRA will be referenced within **Section 3.0** where applicable.

Preliminary Flood Risk Assessment

2.20 A Preliminary Flood Risk Assessment (PFRA) is an assessment of floods that have taken place in the past and floods that could take place in the future. It generally considers flooding from surface water runoff, groundwater and ordinary watercourses, and is prepared by the Lead Local Flood Authorities.

2.21 The Milton Keynes Council PFRA[5] considers flooding from surface water runoff, groundwater, ordinary watercourses and canals. It also references the historical river flooding which occurred in the local area. However, no historic instances of flooding at the site are referenced. Information from the PFRA will be referenced within this report where applicable.

Local Flood Risk Management Strategy

2.22 A Local Flood Risk Management Strategy (LFRMS) is prepared by a Lead Local Flood Authority to help understand and manage flood risk at a local level.

[4] Level 1 Strategic Flood Risk Assessment (Milton Keynes Council, April 2015)
[5] Preliminary Flood Risk Assessment (Milton Keynes Council, June 2011)

2.23 The LFRMS aims to ensure that the knowledge of local flood risk issues is communicated effectively so that they can be better managed. The LFRMS also aims to promote sustainable development and environmental protection.

2.24 The Milton Keynes Council LFRMS[6] has been reviewed and will be referenced within this report where applicable.

Local Plan

2.25 Plan:MK is the proposed local plan for Milton Keynes, developed by Milton Keynes Council. Plan:MK will replace the Core Strategy and the MKLP.

2.26 Plan:MK seeks to steer all new developments towards areas with the lowest probability of flooding. Plan:MK has been reviewed and will be referenced within this report where applicable.

[6] Local Flood Risk Management Strategy (Milton Keynes Council, February 2016)

3. POTENTIAL SOURCES OF FLOOD RISK

3.1 Flooding can occur from a variety of sources, or combination of sources, which may be natural or artificial. **Table 3.1** below identifies the potential sources of flood risk to the site in its current condition, and the impacts which the development could have in the wider catchment, prior to mitigation. These are discussed in greater detail in the forthcoming section. The mitigation measures proposed to address flood risk issues and ensure the development is appropriate for its location are discussed within **Section 4.0**.

Table 3.1: Pre-Mitigation Sources of Flood Risk

Flood Source	Potential Risk				Description
	High	Medium	Low	None	
Fluvial	X				The site is located in Flood Zone 1 of the River Ouzel, but site-specific hydraulic model has shown that the floodplain of two ordinary watercourses are present within the site.
Canals			X		The Grand Union Canal is significantly removed from the site and does not pose a risk.
Groundwater	X				Groundwater levels are relatively shallow and are likely to be in continuity with local river levels.
Reservoirs and waterbodies			X		The site is shown to fall outside of the area at risk of reservoir failure.
Pluvial runoff	X				Several overland flows routes are shown to be present with the site. These are associated with the two ordinary watercourses.
Sewers			X		There is a 150mm public foul sewer across the site. Due to the capacity and depth of the local network, it is not thought to pose a risk to the site.
Effect of Development on Wider Catchment	X				The development of the site has the potential to disturb and redirect the floodplain on the site, unless unsuitable mitigated.
	X				The development will increase the area of impermeable surfaces leading to a potential increase in runoff, unless suitably mitigated.

Fluvial Flood Risk

3.2 Flooding from watercourses occurs when flows exceed the capacity of the channel, or where a restrictive structure is encountered, which leads to water overtopping the banks into the floodplain. This process can be exacerbated when debris is mobilised by high flows and accumulates at structures.

3.3 **Figure 3.1** shows the extents of the flooding in March 1947 from the River Ouzel, as recorded by the Environment Agency. A very small area in the northwest corner of the site is shown to have flooded.

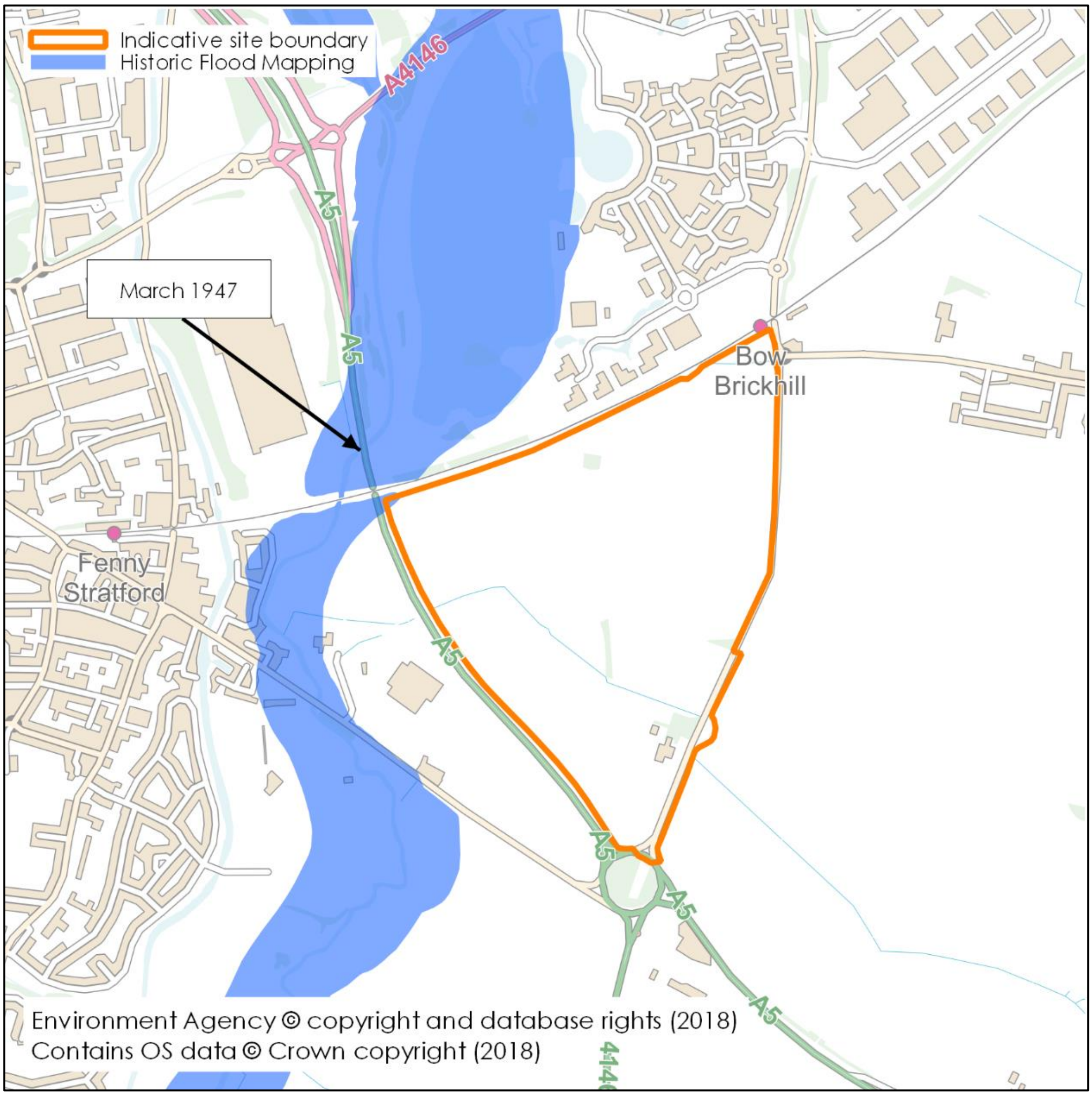


Figure 3.1: Environment Agency Historic Flood Mapping

3.4 As previously discussed, the site is shown to be located entirely within Flood Zone 1 of the River Ouzel. The Environment Agency hold a hydraulic model of the River Ouzel, a copy of which was obtained for use in this assessment. The Ouzel forms part of the larger River Ouse (Upper, Lower) hydraulic model. It is understood that this model was used to inform the Flood Maps for Planning for the area.

3.5 Upon review it was apparent that the EA model does not accurately reflect the hydraulic connectivity at the site (the culverts beneath the A5 are omitted), the model also does not include geometry or inflow associated within the ordinary watercourses on the site. The EA model also does not account for the latest climate change allowances.

3.6 The model includes a 'defended' and 'undefended' geometry. Upon analysis it was found that the defended scenarios generated the more conservative flood levels within the vicinity of the site. This is because Caldecotte Lake is used for flood storage in the defended scenario.

3.7 While the EA model is not considered suitable for assessing flood risk at the site in its current form, it was used as the basis of a site-specific hydraulic model. The Ouzel model was truncated to remove superfluous upstream and downstream reaches, and the domain was extended through the site to include the two ordinary watercourses. A hydraulic model report detailing this exercise is provided within **Appendix 3**.

3.8 The baseline modelled floodplain extents are mapped within **Appendix 1** of the hydraulic modelling report (**see Appendix 3**) and summarised within **Figure 3.2**, and the flood mechanisms are as follows:

1. Flood water from the Railway Brook enters the site via an overland flow route, this is due to the omission of the culvert beneath Brickhill Street. In reality, the magnitude of overland flows would be less extensive. Despite this, the peak flood depths of this flow route are very shallow, peaking in the region of 25mm to 50mm at the 1 in 100-year+35% event.

2. Flood flows from the Railway Brook are shown to flow alongside the railway embankment towards the north-west corner of the site. The open channel on this reach is omitted from the model, so in reality it is expected that the floodplain would be less extensive. The flood route here is also shown to be relatively shallow, 1 in 100-year+35% flood depths remain below 300mm.

3. The River Ouzel is shown to surcharge through the Railway Brook A5 culvert. The River Ouzel is shown to be the predominate control on peak flood level within this corner of the site, driving flood depths up to 950mm in the 1 in 100-year+35% event.

4. The River Ouzel also enters the site via the Brickfield Brook culvert under the A5. Flood depths in the site here peak at 350mm in the 1 in 100-year+35% event. The depths are predominately controlled by the River Ouzel flood levels.

5. The Brickhill Brook is shown to over top Brickhill Street and enter the site in events above the 1 in 100-year flood. This leads to shallow flooding of the fields and yard around the existing farm. Flood depths here are generally below 100mm in the 1 in 100-year+35% event.

6. The Brickhill Brook channel capacity is predicted to be exceeded in events above the 1 in 20-year flood. This leads to shallow out of bank flooding next to the channel. Flood depths are generally below 50mm in the 1 in 100-year+35% event.

7. An inflow from the southern corner is shown to exceed the capacity of the local drainage ditches resulting in shallow flooding of the adjacent fields. Flood depths are generally below 50mm in the 1 in 100-year+35% event.

8. Flood water leaves the site via the A5 culverts as the Ouzel flood waters recede. Additionally, a minor flow route through a railway underpass and into the downstream Ouzel floodplain is predicted.

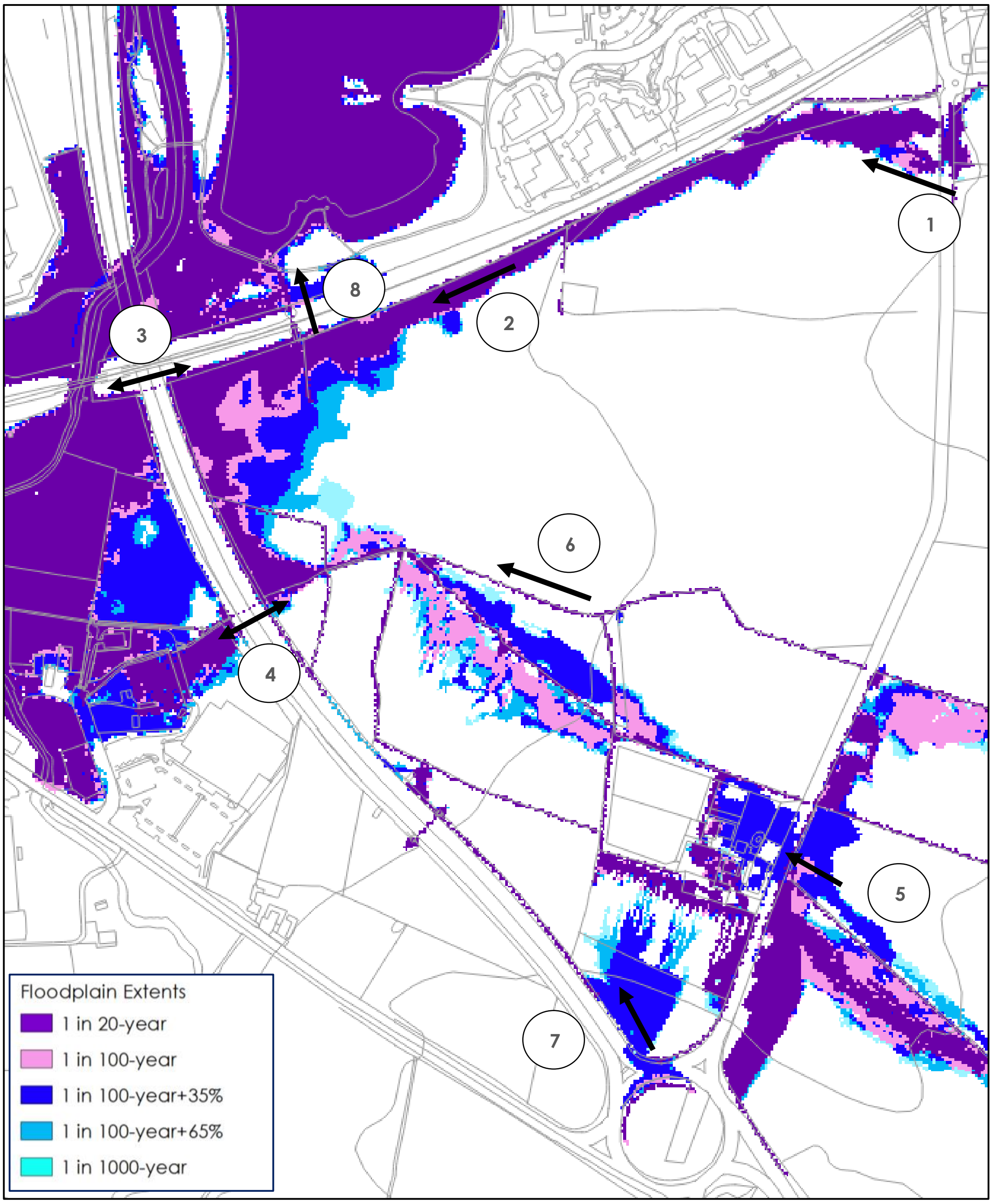


Figure 3.2: Baseline Floodplain Extents

3.9 The modelling has shown that in the east of the site the existing channels are generally undersized, which leads to shallow overland flows, whereas in the west of the site flood levels are predominately control by the River Ouzel. Therefore, the existing fluvial flood risk on the site is considered to be high and to require mitigation.

Flood Risk from Canals

3.10 The Canal and River Trust (CRT) generally maintains canal levels using reservoirs, feeders and boreholes and manages water levels by transferring it within the canal system.

3.11 Water in a canal is typically maintained at predetermined levels by control weirs. When rainfall or other water enters the canal, the water level rises and flows out over the weir. If the level continues rising it will reach the level of the storm weirs. The control weirs and storm weirs are normally designed to take the water that legally enters the canal under normal conditions. However, it is possible for unexpected water to enter the canal or for the weirs to become obstructed. In such instances the increased water levels could result in water overtopping the towpath and flowing onto the surrounding land.

3.12 Flooding can also occur where a canal is impounded above surrounding ground levels and the retaining structure fails.

3.13 Grand Union Canal is located approximately 380m west of the site. A review of Light Detection and Ranging (LiDAR) data shows that the canal is set approximately 8m above the River Ouzel floodplain. The River Ouzel is situated between the Grand Union Canal and the site. Should the canal overtop then the overland flows would be intercepted by the river before reaching the site.

3.14 Due to the distance and well-maintained nature of canals, the flood risk from this source is considered to be low.

Groundwater Flood Risk

3.15 Groundwater flooding occurs when the water table rises above ground elevations. It is most likely to happen in low lying areas underlain by permeable geology. This may be regional scale chalk or sandstone aquifers, or localised deposits of sands and gravels underlain by less permeable strata such as that in a river valley.

3.16 The area is shown to be underlain by the Oxford Clay Formation (Mudstone) and West Walton Formation (Mudstone), which are designated by the Environment Agency as unproductive strata. Unproductive Strata is defined as rock layers or drift deposits with low permeability that have negligible significance for water supply or river base flow.

3.17 Superficial deposits of Clay, Silt, Sand and Gravel, are expected to be present across the south west of the site overlaying the Mudstone. There are alluvium deposits associated with the ordinary watercourse on site (the Brickhill Brook), and river terrace deposits associated with the River Ouzel floodplain. The deposits in this area are likely to be in continuity with the watercourses and during periods of high flows in the river and heavy rainfall, groundwater levels within the site may rise, but this would be in continuity with the floodplain.

3.18 The superficial deposits in the site are designated Secondary A Aquifers. Secondary A aquifers are described as permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers.

3.19 British Geological Survey borehole records indicate the groundwater level in the vicinity of the site varies from 1.0 to 6.1m depth.

3.20 The Milton Keynes Council SFRA indicates that the area of the site that is associated with the Brickhill Brook is considered be at risk of groundwater flooding at surface level. This is likely to be due to the presence of highly permeable superficial deposits which are present over lower permeability mudstones. This has the potential for the vertical movement of groundwater within the alluvium to be impeded by the underlying mudstone resulting in a higher water table during periods of heavy rainfall.

3.21 Due to the risk of groundwater flooding associated with the Brickhill Brook, the overall risk from groundwater flooding within this area is therefore considered to be high. Given that the groundwater is likely to be linked to river levels, the flood risk from groundwater will be address in the same manner as the fluvial flood risk. This is discussed further within **Section 4.0**.

Flood Risk from Reservoirs & Large Waterbodies

3.22 Flooding can occur from large waterbodies or reservoirs if they are impounded above the surrounding ground levels or are used to retain water in times of flood. Although unlikely, reservoirs and large waterbodies could overtop or breach leading to rapid inundation of the downstream floodplain.

3.23 To help identify this risk, reservoir failure flood risk mapping has been prepared, this shows the largest area that might be flooded if a reservoir were to fail and release the water it holds. The map displays a worst-case scenario and is only intended as a guide.

3.24 **Figure 3.3** shows the site is be outside of the area at risk of reservoir flooding. Therefore, the risk of flooding at the site from this source is also considered to be low.

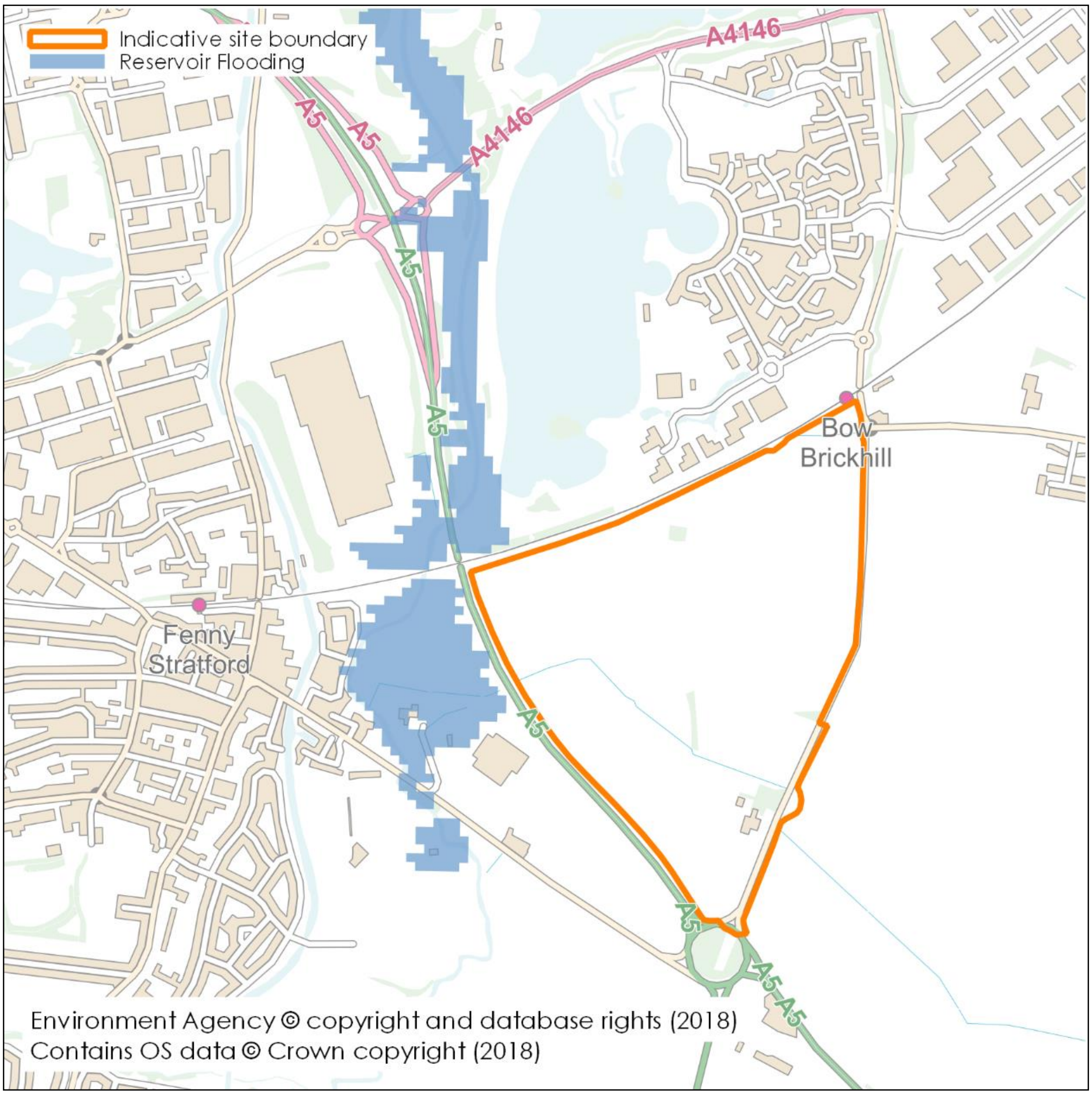


Figure 3.3: Reservoir Failure Flood Risk Map

Pluvial Flood Risk

3.25 Pluvial flooding can occur during prolonged or intense storm events when the infiltration potential of soils, or the capacity of drainage infrastructure is overwhelmed leading to the accumulation of surface water and the generation of overland flow routes.

3.26 Risk of flooding from surface water mapping has been prepared, this shows the potential flooding which could occur when rainwater does not drain away through the normal drainage systems or soak into the ground but lies on or flows over the ground instead. An extract from the mapping is included as **Figure 3.4.**

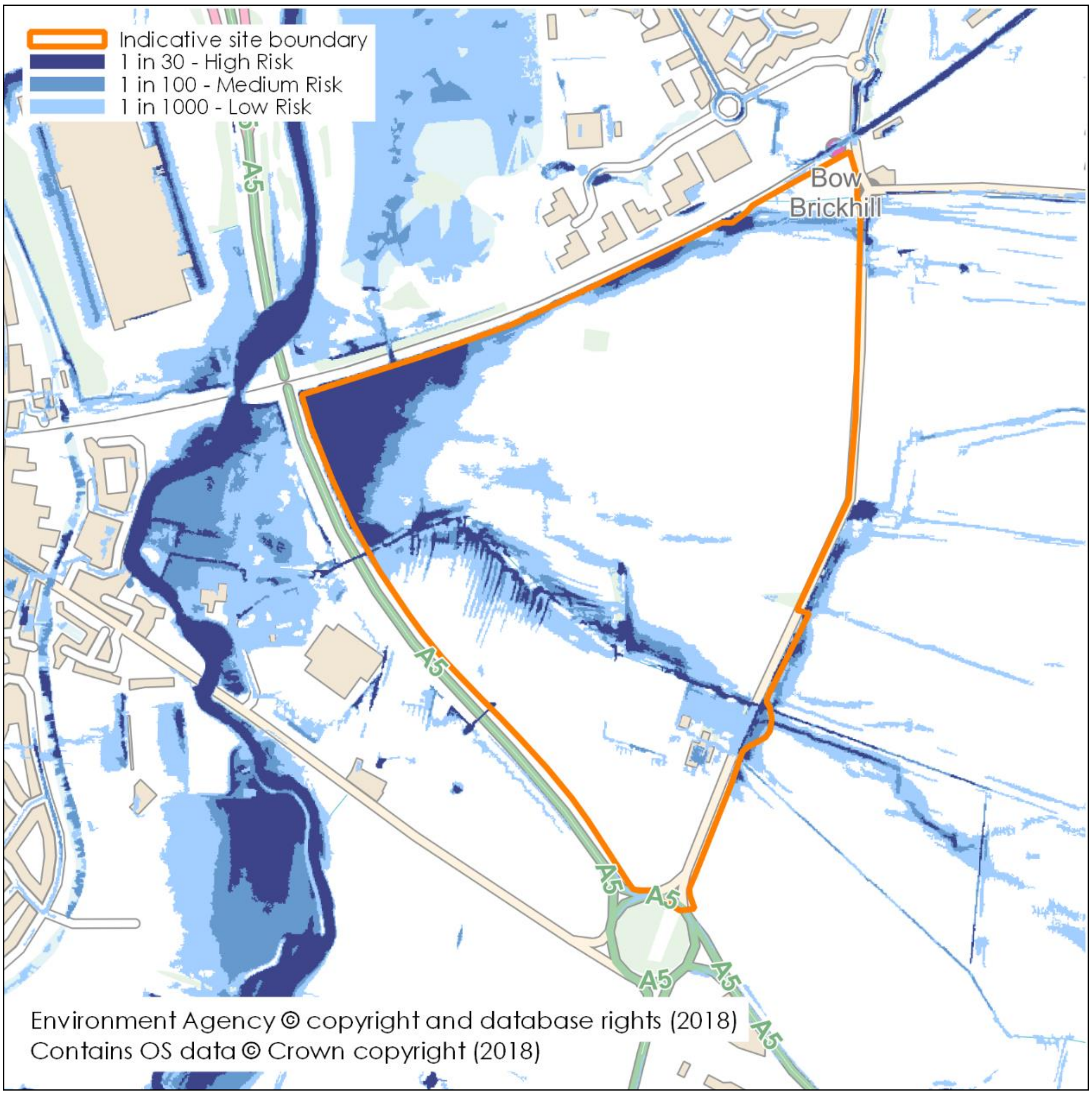


Figure 3.4: Environment Agency's Surface Water Flood Risk Mapping

3.27 The surface water extents shown in **Figure 3.4** are associated with the local watercourse network on site. The potential surface water extents are therefore better represented by the detailed fluvial modelling undertaken by BWB Consulting, and previously discussed.

Flood Risk from Sewers

3.28 Sewer flooding can occur when the capacity of the infrastructure is exceeded by excessive flows, or as a result of a reduction in capacity due to collapse or blockage, or if the downstream system becomes surcharged. This can lead to the sewers flooding onto the surrounding ground via manholes and gullies, which can generate overland flows.

3.29 The local sewerage undertaker is Anglian Water. The local sewer records are included as **Appendix 4**.

3.30 There is shown to be a 150mm public foul sewer crossing the site in the north-eastern corner, north of the Railway Brook. This sewer flows from Station Road to the east of the site, across the site, to the Caldecotte Lake Business Park to the north of the site. This sewer is joined in the Caldecotte Lake Business Park by a second public foul sewer flowing east along the railway line. The public foul sewer network in Caldecotte Lake Business Park is an average of 3.3m below cover level. No levels are available for the foul sewer on site.

3.31 It is required that a 3m easement either side of the public foul sewer on the site is allowed for. However, this appears to have been accounted for in the indicative site layout, included as **Appendix 2**.

3.32 There is a 375mm public surface water sewer originating in the southeast corner of the Caldecotte Lake Business Park. This sewer flows north, away from the site.

3.33 The Milton Keynes Level 1 SFRA indicates there was one recorded incident of internal sewer flooding on the land to the west of the site, details of this flood event are not recorded.

3.34 Due to the relatively small catchment of the foul sewer within the site, and the depth and detachment from the remaining local sewer network, the risk of flooding from sewers is considered to be low.

Effect of Development on Wider Catchment

Displacement of Floodplain & Impedance of Flood Flows

3.35 The proposed development will be located within the modelled floodplain of the ordinary watercourses. This has the potential to redirect overland flows and displace floodplain volume which could cause a detriment to third party flood risk if not suitably mitigated. The developments flood mitigation strategy is discussed in **Section 4.0**.

Development Land Use/Drainage Considerations

3.36 The development will result in an increase in impermeable areas, which will generate more surface water runoff. This may have the potential to increase flood risk to the surrounding areas if not properly mitigated, this is discussed in **Section 4.0**.

4. FLOOD RISK MITIGATION

4.1 **Section 3.0** has identified the sources of flooding which could potentially pose a risk to the site and the proposed development. This section of the FRA sets out the mitigation measures which are to be incorporated within the proposed development to address and reduce the risk of flooding to within acceptable levels.

Sequential Arrangement

4.2 The development site is entirely located within Flood Zone 1. The layout has been arranged to avoid the low-lying areas in the very west of the site, where possible.

4.3 It has not been possible to arrange the layout as to avoid the ordinary watercourses, but corridors through the site have been preserved to allow these channels to be diverted around the development.

Flood Management Strategy

4.4 To facilitate a development of the site, it is proposed to intercept and divert the Brickhill Brook around the proposed development area. This will involve relocating the Brickhill Brook culvert crossing of Brickhill Street approximately 80m to the south.

4.5 It is proposed to reprofile the development to raise it above the River Ouzel flood levels and compensate for the loss in floodplain on the site in a level-for-level manner. A plan outlining the illustrative flood management strategy is included as **Appendix 2** of the hydraulic modelling report (**see Appendix 3**).

4.6 The illustrative flood management strategy has been simulated with the site-specific hydraulic model. The results are mapped within **Appendix 3** of the hydraulic modelling report (**see Appendix 3**), and are summarised within **Figure 4.1**, with peak flood levels provided within **Table 4.1**.

4.7 The results show that the strategy successfully elevates the development out of the River Ouzel floodplain, and also diverts the flood flows from the ordinary watercourse around the development.

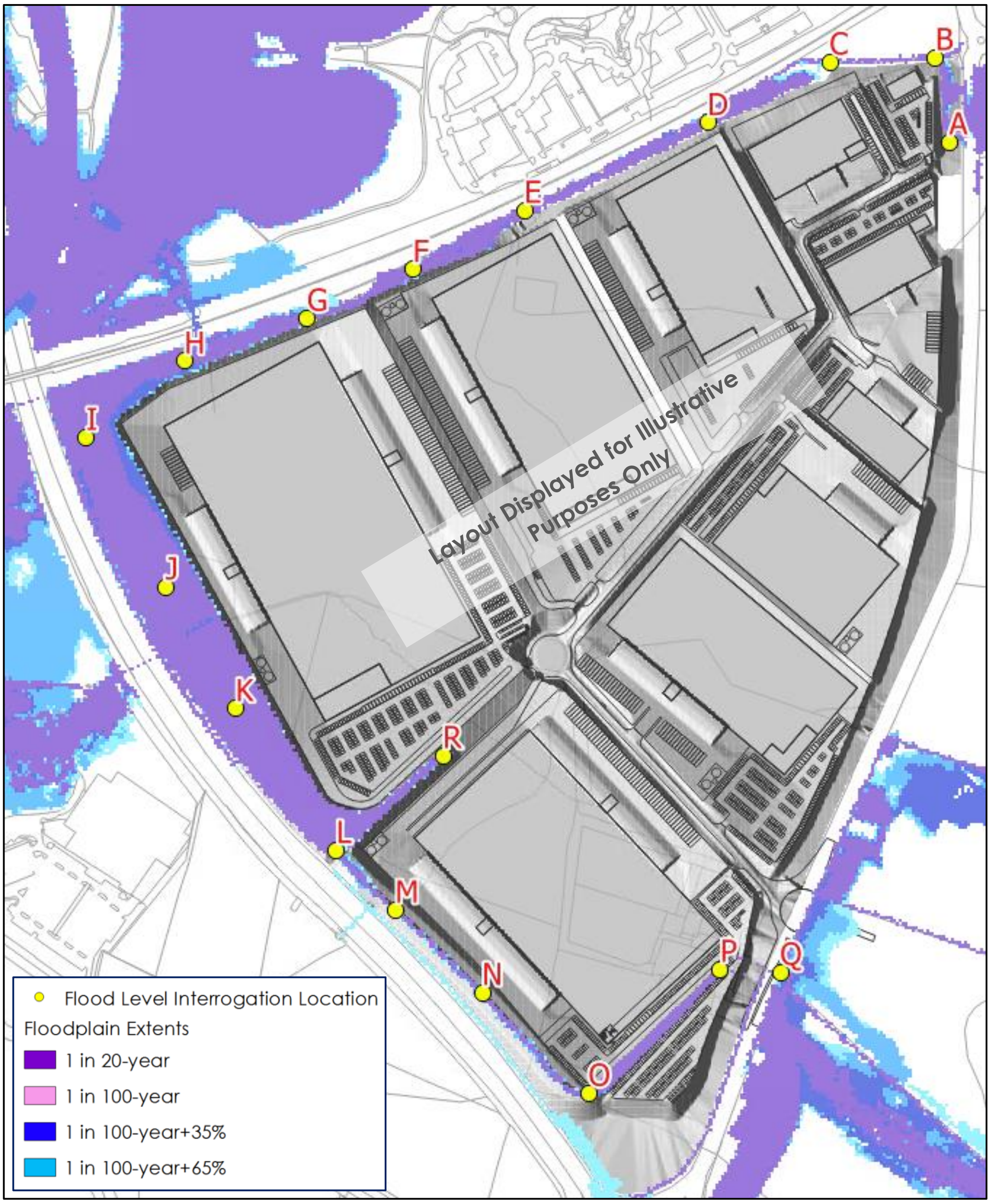


Figure 4.1: Illustrative Post-Development Floodplain Extents

Table 4.1: Illustrative Post-Development Peak Flood Levels (mAOD)

ID	Design Flood Events					1 in 100-year Sensitivity Tests				
	20yr	100yr	100yr+35	100yr+65	1000yr	Roughness +20%	Roughness -20%	Blockage 1	Blockage 2	Blockage 3
A	73.98	73.98	73.98	73.98	73.98	73.98	73.98	73.98	73.98	73.98
B	72.97	73.05	73.09	73.13	73.16	73.05	73.04	73.05	73.05	73.05
C	71.61	71.65	71.70	71.73	71.76	71.66	71.65	71.65	71.65	71.65
D	70.51	70.52	70.54	70.54	70.55	70.53	70.52	70.52	70.52	70.52
E	69.92	69.93	69.93	69.94	69.94	69.93	69.93	69.93	69.93	69.93
F	67.21	67.21	67.22	67.22	67.22	67.21	67.21	67.21	67.21	67.21
G	66.45	66.48	66.57	66.70	66.67	66.49	66.47	66.53	66.48	66.48
H	66.20	66.32	66.56	66.69	66.67	66.34	66.30	66.53	66.40	66.27
I	66.19	66.32	66.56	66.69	66.67	66.34	66.30	66.53	66.40	66.27
J	66.30	66.36	66.56	66.70	66.67	66.37	66.34	66.53	66.42	66.32
K	66.63	66.68	66.70	66.73	66.73	66.68	66.67	66.68	66.69	66.65
L	67.04	67.08	67.08	67.09	67.10	67.08	67.07	67.08	67.08	67.02
M	67.89	67.94	68.03	68.07	68.08	67.97	67.95	67.94	67.94	67.80
N	68.46	68.54	68.58	68.59	68.62	68.54	68.54	68.54	68.54	68.40
O	68.96	69.06	69.12	69.15	69.18	69.07	69.05	69.06	69.06	68.93
P	69.22	69.34	69.42	69.49	69.54	69.38	69.28	69.34	69.34	69.17
Q	72.00	72.23	72.45	72.62	72.75	72.24	72.23	72.23	72.23	72.88
R	66.61	66.69	66.75	66.80	66.83	66.72	66.66	66.69	66.70	66.75

4.8 To account for the seasonal variations in vegetation, and the residual risk of blockages at hydraulic structures, a series of sensitivity tests were conducted using the 1 in 100-year flows. The difference in peak waters between the tests and the design 1 in 100-year event are mapped within **Appendix 5** of the hydraulic modelling report (**see Appendix 3**). Peak flood levels from the tests are also included within **Table 4.1**.

4.9 The modelling has shown that a 20% reduction in channel and floodplain roughness (representative of winter seasonal conditions or following maintenance) results in a general decrease of in-channel flood levels, of between 10 to 46mm within the site. This is shown to have no significant impact on flood risk within the development.

4.10 Similarly, a 20% increase in Manning's 'n' (representative of summer seasonal conditions, and a period without maintenance) is shown to result in a general increase of in-channel flood levels of between 10 to 50mm. This is shown to have no significant impact on flood risk within the development.

4.11 A 75% blockage of the Railway Brook culvert beneath the A5 was shown to increase flood levels within the site by 229mm. This is shown to have no significant impact on floodplain extents within the site.

4.12 A 75% blockage of the Brickhill Brook culvert beneath the A5 resulted in an increase of up to 77mm within the site. This is shown to have no significant impact on floodplain extents within the site.

4.13 A 75% blockage of the Brickhill Brook culvert beneath Brickhill Street was shown to trigger an overflow into the development area leading to flooding. While a blockage of this magnitude is unlikely, this residual risk should be considered in the maintenance strategy for the watercourse to ensure that the culvert is kept free flowing.

Development Levels

4.14 Finished floor levels are to be set a minimum of 300mm above the adjacent 1 in 100-year+35% River Ouzel flood level, or at a level above the 1 in 100-year+65% flood level, whichever is greatest.

4.15 Additionally, ground levels surrounding the proposed buildings should be profiled to encourage pluvial runoff and overland flows away from the built development and towards the nearest drainage point.

Safe Access and Egress

4.16 Following the proposed highway improvements to Brickhill Street, and the diversion of the Brickhill Brook and relocation of its culvert beneath the highway, safe access/egress will be available to the site from Brickhill Street.

4.17 A significant blockage of the Brickhill Brook culvert could cause Brickhill Street to be inundated, but as previously mentioned a blockage of this magnitude is unlikely and this residual risk can be mitigated through regular inspection and maintenance of the watercourse.

Floodplain Compensation

4.18 The floodplain compensation will follow the local policy and be level for level for up to the 1 in 100-year flood event + an allowance for climate change (35%).

4.19 The flood management strategy was tested within the hydraulic model to ensure that this would have no detrimental impact on third party flood risk, this is illustrated within **Appendix 4** of the hydraulic modelling report (**see Appendix 3**). This has shown that the flood management strategy has is no significant impact on flood risk within the wider catchment.

Surface Water Drainage

4.20 To mitigate the development's impact on the current runoff regime it is proposed to incorporate surface water attenuation and storage as part of the development proposals.

4.21 Further information on the drainage approach is provided within the accompanying Sustainable Drainage Statement, reference: *SCD-BWB-ZZ-XX-00-RP-YE-0001_SDS*.

4.22 In brief, the development will continue to discharge surface water to the local watercourse at a rate of 2 l/s/ha as required by the Internal Drainage Board. This is less than the equivalent greenfield QBAR rate and so represents betterment.

4.23 Attenuated surface water storage for events up to and including the 1 in 100-year storm with an allowance for climate change will be provided within the development (outside of the floodplain).

4.24 The drainage should be designed with exceedance in mind. It is recommended that the road network be used to convey excess overland flows towards the attenuation points, and overflows should be provided from the storage locations to the adjacent watercourses. Finished floor levels should be set above the maximum water levels within the surface water attenuated storage features.

Foul Water Drainage

4.25 It is proposed to drain used water from the development separately to surface water.

4.26 Anglian Water have confirmed that there is currently insufficient capacity in the local network to accommodate the site, and therefore offsite local reinforcements are needed.

4.27 It is envisaged that the developer will work with the sewer operator to ensure that the necessary improvement works are made prior to occupation of the development.

4.28 Further information on the drainage approach is provided within the accompanying Sustainable Drainage Statement, reference: *SCD-BWB-ZZ-XX-00-RP-YE-0001_SDS*.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 This Flood Risk Assessment (FRA) has been prepared in accordance with the requirements set out in the National Planning Policy Framework (NPPF) and the associated Planning Practice Guidance. The FRA has been produced on behalf of HB (South Caldecotte) Limited in respect of a planning application for a proposed development of Distribution buildings (B8), with ancillary offices (B1 (a)), car and HGV parking areas, a new primary access off Brickhill Street, with earthworks, drainage and attenuation features and other associated infrastructure, in South Caldecotte, Milton Keynes.

5.2 This FRA is intended to support a planning application and as such the level of detail included is commensurate and subject to the nature of the proposals at the planning stage.

5.3 This report demonstrates that the proposed development is at an acceptable level of flood risk, subject to the recommended flood mitigation strategies being implemented. The identified risks and mitigation measures are summarised within **Table 5.1**.

5.4 In compliance with the requirements of National Planning Policy Framework, and subject to the mitigation measures proposed, the development could proceed without being subject to significant flood risk. Moreover, the development will not increase flood risk to the wider catchment area as a result of suitable management of surface water runoff discharging from the site.

Table 5.1: Summary of Flood Risk Assessment

<table>
<tr><th>Flood Source</th><th>Risk & Proposed Mitigation Measures</th></tr>
<tr><td>Fluvial</td><td rowspan="3">The site is shown to currently be at risk from two ordinary watercourse present in the site, as well as from the influence of the downstream River Ouzel. Surface water overland flows and ground emergence within the site are also associated with these watercourses.

It is proposed to intercept and divert the ordinary watercourses around the development. This will require the Brickfield Brook culvert crossing of Brickhill Street to be relocated approximately 80m to the south. The site will be reprofiled to raise the development out of the floodplain.

Finished floor levels are to be set a minimum of 300mm above the adjacent 1 in 100-year+35% River Ouzel flood level, or at a level above the 1 in 100-year+65% flood level, whichever is greatest.

Additionally, ground levels surrounding the proposed buildings should be profiled to encourage pluvial runoff and overland flows away from the built development and towards the nearest drainage point.

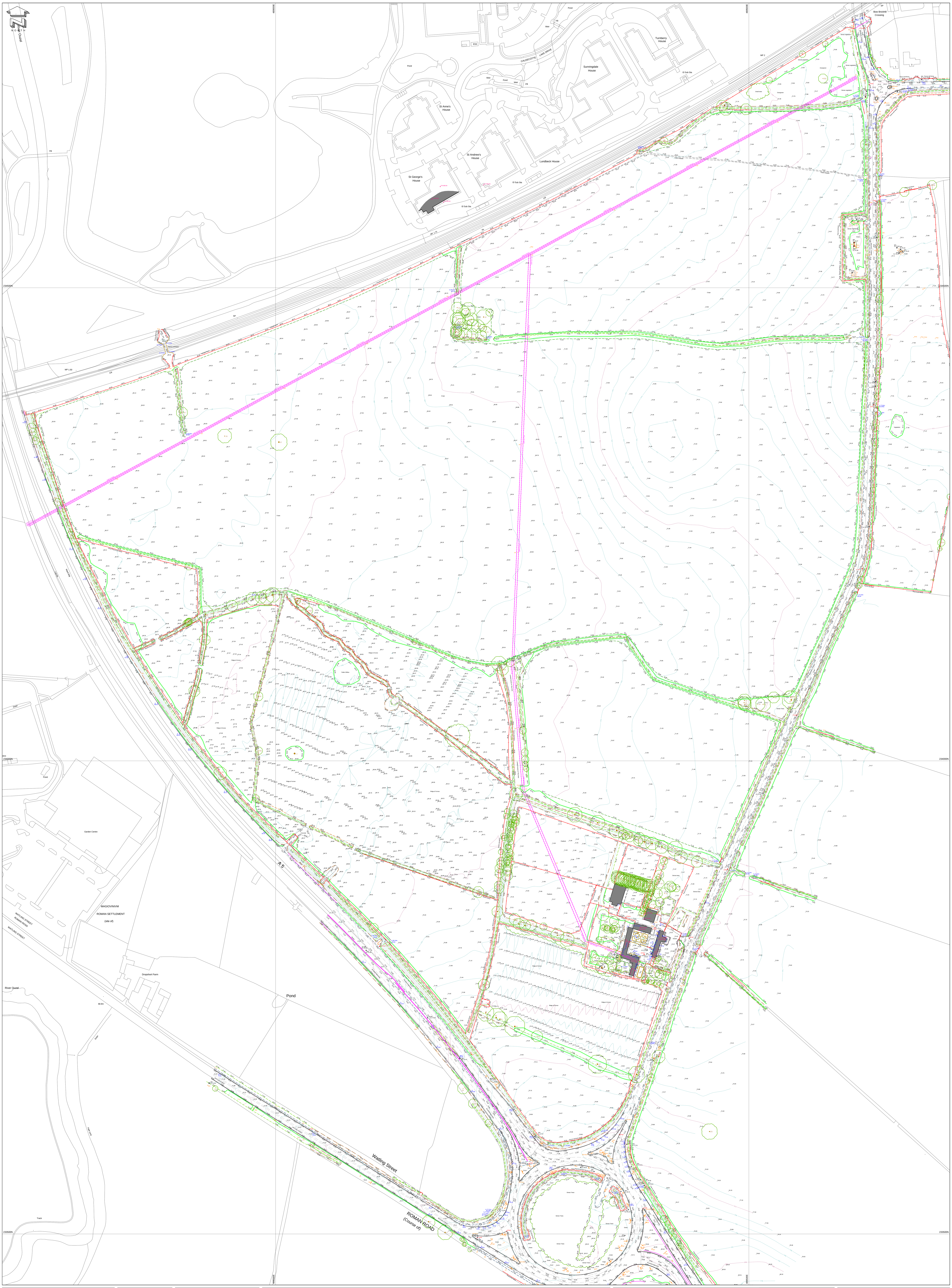
To mitigate the risk of the culverts becoming blocked and watercourses condition degrading it is recommended that these are regularly inspected and maintain where necessary.

There is the potential for groundwater to be encountered during the construction phase, particularly during the excavations. It is recommended that groundwater levels are monitored during the construction phase, and where groundwater is encountered appropriate dewatering solutions should be employed.</td></tr>
<tr><td>Pluvial Runoff</td></tr>
<tr><td>Groundwater</td></tr>
<tr><td>Impact of the Development</td><td>It is proposed to reprofile the development to raise it above the River Ouzel flood levels and compensate for the loss in floodplain on the site within a level-for-level manner.

Surface water runoff from the development will be controlled appropriately and discharged to the local watercourse at 2 l/s/ha to fulfil the IDB requirements. This rate is lower than the current runoff from the site and so represents a betterment. Attenuated surface water storage will be provided within the elevated development, outside of the floodplain.</td></tr>
<tr><td colspan="2">This summary should be read in conjunction with BWB's full report. It reflects an assessment of the site based on information received by BWB at the time of production.</td></tr>
</table>

APPENDICES

APPENDIX 1: Topographic Survey



SITE

SOUTH CALDECOTTE

PROJECT

TOPOGRAPHICAL SURVEY

SCALE

1:1250 @ A0

DATE

06-09-2017

DRAWING No.

9439a

CLIENT

HamptonBrook
Creative Development & Investment
www.hamptonbrook.com

NOTES

Boundaries surveyed are physical features and may not necessarily represent the legally conveyed ownership.

Tree Spreads, Girths and Heights are approximate, any tree species identified should not be relied upon and checked by a specialist if critical

Underground drainage depths, pipe sizes and runs have been recorded from the surface and may have been estimated or assumed

Features surveyed off site such as buildings and trees may have been recorded remotely and may not be shown in full detail due to access / sighting restrictions

SURVEY CONTROL

CO-ORDINATES & DATUM DERRIVED USING GEOID MODEL OSGM15(GB) & HORIZONTAL TRANSFORMATION OSTN15

THIS SURVEY IS ORIENTATED TO ORDNANCE SURVEY GRID NORTH WITH A TRUE OSGM15 CO-ORDINATE NEAR THE CENTRE OF THE SURVEY.

THE SURVEY IS PLOTTED TO A FLAT PLANE GRID. HORIZONTAL MEASUREMENTS TAKEN FROM THIS SURVEY WILL BE TRUE DISTANCES

REFER TO SURVEY CONTROL STATION LISTING FOR RE-ESTABLISHING CONTROL ON SITE

Name	Easting	Northing	Height
STNA	489363.218	233605.041	77.630
STNB	489437.029	233812.595	72.755
STNC	489477.506	233885.623	72.930
STND	489550.436	234048.265	73.625
STNE	489619.801	234203.039	75.014
STNF	489631.911	234376.302	78.078
STNF1	489389.304	233795.439	72.031
STNF2	489400.757	233823.562	72.258
STNF3	489353.107	233846.821	71.624
STNF4	489370.116	233834.671	71.961
STNG	489634.428	234591.278	74.945
STNH	489627.134	234714.783	74.853
STNH1	489635.534	234701.577	75.231
STNH2	489622.075	234774.593	73.853
STNI	489722.863	234719.623	76.493
STNJ	489830.728	234721.510	78.543
STNK	489973.268	234715.875	81.752
STNL	489267.814	233573.958	78.020
STNL1	489109.853	233803.910	72.861
STNM	489388.039	233526.609	79.252
STNN	489320.836	233420.502	80.561
STNO	489244.066	233502.834	78.726
STNP	489213.154	233496.207	78.689
STNQ	489035.589	233610.135	74.346

stafsurv LAND SURVEYORS
www.stafsurv.com
Vernon Courtyard, Main Road, Sudbury, Derbyshire. DE6 5HS
T 01283 584800 > F 01284 584844 > E info@stafsurv.com

APPENDIX 2: Illustrative masterplan

Ref:

Site	GIA (ft²)	NDA (ac)	Plot Density (%)
Unit 1	473,200	27.13	51.2
Unit 2	615,400	21.2	52.1
Unit 3	369,708	15.87	53.5
Unit 4	254,200	10.68	54.7
Unit 5	61,400	3.47	40.7
Unit 6 (office)	10,400	1.22	19.7
Unit 7	53,700	4.33	28.5
Unit 8	49,800	2.87	39.9
Unit 9	164,800	8.39	45.2
Unit 10	278,500	12.24	52.3
Total	**2,331,108**	**107.40**	49.9
	Total	**139.9**	

Revisions:

P1: 07/06/19 kbl Masterplan updated, drawing number P005 updated to PAS 1192 standard.
P2: 24/06/19 kbl Client / team comments.
P3: 27/06/19 kbl Client comments.
P4: 02/07/19 kbl Redline updated.
P5: 04/07/19 kbl Redline updated.

HamptonBrook
Creative Development & Investment
www.hamptonbrook.com

Waterfront House
2a Smith Way
Grove Park
Enderby
Leicester LE19 1SX
t: +44 (0)116 247 0557
www.stephengeorge.co.uk

South Caldecotte

Drawing Name:
Indicative Masterplan 23

Drawing Status: PLANNING
Suitability: S2
Rev: P5
SGP Project: 16-048
Drawn: KBL
Team: IY
Date: 13/11/2018
Scale: 1:2500@ A1
Drawing Number:
16-048-01-SGP-XX-00-DR-A-1006-P5

This drawing, the works and concepts depicted are copyright of Stephen George & Partners and may not be reproduced or made use of, either directly or indirectly without express written consent. Do not scale off this drawing. All heights, levels, sizes and dimensions to be checked on site before any work is put to hand.

APPENDIX 3: Hydraulic Modelling Report

BETTER SOLUTIONS, INTELLIGENTLY ENGINEERED

ENVIRONMENT

HB (South Caldecotte) Limited
South Caldecotte
Milton Keynes
Hydraulic Modelling Report

www.bwbconsulting.com

BWB

ENVIRONMENT

HB (South Caldecotte) Limited
South Caldecotte
Milton Keynes
Hydraulic Modelling Report

Birmingham
Livery Place, 35 Livery Street, Colmore Business District, Birmingham, B3 2PB
T: 0121 233 3322

Cambridge
14-16 High Street, Histon, Cambridge
CB24 9JD
T: 01223 235 173

Leeds
Whitehall Waterfront, 2 Riverside Way, Leeds
LS1 4EH
T: 0113 233 8000

London
11 Borough High Street
London, SE1 9SE
T: 0207 407 3879

Manchester
4th Floor Carvers Warehouse, 77 Dale Street
Manchester, M1 2HG
T: 0161 233 4260

Market Harborough
12a Woodcock House, Compass Point Market Harborough, Leicestershire, LE16 9HW
T: 01858 455020

Nottingham
Waterfront House, Station Street, Nottingham NG2 3DQ
T: 0115 924 1100

July 2019

BWB

DOCUMENT ISSUE RECORD

Document Number:	SCD-BWB-ZZ-XX-RP-YE-0002 _HMR
BWB Reference:	NTS-2682-HMR

Revision	Date of Issue	Status	Author:	Checked:	Approved:
P01	30/11/18	S2	Robin Green BSc (Hons)	Lauren Towle BSc (Hons)	Julian O'Neill BSc. MSc.
P02	18/12/18	S2	Robin Green BSc (Hons)	Lauren Towle BSc (Hons)	Julian O'Neill BSc. MSc.
P03	02/07/19	S2	Robin Green BSc (Hons)	Lauren Towle BSc (Hons)	Robin Green BSc (Hons)
P04	04/07/19	S2	Robin Green BSc (Hons)	Lauren Towle BSc (Hons)	Robin Green BSc (Hons)

Notice

All comments and proposals contained in this report, including any conclusions, are based on information available to BWB Consulting during investigations. The conclusions drawn by BWB Consulting could therefore differ if the information is found to be inaccurate or misleading. BWB Consulting accepts no liability should this be the case, nor if additional information exists or becomes available with respect to this scheme.

Except as otherwise requested by the client, BWB Consulting is not obliged to and disclaims any obligation to update the report for events taking place after: -

(i) The date on which this assessment was undertaken, and
(ii) The date on which the final report is delivered

BWB Consulting makes no representation whatsoever concerning the legal significance of its findings or the legal matters referred to in the following report.

All Environment Agency mapping data used under special license. Data is current as of July 2019 and is subject to change.

The information presented, and conclusions drawn, are based on statistical data and are for guidance purposes only. The study provides no guarantee against flooding of the study site or elsewhere, nor of the absolute accuracy of water levels, flow rates and associated probabilities.

This document has been prepared for the sole use of the Client in accordance with the terms of the appointment under which it was produced. BWB Consulting Limited accepts no responsibility for any use of or reliance on the contents of this document by any third party. No part of this document shall be copied or reproduced in any form without the prior written permission of BWB

CONTENTS

FIGURES

TABLES

APPENDICES

1. INTRODUCTION

1.1 BWB Consulting Ltd has been commissioned to undertake a hydraulic modelling exercise to investigate the potential flood risk at a proposed development site in the south-east of Milton Keynes.

1.2 The modelling exercise will be used to inform a Flood Risk Assessment (FRA) of the site and develop a flood risk management strategy for the development.

Site Description

1.3 The site is located approximately 7.7km south-east of Milton Keynes, in an area known as Caldecotte. The site is bound to the north by the Woburn Sands to Bletchley railway line, to the east by Brickhill Street and to the west by the A5. The site's location is illustrated within **Figure 1.1**

Figure 1.1: Site Location

1.4 The River Ouzel is located to the west of the site on the opposite side of the A5. The river flows past the site in a northerly direction.

1.5 Caldecotte Lake is located to the north of the site, on the opposite side of the embanked railway line. There are known hydraulic interactions between the River Ouzel and Caldecotte Lake.

1.6 The site is largely greenfield and is understood to be used as farmland (arable and pasture). Some minor development (Cross Roads Farm) is present in the south of the site next to Brickhill Street.

1.7 The majority of the site falls westwards, towards the River Ouzel. The north-western corner of the site forms the lowest point, ground levels here are in the region of 65.63m Above Ordnance Datum (AOD). Ground levels are highest in the centre of the eastern site boundary, in the region of 77m AOD.

1.8 The site, and immediate upstream hillside, are crossed by a network of minor ditches which are understood to be associated with land drainage. Two ordinary watercourses are also shown to cross the site.

1.9 An unnamed ordinary watercourse draining the 'Blackwood' hillside to the south east enters the site via a culvert under Brickhill Street. For the purpose of this assessment, it will be referred to as the 'Brickhill Brook'. The watercourse flows through the site in a north-westerly direction picking up outfalls from the ditch network. The watercourse passes beneath the A5 and outfalls to the River Ouzel approximately 360m downstream of the site. A stretch of this watercourse is understood to fall within the control of the Bedford Group of Internal Drainage Boards. A site visit undertaken by BWB Consulting in May 2018 identified the watercourse to be well vegetated, and heavily overgrown.

1.10 A second ordinary watercourse draining the hillside around Bow Brickhill to the north east enters the site via a second culvert beneath Brickhill Street, in the very north of the site. This flows for a short stretch within the site ownership before entering network rail land ownership. For the purpose of this assessment, it will be referred to as the 'Railway Brook'. The watercourse has been observed to flow in a south-westerly direction along the toe of the railway embankment, just to the north of the site ownership. The watercourse passes beneath the A5 before outfalling to the River Ouzel. Due to access restrictions, information and observations on this watercourse is limited.

1.11 A schematic plan of the observed channel network within the vicinity of the site is illustrated within **Figure 1.2**.

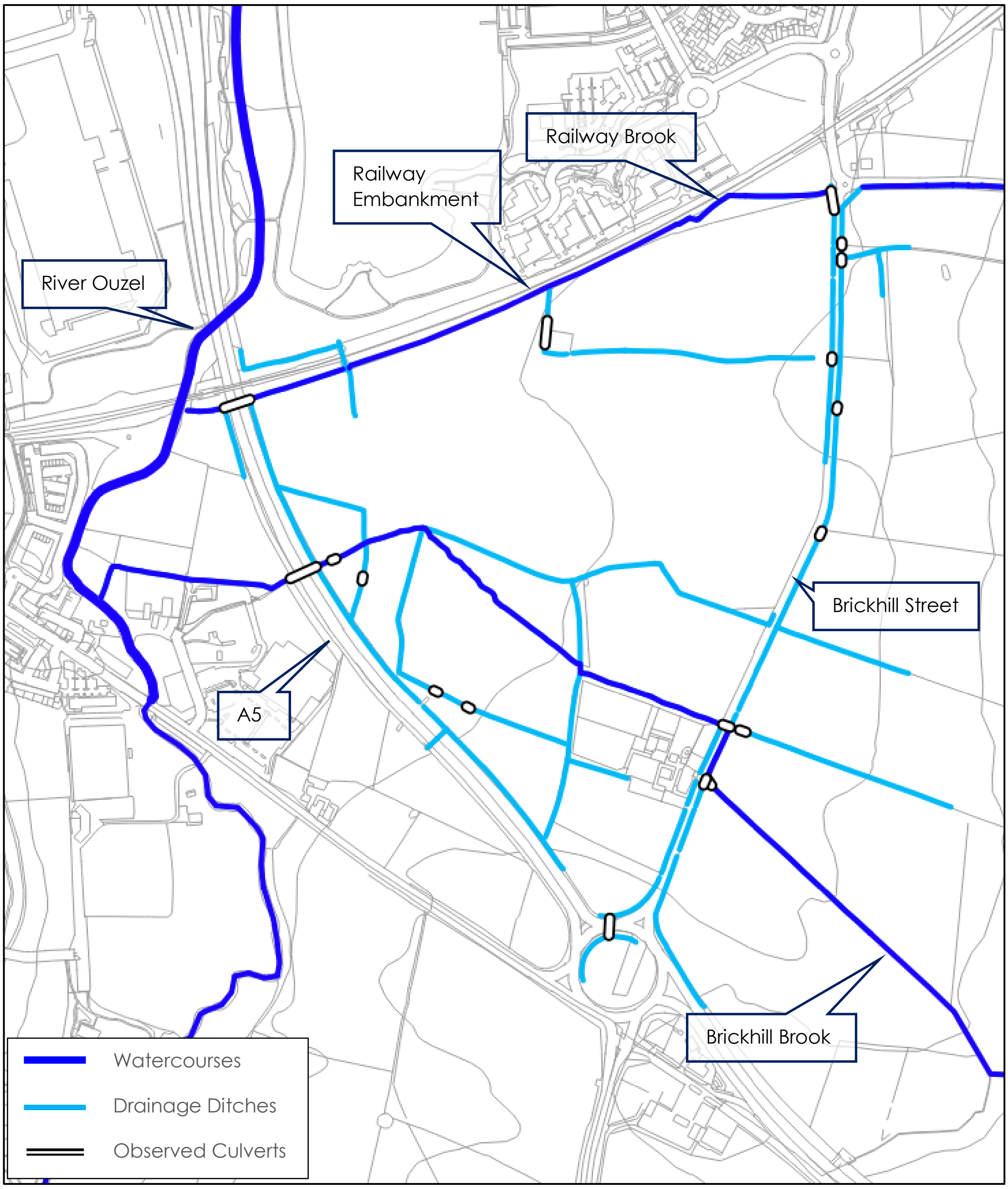


Figure 1.2: Observed Watercourse/Ditch Connectivity

2. PREVIOUS STUDIES & AVAILABLE DATA

Flood Maps for Planning

2.1 The Environment Agency (EA) Flood Maps for Planning identify that the site is located within Flood Zone 1 (low risk) - as illustrated within **Figure 2.1**. This is land assessed as having a less than 1 in 1000-year annual probability of river flooding.

2.2 The Flood Zone Maps for Planning are based on river modelling carried out at a national scale, for catchments over 3km^2 (300ha) they only provide an indication of the areas at flood risk for planning purposes. For smaller catchments, such as those located within the site boundary, additional modelling is required to be undertaken to better understand what flood risk may be posed. Therefore, this dataset is not considered to be reliable illustration of flood risk at the study site.

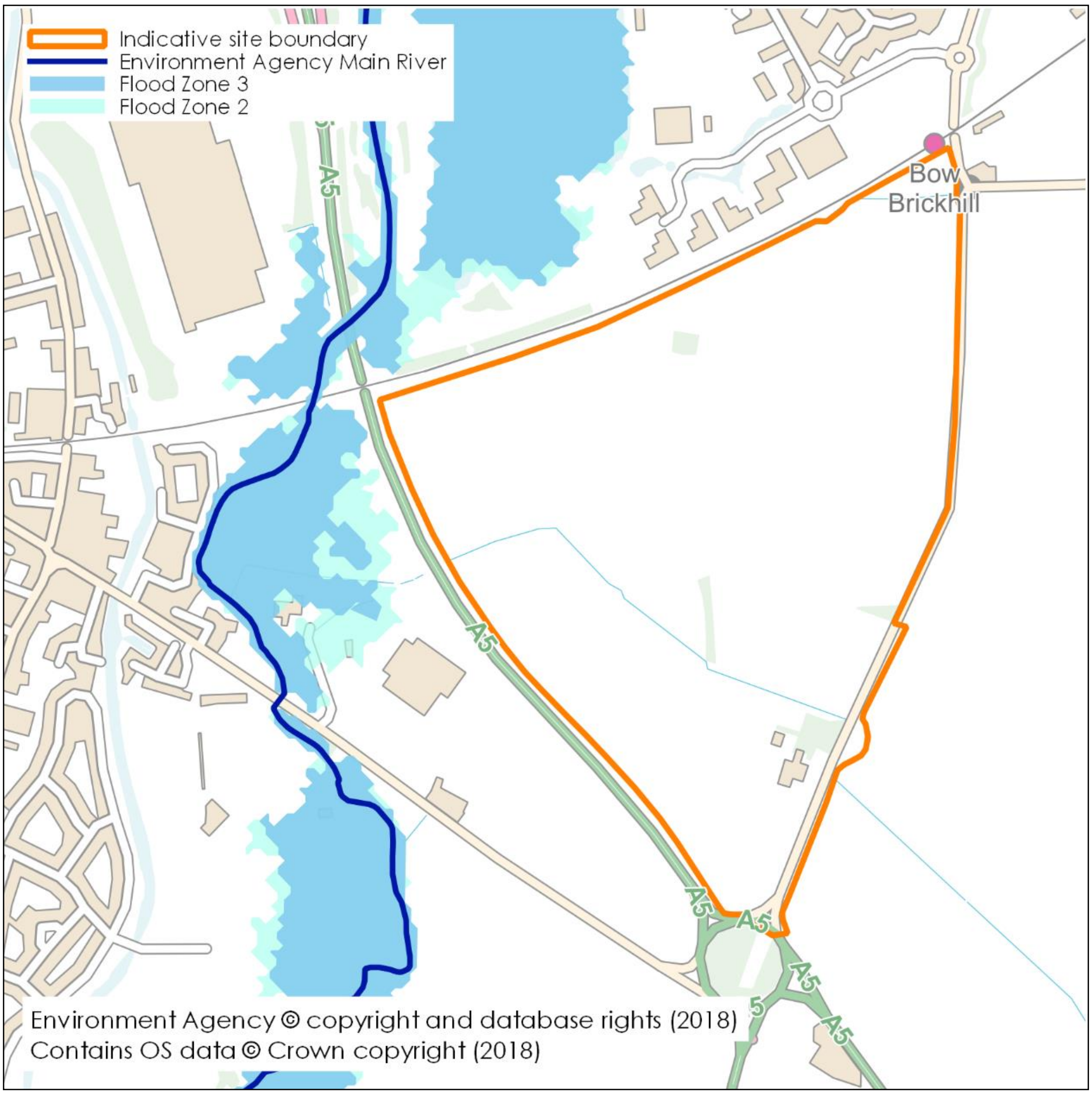


Figure 2.1: Flood Map for Planning

Environment Agency River Ouse & Ouzel Hydraulic Model

2.3 The Environment Agency hold a hydraulic model of the River Ouzel, a copy of which was obtained for use in this assessment. The Ouzel forms part of the larger River Ouse (Upper, Lower) hydraulic model. It is understood that this model was used to inform the Flood Maps for Planning for the area.

2.4 Upon review it was apparent that the EA model does not accurately reflect the hydraulic connectivity at the site (the ordinary watercourse culverts beneath the A5 are omitted), the model also does not include a geometry or inflow associated within the ordinary watercourses on the site. The EA model also does not account for the latest climate change allowances.

2.5 The model includes a 'defended' and 'undefended' geometry. Upon analysis it was found that the defend scenarios generated the more conservative flood levels within the vicinity of the site. This is because Caldecotte Lake is used for flood storage in the defended scenario. The defended model scenario was therefore adopted within this site-specific assessment.

2.6 While the EA model is not considered suitable for assessing flood risk at the site in its currently form, it does form a good representation of the River Ouzel and so will form the basis of a site-specific hydraulic model.

2.7 An extract of the EA modelled results at the site is provided within for reference in **Figure 2.2**.

Ordinary Watercourse Hydraulic Model

2.8 It is understood that the EA, Internal Drainage Board (IDB), and Lead Local Flood Authority (LLFA) do not hold flood model data for ordinary watercourse present within the site.

Surface Water Flood Risk Maps

2.9 EA surface water flood risk maps identify the potential areas at risk of flooding if rain water does not enter the drainage system or infiltrate into the ground. While not strictly a fluvial source, this mapping can provide an indication of the potential flood risk associated with minor watercourses excluded from the Flood Zone maps. An extract of the Surface Water Flood Risk maps is illustrated within **Figure 2.3**.

2.10 The surface water maps suggest that ordinary watercourses are subject to overland flow routes, and that the north-western proportion of the site could be subject to accumulated flood water from the minor watercourses. The mapping suggests that the culverted connection beneath of the A5 on the Railway Brook is not reflected in this dataset. The potential backwater from the River Ouzel is also unlikely to be accounted for. Therefore, this dataset is not considered to be reliable at the study site. However, it does highlight that a site-specific assessment is required.

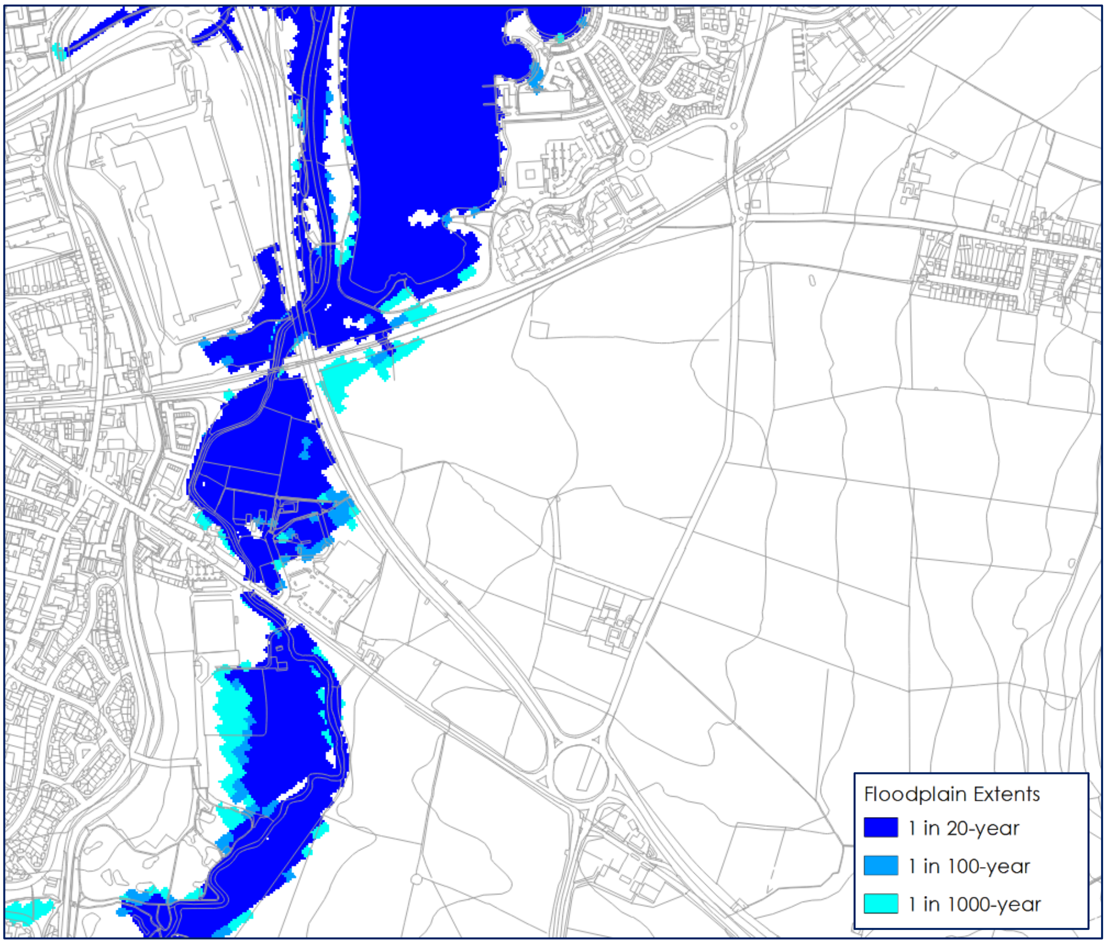


Figure 2.2: Modelled River Ouzel Floodplain Extents

Other Sources of Data

2.11 The following additional datasets were used within the hydraulic modelling exercise:

- LiDAR 1m Digital Terrain Model (DTM)
- A Topographical survey of the study site
- Ordnance Survey 1:1,250 scale mapping
- Ordnance Survey 1:50,000 scale mapping
- Photographs and observations from a site visit and catchment walkover undertaken in May 2018 by BWB Consulting
- Flood Estimation Handbook catchment descriptors
- Version 6 of the National River Flow Archive (current at the time of assessment)
- Highways England asset record data of the A5 culvert crossings

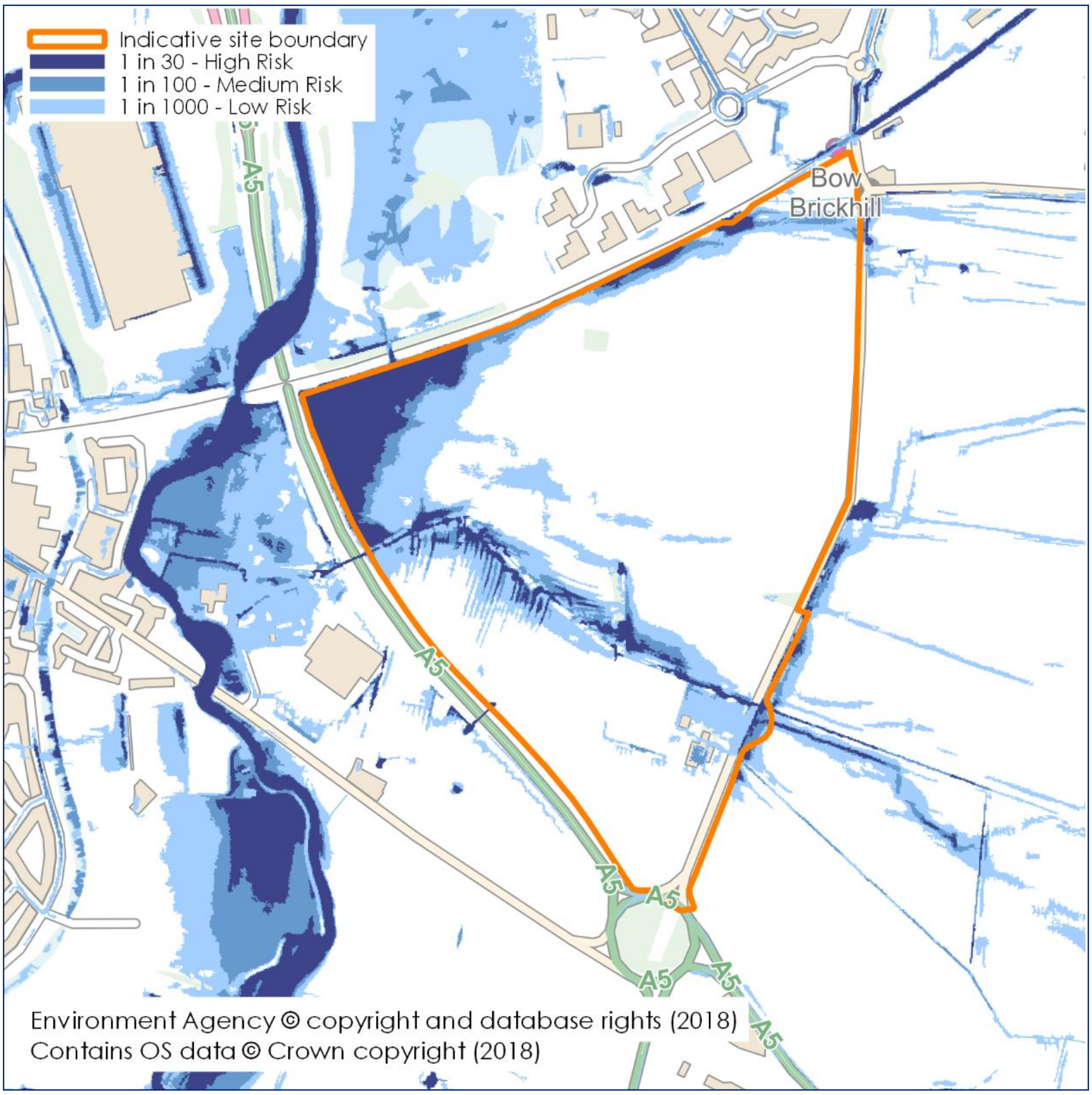


Figure 2.3: Environment Agency's Surface Water Flood Risk Mapping

3. AIMS & OBJECTIVES

Hydraulic Modelling Aim

3.1 The aim of this modelling exercise is to establish a good hydrological and hydraulic representation of the ordinary watercourses as they pass through the study site, and to represent the hydraulic interactions of these watercourses with the River Ouzel.

3.2 The hydraulic model will be used to confirm the current level of fluvial flood risk to the site and will also be used to assess the flood management strategy of a proposed future development.

Objectives

3.3 To achieve this aim, the following objectives were identified:

i. Update the Environment Agency River Ouse (Upper, Lower) 1 in 100-year inflows with the latest climate change allowances and generate a set of results for key return periods, as follows: 1 in 20-year, 1 in 100- year, 1 in 100-year+35%, 1 in 100-year+65%, 1 in 1000-year.

ii. Truncate the Environment Agency model to remove superfluous upstream and downstream reaches. Create new upstream and downstream boundaries from the aforementioned results.

iii. Extend the two-dimensional (2D) model domain to include the study site and upstream hillside. Ground elevations are to be based upon detailed topographical survey of the site and channels, supplemented with 1m LiDAR DTM.

iv. Increase the 2D model resolution to sufficiently represent flow routes through the site.

v. Update the model with one-dimensional (1D) representations of the key hydraulic structures (e.g.: the A5 culverts). Due to the complex network of ditches, and access restrictions around the railway line and A5, a 1D model of the channels was not viable.

vi. Undertake a hydrological assessment of the Brickhill Brook and Railway Brook catchments to estimate peak flood flows and generate flood hydrograph profiles.

vii. Simulate fluvial flood events within the combined 1D-2D site specific model to establish a set of baseline conditions.

viii. Develop an outline flood management strategy within the model to remove the proposed development areas from the design floodplain.

ix. Compare existing and proposed conditions to ensure that the development will not have a negative effect on flood risk in the wider catchment.

x. Simulate sensitivity tests and residual risks within the model, which would include roughness coefficients, blockage scenarios and climate change, to ensure the flood management strategy is robust.

4. HYDROLOGICAL ASSESSMENT

Method Statement

4.1 Flood flows estimates are required to inform a hydraulic model of the watercourses. The assessment will model unsteady flood flows, therefore hydrographs as well as peak flood levels are required.

4.2 To inform the Flood Risk Assessment the following return period events are required: 1 in 20-year, 1 in 100-year, and the 1 in 1000-year.

4.3 The Brickhill Brook is identified by the Flood Estimation Handbook (FEH) web service to have a total catchment area of 3.52km^2.

4.4 The Railway Brook is not specifically identified within the FEH web service. It is shown to fall within the headwaters of another watercourse to the north, whereas in reality the railway line separates it from this northern catchment.

4.5 The catchments are mostly comprised of pasture and arable farm land, and woodland. There is a slight urban influence as follows: the Railway Brook is influenced by the presence of the small village of Bow Brickhill; and the Brickhill Brook by the outskirts of Little Brickhill. A stretch of the A5 also falls within the Brickhill Brook catchment.

4.6 Both catchments are un-gauged. Therefore, there are no hydrometric records of river flows or levels on which a hydrological assessment of flood flows can be made.

4.7 This hydrological analysis is based around the industry standard methodologies which utilise the FEH catchment descriptors: the FEH Statistical Analysis; and the ReFH (Revitalised Flood Hydrograph) rainfall-runoff model.

4.8 The FEH rainfall-runoff hydrological approach was not assessed as it has been superseded by the ReFH. Other methodologies such as IH124, and the Modified Rational method were dismissed due to the size and rural nature of the catchment.

4.9 The catchments as delimited at the downstream extent of the site were assessed in this analysis, so that only flows generated upstream or within the site will be estimated.

4.10 As the flow estimates will be supporting a Flood Study a conservative approach to the decision making was be made where applicable.

Review of the Catchment

Brickhill Brook

4.11 A review of the Brickhill Brook topographical watershed was undertaken against the available Environment Agency 1m LiDAR Digital Terrain Model (DTM), this is illustrated within **Figure 4.1**. This showed a fair correlation, but the 3.52km^2 FEH catchment was extended to 3.64km^2 to include additional areas of the A5 and Bow Brickhill.

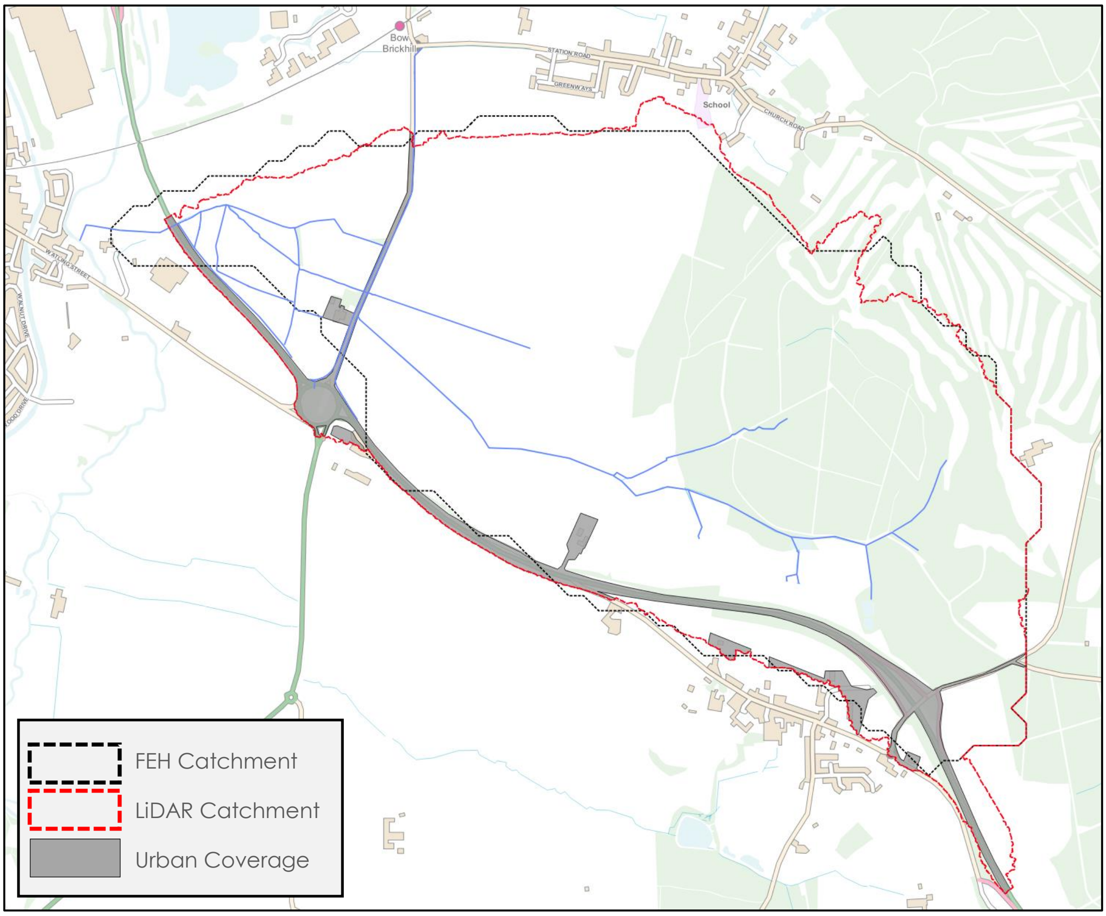


Figure 4.1: Brickhill Brook Catchment Analysis

4.12 Given the additional catchment area, the urban extent was measured from Ordnance Survey mapping. As a precautionary approach, the road network was included within the measurements. This returned an urban coverage of $0.22km^2$, which equates to the $URBEXT_{2000}$ increasing from 0.03750 to 0.03857. The catchment remains categorised as 'moderately' urbanised.

4.13 British Geological Society (BGS) geological mapping indicates that the catchment is underlain by Oxford Clay Mudstone in the lower reaches, which transitions through West Walton Mudstone, and into Woburn Sandstone in the upper watershed.

4.14 Alluvium superficial deposits (sand and gravels, associated with fluvial environments) are present on the course of the Brickhill Brook. Superficial deposits of Head (sands, gravels and silts deposits, associated with solifluction and soil creep) are present across the catchment. River terrace deposits (sands and gravels of fluvial origin) are present in the lower catchment and likely associated with the historic floodplain of the River Ouzel.

4.15 This underlying geology suggests that the BFI_{HOST} and SPR_{HOST} values of the FEH catchment descriptors are reasonable.

4.16 The corrected catchment extent does not alter the composition of the underlying geology, or the general catchment parameters. Therefore, the other catchment descriptors were not altered. Key descriptors are detailed within **Table 4.1**.

Table 4.1: Brickhill Brook Key Catchment Descriptors

Descriptor	Value
AREA (km^2)	3.64
BFI_{HOST} – Base Flow Index	0.602
FARL – Flood attenuation from reservoirs & lakes	1.000
FPEXT – Floodplain extent	0.0891
PROPWET – Proportion of time that soils are wet	0.32
SAAR – Standard Average Annual Rainfall	630
SPR_{HOST} – Standard Percentage Runoff (Host soils classification)	36.95
$URBEXT_{2000}$ – Fraction of Urban Extent	0.03857

Railway Brook

4.17 The Railway Brook is not satisfactorily captured within the FEH descriptors; therefore, it was necessary to define its catchment extent using of the available LiDAR data, this is illustrated within **Figure 4.2**.

4.18 The catchment is in close proximity to the Brickhill Brook, with similar topography and underlying geology. Therefore, the catchment descriptors from the Brickhill Brook were adopted, with the exception of: the measured catchment area ($0.47km^2$); the measured urban coverage ($0.06km^2$, $URBEXT_{2000}$ = 0.08147); and the DPLBAR (0.661 - updated using Equation 7.1 of the FEH Vol. 5).

4.19 Key descriptors are detailed within **Table 4.2**.

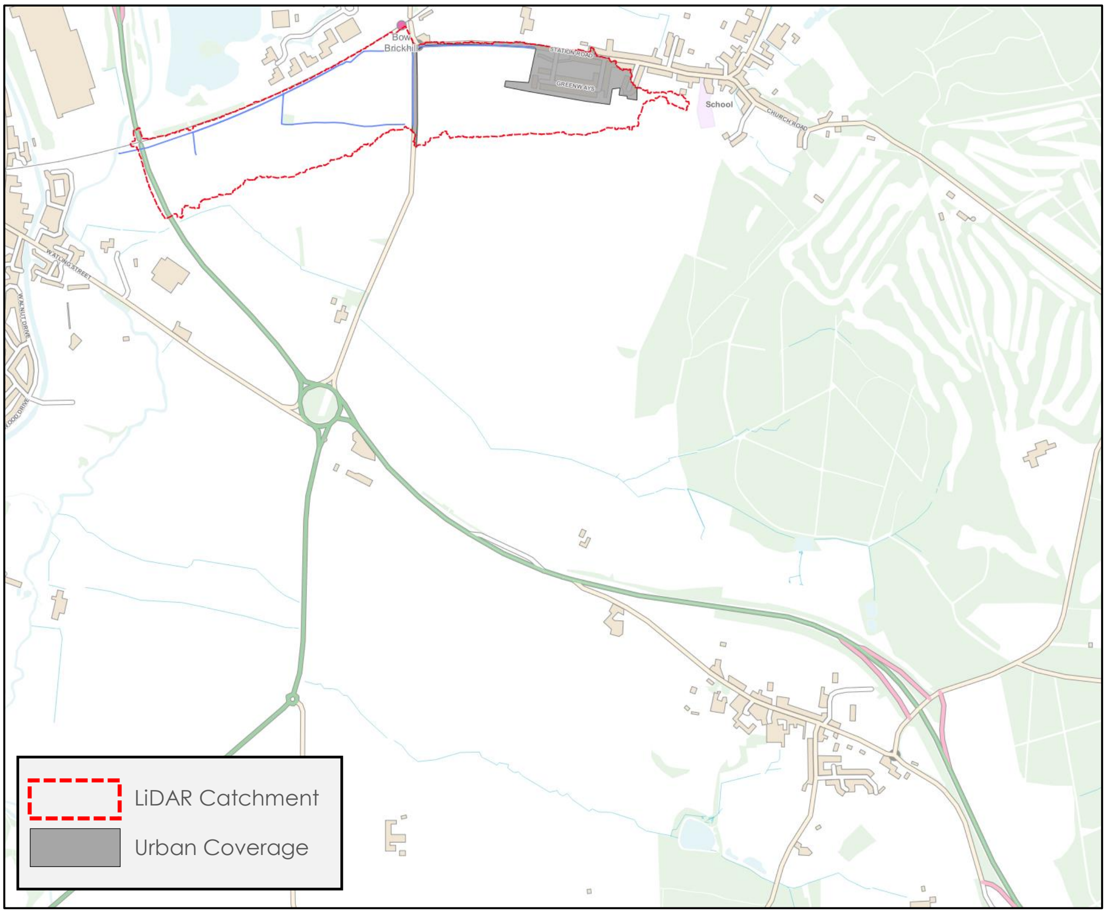


Figure 4.2: Railway Brook Catchment Analysis

Table 4.2: Railway Brook Catchment Descriptors

Descriptor	Value
AREA (km²)	0.47
BFI_{HOST} – Base Flow Index	0.602
FARL – Flood attenuation from reservoirs & lakes	1.000
FPEXT – Floodplain extent	0.0891
PROPWET – Proportion of time that soils are wet	0.32
SAAR – Standard Average Annual Rainfall	630
SPR_{HOST} – Standard Percentage Runoff (Host soils classification)	36.95
$URBEXT_{2000}$ – Fraction of Urban Extent	0.08147

FEH-Statistical Analysis

Brickhill Brook

4.20 WINFAP version 4 was utilised to undertake a statistical analysis of the adjusted catchment using a hydrometric record of gauged catchments with similar catchment descriptors.

4.21 The previously discussed updated catchment descriptors were initially used to estimate the rural QMED of the study site ($QMED_{CDS}$) using the revised equation from Science Report SC050050[1]. $QMED_{CDS}$ was estimated at 0.418m^3/s.

4.22 The Hi-Flows dataset was used to generate a list of 10 potential donor sites from the "OK for QMED & Pooling" dataset. It is the recommended procedure to use six Donor Stations to refine the estimation of QMED. The adopted donor sites are listed within **Table 4.3**. This resulted in an adjusted QMED ($QMED_{ADS}$) of 0.428m^3/s.

Table 4.3: Brickhill Brook Donor Stations

Site	Number	Distance	URBEXT	QMED Suitability
Clipstone Brook	33030	8.15	0.016	Yes
Ouzel	33057	12.93	0.025	Yes
Bedford Ouse	33005	23.35	0.014	Yes
Tove	33018	30.91	0.016	Yes
Kym	330125	35.69	0.007	Yes
Flore	32029	37.55	0.002	Yes

4.23 To account for the influence of the urban extent, the $QMED_{ADS}$ value was adjusted using an Urban Adjustment Factor (UAF) based upon the measured urban coverage. In this instance the software was used to identify a UAF of 1.056, which resulted in a $QMED_{URBAN}$ of 0.452m^3/s.

4.24 A group of hydrologically similar gauged sites was generated by the software from the 'OK for Pooling' dataset.

4.25 The group was reviewed to identify sites which may be inappropriate due to being significantly hydrologically dissimilar to the study site, or if they have any inaccuracies, uncertainties or limitations in their data record.

4.26 Station 49005 (Bollingey Stream at Bollingey Cocks Bridge) was removed due to its record length falling below the accepted minimum of 8 years.

[1] Kjeldsen, T.R., Jones, D. A. and Bayliss, A.C. (2008) Improving the FEH statistical procedures for flood frequency estimation. Science Report SC050050, Environment Agency.

4.27 Station 49006 (Camel at Camelford) was identified to be significantly discordant from the rest of the pooling group, but upon review no reason to remove this station from the group could be identified.

4.28 Three stations within the pooling group were identified as permeable catchments (BFIHOST>0.65, SPRHOST<20%): Brompton Beck (27073), Gypsey Race (26802), and South Winterbourne (44008). Given their permeability is considerably different from the study catchment they were initially removed from the pooling group and replaced with three other sites to meet the minimum record length target. However, upon comparison (see **Table 4.4**) it was found that this reduced the growth factors and led to reduced peak flows. Therefore, the permeable catchments were reinstated to promote a conservative analysis.

Table 4.4: Flow Comparison with Permeable Site Removed

Return Period	Flows - Original Pooling Group (m^3/s)	Flows - Permeable Sites Removed (m^3/s)
$QMED_{CDS}$	0.418	0.418
$QMED_{ADS}$	0.428	0.428
$QMED_{URBAN}$	0.452	0.452
20	0.904	0.878
100	1.338	1.283
1000	2.327	2.198

4.29 All other stations in the pooling group were considered to be acceptable: they were all identified as having sufficient record length, and to be of sufficient hydrological similarity for the purpose of this study (i.e.: no other sites within the Hi-Flows dataset are believed to be more representative). The final pooling group is detailed within **Table 4.5**.

4.30 The final pooling group was identified as 'heterogeneous'. It is believed that the heterogeneous nature of the pooling group is a result of the limited number of small gauged sites which are available for statistical analysis.

4.31 The resultant record length for the pooling group totalled 527 years, which meets the recommended guidelines on required record length.

4.32 In line with the generally accepted approach, the 'generalised logistic' distribution (regarded as the best fit for most UK catchments) was selected to derive a growth curve from the pooling group.

4.33 The growth curve derived from the pooling group was also adjusted to reflect the urban influence, using the standard recommended approach[2].

[2] Kjeldsen, T.K., 2010. Modelling the impact of urbanization on flood frequency relationships in the UK. Hydrology Research, volume 41, issue 5, pp391-405

Table 4.5: Brickhill Brook Pooling Group

Station	Years of Data	Area	SAAR	FPEXT	FARL	$URBEXT_{2000}$
27051 (Crimple @ Burn Bridge)	44	8.170	855	0.013	1.000	0.006
76011 (Coal Burn @ Coalburn)	39	1.630	1096	0.074	1.000	0.000
45816 (Haddeo @ Upton)	23	6.810	1210	0.011	1.000	0.005
27073 (Brompton Beck @ Snainton Ings)	35	8.060	721	0.237	1.000	0.008
28033 (Dove @ Hollinsclough)	37	7.920	1346	0.007	1.000	0.000
26802 (Gypsey Race @ Kirby Grindalythe)	17	15.850	757	0.030	1.000	0.000
25019 (Leven @ Easby)	38	15.090	830	0.019	1.000	0.004
49006 (Camel @ Camelford)	10	12.520	1418	0.013	1.000	0.003
47022 (Tory Brook @ Newnham Park)	23	13.430	1403	0.023	0.942	0.014
25011 (Langdon Beck @ Langdon)	28	12.790	1463	0.012	1.000	0.001
27010 (Hodge Beck @ Bransdale Weir)	41	18.820	987	0.009	1.000	0.001
44008 (South Winterbourne)	37	20.180	1012	0.015	1.000	0.004
203046 (Rathmore Burn @ Rathmore Bridge)	34	22.500	1043	0.072	1.000	0.000
25003 (Trout Beck @ Moor House)	43	11.400	1905	0.041	1.000	0.000
71003 (Croasdale Beck @ Croasdale Flume)	37	10.710	1882	0.016	1.000	0.000
20002 (West Peffer Burn @ Luffness)	41	25.510	616	0.127	0.995	0.002

4.34 The $QMED_{URBAN}$ was applied to the adjusted growth curve to derive a flood frequency curve. The peak flood flow estimates are detailed in **Table 4.8**.

Railway Brook

4.35 The same WINFAP 4 procedure was undertaken for the Railway Brook. The rural QMED of the study site ($QMED_{CDS}$) was estimated at 0.073m^3/s.

4.36 The Hi-Flows dataset was used to generate a list of Donor Stations to refine the estimation of QMED. The adopted donor sites are listed within

4.37 **Table** 4.6. This resulted in an adjusted QMED ($QMED_{ADS}$) of 0.075m^3/s.

4.38 The $QMED_{ADS}$ value was adjusted using an UAF based upon the measured urban coverage. In this instance the software was used to identify a UAF of 1.121, which resulted in a $QMED_{URBAN}$ of 0.084m^3/s.

Table 4.6: Railway Brook Donor Stations

Site	Number	Distance	URBEXT	QMED Suitability
Clipstone Brook	33030	8.15	0.016	Yes
Ouzel	33057	12.93	0.025	Yes
Bedford Ouse	33005	23.35	0.014	Yes
Tove	33018	30.91	0.016	Yes
Kym	330125	35.69	0.007	Yes
Flore	32029	37.55	0.002	Yes

4.39 As with the Brickhill Brook, Station 49005 (Bollingey Stream at Bollingey Cocks Bridge) was removed due to its record length falling below the accepted minimum of 8 years.

4.40 The permeable catchments (Brompton Beck (27073) and Gypsey Race (26802) appeared in the pooling group again, but these were retained to continue with the conservative approach.

4.41 All other stations in the pooling group were considered to be acceptable: they were all identified as having sufficient record length, and to be of sufficient hydrological similarity for the purpose of this study (i.e.: no other sites within the Hi-Flows dataset are believed to be more representative). The final pooling group is detailed within **Table 4.7.**

4.42 The final pooling group was identified as 'possibly heterogeneous', and the resultant record length for the pooling group totalled 535 years. which meets the recommended guidelines on required record length.

4.43 In line with the generally accepted approach, the 'generalised logistic' distribution (regarded as the best fit for most UK catchments) was selected to derive a growth curve from the pooling group.

4.44 The $QMED_{URBAN}$ was applied to the adjusted growth curve to derive a flood frequency curve. The peak flood flow estimates are detailed in **Table 4.8**.

Table 4.7: Railway Brook Pooling Group

Station	Years of Data	Area	SAAR	FPEXT	FARL	$URBEXT_{2000}$
76011 (Coal Burn @ Coalburn)	39	1.630	1096	0.074	1.000	0.000
45816 (Haddeo @ Upton)	23	6.810	1210	0.011	1.000	0.005
27051 (Crimple @ Burn Bridge)	44	8.170	855	0.013	1.000	0.006
28033 (Dove @ Hollinsclough)	37	7.920	1346	0.007	1.000	0.000
27073 (Brompton Beck @ Snainton Ings)	35	8.060	721	0.237	1.000	0.008
91802 (Allt Leachdach @ Intake)	34	6.540	2554	0.003	0.992	0.000
71003 (Croasdale Beck @ Croasdale Flume)	37	10.710	1882	0.016	1.000	0.000
49006 (Camel @ Camelford)	10	12.520	1418	0.013	1.000	0.003
54022 (Severn @ Plynlimon Flume)	38	8.750	2481	0.010	1.000	0.000
25019 (Leven @ Easby)	38	15.090	830	0.019	1.000	0.004
25003 (Trout Beck @ Moor House)	43	11.400	1905	0.041	1.000	0.000
25011 (Langdon Beck @ Langdon)	28	12.790	1463	0.012	1.000	0.001
26802 (Gypsey Race @ Kirby Grindalythe)	17	15.850	757	0.030	1.000	0.000
47022 (Tory Brook @ Newnham Park)	23	13.430	1403	0.023	0.942	0.014
206006 (Annalong @ Recorder)	48	14.440	1704	0.023	0.981	0.000
27010 (Hodge Beck @ Bransdale Weir)	41	18.820	987	0.009	1.000	0.001

Revitalised Flood Hydrograph Analysis

4.45 ReFH version 2.2 was utilised to undertake an estimation of the peak flows from the two catchments.

4.46 A critical duration of 5.5hrs was identified for the Brickhill Brook while a shorter duration of 2.15hrs was identified for the smaller Railway Brook. Analysis showed that adopting the 5.5hrs duration on the Railway Brook generated slightly higher flow than its critical duration, therefore this storm duration was adopted on both catchments.

4.47 Due to the rural nature of the catchments a winter storm profile was adopted; all other parameters were left as default.

4.48 The resultant peak flood flow estimates are detailed in **Table 4.8**, and the hydrographs are illustrated within **Figure 4.3**.

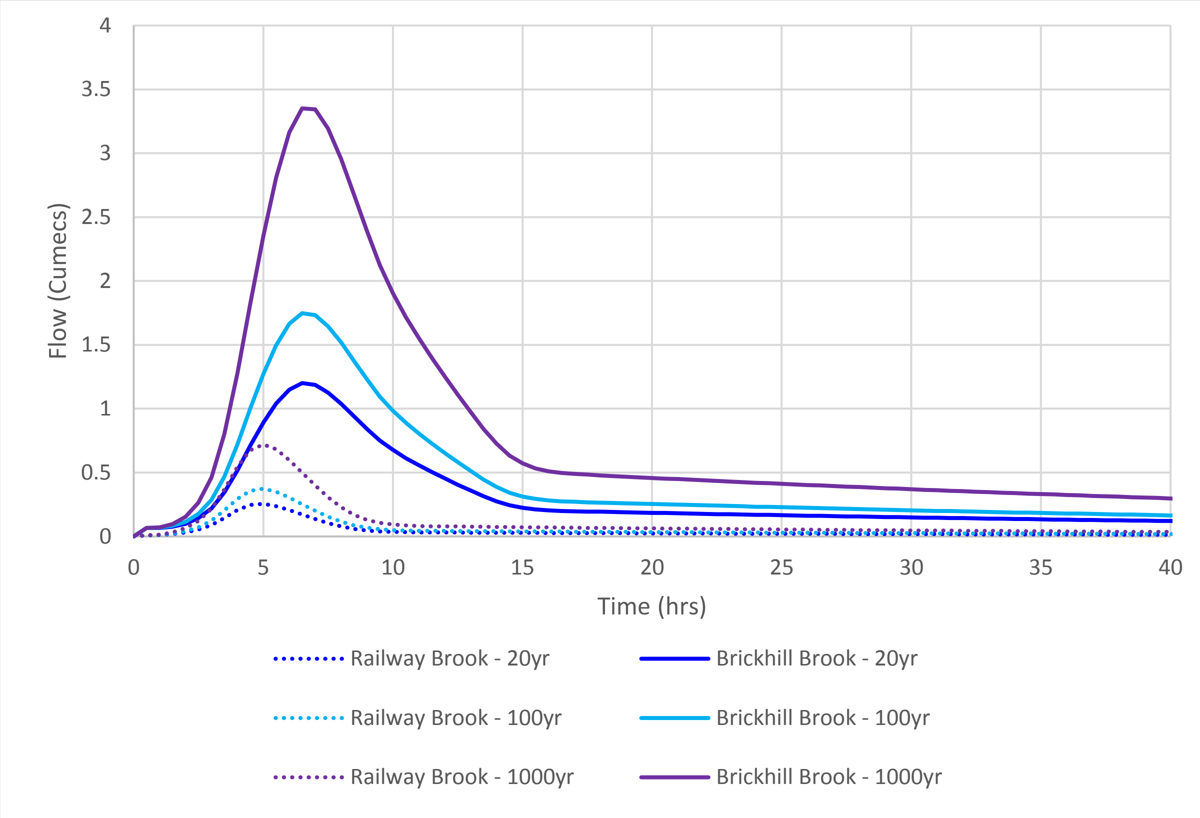


Figure 4.3: ReFH2 Flood Hydrographs

Discussion

4.49 The peak flows from both catchments and methods are summarised in **Table 4.8.** This shows that the ReFH2 approach generates the more conservative flow estimates for both catchments.

Table 4.8: Flow Estimate Comparisons

Return Period	Annual Probability	Brickhill Brook Peak Flow Estimates (m^3/s)		Railway Brook Peak Flow Estimates (m^3/s)	
		FEH-Stat	ReFH2	FEH-Stat	ReFH2
2	50.0%	0.452	0.63	0.084	0.13
10	10.0%	0.757	1.03	0.134	0.22
20	5.0%	0.904	1.20	0.158	0.26
50	2.0%	1.132	1.47	0.195	0.31
75	1.3%	1.249	1.62	0.215	0.35
100	1.0%	1.338	1.75	0.230	0.37
200	0.5%	1.581	2.13	0.270	0.46
1000	0.1%	2.327	3.35	0.396	0.72

4.50 As the ReFH produces the worst case flows, these were adopted with the hydraulic model.

Climate Change

4.51 The two catchments fall within the Anglian river basin district. **Table 4.9** identifies the relevant peak river flow allowances. When determining the appropriate allowance, the Flood Zone classification, the flood risk vulnerability, and the anticipated lifespan of the development should be considered. **Table 4.10** provides a matrix summarising the Environment Agency's guidance on determining the appropriate allowances.

Table 4.9 - Peak River Flow Allowance for the Anglian River Basin District

Allowance Category	Total potential change anticipated for '2020s' (2015 to 39)	Total potential change anticipated for '2050s' (2040 to 69)	Total potential change anticipated for '2080s' (2070 to 2115)
Upper End	25%	35%	65%
Higher Central	15%	20%	35%
Central	10%	15%	25%

Table 4.10 – Environment Agency Guidance on the Application of Climate Change Allowance

<table>
<tr><th>Flood Zone</th><th>Essential Infrastructure</th><th>Highly Vulnerable</th><th>More Vulnerable</th><th>Less Vulnerable</th><th>Water Compatible</th></tr>
<tr><td>1</td><td colspan="4">Use the central allowance</td><td>Use none of the allowances</td></tr>
<tr><td>2</td><td>Use the higher central and upper end to assess a range of allowances</td><td>Use the higher central and upper end to assess a range of allowances</td><td>Use the central and higher central to assess a range of allowances</td><td>Use the central allowance</td><td>Use none of the allowances</td></tr>
<tr><td>3a</td><td>Use the upper end allowance</td><td>Development should not be permitted</td><td>Use the higher central and upper end to assess a range of allowances</td><td>Use the central and higher central to assess a range of allowances</td><td>Use the central allowance</td></tr>
<tr><td>3b</td><td>Use the upper end allowance</td><td>Development should not be permitted</td><td>Development should not be permitted</td><td>Development should not be permitted</td><td>Use the central allowance</td></tr>
<tr><td colspan="6">*If development is considered appropriate when not in accordance with Flood Zone vulnerability categories, then it would be appropriate to use the upper end allowance.</td></tr>
</table>

4.52 The proposed development is for commercial/distribution use (less vulnerable) with an anticipated lifespan of over 60 years, therefore the total potential change for the '2080s' will be adopted. Technically the site is located entirely within Flood Zone 1. However, given the proximity of the watercourses to the development, and the uncertainties associated with estimating flows on ungauged catchments, it is considered prudent to follow a precautionary approach. Therefore, for the purposes of this hydraulic modelling exercise it is proposed to assess the higher central and upper allowances.

The Design Flood

4.53 New developments should be designed to provide adequate flood risk management, mitigation, and resilience against the 'design flood' for their lifetime. The design event for fluvial flooding is generally taken as the 1 in 100-year event (1% AEP)[3].

4.54 To allow the developments flood risk management strategy to be adequately designed for its lifetime the climate change the allowances discussed previously will be applied to the baseline (present day) 1 in 100-year hydrograph.

Flow Distribution

4.55 A watershed analysis of the LiDAR has been undertaken to identify likely sub-catchments for each watercourse, this is illustrated within **Figure 4.4**. The estimated flood flows will be prorated and applied to the hydraulic model based upon these sub-catchments, as detailed within **Table 4.11**. The specific location of the inflows to the hydraulic model are illustrated within **Figure 5.1**.

Table 4.11: Sub-Catchment Flow Distribution

Sub-Catchment	Area (km^2)	Proportion of Flow
Railway Brook		
Railway U/S	0.215	46%
Railway D/S	0.255	54%
Brickhill Brook		
Brickhill U/S 1	1.884	52%
Brickhill U/S 2	0.332	9%
Brickhill U/S 3	0.673	18%
Brickhill U/S 4	0.036	2%
Brickhill A5	0.345	9%
Brickhill D/S (split between 5 channels on the site)	0.370	10%

[3] Planning Practice Guidance. http://planningguidance.planningportal.gov.uk/. Paragraph: 054 & 055

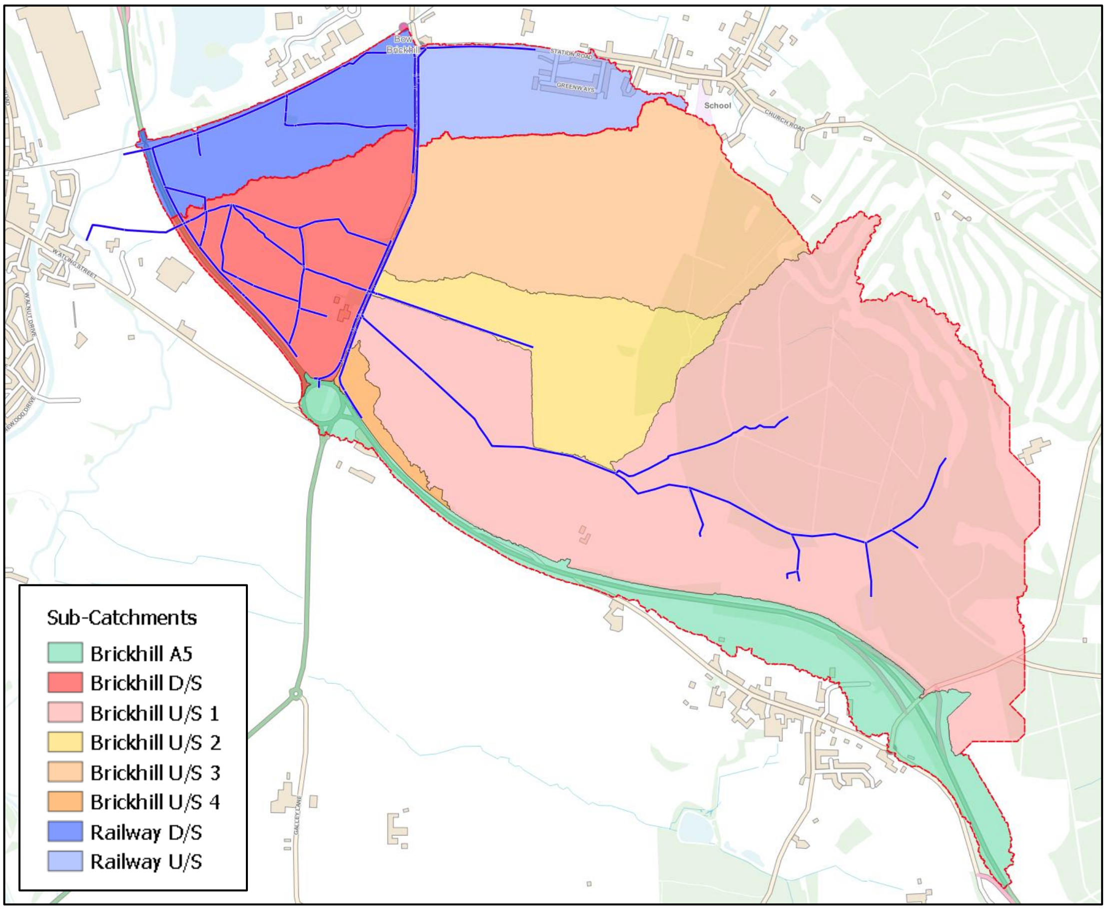


Figure 4.4: Sub-Catchments

5. THE SITE-SPECIFIC HYDRAULIC MODEL

5.1 The EA River Ouse model makes use of a dynamically linked 1D-2D modelling approach: the in-channel conditions and hydraulic structures were modelled within a one-dimensional (1D) ESTRY domain; and the out of bank flow routing and floodplain are modelled within a two-dimensional (2D) TUFLOW domain.

5.2 Both ESTRY and TUFLOW are standard hydraulic modelling packages widely used in the UK and have been benchmarked by the EA.

5.3 This site-specific model retains this approach and software.

5.4 In a similar manner to the hydrological assessment, a conservative approach to the modelling was adopted.

Truncating the River Ouzel

5.5 The EA River Ouse (Upper, Lower) domain extends in region of 17km downstream of the site and 21km upstream and includes significant reaches which have little influence on the study site. To facilitate the development of more detailed site-specific model, the EA model was truncated to remove the superfluous reaches.

5.6 The model was truncated at Watling Street, approximately 400m upstream of the site. The original EA model shows that all flood flows pass beneath the Watling Street Bridge, this allowed a flow-time (QT) boundary based upon data extracted from the EA model to be used as an upstream boundary on the Ouzel.

5.7 The downstream Ouzel was truncated at Simpson Road. This is located over 1,700m downstream of the site, and it is also located downstream of Caldecotte lake. Therefore, the backwater influence from the Caldecotte Lake floodplain storage was retained within the model. A stage-flow (HQ) relationship at Simpson Road bridge was extracted from the original EA model results to be used as a downstream boundary for the truncated 1D domain.

5.8 An automated HQ boundary was applied to the Simpson Road carriageway in the 2D domain to allow flood water to flow over the road and exit the model, as existing.

5.9 All of the original EA model layers within the truncated model domain were retained. The expectation to this was the initial water level that was applied to Caldecotte lake, upon review it was found that the LiDAR ground levels were already largely at this level, so it was considered unnecessary.

Addition of the Study Site

<u>The 2D TUFLOW Domain</u>

5.10 The 2D model domain was extended to encompass the site and the upstream hillside.

5.11 The 2D cell size was reduced from 10-20m, to a fixed grid size of 3m. This smaller grid size allows for overland flow routes through the site to be more accurately represented.

5.12 The ground levels of the new 2D domain were set using a detailed topographical survey, supplemented with 1m resolution LiDAR DTM outside of the survey coverage.

5.13 The LiDAR has undergone a filtering process to remove the presence of buildings and trees to create a bare-earth representation.

5.14 While topographical survey of the watercourses and channels within the site was available, access could not be gained to the Railway Brook to the north of the site, nor to the Railway Brook and Brickhill Brook downstream of the A5. Therefore, these watercourses were modelled within the 2D domain using the topographical data within the LiDAR DTM. The channel bed levels were reinforced within the grid using ‘gully’ lines.

5.15 The original EA model contained material layers which covered the new domain, therefore these were adopted in the site-specific model.

The 1D ESTRY Domain

5.16 The key hydraulic structures on the Brickhill Brook were added as discreate 1D elements using data captured from the topographical survey of the site. This included the A5 culvert, the dimension of which were provided by Highways England from their asset database.

5.17 It was not possible to survey the Railway Brook culvert beneath Brickhill Street, or any of the culverts on this watercourse outside of the site ownership. Therefore, these are omitted from the model. While this represents a limitation on the model accuracy, it is believed that it creates a worst-case depiction of flood risk at the site, as the channel capacity of the Railway Brook is omitted, and all the flood flows pass through the site as overland flows.

5.18 It was possible to measure the culvert dimensions beneath the A5 on the Railway Brook, therefore this culvert was included within the model, thus ensuring that the potential hydraulic interactions between the site and River Ouzel are represented.

5.19 A schematic of the hydraulic model within the site is presented within **Figure 5.1**.

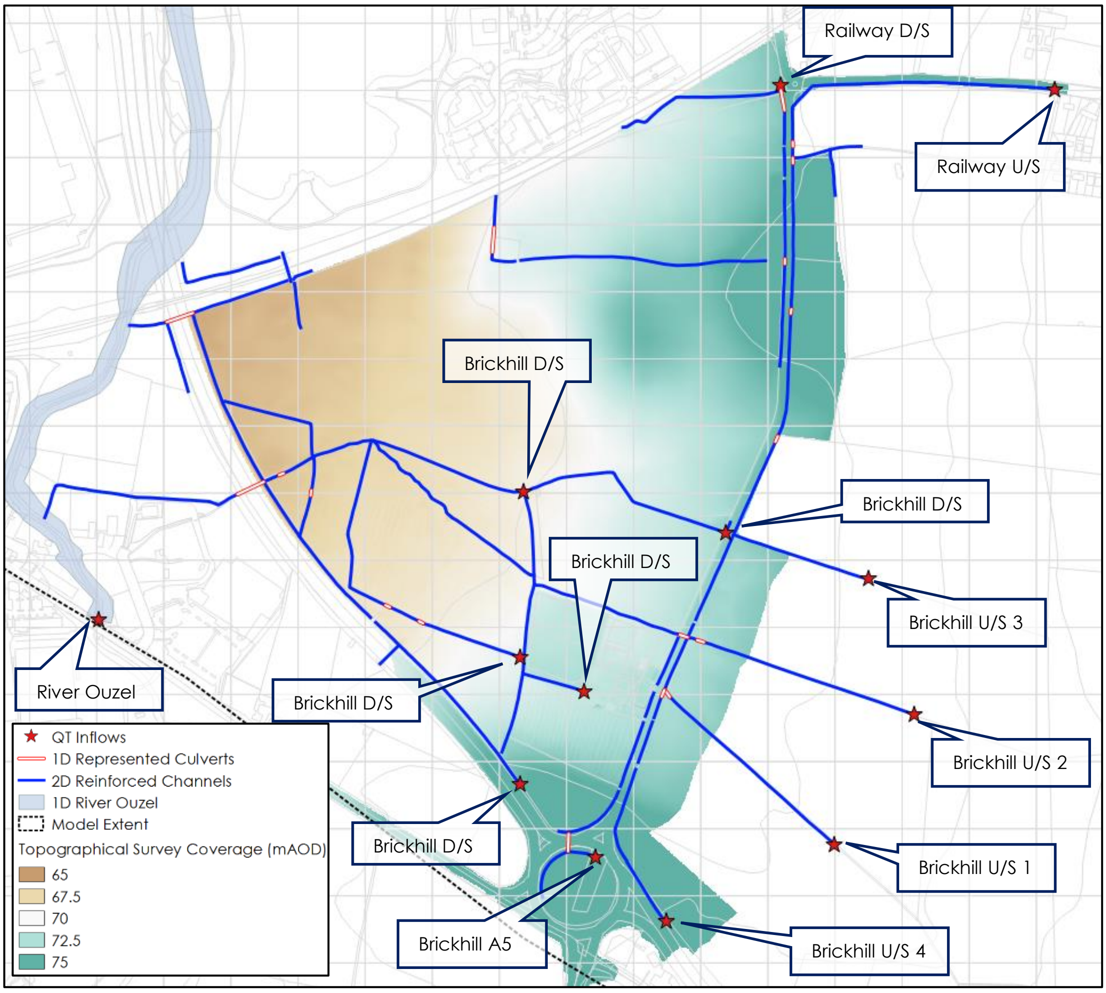


Figure 5.1: Hydraulic Model Schematic within Study Site

Boundary Conditions

5.20 In addition to the aforementioned boundaries on the truncated River Ouzel, the distributed inflows of the Railway Brook and Brickhill Brook were applied to the 2D domain as described within **Section 4.0**.

5.21 Inflows on the ordinary watercourse were delayed by 40hrs to force the flood events on the ordinary watercourses to coincide with the flood peak on the River Ouzel. This promotes a conservative assessment.

Model Calibration & Verification

5.22 As there was no hydrometric data, historic flood mapping, or representative strategic flood maps available, the model could not be directly calibrated against existing data.

5.23 However, it is believed that the conservative approach to the model build should offer a sufficiently robust model for the purposes of assessing flood risk at the site.

Simulation Parameters

5.24 TUFLOW HPC version 2018-AB-iSP-w64 was used in all the simulations. All parameters were retained as default.

5.25 A target time step of 1.0 second was adopted for the ESTRY domain and 1.0 second TUFLOW domain.

Model Stability

5.26 No negative depths were reported, and the model flux (flow in and out) did not show any significant evidence of an unstable/fluctuating ESTRY-TUFLOW interface.

5.27 The ESTRY-TUFLOW mass error remained below 1% for all the simulations.

6. LIMITATIONS

6.1 The model contains no detailed representation of any highway drainage or public sewer inflow. However, it is believed that any contributing flows would have been captured within the wider catchment hydrology. There are not believed to be any instances of cross-catchment transfers that need to be considered.

6.2 The hydrological flood flow estimates made use of the latest available data at the time of assessment. No hydrometric was available to verify or calibrated flow, but a conservative approach to the deriving the flow estimates has been adopted.

6.3 The modelling exercise has made use of the available data at the time of construction and simulation.

6.4 The model uses a detailed DTM within the study site, and a 1m LiDAR DTM with the wider floodplain. The LiDAR has a reported accuracy of +/-0.15m, but this is considered sufficiently accurate for the purpose of this assessment.

6.5 Buildings within the wider floodplain are modelled at ground level with an elevated roughness layer, in line with best practise.

6.6 The model contains no formal representation of the conveyance within the Railway Brook culvert upstream of the site, nor of its channel capacity as in flows along the northern boundary of the site. Consequently, all flood flows from this source flow over land through the site.

6.7 The 3.0m resolution of the model may negate any small-scale topographic features, although all the significant features are believed to have been captured or have been reinforced.

6.8 The exercise has taken a worst-case approach when modelling flood events by forcing the flood hydrograph on the ordinary watercourses to coincide with peak flood levels on the River Wye.

6.9 A conservative approach has also been adopted when determining the joint probability of events, by applying the same return period event to all watercourses.

6.10 This modelling exercise has been undertaken to produce a good representation of flood risk mechanisms in and around the study site. It has not been designed to accurately map flooding in the wider catchment.

7. BASELINE CONDITIONS

7.1 The baseline floodplain extents are mapped within Appendix 1 and summarised within **Figure 7.1**. Peak flood levels through the site are detailed within **Table 7.1**, and the flood mechanisms are described with the forthcoming section.

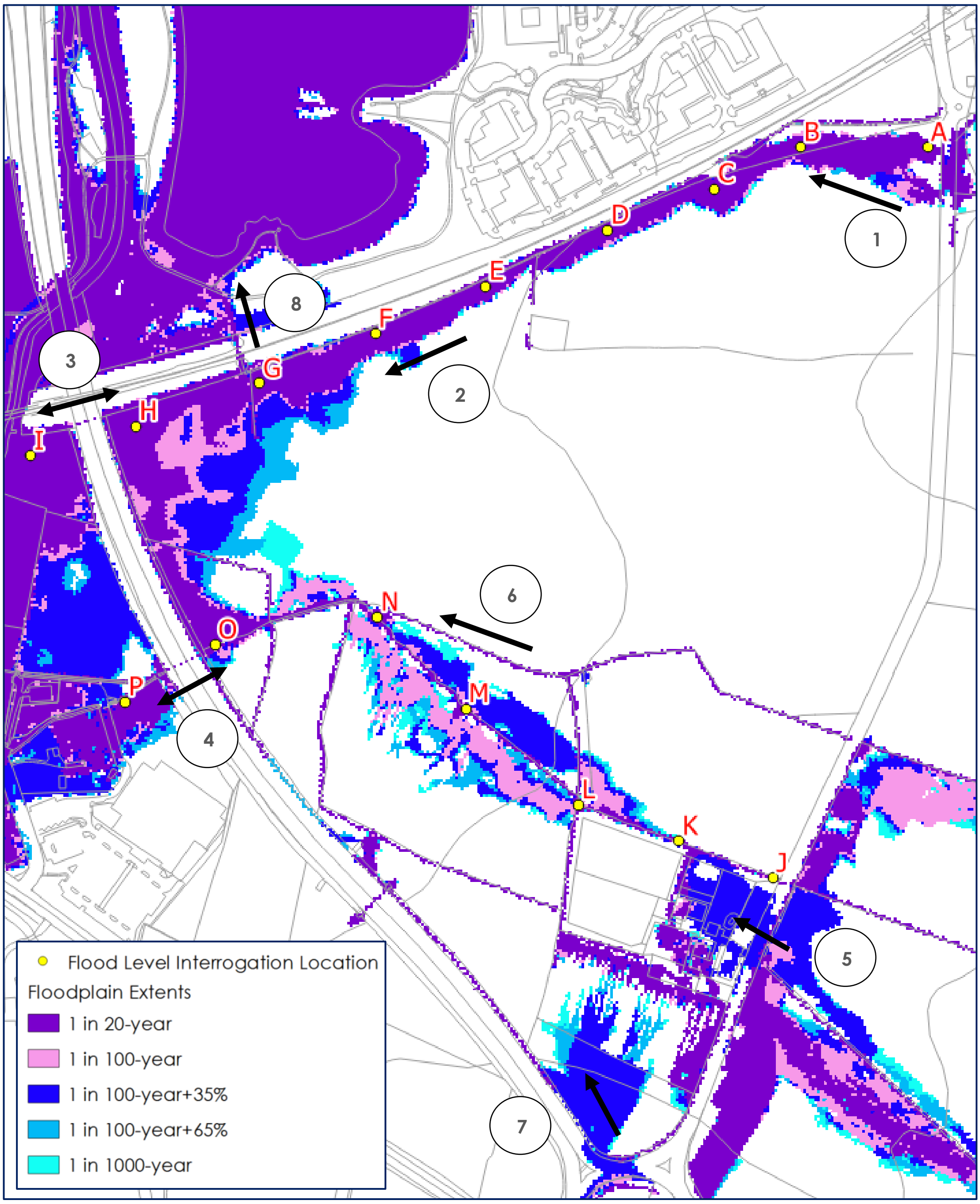


Figure 7.1: Baseline Floodplain Extents

7.2 The flood mechanisms impacting the site are as follows:

1. Flood water from the Railway Brook enters the site via an overland flow route, this is due to the omission of the culvert beneath Brickhill Street. In reality, the magnitude of overland flows would be less extensive. Despite this, the peak flood depths of this flow route are very shallow, peaking in the region of 25mm to 50mm at the 1 in 100-year+35% event.

2. Flood flows from the Railway Brook are shown to flow alongside the railway embankment towards the north-west corner of the site. The open channel on this reach is omitted from the model, so in reality it is expected that the floodplain would be less extensive. The flood route here is also shown to be relatively shallow, 1 in 100-year+35% flood depths remain below 300mm.

3. The River Ouzel is shown to surcharge through the Railway Brook A5 culvert. The River Ouzel is shown to be the predominate control on peak flood level within this corner of the site, driving flood depths up to 950mm in the 1 in 100-year+35% event.

4. The River Ouzel also enters the site via the Brickfield Brook culvert under the A5. Flood depths in the site here peak at 350mm in the 1 in 100-year+35% event. The depths are predominately controlled by the River Ouzel flood levels.

5. The Brickhill Brook is shown to over top Brickhill Street and enter the site in events above the 1 in 100-year flood. This leads to shallow flooding of the fields and yard around the existing farm. Flood depths here are generally below 100mm in the 1 in 100-year+35% event.

6. The Brickhill Brook channel capacity is predicted to be exceeded in events above the 1 in 20-year flood. This leads to shallow out of bank flooding next to the channel. Flood depths are generally below 50mm in the 1 in 100-year+35% event.

7. An inflow from the southern corner is shown to exceed the capacity of the local drainage ditches resulting in shallow flooding of the adjacent fields. Flood depths are generally below 50mm in the 1 in 100-year+35% event.

8. Flood water leaves the site via the A5 culverts as the Ouzel flood waters recede. Additionally, a minor flow route through a railway underpass and into the downstream Ouzel floodplain is predicted.

7.3 The modelling has shown that in the east of the site the existing channels are generally undersized, which leads to shallow overland flows, whereas in the west of the site flood levels are predominately controlled by the River Ouzel.

Table 7.1: Peak Baseline Flood Levels (mAOD)

ID	20yr	100yr	100yr+35	100yr+65	1000yr
A	73.43	73.44	73.44	73.45	73.45
B	71.20	71.21	71.21	71.21	71.22
C	70.50	70.51	70.52	70.53	70.54
D	70.11	70.14	70.16	70.18	70.19
E	68.49	68.49	68.49	68.49	68.49
F	66.75	66.77	66.78	66.79	66.79
G	66.32	66.35	66.57	66.69	66.68
H	66.21	66.34	66.57	66.69	66.68
I	66.17	66.25	66.43	66.52	66.40
J	71.21	71.37	71.48	71.56	71.59
K	70.41	70.53	70.63	70.64	70.67
L	69.50	69.61	69.64	69.68	69.69
M	68.28	68.39	68.41	68.42	68.46
N	67.43	67.48	67.54	67.58	67.62
O	66.64	66.66	66.70	66.74	66.75
P	66.42	66.43	66.51	66.60	66.48

8. ILLUSTRATIVE PROPOSED FLOOD MANAGEMENT STRATEGY

8.1 To facilitate a development of the site it is proposed to intercept and divert the Brickhill Brook around the proposed development area.

8.2 It is proposed to reprofile the site to raise it above the River Ouzel flood levels and compensate for the loss in floodplain on the site within a level-for-level manner. A plan outlining the illustrative flood management strategy is included as **Appendix 2**.

8.3 The hydraulic model geometry was updated with the proposed flood management strategy by inserting a 3D ground model of the proposals and removing the channel network which is to be lost to the development.

8.4 As with the baseline model, the diverted channels were modelled within the 2D domain, and were reinforced using 'gully' lines. As the development and flood management proposals are currently at the planning stage, this is considered to be a sufficient level of detail.

8.5 It is proposed to relocate the Brickfield Brook culvert crossing of Brickhill Street approximately 80m further south to facilitate the formation of a new roundabout. This has been represented within the hydraulic model.

8.6 It is proposed to restrict runoff from the development to 2.0l/s/ha at the request of the Internal Drainage Board. Based upon a development area of 43.54ha this would equate to a fixed rate of 87.1l/s. To represent this within the model, the Brickhill Brook downstream sub-catchment (those within the site) were replaced by a single 87.1l/s inflow.

8.7 Approximately 18.5ha of development area also falls within the downstream Railway Brook sub-catchment, which would now be directed to the Brickhill Brook. Therefore, the prorated flows on this sub-catchment were adjusted to reflect the developments attenuation of surface water runoff. This is described further within **Table 8.1**.

Table 8.1: Post-Development Flow Distribution

Sub-Catchment	Area (km^2)	Proportion of Flow
Railway Brook		
Railway U/S	0.215	46%
Railway D/S – outside of the development	0.071	15%
Railway D/S– within of the development	0.184	No contributing flow (to outfall to the Brickhill Brook)
Brickhill Brook		
Brickhill U/S 1	1.884	52%
Brickhill U/S 2	0.332	9%
Brickhill U/S 3	0.673	18%
Brickhill U/S 4	0.036	2%
Brickhill A5	0.345	9%
Brickhill D/S	0.370	Fixed outflow of 87.2l/s

Post-Development Results

8.8 The illustrative flood management strategy was simulated against the 20-year, 100-year, 100-year+35%, and the 1 in 100-year+65% events. The results are mapped within **Appendix 3** and are summarised within **Figure 8.1**, with peak flood levels provided within **Table 8.2.**

8.9 The results show that the strategy successfully elevates the development out of the River Ouzel floodplain, and also diverts the flood flows from the ordinary watercourse around the development.

8.10 The post-development results are compared to the baseline within **Appendix 4**. This shows that the flood management strategy has no significant impact on flood risk within the wider catchment.

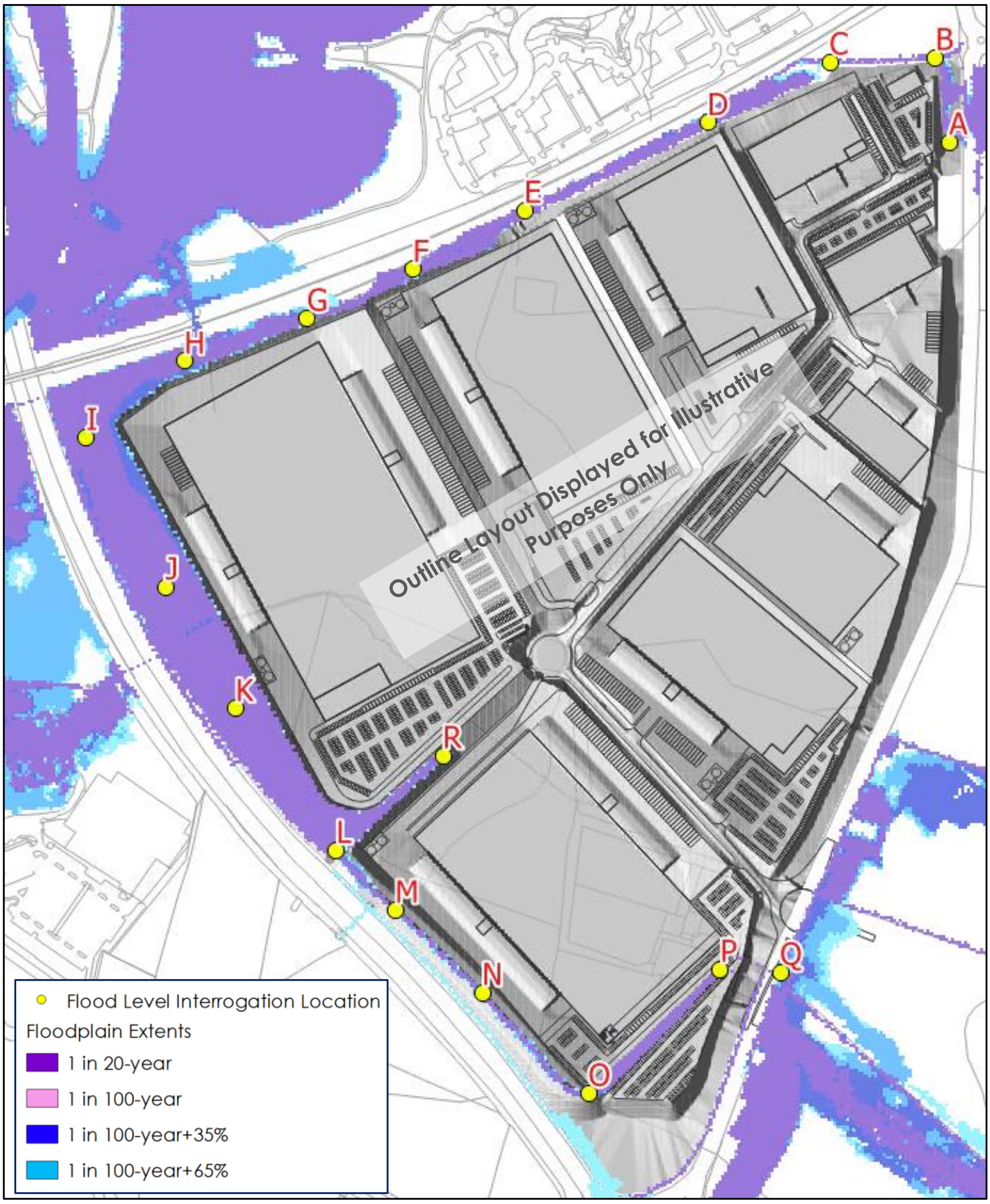


Figure 8.1: Illustrative Post-Development Floodplain Extents

Table 8.2: Post-Development Peak Flood Levels (mAOD)

ID	Design Flood Events					1 in 100-year Sensitivity Tests				
	20yr	100yr	100yr+35	100yr+65	1000yr	Roughness +20%	Roughness - 20%	Blockage 1	Blockage 2	Blockage 3
A	73.98	73.98	73.98	73.98	73.98	73.98	73.98	73.98	73.98	73.98
B	72.97	73.05	73.09	73.13	73.16	73.05	73.04	73.05	73.05	73.05
C	71.61	71.65	71.70	71.73	71.76	71.66	71.65	71.65	71.65	71.65
D	70.51	70.52	70.54	70.54	70.55	70.53	70.52	70.52	70.52	70.52
E	69.92	69.93	69.93	69.94	69.94	69.93	69.93	69.93	69.93	69.93
F	67.21	67.21	67.22	67.22	67.22	67.21	67.21	67.21	67.21	67.21
G	66.45	66.48	66.57	66.70	66.67	66.49	66.47	66.53	66.48	66.48
H	66.20	66.32	66.56	66.69	66.67	66.34	66.30	66.53	66.40	66.27
I	66.19	66.32	66.56	66.69	66.67	66.34	66.30	66.53	66.40	66.27
J	66.30	66.36	66.56	66.70	66.67	66.37	66.34	66.53	66.42	66.32
K	66.63	66.68	66.70	66.73	66.73	66.68	66.67	66.68	66.69	66.65
L	67.04	67.08	67.08	67.09	67.10	67.08	67.07	67.08	67.08	67.02
M	67.89	67.94	68.03	68.07	68.08	67.97	67.95	67.94	67.94	67.80
N	68.46	68.54	68.58	68.59	68.62	68.54	68.54	68.54	68.54	68.40
O	68.96	69.06	69.12	69.15	69.18	69.07	69.05	69.06	69.06	68.93
P	69.22	69.34	69.42	69.49	69.54	69.38	69.28	69.34	69.34	69.17
Q	72.00	72.23	72.45	72.62	72.75	72.24	72.23	72.23	72.23	72.88
R	66.61	66.69	66.75	66.80	66.83	66.72	66.66	66.69	66.70	66.75

Sensitivity Tests

8.11 To account for the seasonal variations in vegetation, and the residual risk of blockages at hydraulic structures, a series of sensitivity tests were conducted using the 1 in 100-year flows.

8.12 As the River Ouzel forms the downstream boundary of the study site, and flood events on the ordinary watercourses have been delayed to coincide with the Ouzel, it was not considered necessary to undertake a sensitivity test on the downstream boundary conditions.

8.13 The sensitivity tests were undertaken against the post-development geometry, to test the robustness of the flood management strategy.

8.14 The difference in peak waters between the tests and the design 1 in 100-year event are mapped within **Appendix 5**. Peak flood levels from the tests are also included within **Table 8.2**.

Roughness

8.15 The modelling has shown that a 20% reduction in channel and floodplain roughness (representative of winter seasonal conditions or following maintenance) results in a general decrease of flood levels, of between 10 to 85mm within the site. This is shown to have no significant impact on flood risk within the development.

8.16 Similarly, an 20% increase in Manning's 'n' (representative of summer seasonal conditions, and a period without maintenance) is shown to result in a general increase of flood levels of between 10 to 60mm. This is shown to have no significant impact on flood risk within the development.

Blockage Scenarios

8.17 As the Railway Brook culvert beneath Brickhill Street is already omitted from the model, there are considered to be three main culverts which could influence flood levels within the site:

- **BL1** - the Railway Brook culvert beneath the A5.
- **BL2** - the Brickhill Brook culvert beneath the A5.
- **BL3** - the Brickhill Brook beneath Brickhill Street.

8.18 A 75% blockage of the Railway Brook culvert beneath the A5 was shown to increase flood levels within the site by 229mm. This is shown to have no significant impact on floodplain extents within the site.

8.19 A 75% blockage of the Brickhill Brook culvert beneath the A5 resulted in an increase of up to 77mm within the site. This is shown to have no significant impact on floodplain extents within the site.

8.20 A 75% blockage of the Brickhill Brook culvert beneath Brickhill Street, was shown to trigger an overflow into the development area leading to flooding. While a blockage of this magnitude is unlikely, this residual risk should be considered in the maintenance strategy for the watercourse to ensure that the culvert is kept free flowing.

9. SUMMARY & RECOMMENDATIONS

9.1 The primary aim of this exercise was to establish a good hydrological and hydraulic representation of the fluvial flood risk within the study site. To achieve the model has included elements of the River Ouzel and two ordinary watercourse which flow through the site.

9.2 The model has used the best available data at the time of construction.

9.3 Due to access restrictions it was not possible to survey and include all of the channels reaches and hydraulic structures within the model. However, it is considered that this has resulted in a conservative assessment of the potential flood risk within the study site.

9.4 The modelling has shown that in the east of the site the existing channels are generally undersized, which leads to shallow overland flows. Whereas, in the west of the site in the River Ouzel floodplain, flood levels are predominately control by the River Ouzel.

9.5 To facilitate development within the site, it is proposed to intercept and divert the ordinary watercourses around development area. This will allow the site to be re-profiled into a series of plateaus suitable for development.

9.6 The developments attenuated surface water storage has also been accounted for within the model by reducing peak runoff from the site to the equivalent greenfield QBAR rate.

9.7 It is proposed to reprofile the site to raise it above the River Ouzel flood levels, and compensate for the loss in floodplain on the site within a level-for-level manner. The hydraulic modelling has shown that the proposed flood management strategy does not affect flood risk outside of the site ownership.

9.8 At this planning stage a simple channel arrangement was assessed to show that the diversion will work hydraulically.

9.9 The modelling has shown that the proposed flood management strategy will remove the development from the 1 in 100-year+65% floodplain.

9.10 Sensitivity testing has shown that the proposed flood management strategy is resilient to changes in floodplain and channel roughness, and blockages of the downstream A5 culverts up.

9.11 A blockage of the Brickhill Brook culvert beneath Brickhill Street, was shown to trigger an overflow into the development area leading to flooding of external areas. While a blockage of this magnitude is unlikely, this residual risk should be considered in the maintenance strategy for the watercourse to ensure that the culvert is kept free flowing.

APPENDICES

APPENDIX 1: Baseline Floodplain Maps