Appendices to Chapter L
Water Environment and Drainage

Contents:

Appendix L1
Flood Risk Assessment

St James Group Limited

MILTON KEYNES EAST

Flood Risk Assessment

FRA-RV1
MARCH 2021

PUBLIC

St James Group Limited

MILTON KEYNES EAST

Flood Risk Assessment

REPORT (RV1) PUBLIC

PROJECT NO. 70057521

OUR REF. NO. FRA-RV1

DATE: MARCH 2021

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EXECUTIVE SUMMARY

This Flood Risk Assessment has been undertaken to accompany the outline planning application for the proposed strategic development of Milton Keynes East, in accordance with the guidelines set out in the National Planning Policy Framework (NPPF) published in February 2019 along with other relevant local and national guidance.

The Environment Agency have confirmed their support for the Scheme stating that they have no in principle objections to the scheme.

Item	Overview
Site Location	The site is located between the M1 which largely forms the southern boundary of the site and the A422 which forms the northern boundary. The grid reference for the site is 488630, 241770, with a nearest postcode of MK15 9LZ. The site is allocated for strategic development under the local plan.
Development Proposals	The masterplan for the development is appended to Chapter C of the ES at Appendix C2, this is for A large-scale mixed-use urban extension (creating a new community) including: ▪ Approximately 4,000 up to a maximum of 4,600 new homes; ▪ Up to 403,650 sq.m of employment floorspace; ▪ A community hub containing a range of commercial and community uses; ▪ Associated services, amenities and open space; and ▪ New road and redway extensions, including a new bridge over the M1 motorway and works to the Tongwell Street corridor. The development will also include the creation of a linear park along the floodplain of the River Ouzel, along with a new highway link across the floodplain with a 30m bridge opening centred on the River Ouzel.
Environment Agency Flood Zone(s)	The majority of the site is located in Flood Zone 1 based on the Environment Agency's Flood Map for Planning. Within the west of the site the land adjacent to the River Ouzel is located in Flood Zone 3. There is also a small area in the south of the site within Flood Zone 3, located next to Broughton Brook.
Vulnerability Classification(s)	Essential Infrastructure for the proposed Highway Link over the River Ouzel. More Vulnerable for the proposed residential dwellings, educational establishments and healthcare facilities. Less Vulnerable for the Employment land. Water-compatible for the proposed play area and the linear park along the River Ouzel.

Fluvial Flood Risk	The majority of the site is located in Flood Zone 1 based on the Environment Agency's Flood Map for Planning. Within the west of the site the land adjacent to the River Ouzel is located in Flood Zone 3. There is also a small area in the south of the site within Flood Zone 3, located next to Broughton Brook. Hydraulic modelling of the River Ouzel and the Broughton Brook has been undertaken for present day baseline conditions and for the proposed post-development scenario. Excluding the water compatible parts of the development, such as the proposed linear park along the River Ouzel, all of the proposed development is to be situated above the modelled 1 in 100 year plus 65% climate change flood level. The post-development hydraulic modelling demonstrates that there will be no increase in flood risk downstream of the site (including at Newport Pagnell) as a result of the proposed development. With negligible impacts on land upstream of the scheme. This constrained to land owned by the Milton Keynes Development Partnership (MKDP), who intend to write in support of the proposals and is part of the current floodplain.
Tidal Flood Risk	The site is located inland at elevations of between approximately 55mAOD and 80mAOD and there are no tidally influenced watercourses in the vicinity of the site.
Surface Water Flood Risk	Based on information from the Flood Risk from Surface Water map, the risk of surface water flooding to the majority of the proposed development is assessed to be very low. The post-development surface water drainage strategy will restrict peak flows from the impermeable areas to the equivalent greenfield flow (QBAR) or 4/l/s/impermeable hectare, whichever is less, thereby ensuring the risk of surface water flooding does not increase. The surface water drainage strategy accounts for the impacts of climate change for the lifetime of the Scheme. There are several High Risk surface water flowpaths across the site and these are associated with IDB designated watercourses and drains. As a result of the development the majority of these drains will have their catchments significantly altered with the surface water runoff becoming controlled and managed by the drainage strategy, thus managing the flood risk, with exceedance flow paths incorporated into the layout.
Groundwater Flood Risk	Medium: The western half of the site, associated with the floodplain of River Ouzel is in an area with a high susceptibility to groundwater flooding. There is surface water – groundwater interaction within the superficial aquifers along the River Ouzel and its tributaries. There are however no recorded incidents of groundwater flooding within the site boundary and the majority of the proposed development is to be situated away from the floodplain of the River Ouzel where this surface water – groundwater interaction may occur.
Sewer Flood Risk	Low. There are no recorded incidents of sewer flooding within the vicinity of the site.

Artificial Flood Risk	Low. The site is within the maximum flood extents in the event of a failure of Willen Lake Reservoir, which is heavily managed under UK legislation.
Sequential & Exception Test	The site is allocated for development under the local plan (policy SD12) and therefore it is not necessary to undertake the sequential test. The exception test is only required for the River Ouzel crossing (Highway Link 107) which is categorised as essential infrastructure and is located in flood zones 3a and 3b. Highway Link 107 passes the exception test because it will provide wider sustainability benefits to the community and through hydraulic modelling it has been demonstrated that Highway Link 107 will be safe for the its lifetime and does not increase the risk of flooding outside of the scheme extents.

1. INTRODUCTION

1.1. BACKGROUND

1.1.1. WSP UK Ltd (WSP) has been appointed by St James Group Ltd (St James) to prepare a Flood Risk Assessment (FRA) to support the planning application for a large mixed use development located on land to the east of the M1 Motorway at Milton Keynes, (Approximate Post Code: MK15 9LZ).

1.1.2. The proposed development, referred to as Milton Keynes East (MKE) will consist of up to 4,600 homes, with approximately 80 to 90 hectares of land for a mix of employment uses, along with associated community facilities and infrastructure.

1.1.3. The objective of the study is to demonstrate that the site can be developed safely, without exposing the development to an unacceptable degree of flood risk or increasing the flood risk to third parties. The objectives are to:

- Confirm the sources of flooding which may affect the site;
- Provide an appraisal of the availability and adequacy of existing information; and
- Undertake an appraisal of the flood risk posed to the site and potential impact of the development on flood risk elsewhere.

1.2. LIMITATIONS

1.2.1. WSP has prepared this report in accordance with the instructions of their client, St James, for their sole and specific use relating solely to the above site. Any person who uses any information contained herein does so at their own risk and shall hold WSP harmless in any event.

1.2.2. Whilst this report was prepared using the reasonable skill and care ordinarily exercised by engineers practicing under similar circumstances and reasonable checks have been made on data sources and the accuracy of the data, WSP accepts no liability in relation to the report should any data, information or condition be incorrect or have been concealed, withheld, misrepresented or otherwise not fully disclosed to WSP. In any event, WSP shall not be liable for any loss or damages arising under or in connection to the use of this report

1.3. SCOPE OF ASSESSMENT

1.3.1. The assessment has been undertaken in accordance with the overarching national requirements for Flood Risk Assessments for proposed developments including, but not limited to, the following:

- National Planning Policy Framework (NPPF)
- Flood Risk Assessments: Climate Change Allowances 2019

1.4. CONSULTATION

1.4.1. The Scheme has been developed in line with on-going consultation with the Environment Agency, the key consultations are summarised below.

- Letter of in principle agreement for the Scheme dated February 2019 – The Environment Agency provided the In Principle in Agreement to support the HIF application following the submission of a Hydraulic Modelling Report dated February 2019.
- Meeting on 16 January 2020;

- Meeting on 30 July 2020;
- Meeting on 11 January 2021; and
- Letter of support for the scheme, dated March 2021 – The Environment Agency confirmed their support for the Milton Keynes SUE development, stating that they have no in principle objections to the scheme (Appendix G).

1.4.2. The key agreements are:

- **Baseline Flood Model** - The baseline flood model (as developed from the existing Environment Agency model) was deemed suitable for use in developing the Scheme on 16 January 2020. However, since this agreement, WSP have further refined the model to include the inflows on the Broughton Brook, the Moulsoe Stream and improved channel representation of the watercourses as they flow under and in close proximity to the M1. The Environment Agency have undertaken a review of this iteration of the baseline hydraulic model and confirmed that it is suitable for use (agreed January 2021). The final iteration of the baseline model is documented in a Technical Note dated 11 May 2020;
- **Willen Lake Weirs** – The modelling has been developed based on the Environment Agency assumption that the weirs associated with the overflow lakes are in the lifted flood position (agreed January 2020);
- **Hydrology** - The timing of the River Ouzel and the Broughton Brook over the period February 2019 to February 2020 do not indicate any substantial differences in time to peak, therefore they are modelled with the peaks aligning. The approach to the hydrology is summarised in the baseline flood model submission which the Environment Agency have approved (agreed January 2021);
- **Climate Change** – The 1 in 100 year plus 35% climate change allowance is to be the design scenario with sensitivity undertaken on the 65% climate change allowance (agreed in January 2020). There is no requirement to consider the H++ scenario (agreed in July 2020)..
- **Freeboard** – the Finished Floor Level (FFL) to be 300mm above the 1 in 100 year plus 35% climate change flood level (agreed January 2020);
- **Compensation** – in relation to the highway crossing, flood plain compensation for the embankment is not required in level for level volume for volume terms, this will instead need to be achieved by demonstrating that there is no increase in flows at the peak of the hydrograph at the downstream boundary of the site. The modelling submitted shows there is a small overall reduction in the peak flows that continue downstream to Newport Pagnell.
- In other areas of the development, i.e. excluding the highway crossing, the floodplain compensation will be provided on a level for level, volume for volume basis, but only if the increase in flood risk is not on land under St James' control or on third party land with their agreement (agreed January 2020).
- **Post Development Scenario** – the Environment Agency have agreed (January 2020) the baseline and post development flood modelling along with the flood management strategy for the Scheme detailed in the Approach to Flood Management (dated 14 December 2020), this forms Appendix C).
- **Moulsoe Steam** – the Environment Agency have been consulted on the flood modelling, the model and accompanying report was issued in February 2021.

1.4.3. This report is also based on information from the following:

- Environment Agency online flood mapping

- British Geological Survey online Geology of Britain Viewer
- Milton Keynes Council Level 1 Strategic Flood Risk Assessment (April 2015)
- Plan:MK 2016-2031 (Adopted March 2019)
- Bedford Group of Internal Drainage Boards Upper River Great Ouse Tri Lead Local Flood Authority Preliminary Flood Risk Assessment (PFRA) (June 2011)
- The Indicative Parameter Plans (Appendix E)

2. SITE SETTING

2.1. LOCATION

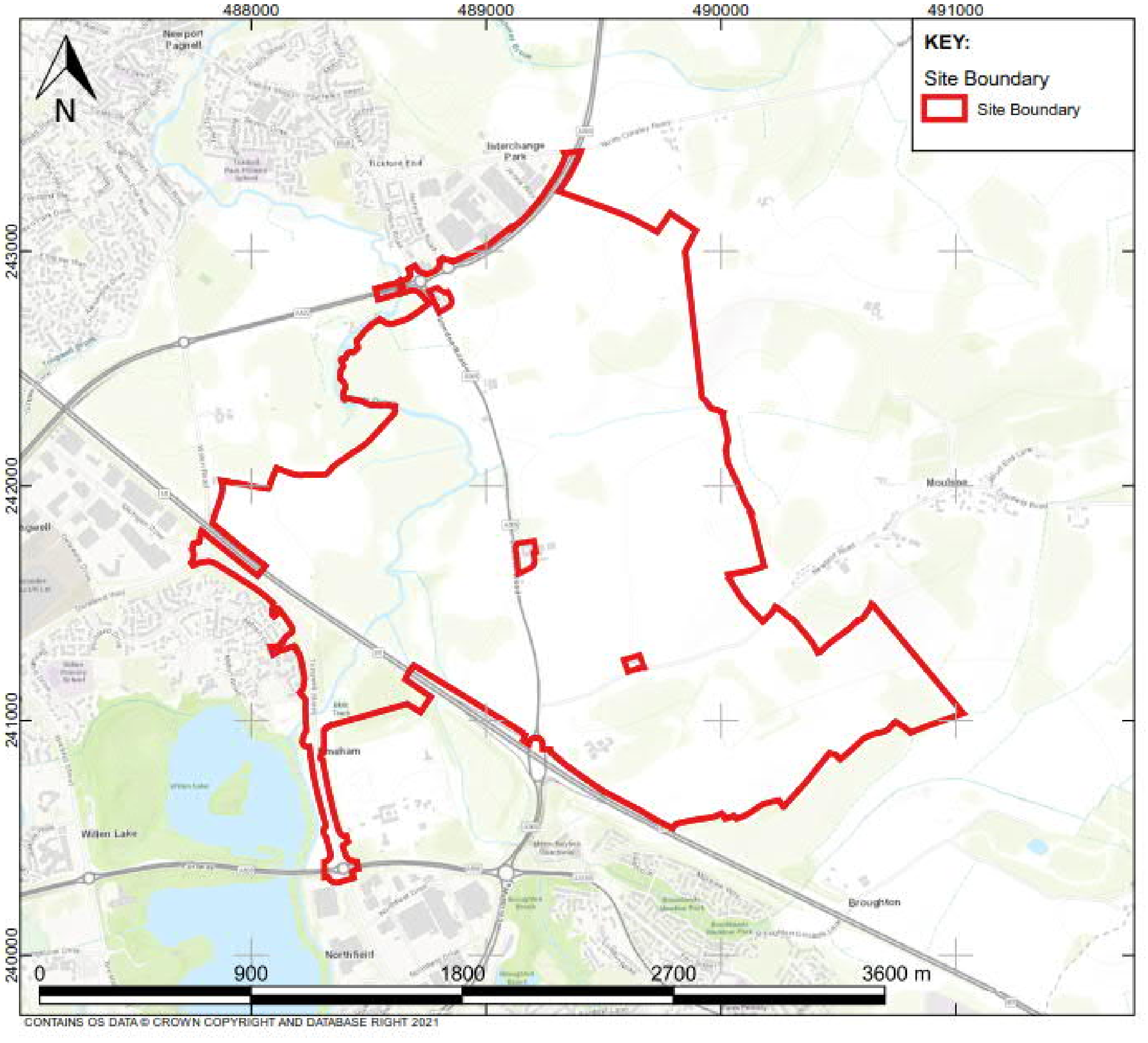
2.1.1. The site is located between the M1 which largely forms the southern boundary of the site and the A422 which forms the northern boundary. The grid reference for the site is 488630, 241770, with a nearest postcode of MK15 9LZ. The Site covers an area of 437 hectares.

2.1.2. The Site largely consists of undeveloped land and is bordered by:

- The A422 to the north;
- Agricultural land to the east;
- The M1 Motorway / Willen Lake to the south; and
- Willen Road to the west.

2.1.3. The site location plan is shown in Figure 1**.**

Figure 1 – Site Location



2.2. DEVELOPMENT PROPOSALS

2.2.1. 'Milton Keynes East' (MKE) has been identified as an allocation for a strategic urban extension within Plan:MK and Milton Keynes Council's (MKC) aspirations for the allocation is set out within Policy SD12 of Plan:MK.

2.2.2. The broad configuration of the proposed layout / land uses for the Scheme is shown in Figure 2 against which this assessment has been prepared, subsequently the land use parameter plan has been updated and is appended to Chapter C of the ES at Appendix C2 and the illustrative plot plan which is included as Figure C3.2 of Chapter C. This updated parameter plan does not change the findings of the assessment. The proposed Scheme is a large-scale mixed-use urban extension (creating a new community) including:

- Approximately 4,000 up to a maximum of 4,600 new homes;
- Up to 403,650 sq.m of employment floorspace;
- A community hub containing a range of commercial and community uses;
- Associated services, amenities and open space; and
- New road and redway extensions, including a new bridge over the M1 motorway and works to the Tongwell Street corridor."

Figure 2 - Indicative Parameter Plan

Source: JTP

2.2.3. The proposed works that have the potential to impact the flood regime associated are outlined below and shown in Figure 3:

2.2.4. **Highway Link 107 (the River Ouzel Crossing), with a 30m bridge opening centred on the River Ouzel**. The bridge opening will include a share footpath / cycle way on each bank along with the 20m wide river channel. Additionally, two flood relief culverts (each 3m high by 5m wide), which outside of times of flooding will act as pedestrian routes, are proposed beneath the highway connecting the floodplain. These flood relief culverts are also intended to provide vehicular access for maintenance purposes (including that undertaken by the Environment Agency). The proposed cross section showing the bridge and pedestrian routes is contained in Appendix E (Scheme Drawings).

2.2.5. **Widening of V11 (Tongwell Street)**, this is to be a new bridge structure and will be constructed largely mirroring the existing piers and embankments. The general arrangement for this included as Appendix C;

2.2.6. **Managing future flood risk to the development platforms.** The changes to the floodplain by Highway Link 107 (the River Ouzel Crossing) introduce an element of risk to some of the proposed development parcels adjacent to the floodplain, to counter this they have been raised, a minimum of 600mm;

2.2.7. **Recreational uses to be located within the floodplain, including one formal playground with two raised walkways**. This play area and the associated raised walkways are located within the linear park to ensure the sustainability and amenity value of the Scheme. To ensure that they are safe for their users they are to be set above the 1 in 100 year plus 65% climate change flood level;

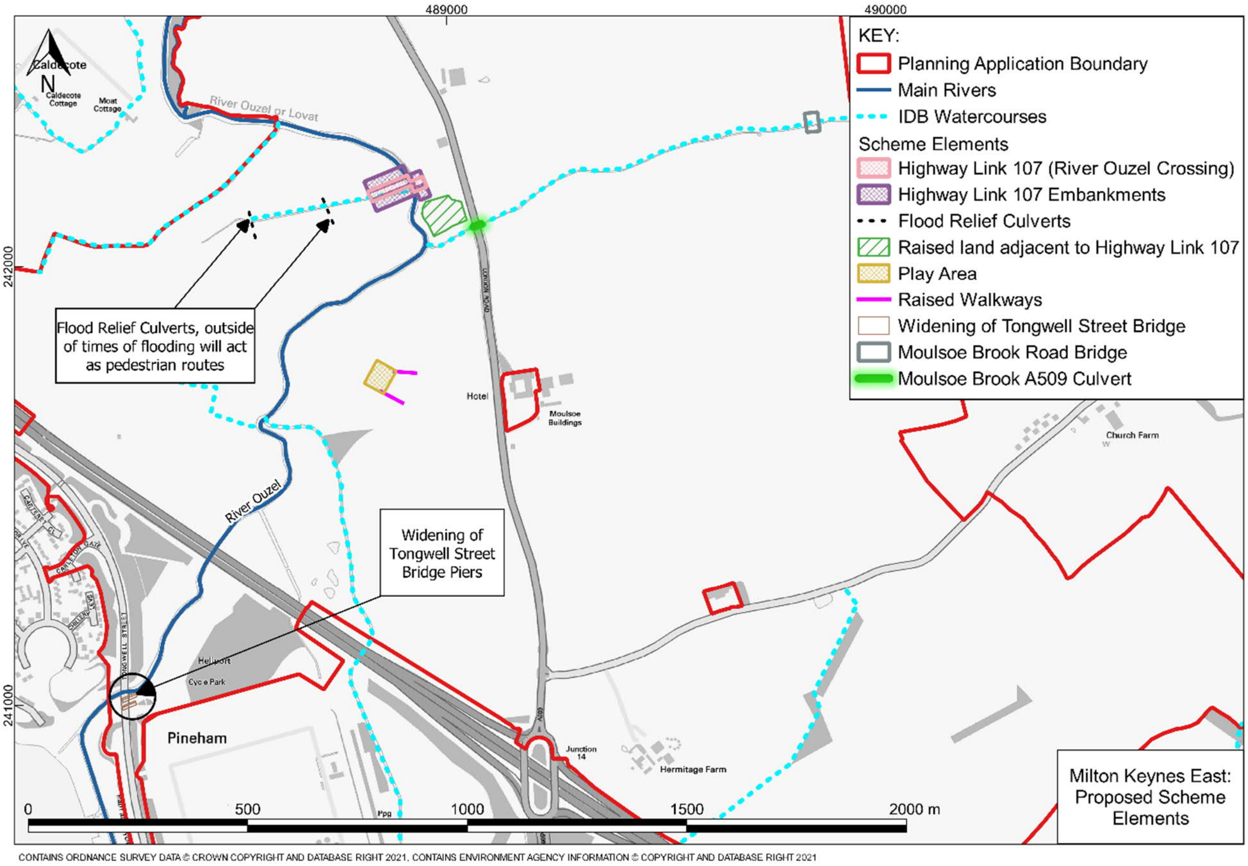
2.2.8. **Raising of land adjacent to the upstream face of Highway Link 107 (the River Ouzel Crossing).** A small parcel of land on the right bank on the upstream face of the Highway Link has been raised by 400mm, to a minimum level of 58.2mAOD. This is required to ensure that the flow through the bridge structure are suitably throttled to prevent an increase in flood flows conveyed downstream. This approach ensures that all impacts are contained within the redline boundary (i.e. land which is under the applicants control to prevent third party impacts). This is inline with the approach discussed with the Environment Agency in January 2020;

2.2.9. **Replacement of the Moulsoe Stream culvert beneath the A509 (Culvert 3)**. The widening of the A509 means that the existing 19m 900mm diameter culvert needs to be replaced with one an equivalent diameter but 21m in length; and

2.2.10. **New road bridge crossing of Moulsoe Stream**. The eastern link will cross the Moulsoe Stream at / in close proximity to the eastern boundary; and

2.2.11. **Change in surface permeability**. The development will result in the change of surface permeability from permeable surfaces to a combination of impermeable / permeable surfaces which, unmitigated, would result increase surface water runoff.

Figure 3 - Proposed scheme elements which may impact flood regime



2.3. TOPOGRAPHY

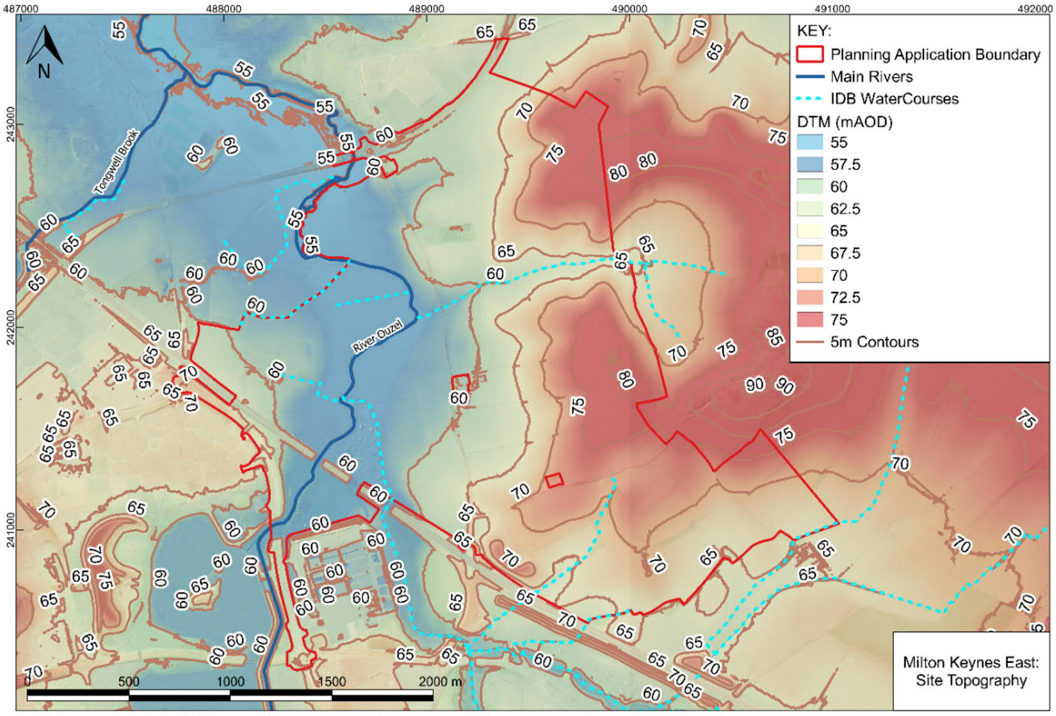
2.3.1. The Environment Agency 1m DTM LiDAR has been used to assess the topography at the site, as shown in Figure 4, with topographical survey obtained at key locations across the site (e.g. watercourses to aid the development of hydraulic models).

2.3.2. There is a gentle slope from south to north through the site, along the channel route of the River Ouzel, from approximately 60mAOD in the south of the site down to approximately 55mAOD in the north of the site.

2.3.3. The land either side of the River Ouzel significantly elevated above the floodplain, rising to a high point of approximately 80mAOD to the east of the site, with a high point in the land to the west of the Ouzel of approximately 70mAOD.

2.3.4. The high land either side of the river corridor can be seen in Figure 4, with the low lying floodplain area shown in blue. The main areas of development are to be located outside of the river corridor.

Figure 4 - Site Topography



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2.4. GEOLOGICAL AND HYDROGEOLOGICAL CONTEXT

Geology

2.4.1. The British Geological Survey (BGS) GeoIndex indicates that the majority of the site is underlain by Mudstone bedrock from the Peterborough Member.

2.4.2. In the northwest of the site the bedrock comprises of Sandstone, Siltstone and Mudstone from the Kellaways Formation. To the east of the site, towards Moulsoe, the site is underlain by bedrock from the Stewartby Member Mudstone.

2.4.3. Superficial Head and Alluvium deposits are present across the floodplain of the River Ouzel and the Broughton Brook. There is also an area of superficial sand and gravel deposits to the west of the site, with superficial Diamicton deposits from the Oadby member present in the east of the site towards Moulsoe.

Hydrogeology

2.4.4. According to the Source Protection Zone map provided by the Environment Agency, the site does not lie within any Source Protection Zones (see Appendix A).

2.4.5. According to the Environment Agency's aquifer designation map, the bedrock to the west of the site is classified as a Secondary A Aquifer, whilst the bedrock to the east of the site is classified as Unproductive Strata. The superficial alluvium and head deposits associated with the floodplain of the River Ouzel and its tributaries are categorised as Secondary A aquifers.

2.4.6. Secondary A aquifers are defined as permeable layers capable of supporting water supplies at a local rather than strategic scale, in some cases forming an important source of base flow to rivers.

3. PLANNING POLICY CONTEXT

3.1. NATIONAL PLANNING POLICY FRAMEWORK 2019

3.1.1. The National Planning Policy Framework (NPPF) as updated in February 2019, sets out the Government's national policies for flood risk management in a land use planning context within England.

3.1.2. Paragraph 155 of the NPPF states "*Inappropriate development in areas at risk of flooding should be avoided by directing development away from areas at highest risk (whether existing or future). Where development is necessary in such areas, the development should be made safe for its lifetime without increasing flood risk elsewhere.*"

3.1.3. *As the proposed development contains residential as well as commercial development, the lifetime of the development is considered to be 100 years.*

3.1.4. The guidance further states that local planning authorities should "*ensure that flood risk is not increased elsewhere. Where appropriate, applications should be supported by a site-specific flood-risk assessment.*"

3.1.5. Allocation and planning of development must therefore be considered against a risk-based search sequence as provided by the guidance.

3.1.6. A sequential risk-based approach to determining the suitability of land for development in flood risk areas is central to the policy statement and should take into account the current and future impacts of climate change (Para. 157). This includes the intent to steer the most vulnerable parts of the development to the areas that experience the least, or an acceptable, degree of flood risk.

3.2. LOCAL PLANNING POLICY

Local Plan

3.2.1. Policy FR1 of Milton Keynes Council's local plan (Plan:MK 2016-2031[1]) sets out the council's current approach to flood risk management. Policy FR1 states that:

> *"All new development must incorporate a surface water drainage system with acceptable flood control and demonstrate that water supply, foul sewerage and sewage treatment capacity is available or can be made available in time to serve the development. Suitable access is safeguarded for the maintenance of water supply and drainage infrastructure.*
>
> *Plan:MK will seek to steer all new development towards areas with the lowest probability of flooding. The sequential approach to development, as set out in national guidance, will therefore be applied across the Borough, taking into account all sources of flooding as contained within the Council's Strategic Flood Risk Assessment (SFRA).*

[1] Milton Keynes Council (2019) Plan:MK Adopted Version. Available online: https://www.milton-keynes.gov.uk/assets/attach/59718/PlanMK-Adoption-Version-March-2019-.pdf

Development within areas of flood risk from any source of flooding, will only be acceptable if it is clearly demonstrated that it is appropriate at that location, and that there are no suitable available alternative sites at a lower flood risk."

3.2.2. Policy FR2 of the local plan sets out the requirement for new developments to incorporate Sustainable Drainage Systems (SuDS) and to take an integrated approach to flood risk management.

3.2.3. Policy FR3 (Protecting and Enhancing Watercourses) states that "*all new development must be set back at a distance of at least 8 metres from any main rivers, at least 9 metres from all other ordinary watercourses, or at an appropriate width as agreed by the Environment Agency, Lead Local Flood Authority or Internal Drainage Board".*

4. VULNERABILITY AND SEQUENTIAL AND EXCEPTION TESTS

4.1. VULNERABILITY CLASSIFICATION

4.1.1. Under the NPPF the proposed Link 107 (the highway link across the River Ouzel) is classified as 'Essential Infrastructure' 'using the flood risk vulnerability classification. Essential Infrastructure development in Flood Zone 3 is considered acceptable as shown in Table 1.

4.1.2. The proposed residential dwellings, educational establishments and healthcare facilities would be classified as 'More Vulnerable' and should be located outside of Flood Zone 3.

4.1.3. Employment land (including uses B2 'General Industrial' and B8 'Storage or distribution' would be classified as 'Less Vulnerable' and as such is permitted to be located in Flood Zone 1, 2 or 3a.

4.1.4. Water-compatible development, such as the proposed play areas and the linear park along the River Ouzel is permitted to be located in Flood Zones 3a and 3b.

Table 1 - Flood Vulnerability and Flood Zone Compatibility (PPG Table 3)

Flood Risk Vulnerability Classification		Essential Infrastructure	Water Compatible	Highly Vulnerable	More Vulnerable	Less Vulnerable
Fluvial Flood Zone	Zone 1	✓	✓	✓	✓	✓
	Zone 2	✓	✓	Exception Test Required	✓	✓
	Zone 3a	Exception Test Required	✓	×	Exception Test Required	✓
	Zone 3b	Exception Test Required	✓	×	×	×

Sequential Test

4.1.5. The PPG and NPPF Guidance states that Planning Authorities should complete a risk based "Sequential Test" when developing Local Plans, to ascertain areas most suitable, from a flood risk perspective, for future development.

4.1.6. The essence of the "Sequential Test" is to "*steer new developments to areas with the lowest probability of flooding*" (Paragraph 158 of the NPPF, February 2019).

4.1.7. Developments within Flood Zone 2 and Flood Zone 3 require a sequential test if a sequential test has not already been carried out for the development type in question at the proposed site.

4.1.8. The site is allocated for development under Policy SD12 (Milton Keynes East Strategic Urban Extension) of Plan:MK, therefore it is not necessary to undertake the sequential test. However, the proposed land uses have been sequentially steered within the Scheme extents, as demonstrated within the Illustrative Parameter Plan (Appendix E), with the water compatible uses within the linear park and the other uses within Flood Zone 1.

Exception Test

4.1.9. While the Sequential Test should be employed on all sites to direct development to locations having the lowest probability of flooding, the Exception Test is to be used on select sites where it is shown necessary, through the Sequential Test, to apply development of a given Flood Risk Use Vulnerability in a Flood Zone that is ordinarily reserved for a less vulnerable use.

4.1.10. Table 3 of Planning Practice Guidance identifies four circumstances where the combination of a given Vulnerability of Use and Flood Zone justify the application of the Exception Test. PPG Table 3 is reprinted as Table 1.

4.1.11. The Exception Test is only required for Link 107 (the essential infrastructure which is located within Flood Zone 3 a and b). The Exception Test is not required for the other aspects of the Scheme as the site has been allocated for development and a sequential test is not required.

4.1.12. To pass the Exception Test it should be demonstrated that:

(a) the development would provide wider sustainability benefits to the community that outweigh the flood risk; and

(b) the development will be safe for its lifetime taking account of the vulnerability of its users, without increasing flood risk elsewhere, and, where possible, will reduce flood risk overall.

With both elements needing to be satisfied for the development to be permitted.

4.1.13. In terms of part A of the Exception Test Link 107 will provide wider sustainability benefits to the community by providing enhanced transport linkages between MK, the Scheme and Newport Pagnell, the need for this aspect is detailed within Plan:MK.

4.1.14. In terms of Part B of the Exception Test this FRA demonstrates that Link 107 will be safe for its lifetime and does not increase flood risk outside of the Scheme Extents.

5. ASSESSMENT OF FLOOD RISK

5.1. RETURN PERIODS

5.1.1. The PPG identifies Flood Zones in relation to flood frequency. In this instance the zones refer to the probability of river (fluvial) ignoring the presence of defences. Table 2 summarises the relationship between Flood Zone category and the identified flood risk.

Table 2 - Flood Zone Categorisations

Flood Zone	Identification	Annual probability of fluvial flooding	Annual Exceedance Probability
Zone 1	Low probability	< 1 in 1000	<0.1%
Zone 2	Medium probability	1 in 100 – 1 in 1000	0.1% - 1.0%
Zone 3a	High probability	> 1 in 100	> 1.0%
Zone 3b*	Functional Floodplain	>1 in 20	> 5.0%

*The definition of the functional floodplain should take account of local circumstances. The annual flood probability is stated as a starting point for consideration.

When assessing the flood risk to the site the above return periods have been utilised, with the exception of the 1 in 100 year event, which given it is the design flood event, in accordance with the NPPF, it is imperative that an allowance for climate change is added in accordance with the Environment Agency's guidance[2]. For this Scheme it has been agreed with the Environment Agency to use a climate change allowance of 35% for the design scenario and 65% as a sensitivity test, as stated in section 1.4.

5.2. OVERVIEW

5.2.1. An overview of flood risk for the proposed development at Milton Keynes East and its surroundings is provided below, based on information obtained from a desk-based assessment and consultation responses that have been provided by the Environment Agency.

[2] https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

Table 3 - Flood Risk Overview

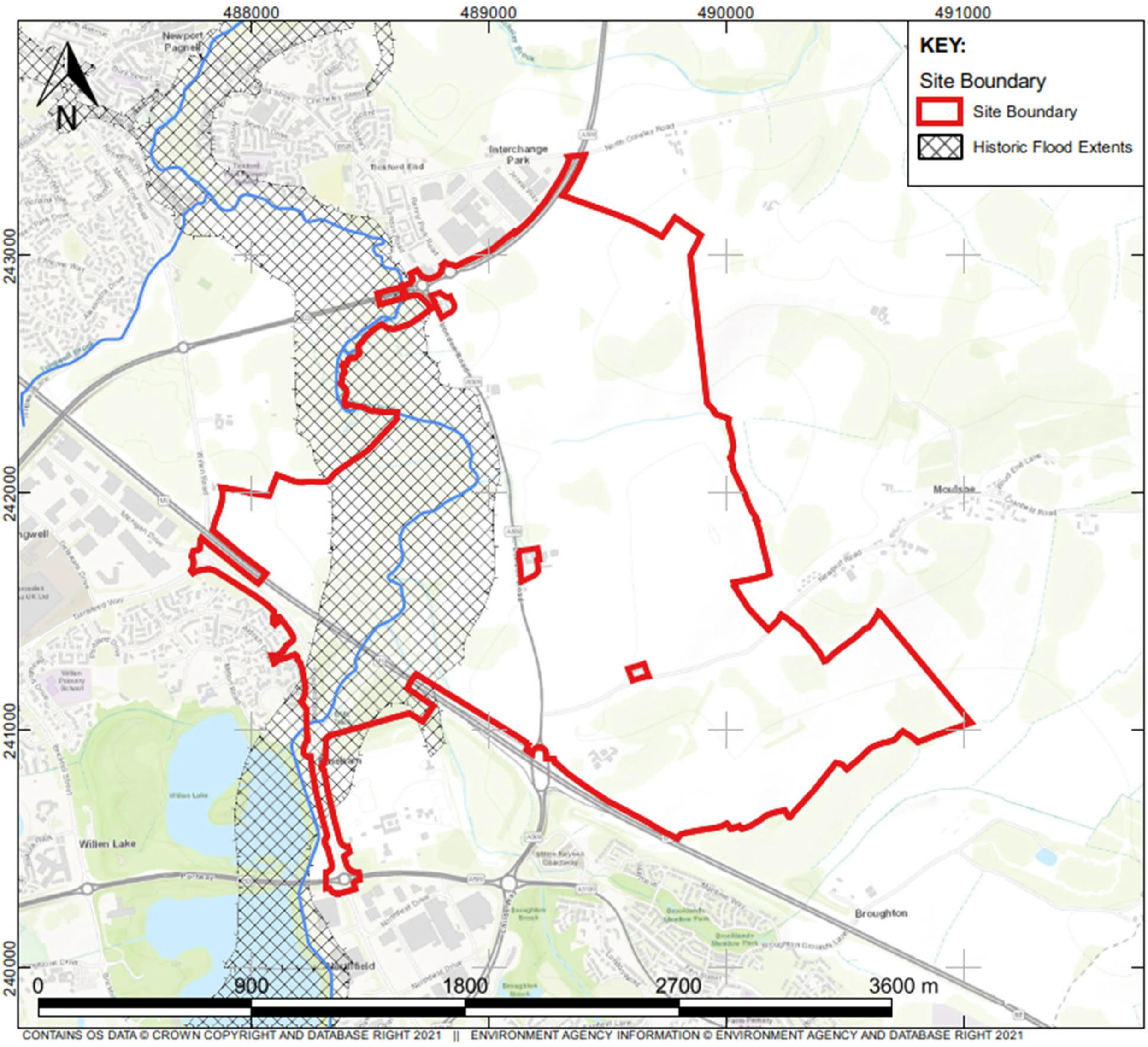
Mechanism	Risk	Comment
Fluvial	Low for the built aspects of the Scheme High for the water compatible uses	The majority of the site is located in Flood Zone 1 based on the Environment Agency's Flood Map for Planning. Within the west of the site the land adjacent to the River Ouzel is located in Flood Zone 3. There is also a small area in the south of the site within Flood Zone 3, located next to Broughton Brook. Hydraulic modelling of the River Ouzel and the Broughton Brook has been undertaken for present day baseline conditions and for the proposed post-development scenario. Excluding the water compatible parts of the development, such as the proposed linear park along the River Ouzel, all of the proposed development is to be situated outside the modelled 1 in 100 year plus 65% climate change flood extents. The post-development hydraulic modelling demonstrates that there will be no increase in flood risk downstream of the site as a result of the proposed development.
Tidal	Negligible	The site is located inland at an elevation of between approximately 55mAOD and 80mAOD and there are no tidally influenced watercourses in the vicinity of the site.
Surface Water	Low	Based on information from the Flood Risk from Surface Water map, the risk of surface water flooding to the majority of the proposed development is assessed to be very low. There is a high risk associated with the Moulsoe Stream for which hydraulic modelling has been undertaken for present day baseline conditions and for the proposed post-development scenario. This demonstrates that the flood waters are constrained to the channel For the other areas across the site the flow paths and risk areas will be substantially altered as a result of the development, this will be managed through a comprehensive surface water drainage strategy. The post-development surface water drainage strategy will restrict peak flows from the impermeable areas to the equivalent greenfield flow (QBAR) or 4/l/s/impermeable hectare, whichever is less, thereby ensuring the risk of surface water flooding does not increase. There are several High Risk surface water flowpaths across the site and these are associated with IDB designated watercourses and drains. These drains will largely be utilised within the development as part of the drainage strategy, which will control and manage the surface water runoff.
Ground Water	Medium	Based on the Environment Agency's Areas Susceptible to Groundwater Flood Map, the western half of the site, associated with the floodplain of River Ouzel is in an area with a high susceptibility to groundwater flooding. According to the MKC Level 1 SFRA, there is surface water – groundwater interaction within the superficial aquifers along the River Ouzel and its tributaries. There are however no recorded incidents of groundwater flooding within the site boundary and the majority of the proposed development is

		to be situated away from the floodplain of the River Ouzel where this surface water – groundwater interaction may occur.
Sewers	Low	There are no recorded incidents of sewer flooding within the vicinity of the site.
Artificial Sources	Low	In the event of a failure of the nearby Willen Lake Reservoir the site would be within the maximum flood extents. However, the likelihood of reservoir flooding impacting the site is considered to be low.

5.3. HISTORIC FLOODING

5.3.1. The Environment Agency's Historic Flood Map (see Figure 5) shows that part of the site has previously flooded, with this dataset indicating that the site experienced flooding in March 1947, September 1992 and Easter 1998.

Figure 5 - Environment Agency Historic Flood Map



5.3.2. The 2015 MKC Level 1 SFRA[3] confirms that fluvial flooding occurred in the vicinity of the site from River Ouzel and Great Ouse in March 1947 and in September 1992 from the River Ouzel.

5.3.3. It is also understood from antedotal sources that there was flooding on part of the site from the River Ouzel during December 2020.

5.3.4. All these flood incidences are a result of flood waters exceeding the capacity of the River Ouzel channel and are constrained to the associated floodplain which is to be maintained within the Scheme as a linear park.

5.4. FLUVIAL FLOOD RISK

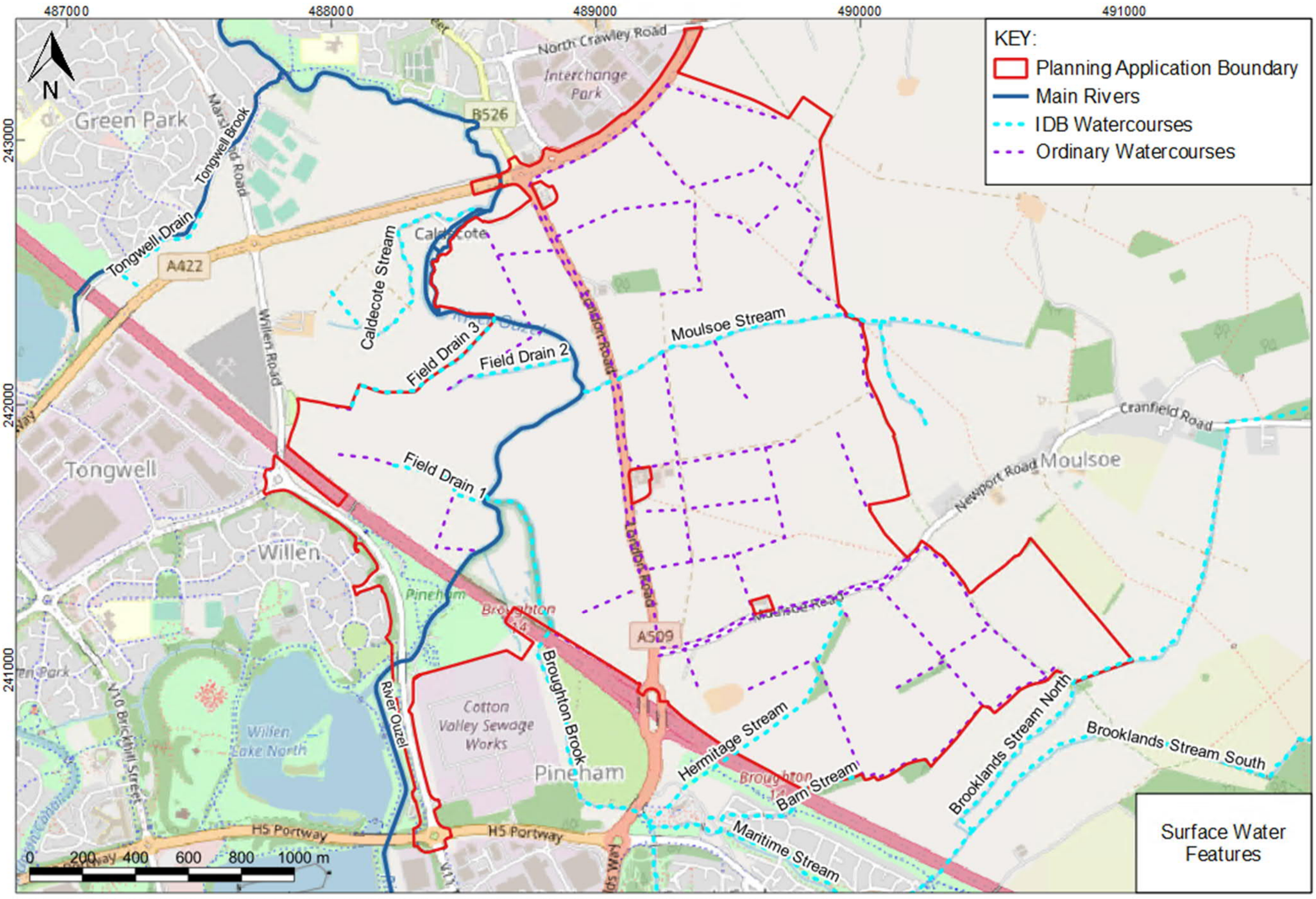
5.4.1. There are a number of watercourses in proximity to the site which pose a risk of fluvial flooding to the site, these are:

- **The River Ouzel,** a Main River, which flows from south to north through the western half of the site, before it joins the River Great Ouse approximately 1.3km downstream of the site.
- **The Broughton Brook**, an ordinary watercourse overseen by the Bedford Group of IDB's, which flows along the southern boundary of the site before flowing north and discharging into the River Ouzel.

5.4.2. The location of the River Ouzel and Broughton Brook, along with several tributaries of these watercourses are shown in Figure 6.

[3] Milton Keynes Council (2015) Level 1 Strategic Flood Risk Assessment. Available online: https://www.milton-keynes.gov.uk/assets/attach/29342/Update_Milton-Keynes-L1-SFRA-FINAL-with-Appendices.pdf

Figure 6 - Surface Water Features



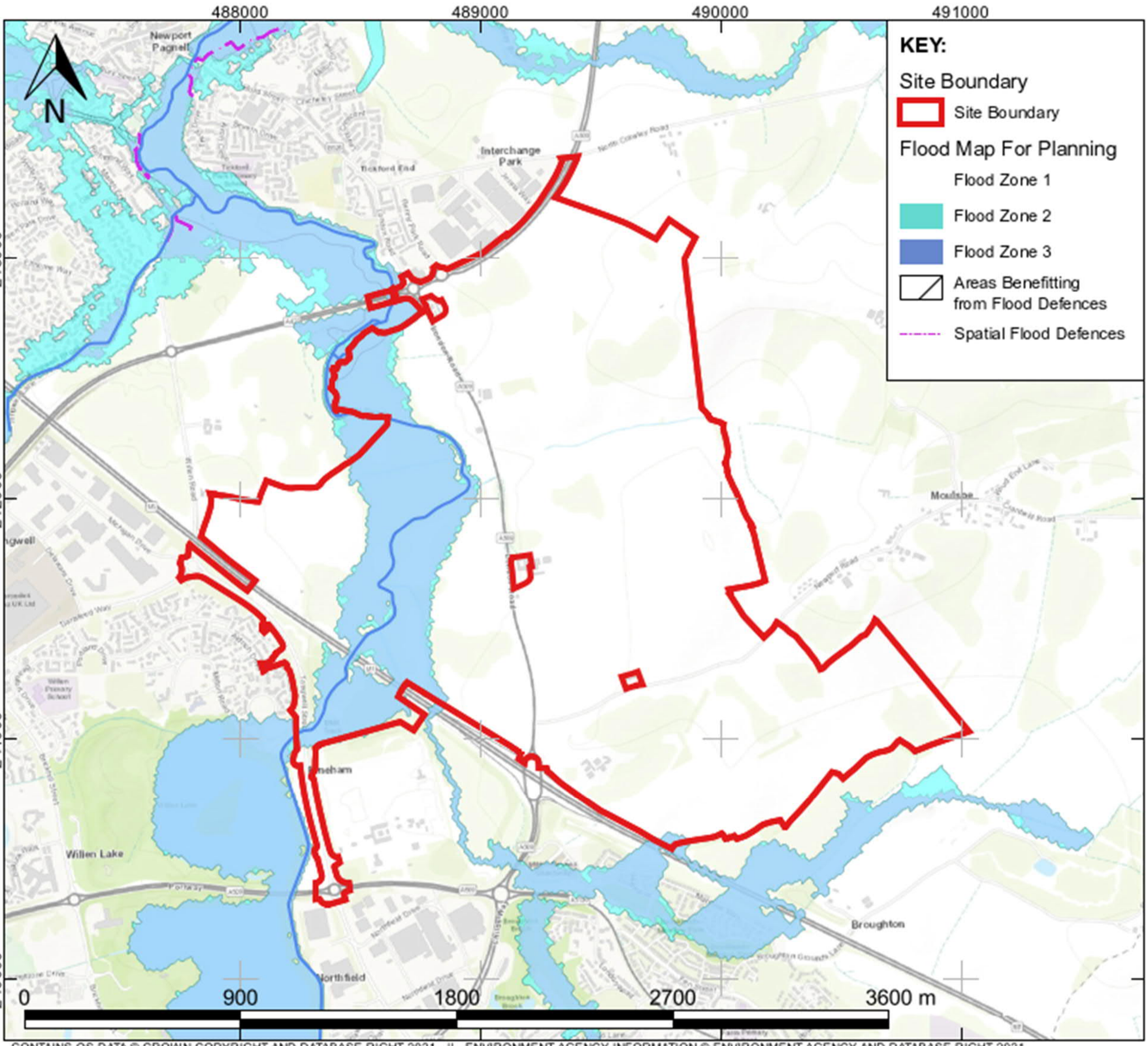
5.4.3. Figure 7 shows the Environment Agency's Flood Map for Planning for the Scheme and the surrounding area. The map shows areas that are affected by tidal and/or fluvial flooding and provides a classification of whether there is a High level of risk (Flood Zone 3), Medium level of risk (Flood Zone 2) or a Low level of risk (Flood Zone 1).

5.4.4. There are no tidally influenced watercourses in the vicinity of the site, therefore the risk of the flooding shown on the flood map for planning corresponds entirely to fluvial flooding.

5.4.5. The Environment Agency's Flood map for Planning shows that the majority of the site is located in Flood Zone 1, which corresponds to less than a 1 in 1000 annual probability (0.1% AEP) of fluvial flooding, for which all types of development in accordance with the NPPF vulnerability classes are acceptable.

5.4.6. In the west of the site, is the River Ouzel corridor, which is designated as Flood Zone 3, meaning a greater than 1 in 100 (1%) annual probability of fluvial flooding. This also extends along the Broughton Brook.

Figure 7 - Environment Agency Flood Map for Planning



5.4.7. Mapping from the Level 1 SFRA[4] indicates that part of the River Ouzel floodplain through the Scheme is within Flood Zone 3b, the functional floodplain. The functional floodplain comprises land where water has to flow or be stored in times of flood and is defined as land which would flood with an annual probability of 1 in 20 (5% AEP) or greater or is designed to flood in an extreme (0.1% AEP) flood.

[4]Milton Keynes Council (2015) Level 1 SFRA: Risk of Flooding from Rivers Mapping. Available online at: https://www.milton-keynes.gov.uk/assets/attach/29344/Appendix-C.pdf

FLOOD DEFENCES

5.4.8. Whilst there are no flood defences within the Scheme extents, there are defences immediately upstream (Willen Lake) and downstream within Newport Pagnell, these are outlined below and shown on the Environment Agency's Flood Map for Planning (Figure 7, above).

5.4.9. The site is located downstream of Willen Lake which acts as a balancing lake for the River Ouzel. Willen Lake has control gates to regulate flow on the River Ouzel and was built to compensate for increased flows in Broughton Brook and increased discharge from the sewage treatment works, as well as increased surface water run off flows in the River Ouzel[1] as a result of the development of Milton Keynes.

5.4.10. Caldecotte Lake (upstream of the Scheme and within Milton Keynes) is another a balancing lake on the River Ouzel, which works in tandem with Willen Lake. It is understood that the original design criteria for Caldecotte and Willen Lakes was that the development of Milton Keynes should not result in a decrease in flood storage along the River Ouzel, therefore the lakes were designed to provide the replacement storage capacity for a flood event of equivalent magnitude of the 1947 floods[3]. Whilst a return period of the 1947 floods is not documented within the SFRA, there is evidence that this is one of the worst flood events in the region in the 20th century[5].

5.4.11. There are several discrete sections of flood defences throughout Newport Pagnell, these consist of raised walls, embankments, areas of high ground and flapped outfalls. These are maintained and managed by the Environment Agency and are shown on their Asset Management Database[6]. These defences protect the properties in the lower lying areas adjacent to the Rivers Ouzel and Ouse. For flood defences to be shown on the Environment Agency's Flood Map for Planning, they have to generally offer a Standard of Protection greater than or equal to the 1 in 100 year event (1% AEP).

5.5. RIVER OUZEL HYDRAULIC MODELLING

The Environment Agency's Flood Map for Planning is based upon strategic scale hydraulic modelling which does not include a detailed representation of the channel characteristics of the River Ouzel through the Scheme extents, furthermore, the Broughton Brook is not included within the model. To gain a better understanding of the nature of the flood mechanisms and regime through the Scheme Extents and the immediate vicinity Scheme specific hydraulic modelling was undertaken, this is summarised below with further detail in Appendices B and C. This modelling has been reviewed by the Environment Agency who have confirmed their support for the Scheme stating that they have no in principle objections to the scheme.

BASELINE MODELLING

5.5.1. The baseline flood model is detailed in the WSP Report "*Hydraulic Modelling Report - Proposed Highway*" (Ref: 51078-HMR-001, February 2019), this was subsequently refined as detailed in the

[5] https://www.theguardian.com/world/2007/jul/25/weather.flooding1
[6] https://environment.data.gov.uk/asset-management/index.html?element=http%3A%2F%2Fenvironment.data.gov.uk%2Fasset-management%2Fid%2Fasset%2F122650&layer=all-assets

WSP Technical Note "*Milton Keynes East - St James - Revised baseline hydraulic modellin*g" (May 2020) with the Environment Agency's comments addressed in the WSP Technical Note "*Response to Environment Agency Queries on Baseline Flood Modelling*" (October 2020). No further changes to the baseline model have been made. A summary of the baseline model is provided below:

5.5.2. The baseline flood model represents the flood risk to the development site area prior to development. The modelling has been based on the existing ESTRY-TUFLOW model of the River Ouzel and tributaries provided by the Environment Agency. The full Environment Agency model was run with output locations included to capture out of bank flows for input into a cut down version.

5.5.3. The Environment Agency model was trimmed between the Ouzel Valley Park and Newport Pagnell and the 1D and 2D results from the full model used as inputs to the site specific trimmed model. This is common practise in scheme specific flood modelling, as it reduces the model run time, to enable a number of iterations to be assessed, to ensure that the optimum post development scenario can be derived.

5.5.4. A number of improvements were identified and included within the baseline model. These are listed below:

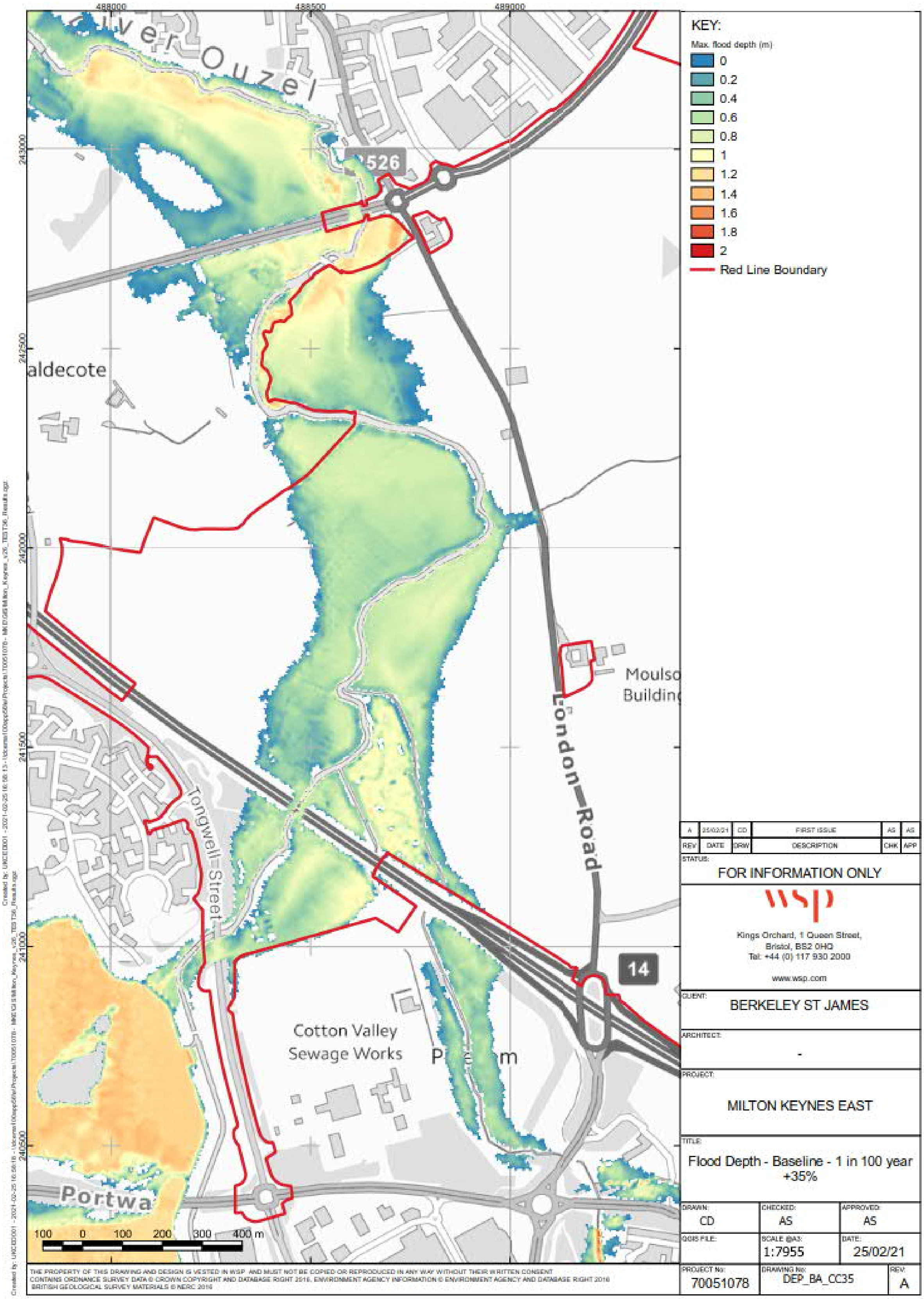
- Inclusion of additional cross sections along the River Ouzel;
- Inclusion of the Broughton Brook as a 1D ESTRY channel element;
- Inclusion of a small channel flowing adjacent to the Cotton Valley Sewage Treatment Works (STW), under the M1 through Pineham Nature Reserve;
- Inclusion of an additional ordinary watercourse on the right bank of the River Ouzel upstream of the proposed highway crossing location as a point input;
- Revised hydrology for the Broughton Brook and additional watercourses (e.g. the Moulsoe Stream).

Baseline Flood Depths / Extents

5.5.5. The baseline modelling demonstrates that all the flood extents are relatively well constrained by the topography within the site. The future baseline (i.e. the design scenario) 1 in 100 year plus 35% climate change flood extents cover approximately 12% of the site and the 1 in 1000 year flood extents cover approximately 12.8% of the site. Approximately 10.2% of the site is shown to be within the 1 in 20 year flood extent and is therefore considered to be within the functional floodplain. Baseline flood extents for the 1 in 20 year, 1 in 100 year, 1 in 100 year +35% climate change, 1 in 100 year +65% climate change and 1 in 1000 year events are shown in Appendix B.

5.5.6. Modelled flood depths for the River Ouzel for the baseline 1 in 100 year + 35% climate change event are shown in Figure 8. Across most of the site flood depths are expected to be below 0.6m, with areas of depths of up to 1.0m near the confluence of the Broughton Brook and the River Ouzel in the south of the site.

Figure 8 - Baseline modelled flood depths for the River Ouzel (1 in 100 year+35% event)



POST DEVELOPMENT HYDRAULIC MODELLING

5.5.7. The baseline model was modified to incorporate the post-development aspects of the scheme as detailed in Section 6 of the Approach to Flood Management Report (Appendix C). The key differences between the baseline model are as follows:

- Highway Link 107 (the River Ouzel Crossing) has been added to the model;
- Two flood relief culverts which outside of times of flood will act as pedestrian routes measuring 5m by 3m have been added through Highway Link 107 (the River Ouzel Crossing;
- The development parcels adjacent to the floodplain (R11, R12, R02, R03a, R03b, and R04) have been raised, with the new ground level for the parcels set 600mm above the design event flood level (1 in 100 year plus 35% climate change);
- The piers of the Tongwell bridge are increased in size following the construction of the scheme; and
- A formal playground area within the linear park but connected to the adjacent development platform, all raised above the 1 in 100 year plus 65% flood level. This playground area has been designed to ensure the provision of safe access / egress during flood events and the avoidance of dry islands within the linear park.

5.5.8. Both the baseline and post development models, demonstrates that the A422 bridge, at the downstream extent of the site, is the key constraint to downstream flow conveyance, with flood waters starting to back up across the floodplain (within the Scheme Extents) once the A422 bridge capacity is exceeded. This is the primary constraint to the flows which can pass under Highway Link 107 (the River Ouzel Crossing).

5.5.9. The flood extents in the post-development scenario remain largely the same as those in the baseline scenario. Changes to the flood depth and extent occur on land within the Scheme's red line boundary, with no impacts on third party land, with the exception of area downstream of Highway Link 107, where the levels increase between 0.01m to 0.1m, and land to the west of the Anglian Water WWTW where the levels increase by between 0.01m and 0.1m.

5.5.10. The area downstream of Highway Link 107 is part of the current floodplain and is owned by Milton Keynes Council, who in their role as the Local Planning Authority will give planning consent for the Scheme and have stated that it is their aspiration for this land to become part of the Adjacent Linear Park (as shown in Figure 10).

5.5.11. The land adjacent to the Anglian Water WWTW is also situated on land owned by the Milton Keynes Development Partnership (MKDP) and is part of the current floodplain. There is very limited increase in flood extents here and the increase in flood depths are considered to be negligible when the baseline flood depths are taken into account.

5.5.12. The impacts of the scheme on both flood levels and flows are summarised in Table 4 and Table 5, with an explanation following these tables. The locations of the key on-site areas are shown in Figure 9, whilst the key offsite areas are shown in Figure 10.

Figure 9 - Key Flood Level Locations

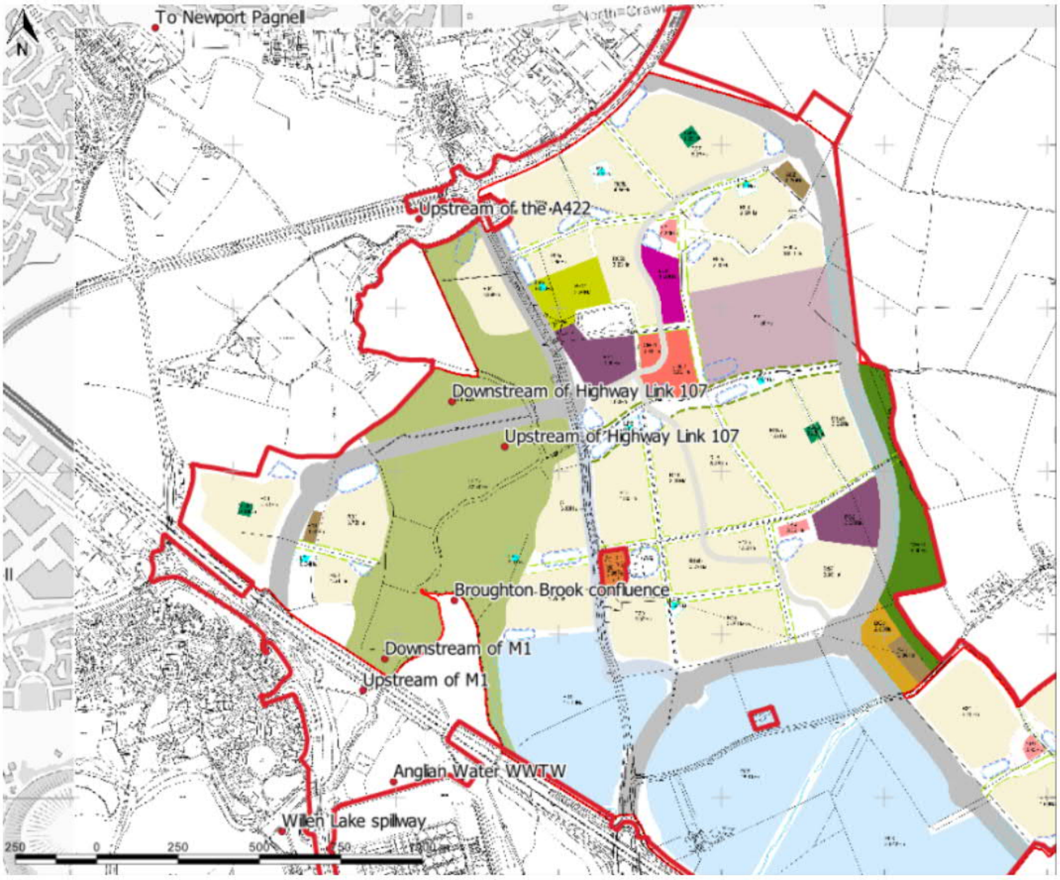


Figure 10 - Key Off-Site Locations

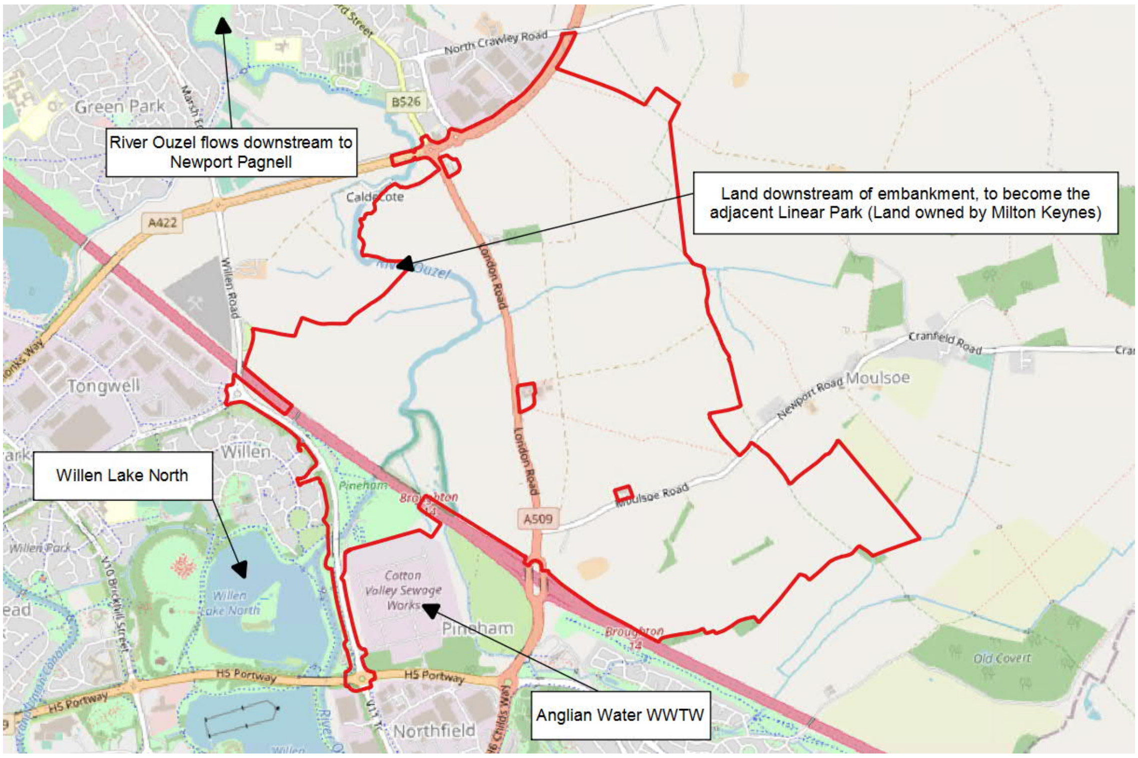


Table 4 - Flood depths (m) at key locations

		Designated Floodplain			Design Scenario			Sensitivity Scenario			Extreme Scenario		
Area	Critical level	1 in 20 year			1 in 100 year + 35% Climate Change			1 in 100 year + 65% Climate Change			1 in 1,000 year		
	mAOD	Baseline	Proposed	Difference	Baseline	Proposed	Difference	Baseline	Proposed	Difference	Baseline	Proposed	Difference
Anglian Water WWTW	61.2	57.36	57.37	0.01	57.85	57.98	0.13	57.99	58.16	0.17	57.83	57.96	0.13
Willen Lake Spillway	58.95	58.10	58.11	0.00	58.40	58.42	0.02	58.50	58.53	0.03	58.37	58.39	0.02
Willen Lake Weir	59.7	59.30	59.30	0.00	59.57	59.57	0.00	59.64	59.64	0.00	59.55	59.55	0.00
Upstream of M1	60.46	57.47	57.48	0.01	57.94	58.03	0.09	58.05	58.18	0.14	57.92	58.01	0.9
Downstream of M1	60.46	57.38	57.39	0.01	57.71	57.87	0.16	57.80	58.03	0.23	57.70	57.86	0.16
Broughton Brook confluence	-	57.32	57.33	0.01	57.59	57.82	0.22	57.68	57.98	0.30	57.59	57.80	0.21
Upstream of Highway Link 107 (the River Ouzel Crossing)	62.21	56.75	57.11	0.36	57.20	57.70	0.50	57.29	57.87	0.58	57.19	57.69	0.50
Downstream of Highway Link 107 (the River Ouzel Crossing)	62.21	56.74	56.72	-0.02	57.10	57.05	-0.05	57.18	57.15	-0.03	57.09	57.04	-0.04
Upstream of the A422	-	55.85	55.85	0.00	56.44	56.44	0.00	56.60	56.60	0.00	56.42	56.42	0.00
Newport Pagnell	-	54.83	54.83	0.00	55.21	55.21	0.00	55.32	55.32	0.00	55.20	55.20	0.00

Table 5 - Comparison of flood flows (m^3/s) at key locations

Area	Frequent Event			Design Scenario			Sensitivity Scenario			Extreme scenario		
	1 in 20 year			1 in 100 year + 35% Climate Change			1 in 100 year + 65% Climate Change			1 in 1000 year		
	Baseline	Proposed	Difference	Baseline	Proposed	Difference	Baseline	Proposed	Difference	Baseline	Proposed	Difference
Willen Lake	32.9	32.9	0.0	62.3	62.3	0.0	69.9	69.9	0.0	59.8	59.8	0.0
Downstream of Highway Link 107 (the River Ouzel Crossing)	56.8	56.6	-0.2	138.0	137.3	-0.7	167.2	166.8	-0.4	135.4	134.9	-0.5
Newport Pagnell	57.4	57.3	-0.1	133.5	133.5	0.0	163.4	163.4	-0.1	131.20	131.24	0.0

Onsite Changes

5.5.13. The post-development model shows that there are a range of impacts on the flood regime within the application boundary these are summarised below and shown in Figure 9 (flood difference maps for all return periods are in the appendices of the Approach to Flood Management Report, see Appendix C):

- A reduction in flood levels of 0.04m immediately downstream of Highway Link 107 (the River Ouzel Crossing) for the 1 in 100 plus 65% climate change scenario.
- Downstream of parcel R04, point there is a negligible to no change to the flood levels (0.03m for the 1 in 100 year plus 35% climate change and 0.01 for the 1 in 100 year plus 65% scenarios), this continues decreases with distance to the A422, by which point there is no change, and for clarity there is no change downstream beyond the A422.
- Upstream of Highway Link 107 (the River Ouzel Crossing) flood waters have a greatest increase in depth in the reach where the Broughton Brook converges with the River Ouzel. In this section an increase in modelled peak flood depths of 0.51m is predicted for the 1 in 100 plus 35% climate change scenario, and an increase of 0.58m is predicted for the 1 in 100 plus 65% climate change scenario. This is an area designated as a linear park.
- At the M1, for the 1 in 100 plus 65% scenario the peak flood level reaches 58.18mAOD which remains 2.28m below the deck level of the carriageway, which is at a level of 60.46mAOD. Given that the level of the carriageway is significantly above the maximum flood level, no increase in flood risk to the M1 is predicted. The increase of flood depth adjacent to the M1 is currently under discussion with Highways England.

Offsite changes

Land Between Link 107 and the A422

5.5.14. Parts of this area lie outside the red line boundary in land owned by Milton Keynes. Milton Keynes have aspirations for the land to be incorporated onto the proposed linear park. The maximum change in levels here occurs adjacent to parcel R04 in the 1 in 100 year plus 35% climate change event and is 0.03m.

5.5.15. The change in the maximum water level is negligible upstream of the A422 for all modelled return periods.

Willen Lake

5.5.16. The change in flood levels gradually reduces with distance from Highway Link 107 (the River Ouzel Crossing) towards Willen Lake. At Willen Lake adjacent to the spillway, the pertinent information is:

- The top of the exceedance spillway is 58.95mAOD.
- The crest of the weir which controls the flows between the main River Ouzel channel towards the site is at a level of 59.7mAOD. In the baseline scenario, the maximum water level in the channel is 59.64mAOD in the 1 in 100 year + 65% climate change scenario.

5.5.17. At Willen Lake adjacent to the exceedance spillway, , there is no change in the flood level (<1mm, which is well within the model tolerance). Whilst at the crest of the weir which controls the flows between the main River Ouzel channel towards the site and those diverted into Willen Lake there is no change in modelled flood level.

Anglian Water WWTW

5.5.18. The Anglian Water WWTW lies to the south of the scheme, to the north east of Willen Lake. Whilst there are very minor changes in water levels on the floodplain, the WWTW is elevated above the floodplain at a level of 61.2mAOD which is 3.04m above the 1 in 100 year plus 65% climate change post development flood level. Therefore, no change in flood risk is predicted.

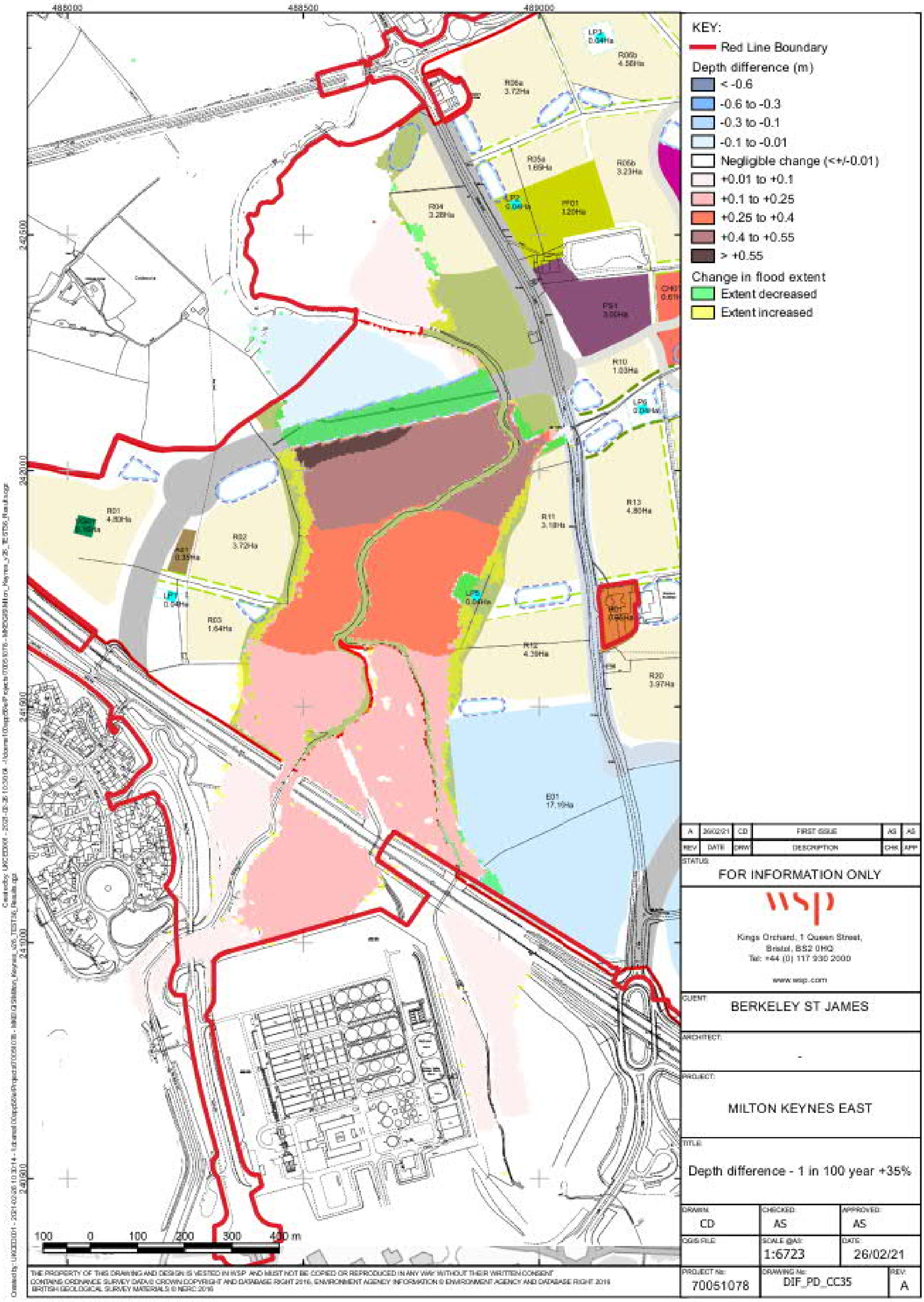
5.5.19. Land adjacent to the east of the WWTW is also shown to experience very minor increases in flood depths, with increases of up to 0.1m in the 100 year plus 35% climate change event. Baseline flood depths here are between 0.6m to 0.8m, therefore increases of depths of up to 0.1m are considered to have only a marginal impact. Changes in flood extent are negligible (limited to the odd model cell).

Newport Pagnell

5.5.20. As outlined in Table 4 the model demonstrates that for all design scenarios there is no change in the peak flows that are conveyed downstream towards Newport Pagnell, or the flood levels at Newport Pagnell as shown in the flood difference maps in the Approach to Flood Management Report (Appendix D). This demonstrates that the Scheme does not result in changes in peak flood depths at or downstream of the A422.

5.5.21. There is no change in the overall duration of the flood event for any of the modelled scenarios, the flood peak occurs at 40 modelled hours and returns to baseline conditions at 62 hours. This is comparable to the baseline model results.

Figure 11 - In 100 year +35% climate change flood difference map



RESIDUAL RISK

5.5.22. The residual risk of blockage of the River Ouzel Crossing (Highway Link 107) is discussed in section 6.2.

FLUVIAL FLOOD RISK SUMMARY

5.5.23. The majority of the site is not at risk of fluvial flooding, however approximately 13% of the site is shown to be within the 1 in 100 year plus 35% climate change flood extents.

5.5.24. Scheme specific hydraulic modelling has been undertaken to assess the impact on flood risk of the proposed Scheme. The modelling has been based on the baseline model which was submitted to the Environment Agency for their review. The post development model incorporates changes that include the representation of Highway Link 107 (the River Ouzel Crossing) which includes two flood alleviation culverts / pedestrian walkways, development parcels raised out of the floodplain and the inclusion of the play area in the linear park. The Environment Agency have approved both the models for use in supporting the planning application.

5.5.25. The results of the modelling indicate that the scheme causes an increase in flood depth and extent upstream of Highway Link 107 (the River Ouzel Crossing), but that this increase is largely contained within the red line boundary with the exception being negligible impact on third party land to the east of the Anglian Water WWTW. This land is owned by the Milton Keynes Development Partnership (MKDP), who intend to write in support of the proposals and is part of the current floodplain.

5.5.26. The modelling has been incorporated within the masterplan for the Scheme to ensure that it will be safe for events up to and including the 1 in 100 plus 65% (the sensitivity scenario) as well as the 1 in 1,000 year event (the extreme scenario).

5.5.27. There is no difference in flood flows or levels downstream of the Scheme for any design scenario, it is therefore demonstrated that the Scheme does not alter the flood risk up or downstream.

5.5.28. Details of the fluvial flood risk mitigation measures are included in section 6.

Identified Fluvial Flood Risk: Low for all parts all of the development apart from the linear park which is at High Risk

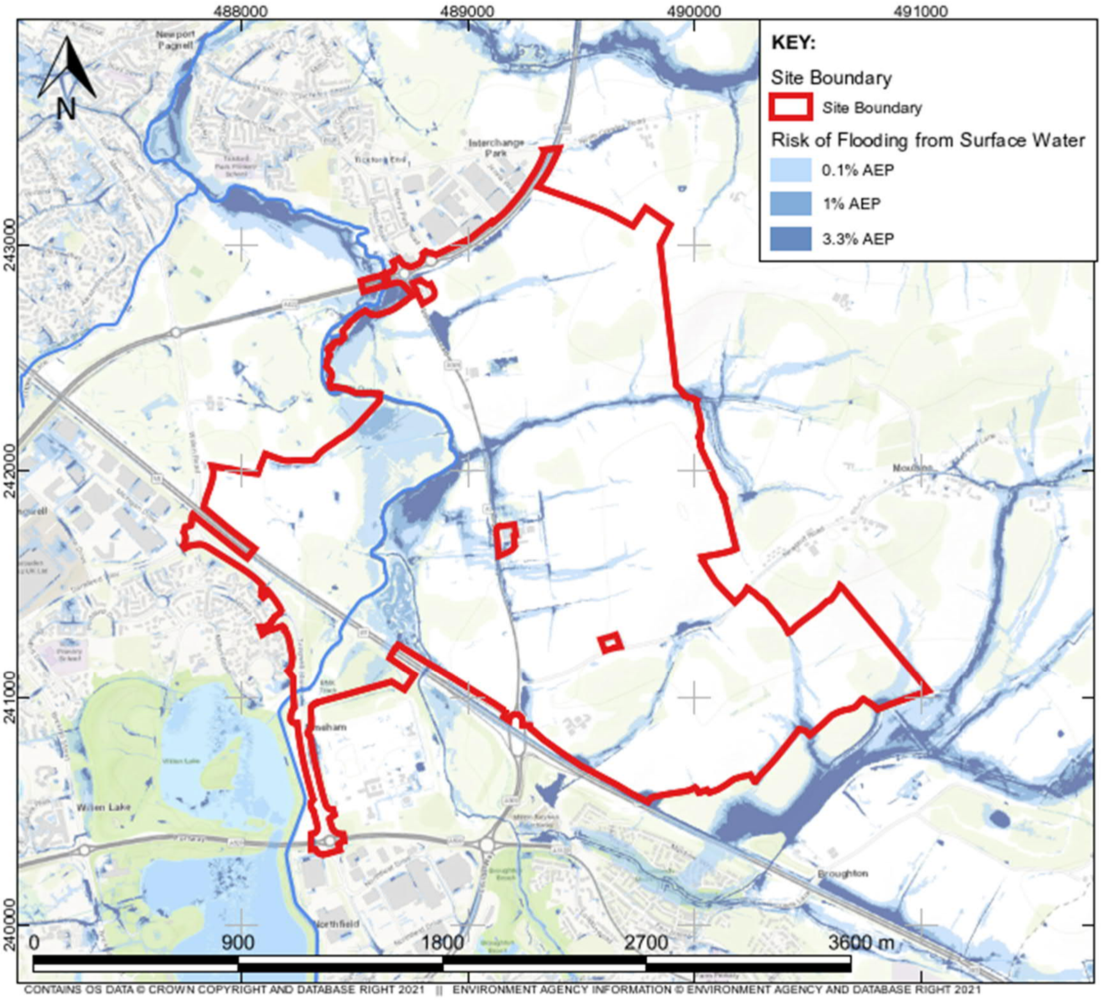
5.6. SURFACE WATER FLOOD RISK

5.6.1. Flooding from surface water is caused when rainfall cannot soak away because the ground is fully saturated, or drainage systems are full. This form of flooding is usually associated with high intensity rainfall events but can also occur with lower intensity rainfall or melting snow where the ground is saturated, frozen, developed or otherwise has a low permeability. The flood risk relates to both the conveyance of waters to the site by overland flow from areas outside the site and also areas within the site itself, and the ponding of these waters in depressions in the topography.

5.6.2. The Environment Agency's Risk of Flooding from Surface Water Map (see Figure 12) indicates that large parts of the site are at very low risk of surface water flooding, meaning a less than 1 in 1000 (0.1%) annual probability of surface water flooding.

5.6.3. However, this mapping also shows that there are several high risk surface water flowpaths across the site, with high risk referring to that land has a 1 in 30 year or greater annual probability of flooding (>3.3% AEP).

Figure 12 - Risk of Surface Water Flooding Map

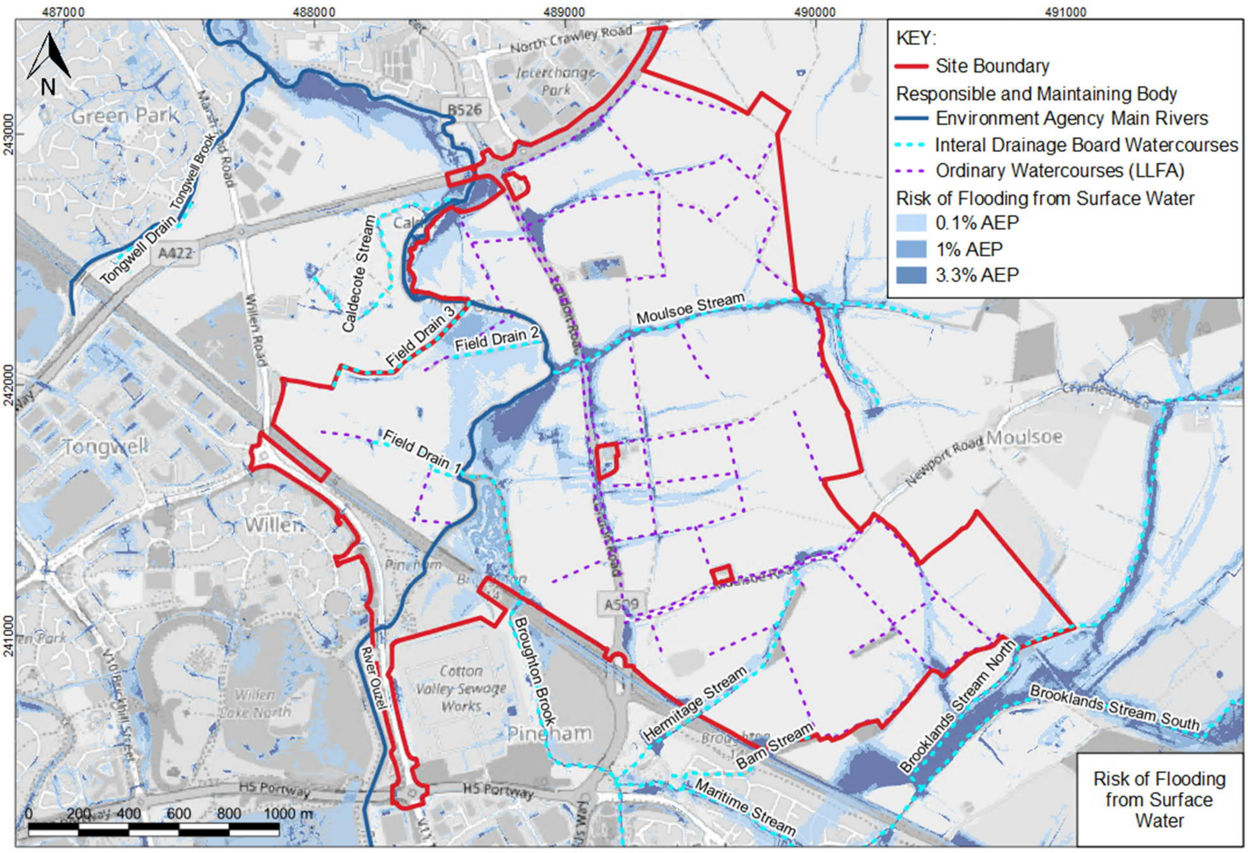


5.6.4. Within the site boundary there are high risk (>3.3% AEP) surface water flowpaths along the following IDB designated watercourses; the Moulsoe Stream; the Hermitage Stream; the Barn Stream and Brooklands Stream North. The locations of these IDB designated watercourses are shown in Figure 13. It is envisaged that most of these watercourses will remain in the post development scenario, this is discussed in later sections.

5.6.5. Adjacent to the River Ouzel and Field Drains 3 there in an area at medium risk (1.0% - 3.3%AEP) of surface water ponding.

5.6.6. The land next to Field Drains 1 and 2 and the land to the east of the River Ouzel is shown to be at Low Risk (0.1% - 1.0% AEP) of surface water flooding.

Figure 13 - IDB Watercourses and Surface Water Flowpaths



SURFACE WATER MODELLING

5.6.7. To refine the surface water flood extents for the site, hydraulic modelling has been undertaken of the Moulsoe Stream, as this is the most significant surface water flowpath through the site. This modelling has been reviewed by the Environment Agency who have confirmed their support for the Scheme stating that they have no in principle objections to the scheme.

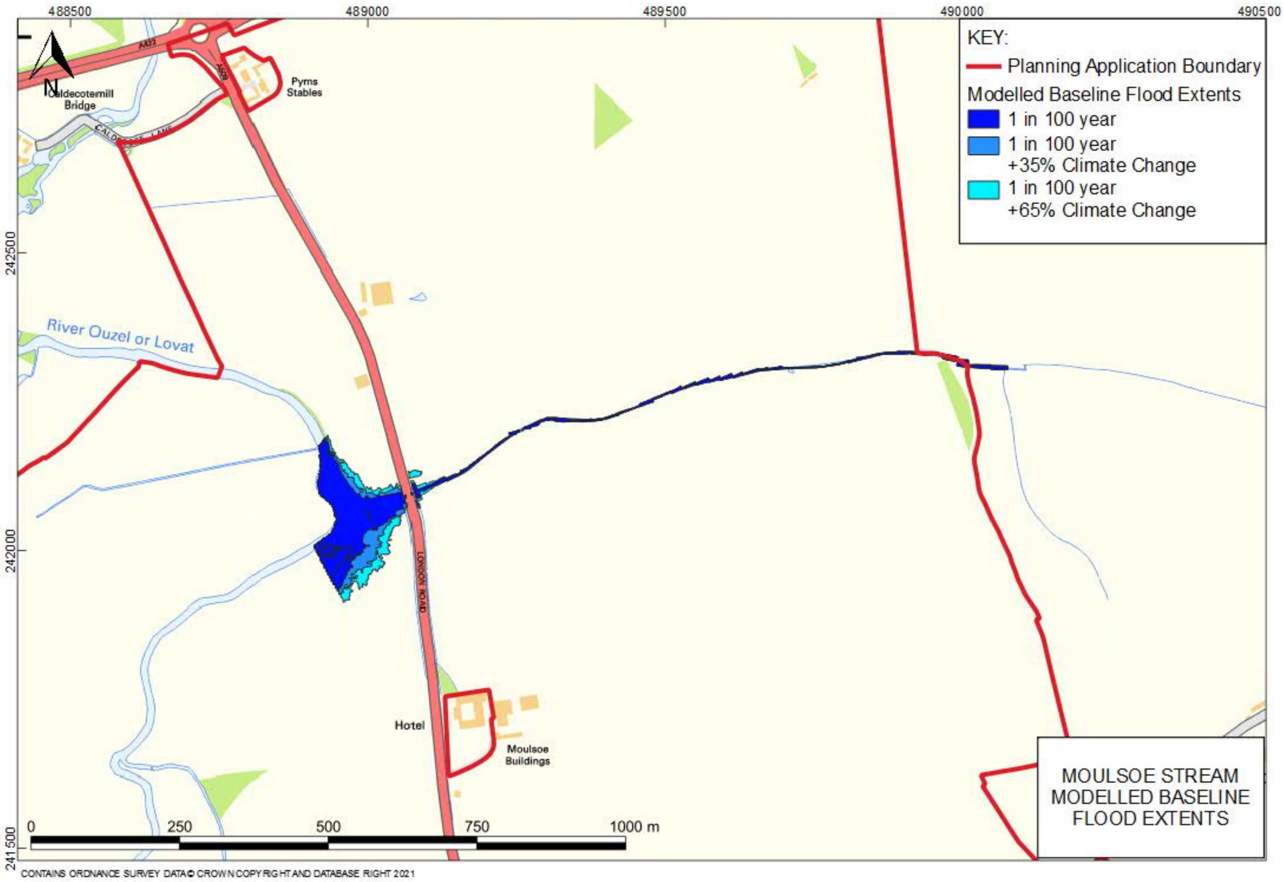
5.6.8. A 1D/2D Estry- Tuflow hydraulic model was constructed for the Moulsoe Stream, extending from where the stream crosses the site boundary (in the west) to where it meets the River Ouzel in the centre of the site.

5.6.9. The inflows for the model were derived from the hydrology derived as part of the River Ouzel model that was submitted to and approved by the Environment Agency. The downstream boundary for the model was also based upon information taken from the Scheme specific River Ouzel model.

5.6.10. The baseline modelled flood extents (see Figure 14) show that the flows are mostly contained within the extent of the channel for all events up to and including the 1 in 100 event plus 65% climate change. There are small areas of out of bank flow just upstream of London Road / A509. These are however contained to a small area and do not lead to overtopping of the road. The only notable flooding is as a result of high water levels modelled in the River Ouzel at the downstream extent and extracted from the MKE River Ouzel flood model. These lead to flood extents that reach up the watercourse as far as the downstream end of the London Road culvert.

5.6.11. As a result of maintenance undertaken by the IDB, the channel of the Moulsoe Stream has been engineered and therefore has very uniform channel dimensions along the reach through the site, thereby maximising the volume of water that it can convey. Therefore significantly more volumes can be contained within the channel than would be expected from a natural channel and this explains why the flood extents are largely contained in bank for events up to the 100 year plus 65% climate change event.

Figure 14 - Modelled Baseline Flood Extents for the Moulsoe Stream

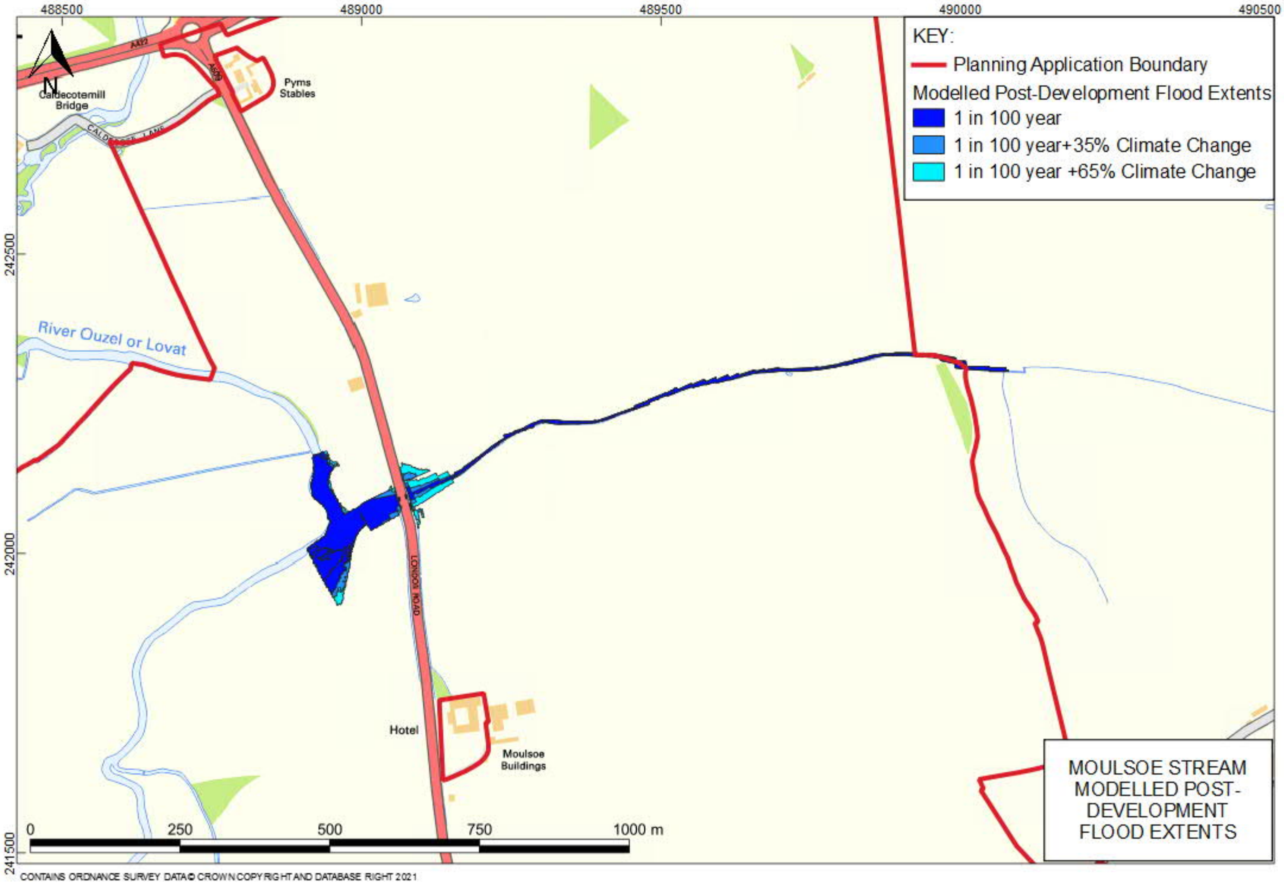


5.6.12. The post-development flood extents (see Figure 15) are largely the same as the baseline extents upstream of London Road and are mostly contained to the channel.

5.6.13. Downstream of London Road, the proposed ground raising removes the development areas from flood risk, this is shown by the reduced flood extents in Figure 15. This land raising has been agreed within the Environment Agency for both the River Ouzel and Moulsoe Stream, as the River Ouzel includes flow estimates for the River Ouzel immediately downstream of London Road.

5.6.14. At the upstream boundary of the site the Moulsoe Stream will flow under the eastern link road. This crossing is to be a clear span bridge, to include the Moulsoe Stream (channel remaining as is) and an adjacent footpath / bridleway). No change in flood risk as a result of this structure is expected given the flood waters associated with the Moulsoe Stream remain in bank and the new bridge structure is clear of the channel and significantly higher.

Figure 15 - Modelled Post-Development Flood Extents for the Moulsoe Stream



SURFACE WATER FLOOD RISK SUMMARY

5.6.15. Whilst the majority of the site is at low to very low risk of surface water flooding, there are several areas within the application boundary that are currently shown to be at medium to high risk.

5.6.16. The most significant surface water flowpath across the site is associated with the Moulsoe Stream. Hydraulic modelling of the stream has demonstrated that the post-development flood extents are largely the same as the baseline extents upstream of London Road and are mostly contained to the channel.

5.6.17. Following the development, for the majority of the drains and non main river watercourses within the development, surface water runoff will be controlled by the SuDS strategy (see section 6.5).

5.6.18. Details of the SuDs strategy and surface water flood risk mitigation measures are included in section 6.5.

Identified Surface Water Flood Risk: Low

5.7. GROUNDWATER FLOOD RISK

5.7.1. According to the Source Protection Zone map provided by the Environment Agency, the site does not lie within any Source Protection Zones.

5.7.2. Figure 5.6 of the 2011 Tri LLFA PFRA shows an extract of the Environment Agency's Areas Susceptible to Groundwater Flooding (AStGWF) Map[7], which indicates that the western half of the site, associated with the floodplain of the River Ouzel, is in an area with a high susceptibility to groundwater flooding. The eastern half of the site is shown to have a low susceptibility to groundwater flooding.

5.7.3. The 2015 Level 1 SFRA states that there is surface water – groundwater interaction within superficial aquifers along the River Ouzel, the River Great Ouse and their tributaries. Figure B8 of the Level 1 SFRA indicates that there are no groundwater flood records within the site boundary, however groundwater flooding has been recorded downstream of the site in Newport Pagnell.

5.7.4. Groundwater monitoring was undertaken at the site in August – September 2020 by CC Ground Investigations Ltd. Across a series of boreholes on the western floodplain of the River Ouzel (close to field drain 2), groundwater was encountered at depths of between 0.5mbgl and 3.2mbgl. These groundwater levels are at/around same level as river ouzel water level. It is expected that in winter that these groundwater levels may be higher.

5.7.5. Based on the Environment Agency's AStGWF map and the absence of any recorded groundwater flooding incidents in the vicinity of the site, the risk that groundwater flooding poses to the site is assessed to be medium. It is envisaged that a lower risk is likely to be experienced at the development parcels which are at a higher elevation than the linear park and the units will have the finished floor levels raised above the adjacent ground levels.

Identified Groundwater Flood Risk: Medium

5.8. SEWER FLOOD RISK

5.8.1. Sewer flooding occurs as a result of a number of influencing factors. It is most likely to occur during storms, when large volumes of rainwater enter the sewers. However, it can also occur when pipes become blocked or damaged.

5.8.2. Figure B7 of the 2015 Level 1 SFRA shows that the site is located in an area where external sewer flooding has been recorded, however it is not known if the incident of sewer flooding occurred within the site boundary.

Identified Sewer Flood Risk: Low

5.9. ARTIFICIAL SOURCES FLOOD RISK

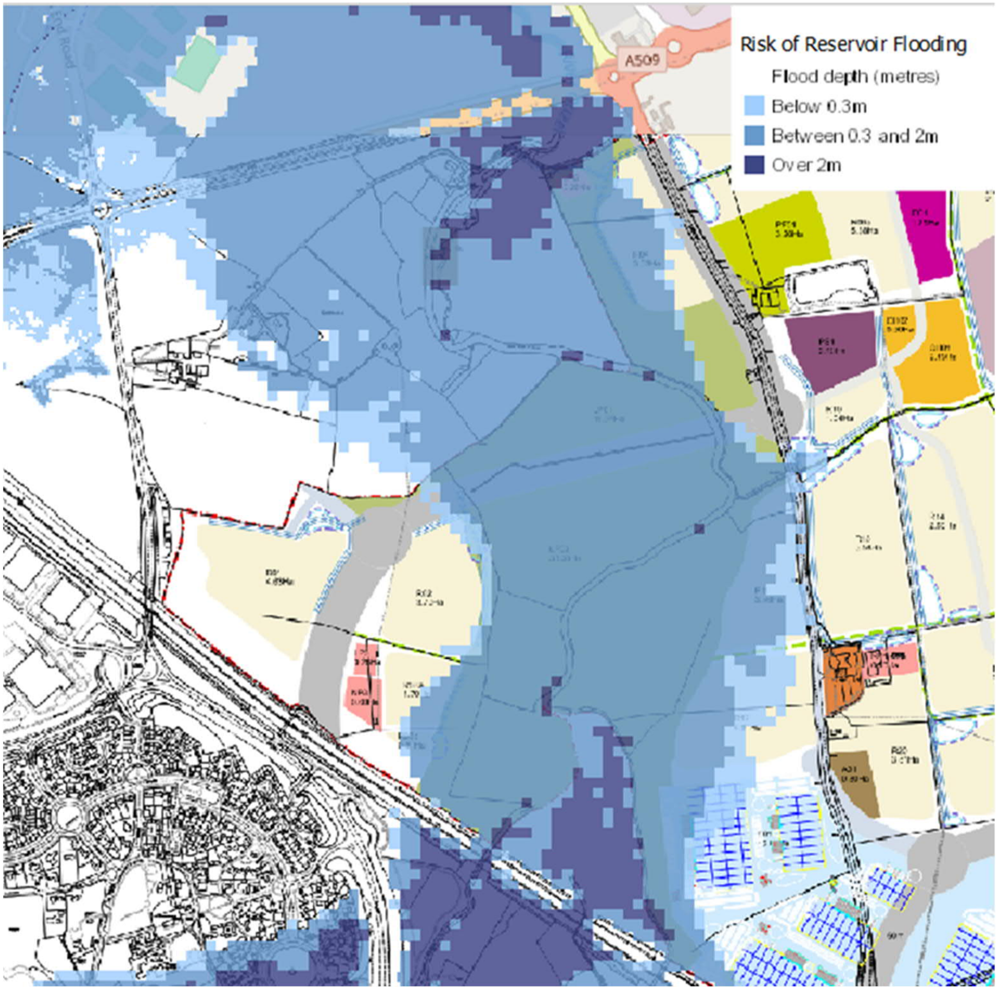
5.9.1. The Scheme is located within the Environment Agency's Risk of Flooding from Reservoir map. These are associated with the failure of Willen Lake and other upstream reservoirs (Figure 16). In the event of such a failure occurring depths of flooding would mostly be between 0.3m and 2.0m, with small areas in the southwest and northwest corners at the site at risk of depths in excess of 2.0m.

[7] Bedford Group of Internal Drainage Boards (2011) Joint Preliminary Flood Risk Assessment – Milton Keynes Groundwater Flooding. Available online at: https://bbcdevwebfiles.blob.core.windows.net/webfiles/Files/Fig%205.6%20MKC%20AStGW.pdf

5.9.2. These flood extents are largely outside of the areas which will be developed as part of the Scheme, with the lower risk categories impacting some of the development parcels. Although it should be considered that this mapping does not take account of the construction of Link 107 or the raising of the development parcels to protect against fluvial flooding. Given that reservoirs are highly regulated with regular inspections, this is considered to be of residual risk with no further design considerations required.

5.9.3. Consultation was undertaken with the Milton Keynes Council Emergency Planning Officer on 25th February 2021 and no flood risk concerns with the proposed development were raised.

Figure 16 - Environment Agency Reservoir Flood Risk Map



Identified Flood Risk from Reservoirs: Low

Other sources

5.9.4. No canals or other artificial waterbodies in the vicinity of the Scheme that could pose a risk of flooding to the site have been identified.

6. FLOOD RISK MITIGATION

6.1.1. This section explores the flood risk to each section of the Scheme and how appropriate management approaches will be included to ensure that the development is not exposed to an unacceptable level of flood risk.

6.1. DEVELOPMENT PARCELS

6.1.1. Each of the development parcels which are adjacent to the River Ouzel floodplain have been raised 600mm above the 1 in 100 year plus 35% climate change flood level. This platform level remains above the sensitivity design threshold of the 1 in 100 year plus 65% climate change flood level along with the 1 in 1,000 year flood level, this is detailed in Table 6.

Table 6 - Minimum Platform Levels

	Design Scenario - 1 in 100 year plus 35% climate change		**Sensitivity Scenario - 1 in 100 year plus 65% climate change**		**Extreme Scenario - 1 in 1,000 year**	
Development Parcel	Flood Level (mAOD)	Minimum Platform Level (mAOD)	Flood Level (mAOD)	Freeboard (m)	Flood Level (mAOD)	Freeboard (m)
RO3B	57.84	58.44	58.00	-0.44	57.82	0.62
RO3A	57.83	58.43	57.99	-0.44	57.81	0.62
R02	57.80	58.40	57.97	-0.43	57.79	0.61
R12	57.84	58.44	58.00	-0.44	57.83	0.61
R11	57.74	58.34	57.94	-0.4	57.73	0.61
RO4	56.86	57.46	57.01	-0.45	56.85	0.61

6.2. HIGHWAY LINK 107 (RIVER OUZEL CROSSING)

6.2.1. The soffit level of the bridge and flood relief culverts of Highway Link 107 (the River Ouzel Crossing) will be set above the 1 in 100 year plus 35% flood level plus 600mm freeboard, see Table 7.

Table 7 - Comparison of Soffit and Flood Levels for Highway Link 107 (the River Ouzel Crossing)

Soffit Level [MAOD]				
Opening	**Soffit Level**	**Design Scenario - 1 in 100 year plus 35% climate change**	**Sensitivity Scenario - 1 in 100 year plus 65% climate change**	**Extreme Scenario - 1 in 1,000 year**
Bridge	61.00	57.58	57.75	57.58
Central Pedestrian Underpass	59.52	57.72	57.88	57.7
Western Pedestrian Underpass	59.46	57.75	57.90	57.73

6.2.2. The residual risk of blockage of these features has been assessed as a part of the hydraulic modelling carried out for the scheme. A percentage blockage of 50% has been used to inform the blockage sensitivity testing of the pedestrian access routes under Highway Link 107 (the River Ouzel Crossing).

6.2.3. Flood extents largely remain the same in the 50% blockage scenario as they were in the approved post-development scenario.

6.2.4. Minor increases in flood depths are predicted in the 50% blockage scenario within the development boundary. For the 1 in 100 year +35% climate change design event plus 50% blockage scenario there is a maximum flood depth increase of approximately 0.03m, immediately upstream of Highway Link 107. In the context of the predicted flood depths at this location (approximately 1.2m), a 0.03m increase in flood depths is considered negligible.

6.2.5. Flood difference maps illustrating the difference between the post-development and 50% blockage scenario results are shown in Appendix F.

6.2.6. Given there is a negligible difference in flood depths and extents in the modelled 50% blockage scenario, it is not considered that a blockage of Highway Link 107 would cause an increase in flood risk.

6.3. PLAY AREA

6.3.1. To ensure the safety of the playground area users, the proposed playground on the edge of the linear park has a platform level above the 1 in 100 year plus 65% climate change level (57.95mAOD), this includes the two walkways that serve as access and egress routes from the adjacent development platform to the play area, to ensure that in large flood events all users would be able to safely leave the play area.

6.4. LINEAR PARK

6.4.1. The inclusion of the linear park within the Scheme will result in additional users within the floodplain. No increase in risk to people is predicted as the flood waters are considered to raise relatively slowly given the size of the catchment. This will provide sufficient time for users of the linear park to exit the area via the numerous access / egress points which will be located along the boundaries of the park to the development parcels, with connection between the two sides of the development provided, in the immediate vicinity, by Link 107 and the A422.

6.4.2. The detailed design stage will also consider the inclusion of additional signage at the access / egress points to the linear park to ensure that all users are aware that this is an active floodplain.

6.5. POST-DEVELOPMENT SURFACE WATER STRATEGY

6.5.1. To mitigate the risk of surface water flooding to the development a comprehensive drainage / SUDS strategy has been developed and is provided as a standalone document. This strategy involves attenuating the surface water runoff at source, attenuating in ponds and swales, prior to discharge to the River Ouzel or the Broughton Brook.

6.5.2. In summary the SuDS Strategy has been developed in accordance with the policies set out within Plan MK, this requires the Scheme to continue the exemplar sustainable drainage model of Milton Keynes, with drainage infrastructure to be provided as strategically as possible and as part of a maintained, multi-functional blue-green infrastructure. The drainage strategy is being developed in accordance with these guiding principles.

6.5.3. Watercourses will be maintained and enhanced within the development wherever possible. The future maintenance regime associated with these watercourses is currently under review with the relevant stakeholders to ensure that drainage, flood risk, bio-diversity and amenity requirements are aligned.

6.5.4. There may be a range of small field drains / ordinary watercourses which are removed / realigned to become part of the SuDS strategy as a result of the Scheme, however, this will be determined during the detailed design phase and permission will be sought as part of the reserved matters applications. There may be a range of small field drains / ordinary watercourses which are removed / realigned to become part of the SuDS strategy as a result of the Scheme, however, this will be determined during the detailed design phase and permission will be sought as part of the reserved matters applications.

6.5.5. During exceedance events surface water will be directed along highways and towards open attenuation facilities.

7. MAINTENANCE REQUIREMENTS

7.1.1. The Drainage Strategy Report which accompanies this FRA outlines the likely maintenance requirements for the various aspects of the drainage features, these requirements will be confirmed during detailed design.

7.1.2. There are other parts of the Scheme require an appropriate maintenance strategy, to manage the residual flood risk, these are associated with the highway network, as such the responsibility will fall to Milton Keynes Council as the Highway Authority. These aspects include:

- Link 107 flood relief culverts (*2) and associated bridge opening;
- The Moulsoe Stream Culvert under the A509;
- The Moulsoe Stream under the eastern link road (this is to remain in channel); and
- The River Ouzel beneath the widened Tongwell Street Bridge.

8. CONCLUSIONS

8.1.1. This FRA determines that the risk of flooding to and from the proposed development is compliant with the NPPF. Pre-application consultation has been held with the Environment Agency, who have confirmed their support for the Scheme, stating that they have no in principle objections to the scheme.

8.1.2. The site is located adjacent to the River Ouzel, with the River Ouzel flowing from south to north through the western half of the site, this means that part of the site is located within Flood Zones 2 and 3. Several tributaries of the River Ouzel are also located within the site boundary, the most significant of which is the Broughton Brook. This watercourse flows through the southern boundary of the site and underneath the M1 motorway before it reaches its confluence with the River Ouzel in the centre of the site. Where the Broughton Brook passes through the south of the site there is land designated within Flood Zone 2 and 3.

8.1.3. Extensive hydraulic modelling has been undertaken for the River Ouzel and the Broughton Brook to better understand the baseline fluvial flood risk to the site and to assess the impact on flood risk of the proposed scheme (which includes Highway Link 107 (the River Ouzel Crossing) and the raising of the development parcels). Given that climate change is expected to increase the risk of fluvial flooding, this modelling has accounted for the impacts of climate change over the lifetime of the development. The development parcels are designed to be above the 1 in 100 year plus 35% climate change fluvial flood level to ensure they remain safe over the course of their lifetime. Furthermore, sensitivity testing demonstrates that they will remain safe for the 1 in 100 year plus 65% climate change scenario.

8.1.4. The baseline and post development hydraulic models have been deemed acceptable by the Environment Agency to form part of the evidence base supporting this planning application.

8.1.5. The modelling demonstrates that the Scheme will be safe for events up to and including the 1 in 100 plus 65% (the sensitivity scenario) as well as the 1 in 1,000 year event (the extreme scenario) and there is no alteration in the fluvial flood risk up or downstream of the Scheme.

8.1.6. The modelling demonstrates that the scheme does not result in any differences in flood flows or levels downstream of the Scheme. This means that the Scheme does not impact the flood risk to Newport Pagnell, which is understood to be largely protected from flooding caused by the River Ouzel due to flood defences maintained by the Environment Agency.

8.1.7. The modelling demonstrates that the scheme causes an increase in flood depth and extent upstream of Highway Link 107 (the River Ouzel Crossing), but that this increase is largely contained within the red line boundary with the exception being negligible impacts on third party land to the east of the Anglian Water WWTW. This land is owned by the Milton Keynes Development Partnership (MKDP), who intend to write in support of the proposals and is part of the current floodplain.

8.1.8. There is no risk of tidal flooding (either in the current day or future scenarios) as the site is located inland at elevations between approximately 55mAOD and 80mAOD.

8.1.9. The majority of the proposed development is to be situated outside Flood Zone 3, and is such acceptable under the NPPF, with no requirement for the sequential or exception tests. The exceptions are Highway Link 107 and the linear park.

- The proposed River Ouzel crossing (Highway Link 107) is classified as being 'Essential Infrastructure'. Table 3 of the PPG identifies that 'Essential Infrastructure' is a compatible use for sites in Flood Zone 3, if the site can pass the exception test. This report demonstrates that Highway Link 107 passes the exception test as detailed in section 4.1.
  - Part A of the exception test is passed as Highway Link 107 provides wider sustainability benefits to the community by providing enhanced transport linkages between Milton Keynes, the scheme and Newport Pagnell.
  - Part B of the exception test is passed as the hydraulic modelling demonstrates that Highway Link 107 will be safe for its lifetime and does not increased flood risk outside of the scheme extents.
- Table 3 of the PPG demonstrates that the proposed play area and linear park are considered 'water compatible' infrastructure and are therefore permitted to be located in Flood Zones 3a and 3b with no requirement to undertake the exception test.

8.1.10. The risk of flooding from surface water is considered to be very low, for the majority of the site. There are however several areas within the application boundary that are currently shown to be at medium to high risk, these are associated with IDB designated watercourses and drains. As a result of the development the majority of these drains will have their catchments significantly altered with the surface water runoff becoming controlled and managed by the drainage strategy, thus removing the flood risk, with exceedance flow paths incorporated into the layout.

8.1.11. The surface water drainage strategy, implemented as part of the development, will manage the surface water flows across the site and restrict peak flows from the impermeable areas to the equivalent greenfield flow (QBAR) or 4/l/s/impermeable hectare, whichever is less. This surface water drainage strategy has been designed to accommodate climate change for the lifetime of the Scheme.

8.1.12. The risk from groundwater flooding is considered to be medium within the linear park, the development parcels are at a higher elevation and the FFL will be raised above the adjacent land.

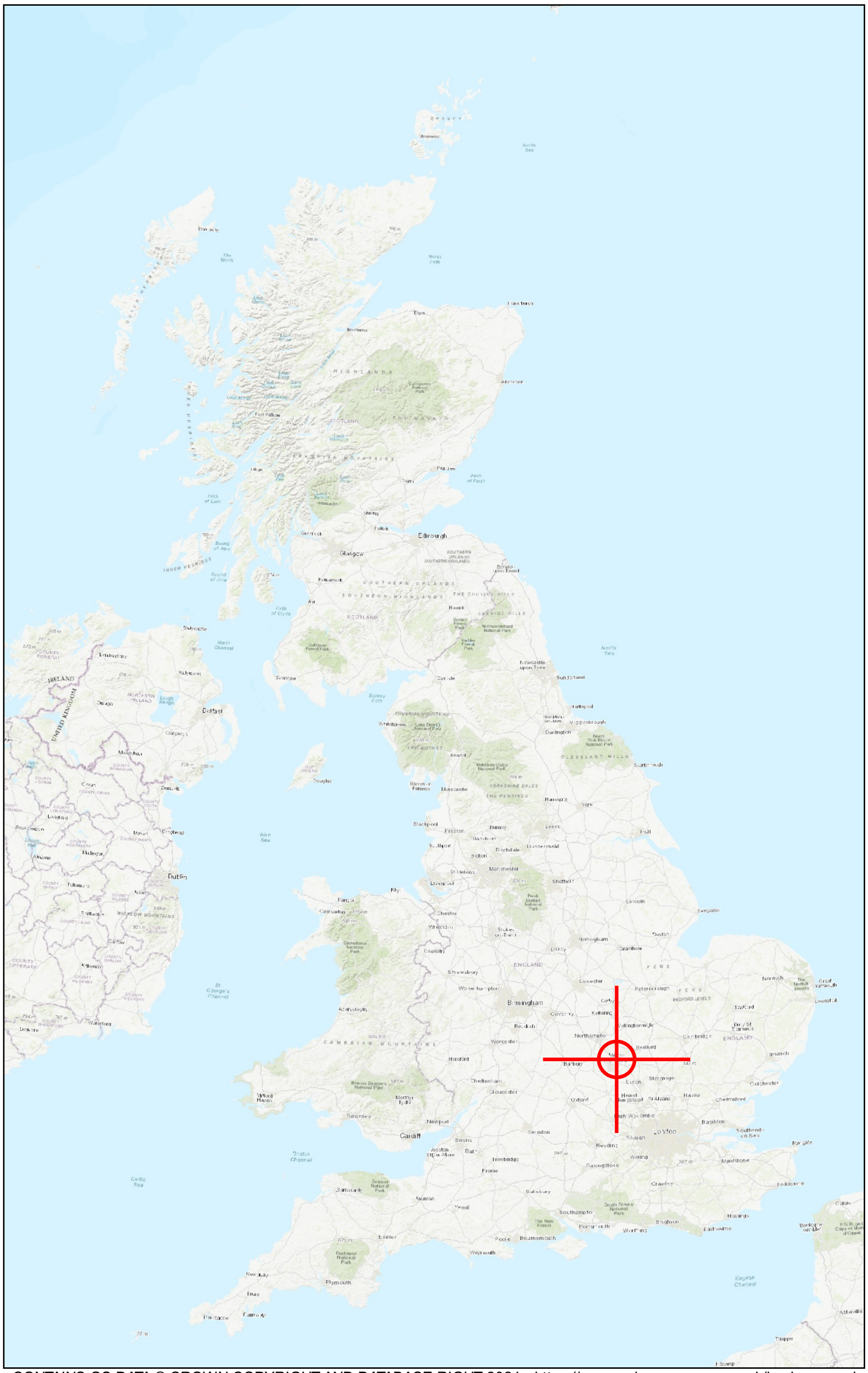
8.1.13. The site is located downstream of Willen Lake, a large raised reservoir, as such there is a residual risk of failure, however, given the management of reservoirs in the UK, the risk from artificial sources considered to be low.

Appendix A

ENVIRONMENT AGENCY FLOOD MAPS

PUBLIC

FLOOD RISK PACK



Client:
St James Group Ltd

Project Reference:
70057521 MKE PLANNING APPLICATION

Site Reference:
70057521 - Milton Keynes East

Site Location
489313, 241780

Site Area:
439 hectares

Map Scale:
1:25000

CONTENTS:

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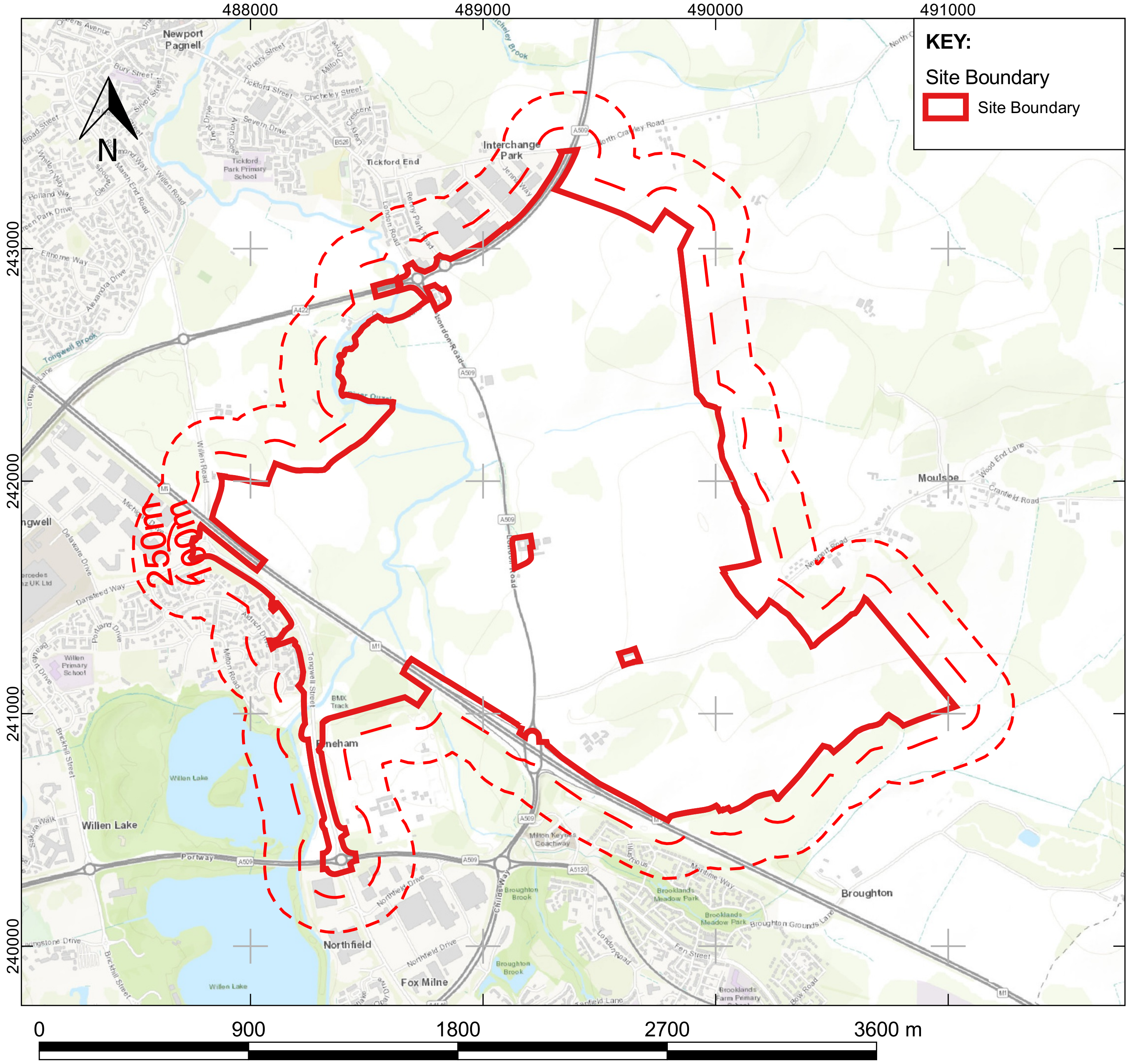
SITE LOCATION



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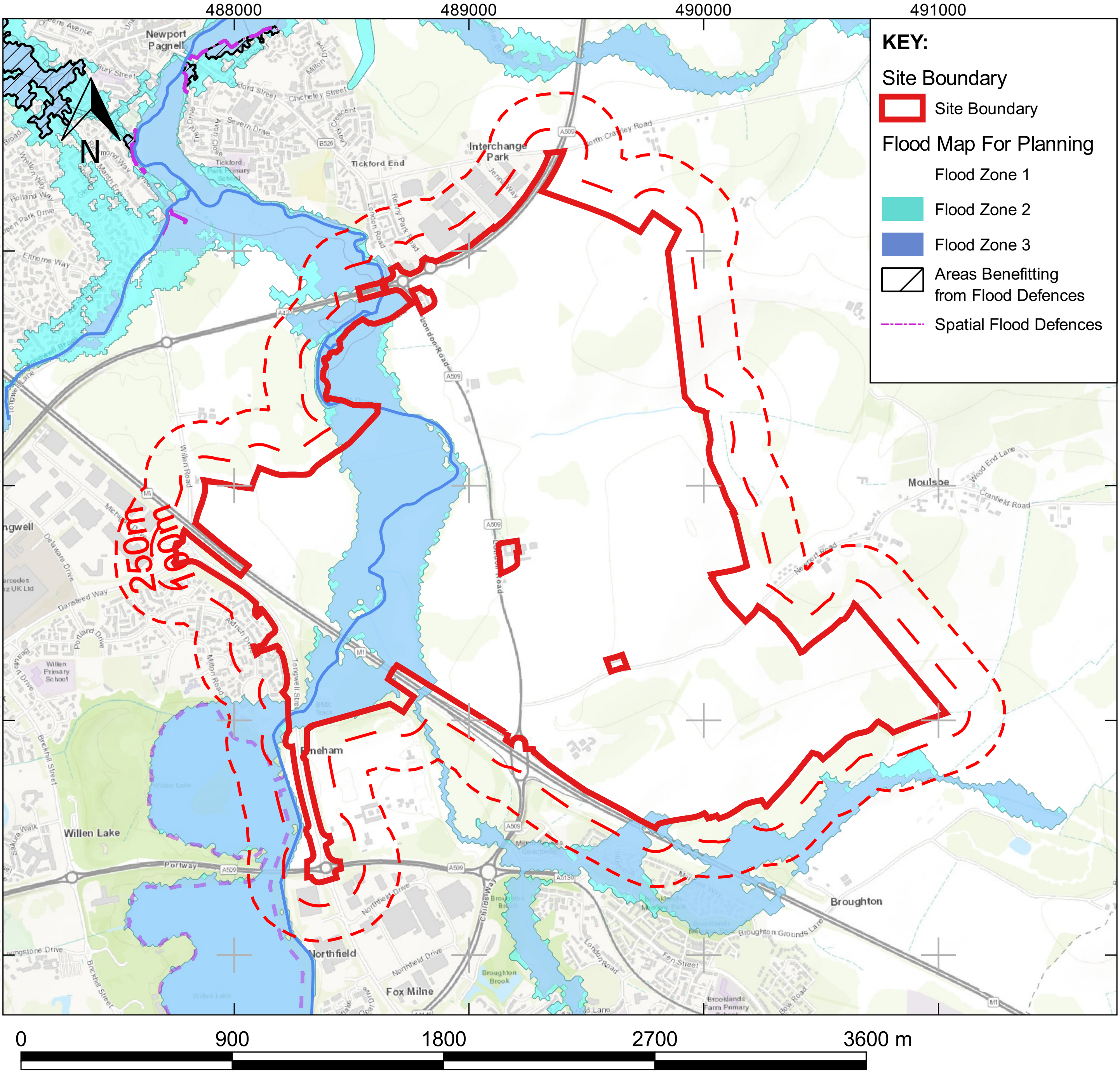
ENVIRONMENT AGENCY FLOOD MAP FOR PLANNING



Flood zone maps are modelled using local and national river and sea data. This information provides an indication of the likelihood of flooding and is intended for planning use only.

Flood Zone 1 - Land having a less than 1 in 1,000 annual probability of river or sea flooding. (Shown as 'clear' on the Flood Map – all land outside Zones 2 and 3).

Flood Zone 2 - Land having between a 1 in 100 and 1 in 1,000 annual probability of river flooding; or land having between a 1 in 200 and 1 in 1,000 annual probability of sea flooding. (Land shown in light blue on the Flood Map)

Flood Zone 3 - Land having a 1 in 100 or greater annual probability of river flooding; or Land having a 1 in 200 or greater annual probability of sea flooding. (Land shown in dark blue on the Flood Map)

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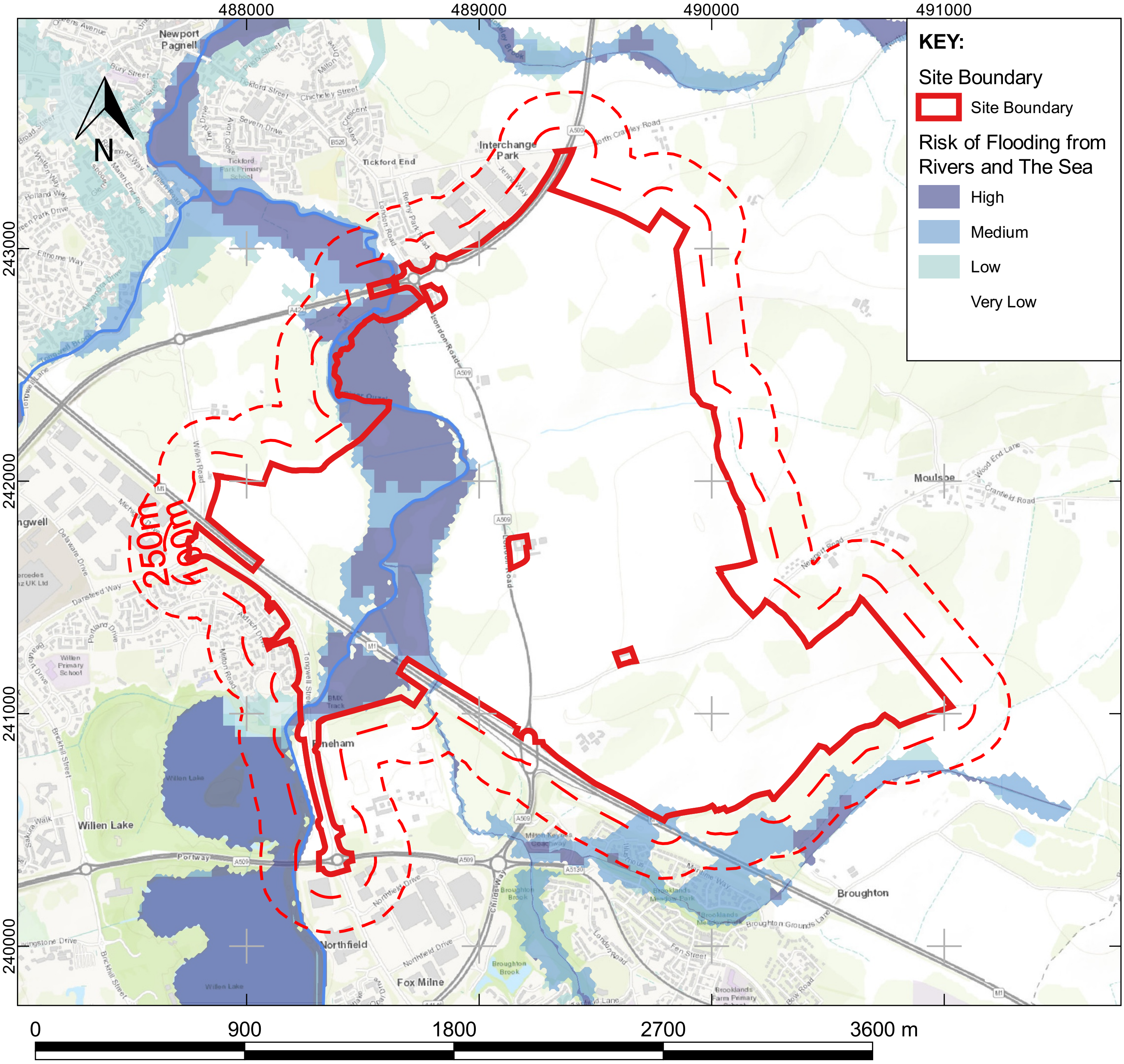
ENVIRONMENT AGENCY RISK OF FLOODING FROM RIVERS AND THE SEA



High risk means that each year this area has a chance of flooding of greater than 3.3%.

Medium risk means that each year this area has a chance of flooding of between 1% and 3.3%.

Low risk means that each year this area has a chance of flooding of between 0.1% and 1%.

Very low risk means that each year this area has a chance of flooding of less than 0.1%.

This takes into account the effect of any flood defences in the area. These defences reduce but do not completely stop the chance of flooding as they can be overtopped, or fail.

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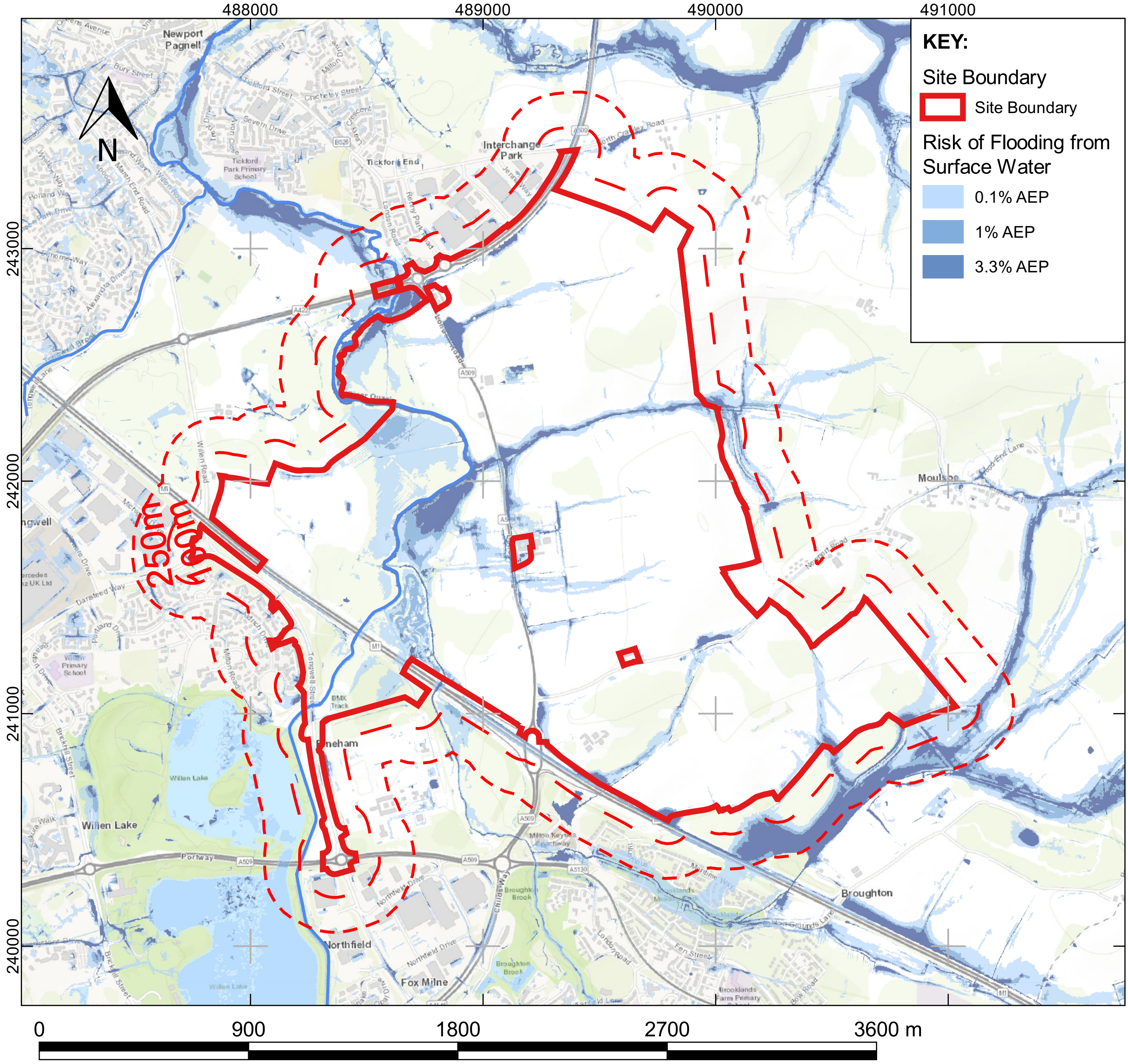
ENVIRONMENT AGENCY RISK OF FLOODING FROM SURFACE WATER



High risk means that each year this area has a chance of flooding of greater than 3.3%.

Medium risk means that each year this area has a chance of flooding of between 1% and 3.3%.

Low risk means that each year this area has a chance of flooding of between 0.1% and 1%.

Very low risk means that each year this area has a chance of flooding of less than 0.1%.

Flooding from surface water is difficult to predict as rainfall location and volume are difficult to forecast. In addition, local features can greatly affect the chance and severity of flooding.

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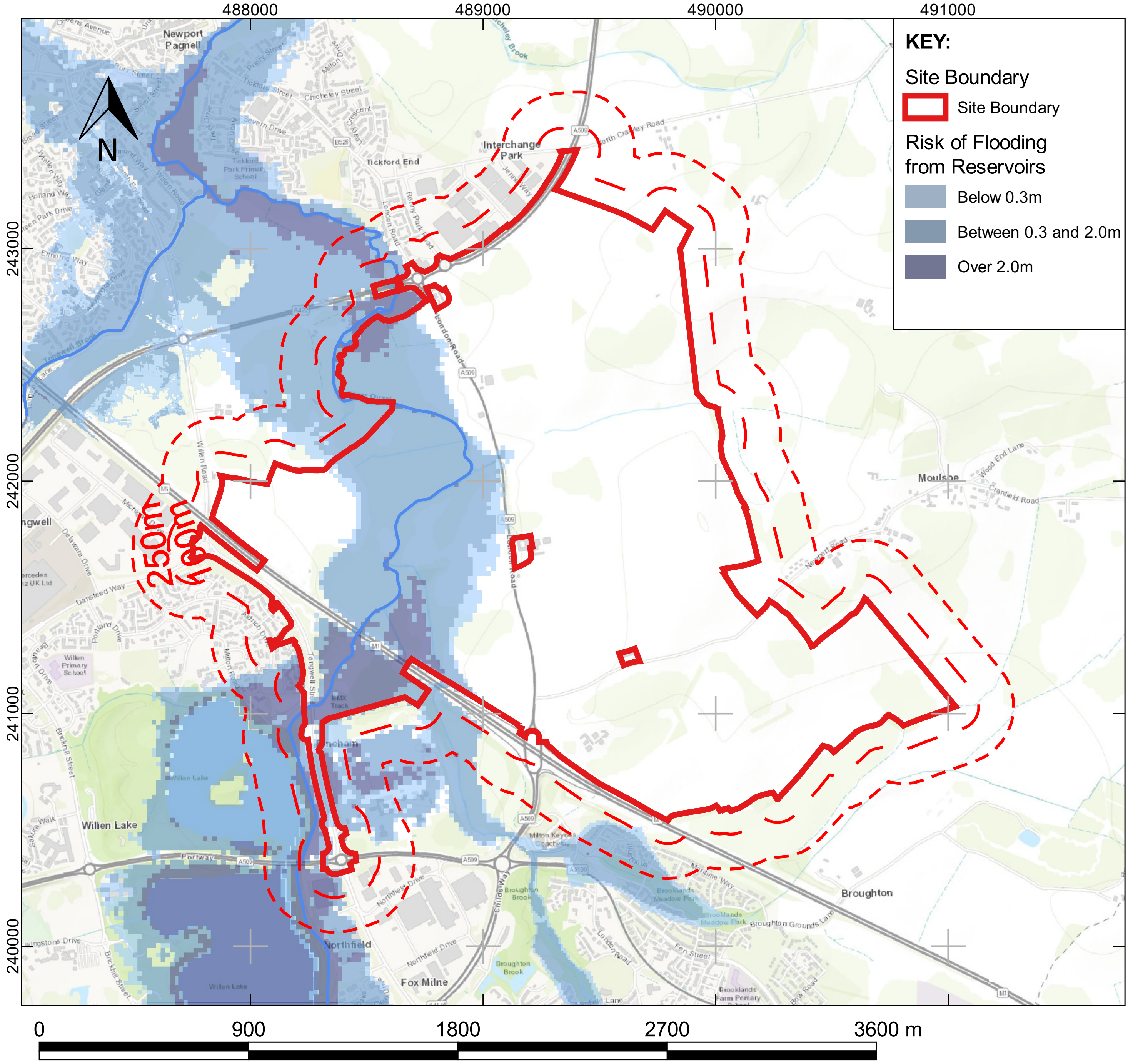
ENVIRONMENT AGENCY RISK OF FLOODING FROM RESERVOIRS



If a location is at risk, flooding from reservoirs is extremely unlikely. There has been no loss of life in the UK from reservoir flooding since 1925.

An area is considered at risk if peoples' lives could be threatened by an uncontrolled release of water from a reservoir.

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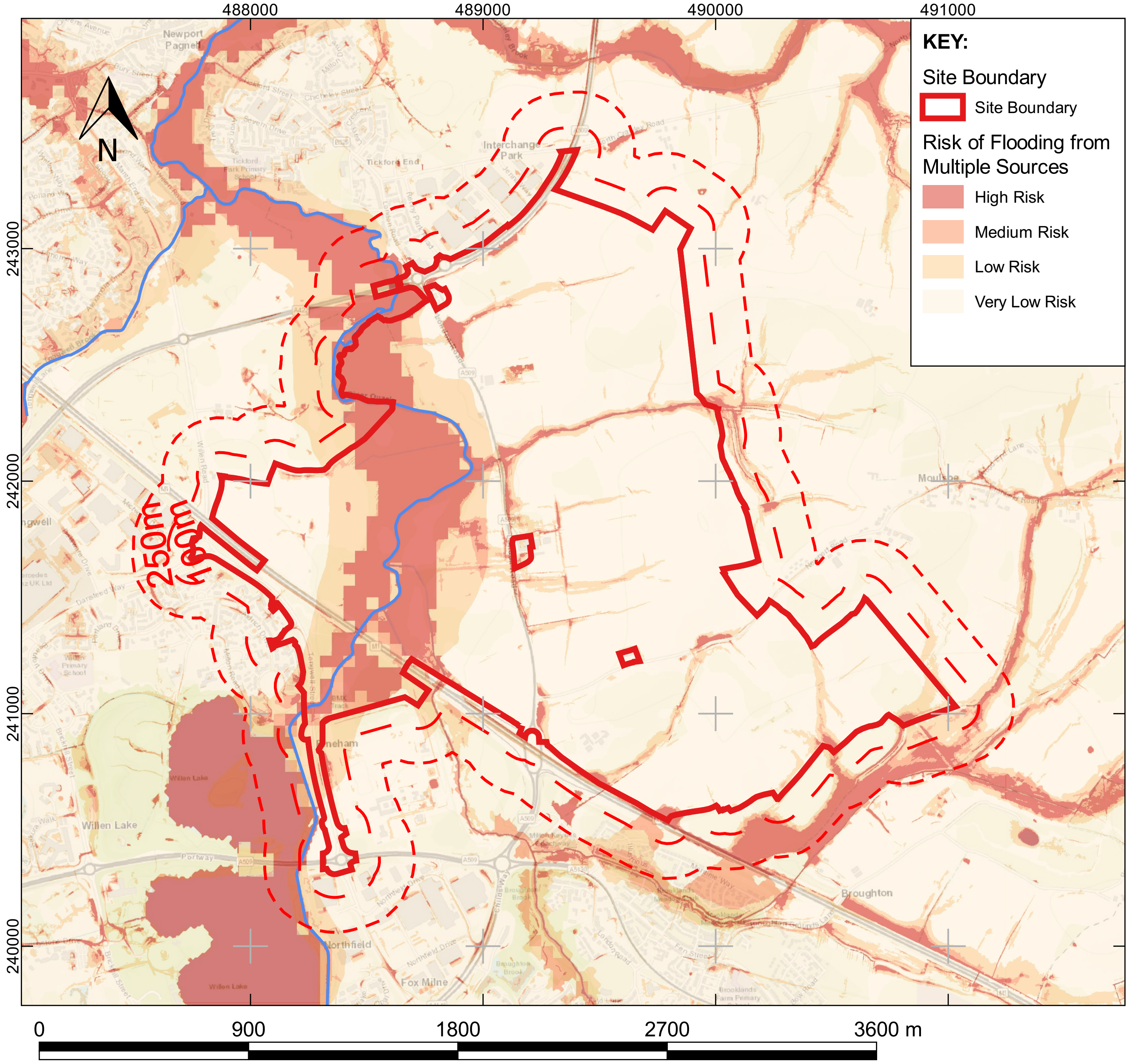
ENVIRONMENT AGENCY RISK OF FLOODING FROM MULTIPLE SOURCES



High risk means that each year this area has a chance of flooding of greater than 3.3%.

Medium risk means that each year this area has a chance of flooding of between 1% and 3.3%.

Low risk means that each year this area has a chance of flooding of between 0.1% and 1%.

Very low risk means that each year this area has a chance of flooding of less than 0.1%.

This dataset is not suitable for identifying whether an individual property will flood. The Risk of Flooding from Multiple Sources (RoFMS) information is a national scale assessment. It gives an indication of what areas of land may be at risk of flooding from more than one source. This first version of the assessment considers flooding from rivers, the sea and surface water.

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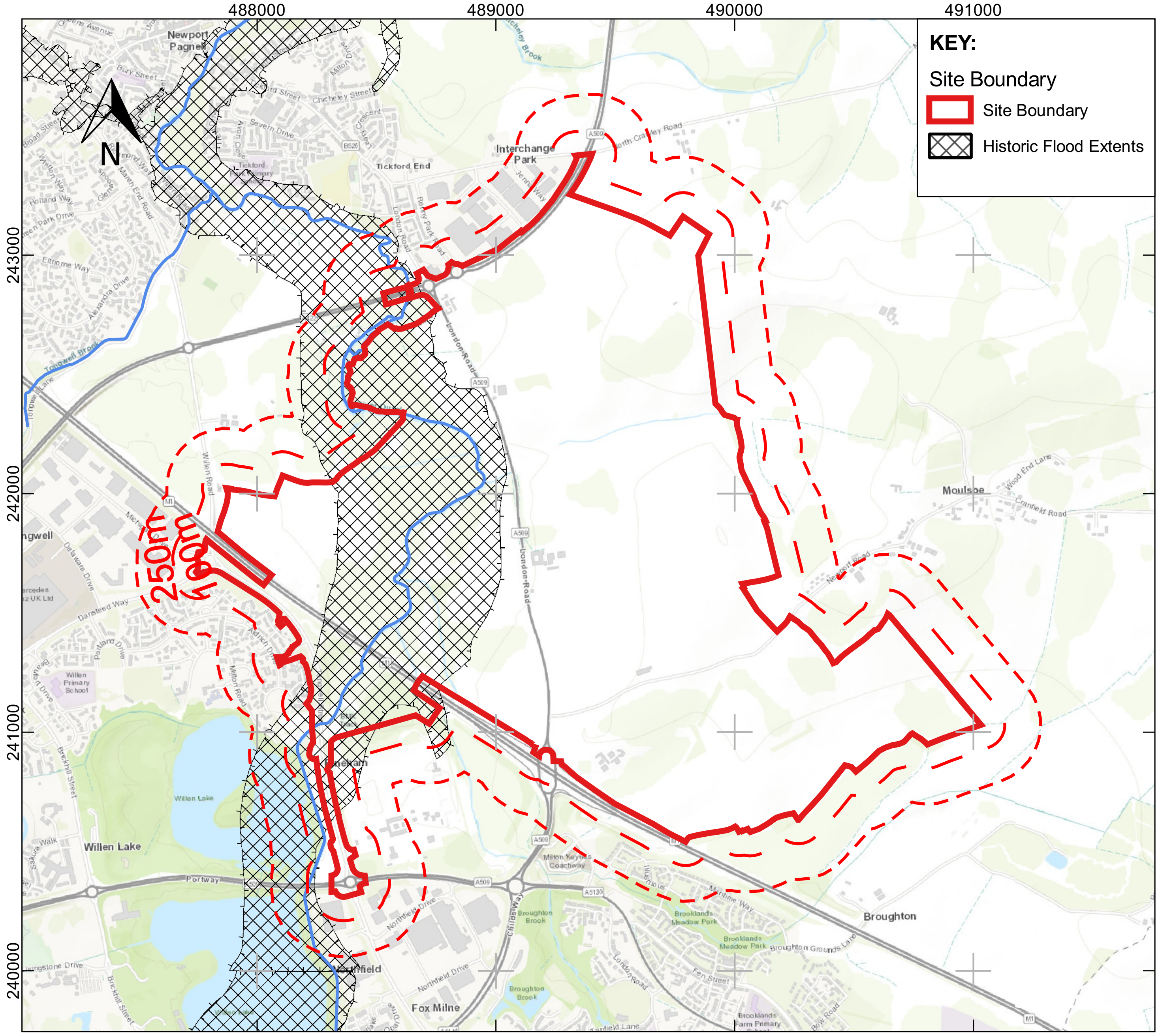
ENVIRONMENT AGENCY HISTORIC FLOOD MAP



0 900 1800 2700 3600 m

The Historic Flood Map is a GIS layer showing the maximum extent of all individual Recorded Flood Outlines from river, the sea and groundwater springs and shows areas of land that have previously been subject to flooding in England. Records began in 1946 when predecessor bodies to the Environment Agency started collecting detailed information about flooding incidents, although limited details may be held about flooding incidents prior to this date.

The absence of coverage by the Historic Flood Map for an area does not mean that the area has never flooded, only that we do not currently have records of flooding in this area. It is also possible that the pattern of flooding in this area has changed and that this area would now flood under different circumstances. The Historic Flood Map will take into account of the presence of defences, structures, and other infrastructure where they existed at the time of flooding. It will include flood extents that may have been affected by overtopping, breaches or blockages. Flooding shown to the land and does not necessarily indicate that properties were flooded internally.

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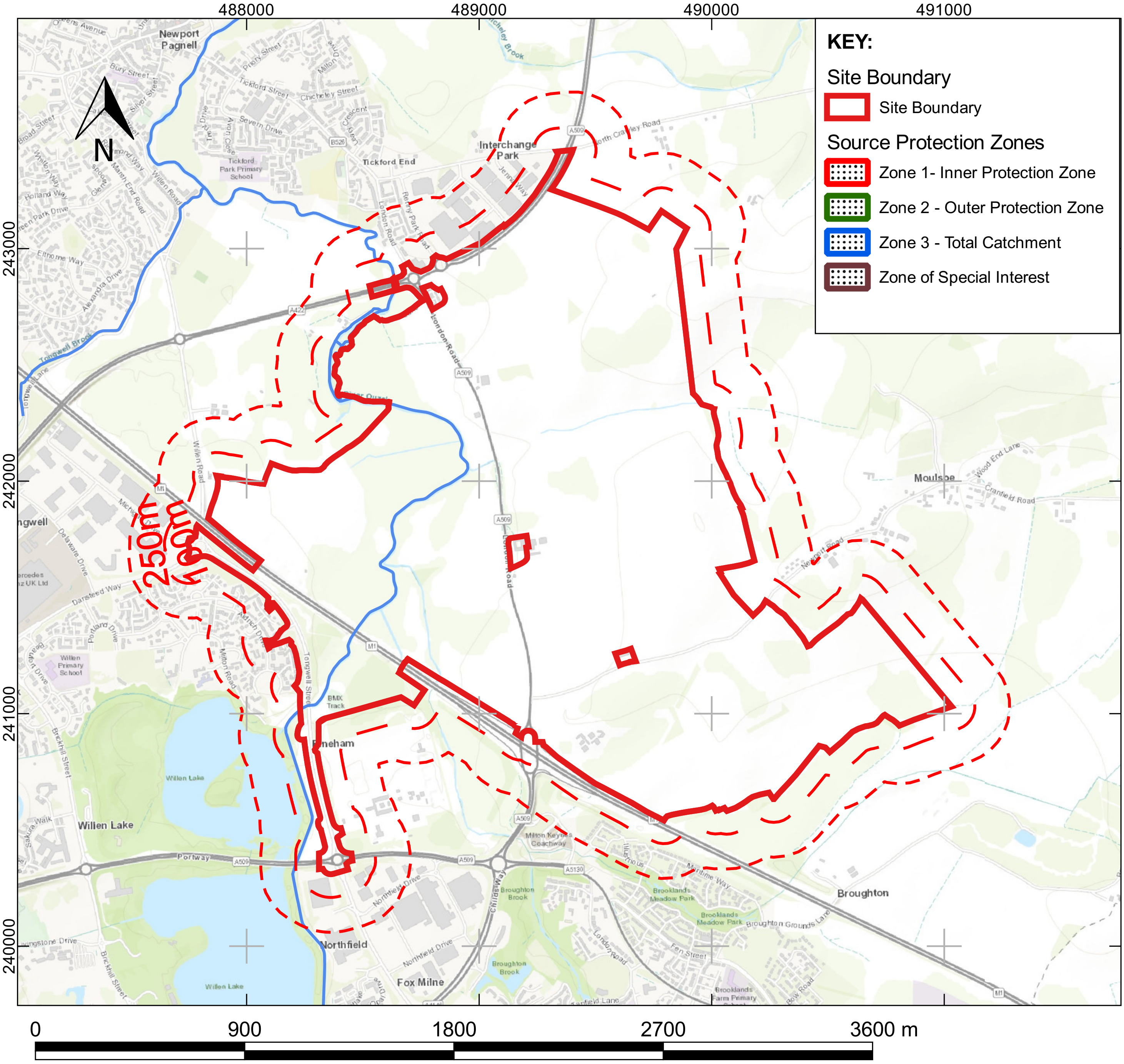
ENVIRONMENT AGENCY SOURCE PROTECTION ZONES



Inner zone (Zone 1) - Defined as the 50 day travel time from any point below the water table to the source. This zone has a minimum radius of 50 metres;

Outer zone (Zone 2) - Defined by a 400 day travel time from a point below the water table. The previous methodology gave an option to define SPZ2 as the minimum recharge area required to support 25 per cent of the protected yield. This option is no longer available in defining new SPZs and instead this zone has a minimum radius of 250 or 500 metres around the source, depending on the size of the abstraction;

Total catchment (Zone 3) - Defined as the area around a source within which all groundwater recharge is presumed to be discharged at the source.

Special interest (Zone 4) - A fourth zone SPZ4 or 'Zone of Special Interest' was previously defined for some sources. SPZ4 usually represented a surface water catchment which drains into the aquifer feeding the groundwater supply (i.e. catchment draining to a disappearing stream).

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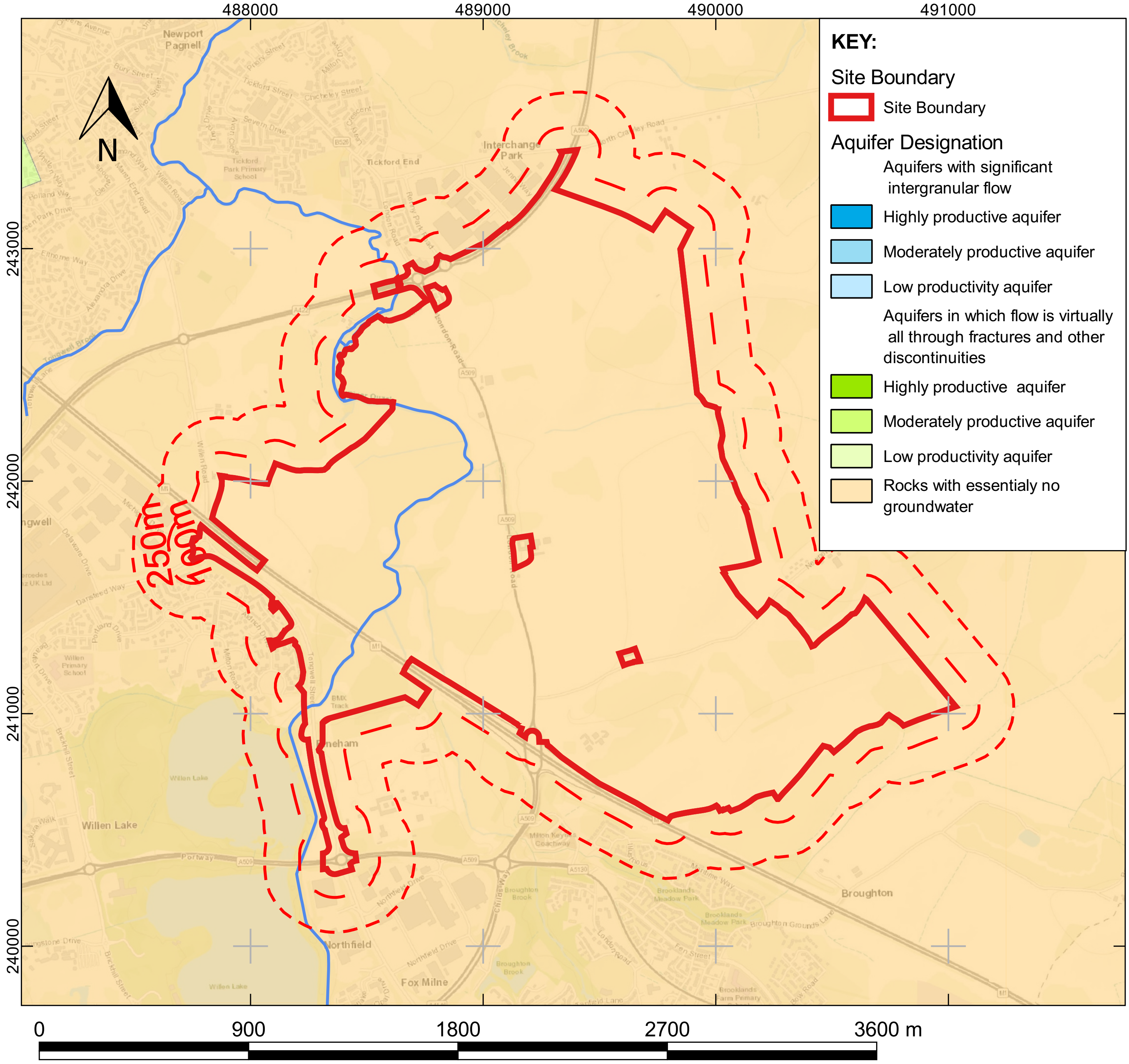
ENVIRONMENT AGENCY 1:625,000 SCALE AQUIFER DESIGNATION



The hydrogeological map indicates aquifer potential in generalised terms using a threefold division of geological formations:

1. those in which intergranular flow in the saturated zone is dominant
2. those in which flow is controlled by fissures or discontinuities
3. less permeable formations including aquifers concealed at depth beneath covering layers

Highly productive aquifers are distinguished from those that are only of local importance or have no significant groundwater. Within each of these classes the strata are grouped together according to age or lithology.

The 1:625 000 scale data may be used as a guide to the aquifers at a regional or national level, but should not be relied on for local information.

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Appendix B

RIVER OUZEL BASELINE
HYDRAULIC MODELLING REPORT

St James

MILTON KEYNES SUSTAINABLE URBAN EXTENSION

Hydraulic Modelling Report - Proposed Highway

51078-HMR-001
FEBRUARY 2019

PUBLIC

St James

MILTON KEYNES SUSTAINABLE URBAN EXTENSION

Hydraulic Modelling Report - Proposed Highway

TYPE OF DOCUMENT (VERSION) PUBLIC

PROJECT NO. 70051078

OUR REF. NO. 51078-HMR-001

DATE: FEBRUARY 2019

St James

MILTON KEYNES SUSTAINABLE URBAN EXTENSION

Hydraulic Modelling Report - Proposed Highway

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1 INTRODUCTION

1.1.1. WSP was commissioned by St James to undertake hydraulic modelling to support the proposed Milton Keynes East Sustainable Urban Extension (MKESUE). This includes the area of strategic housing (and wider employment use) development area in Plan:MK. The scheme allows for the expansion of Milton Keynes to the north east of the M1 and significantly contribute to the delivery of the economic ambitions of the Cambridge, Milton Keynes, Oxford growth corridor.

1.1.2. The scale of MKESUE is:

- 5,000 homes by 2035 with the potential for a further 3,000 dwellings to be delivered beyond that;
- 31% affordable housing;
- 6,330 jobs (created from 105 hectares of logistics space and knowledge intensive business space);
- New schools, health care facilities and a local centre along with other ancillary land uses.

1.1.3. Given the scale of the development the flood risk assessment is being undertaken in phases. This report provides the assessment of the first phase, which is the definition of the flood plain associated with the River Ouzel and the construction of a new highway across the River Ouzel and its associated floodplain.

1.1.4. The purpose of the modelling exercise is to determine:

- To define the flood plain associated with the River Ouzel including the current allowances for climate change of 35 and 65%.
- The impact of the new bridge over the River Ouzel in the centre of the proposed development on flood levels.
- The need to ensure that the flood flows from the River Ouzel are not delayed for the critical 1 in 100 year event as it is understood that the peak currently passes through Newport Pagnell before that from the River Great Ouse.

2 FLOOD MODELLING

2.1 TOPOGRAPHICAL AND CHANNEL SURVEY

2.1.1. A topographical and channel survey for the Scheme and to support this hydraulic modelling was completed in June 2008 by Cartographical Surveys Ltd. The survey covers the relevant reach of the River Ouzel (between NGR488631, 242879 and NGR 488455, 241330) as shown on Figure 2-1.

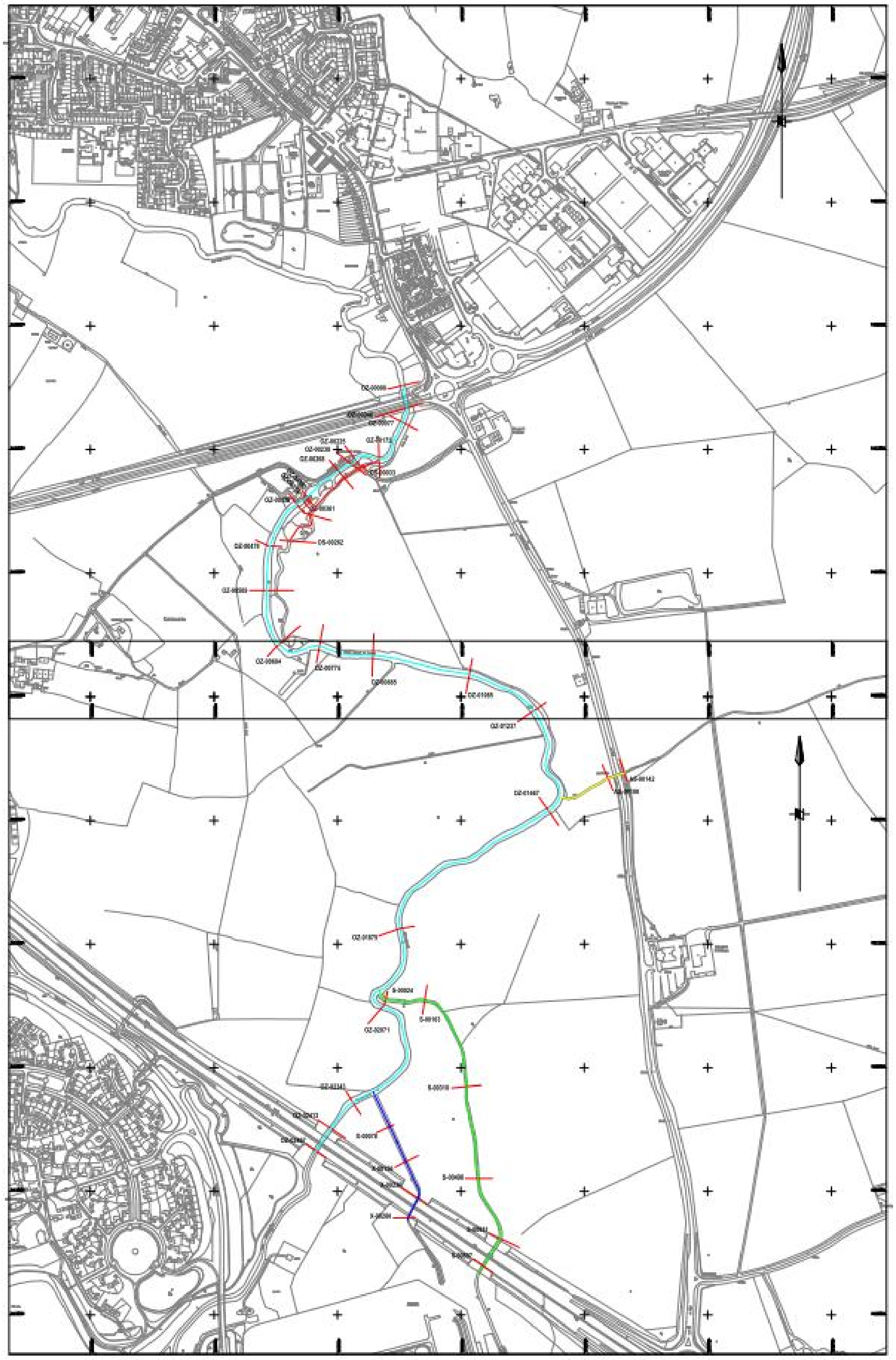

Figure 2-1 - Topographical and Channel Survey Extents

2.2 EXISTING HYDRAULIC MODELS

2.2.1. The Environment Agency (EA) have provided WSP with two ESTRY-TUFLOW hydraulic models for the River Ouzel which includes the study area.

- The Upper River Great Ouse ESTRY-TUFLOW Model, 2011 (the 2011 EA model)
- The Upper River Great Ouse ESTRY-TUFLOW Model, 2018 (the 2018 EA model).

2.2.2. A review of the latest 2018 EA model, obtained in July 2018, confirms that there have been very few changes, particularly within the area of interest. The main changes undertaken by the Environment Agency have been limited to realignment of the cross sections, which has not had an impact on the flood regime or extents in the area of interest.

2.2.3. The 2011 Environment Agency model has been used as the basis for this study, as it was cut down to facilitate model run times prior to the updated 2018 Environment Agency model, with no observed differences it was deemed suitable for continued use. This is referred to the 'cut model' and is covers the areas between Ouzel Valey Park, near Woolstone (OS grid reference SP 87749 39063) and Newport Pagnell (OS grid reference SP 87837 43229).

2.3 ENHANCEMENTS

2.3.1. We have enhanced the model to transform it from a strategic model to a site specific model, that is suitable for use in a scheme specific flood risk assessment through the implementation of the following changes:

- Comparison of the Environment Agency data used to represent the 1D channel and the channel survey indicates consistency. Therefore, the Environment Agency model only required an additional six cross sections: OZ-02413, OZ-01875, OZ-01467, OZ-01237, OZ-00172, OZ-00000, which are mainly located near the structures and when the distance between Environment Agency sections is significant.
- The trimmed model upstream section is BR_08_03_106_CH8.2.csv and downstream section is BR_08_01_101_ch000_800.csv. The sections were chosen making sure appropriate distance is given from the site of interest boundaries.
- In some locations within the site the Environment Agency model has the 1D channel width being wider than the width allowed for in the 2D domain, which is likely to cause double counting of the volume of floodplain. Therefore, the cross sections were checked to ensure that the width if the xs database is relevant with the hydraulic model width and bank points included overlap. Where it was deemed that the cross sections are not represented accurately the changes detailed in Appendix A were made
- Where discrepancies between the width of the 1D active domain (2D_Code = 0) and width of the 2D_HXI were greater than 0.3m, the width of the 1D active code in GIS was corrected to match the width of the active channel cross section as read by ESTRY in the section CSV file. New elevation points (ZP) were added at the intersection of CN and HXI lines.
- At the edges of the area of interest the M1 bridge and A422 bridge have been included and represented in the model as in the 2008 WSP topographical survey. The bridge piers have been represented by increased manning roughness polygons.
- The Caldecote Mill structure representation which is very simplified in the Environment Agency model has been left unchanged. The parallel channel not included within the Environment Agency model has been included by changing upstream section based on the WSP 2008 survey and widening the code polygon within 2D.

- The 1m LiDAR data have been downloaded from the Environment Agency website on 27 October 2016 and included within the model with an improved grid size (8m) which has improved representation of the floodplain, which was originally 20m.
- A roughness value of 0.035 for river bed and banks has been used. For the 2D domain, OS MasterMap was used to inform varying roughness based on surface type. The values used are described in Table 2-1 – 2D Domain Manning's 'n' values used.

Table 2-1 – 2D Domain Manning's 'n' values used.

Material Code (From OS Mastermap)	Manning's 'n'	Description
10021	0.5	Buildings
10062	0.5	Glasshouse
10187	0.5	Structures
10185	0.03	Structures (Eg-Moveable structure, upper level of communication, rail structure extent, roadside structure extent)
10053	0.05	Residential Yards
10054	0.025	Land (Step)
10056	0.05	Land (General Surface)
10076	0.5	Heritage and Antiquities (manmade)
10089	0.03	Water (Inland Water)
10096	0.03	Manmade embankment around ponds
10111	0.08	Land (Natural Environment, Eg; Tree, Rough Grassland)
10119	0.03	Paths
10123	0.03	Paths (some tarmac some dirt tracks)
10167	0.05	Railway lines
10172	0.025	Roads Tracks and Paths
10183	0.025	Roads Tracks and Paths (Roadside)
10217	0.035	Land (Unclassified; e.g.- Industrial Yards, Car parks; Kind of maintained land)
20000	0.06	Fences/bushes perpendicular to floodplin at Newport Pagnell
15	1	Piers

- The field ditch that crosses the proposed bridge location flowing west to east towards the River Ozel was infilled using a Z shape polygon. This was undertaken as it was not represented in the model, only picked up by the LiDAR and thus not a continuous flow path. This will be relocated with location and parameters subject to detailed design.

2.3.2. Following completion of the enhancements a comparison between the two models was undertaken, this confirmed that the two models compared very well and provides an appropriate level of confidence in the WSP model for the use of climate and infrastructure scenario testing. The various models demonstrate that at the location of the scheme the river corridor is well defined and there is marginal differences for changes in flow. Further information on the model comparison is provided in Appendix B.

2.4 DOWNSTREAM BOUNDARY CONDITIONS

2.4.1. The downstream boundary condition was derived using a HQ relationship obtained from the larger Environment Agency model.

2.5 TUFLOW VERSION

2.5.1. The model has been run with the latest version of TUFLOW (TUFLOW 2018-03-AB w64 with single precision).

2.6 HYDROLOGY

2.6.1. The WSP model abstracts the flows at the cut location and therefore can be considered to utilise the hydrological inputs as the 2018 EA model, which in turn uses the 2011 EA model hydrology. The inflows were derived by recording the flood hydrograph at the upstream end of the WSP model by using 2D PO lines on both the left and right floodplain. The recorded hydrographs were added as inflows on both banks of the 1D network at the upstream end of the model.

2.7 CLIMATE CHANGE ALLOWANCES

2.7.1. In accordance with the NPPF Guidance – "*Flood risk assessments: climate change allowances*"[1] the scheme is assessed against the Anglian climate change allowances of 35% and 65% for the higher central and upper end estimates.

2.8 PROPOSED HIGHWAY

The scheme requires a new bridge across the River Ouzel in the centre of the MKESUE area. The design of the bridge is being informed by and tested within the WSP model. The inclusion of the highway and associated bridge has required alterations within the 2D network and has been designed to ensure that there is no change in flood risk beyond the site boundaries whilst ensuring that the proposed highway remains dry for the 1 in 100 years plus climate change event.

As the design of the bridge has yet to be finalised, the three potential options have been assessed within the hydraulic model, these are:

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[1] https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

Option 1 – Model Scenario A2

- 20m opening across the river channel
- 40m wide opening on the left hand bank
- 16m wide opening on the flood plain

Option 2 – Model Scenario B2

- 20m opening across the river channel
- 48m wide opening on the left hand bank
- 16m wide opening on the flood plain

Option 3 – Model Scenario G

- 20m opening across the river channel
- 56m wide opening on the left hand bank
- 16m wide opening on the flood plain

The location of the highway and associated river crossing along with the proposed culverts are shown in Appendix C.

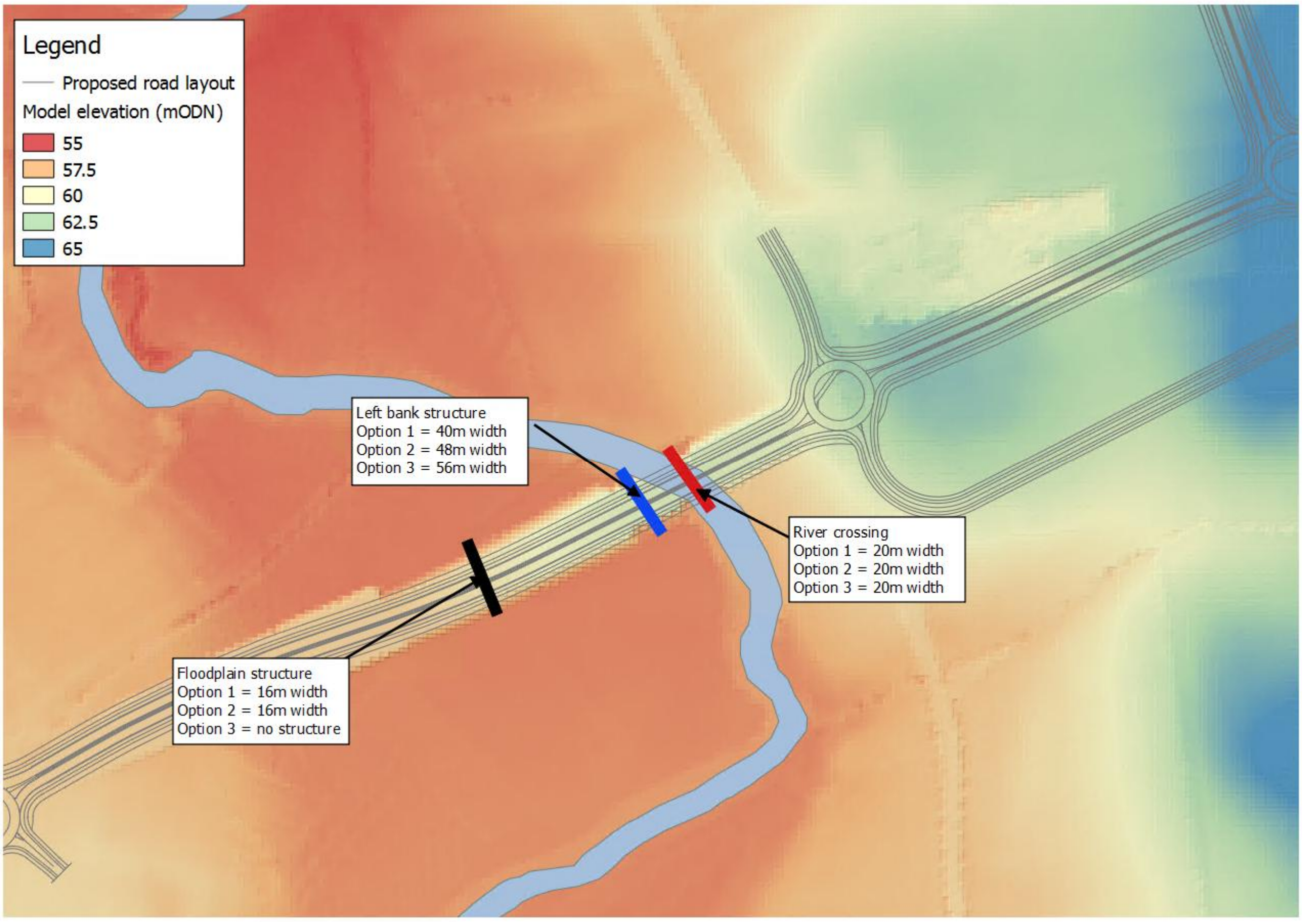

Figure 2-2 – Location of the Proposed Highway and Flow Conveyance Structures

These were modelled as a ESTRY culvert parallel to the watercourse, the width as described above, 2.75m high, 32m long, with a SX line of 5 cells. Where required the culvert in the floodplain covers two cells and is represented by a zshape.

It is deemed that the culverts adjacent to the river are of sufficient size (2.7m high adjacent to the river and where a floodplain culvert is incorporated these will need to be marginally lower in overall height to accommodate suitable cover as the road grades back to existing ground levels) to enable continuation of the bridleway that is adjacent to the left bank to accommodate an appropriate level of freeboard within the culverts.

3 MODEL RESULTS

3.1.1. The modelling demonstrates that the inclusion of the proposed highway bridge increases the flood levels within the site boundary. The most significant increases are in close proximity upstream of the bridge, whilst downstream of the bridge there is a decrease in flood levels. At the edges of the site the changes in flood levels decrease to negligible for the in 1 in 100 year event.

3.1.2. The flood depths for the baseline and proposed scenarios are shown in Appendix D. Whilst the flood difference maps are shown in Appendix E. These maps are proposed flood level – baseline with the differences extracted at the key locations, which are shown in Figure 3-1 and are reported in Table 3-2.

3.1.3. These differences in flood waters are constrained to land under our clients control or ownership apart from the small segment of land between the Broughton Brook and the River Ouzel north of the M1, which is covered by class C points in the point inspections as shown in Figure 3-1. This section of the site is referred to as Area ‘C’.

3.1.4. The proposed scheme does not have any impact on the hydrograph downstream of the site, thus there is no impact on flood risk downstream. This is important as the Environment Agency have reported that the peak flows on the River Ouzel currently pass through Newport Pagnell before those on the River Great Ouse and if they were to occur at the same time flood risk could be exacerbated downstream. This is shown by the hydrographs in Appendix F.

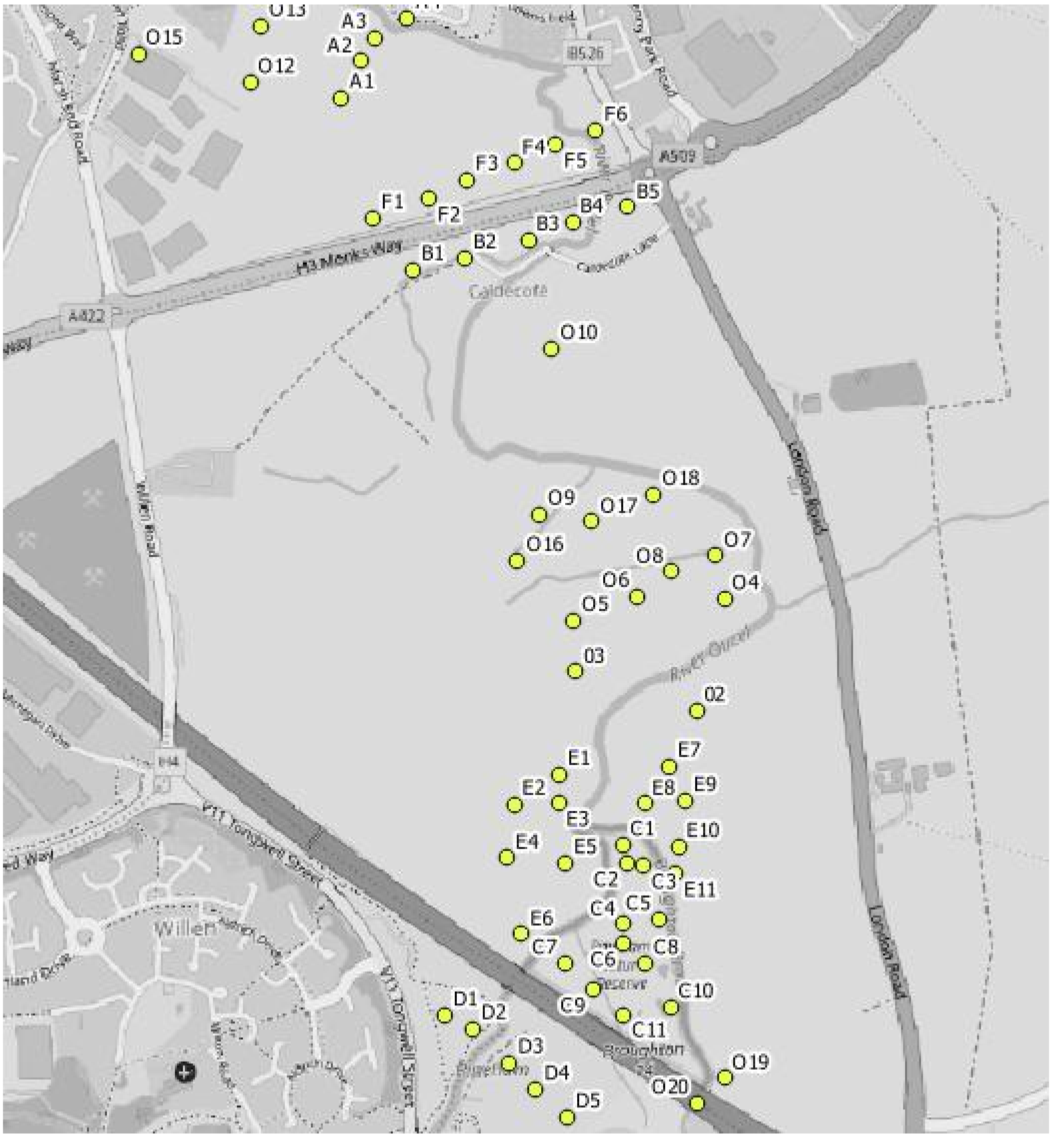

Figure 3-1 - Inspection Point Location

Contains OS data © Crown copyright and database right (2019)

3.1.5. Given the magnitude of these changes in flood levels which hare are contained within the Scheme extents for the critical 1 in 100 year event, it is considered that any of the three options could be progressed to detailed designs without the need for further mitigation measures. The final design will be incorporated within the hydraulic model to ensure that there are no adverse impacts.

Table 3-1 - Differences in flood levels at key locations

Scenario		Option 1		Option 2		Option 3	
Area 'C'	1000	C3	17.3	C3	14.5	C3	21.3
	100+65%	C1	50.1	C1	44.9	C1	60.1
	100+35%	C3	23.2	C3	20.1	C3	28.2
	100	C4	3.2	C5	2.6	C4	3.8
US M1	1000	D5	7.2	D5	6.1	D5	8.8
	100+65%	D5	17.6	D5	15.8	D5	20.7
	100+35%	D5	8.9	D5	7.9	D4	10.3
	100	D5	2.7	D5	2.3	D5	3.7
DS A422	1000	A2	0.9	A2	0.5	A2	1.0
	100+65%	A2	-1.4	A1	-1.1	A2	-1.9
	100+35%	A3	1.5	A3	1.6	A1	1.6
	100	A1	0	A1	0	A1	0

3.1.6. As outlined above the land between the Broughton Brook and the River Ouzel north of the M1, is owned by a third party land. To demonstrate that there is no impact a long section has been extracted across this third party land and is shown in Table 3-2.

Table 3-2 - Cross Section Through Area 'C'

Scenario	Option 1		Option 2		Option 3	
1000	C1	15.5	C1	12.9	C1	19.2
	C2	16.8	C2	14.0	C2	20.6
	C4	14.7	C4	12.3	C4	18.1
	C6	14.4	C6	12.0	C6	17.7
	C11	13.3	C11	11.1	C11	16.3
100+65%	C1	50.1	C1	44.9	C1	60.1
	C2	48.6	C2	43.6	C2	57.5
	C4	37.1	C4	33.4	C4	43.5
	C6	35.6	C6	32.1	C6	41.8
	C11	31.6	C11	28.4	C11	37.1
100+35%	C1	21.3	C1	18.2	C1	26.2
	C2	22.6	C2	19.6	C2	27.6
	C4	18.7	C4	16.4	C4	22.4
	C6	18.2	C6	16	C6	21.8
	C11	16.8	C11	14.8	C11	20
100	C1	2.9	C1	2.3	C1	3.3
	C2	3	C2	2.4	C2	3.5
	C4	3.2	C4	2.6	C4	3.8
	C6	3.1	C6	2.5	C6	3.7
	C11	3	C11	2.4	C11	3.6

4 FUTURE WORKS

4.1.1. Once we have agreed the principles of the modelling to define the baseline flood conditions for the site and the flood extents for the range of design events and the acceptability of the bridge options the scheme is likely to progress to the planning stage and a planning application submitted for the site as a whole and the infrastructure in detail. This will also include the design of the watercourse that is to be relocated from the south of the proposed highway to the north.

4.1.2. To support the future master planning work and application we would like to work in partnership with the EA review the bridge layouts in detail and allocate the bridges and culverts in the correct location for the flooding, environmental, pedestrian and wildlife benefits to ensure the highway bridge and associated embankments create a minimal barrier to this new green infrastructure route. Additionally:

- The overland flow routes associated with the surface water flooding that extend from the east and pool against the A509;
- SUDS strategy will be developed for the site and agreed with EA/IDB and MKC.
- We will be working with the IDB on the network of watercourses to the west of the River Ouzel to either integrate these into the master plan or part of the SUDS strategy .

4.1.3. In addition to the Scheme specific aspects outlined above the Environment Agency have requested that investigations are undertaken to establish whether there are any opportunities for works that may alleviate the flooding which occurs within Newport Pagnell, which is located immediately downstream of the site.

4.1.4. The key constraint associated with this aspect is the need to ensure that the flood flows from the River Ouzel are not delayed for the critical 1 in 100 year event as it is understood that the peak currently passes through Newport Pagnell before that from the River Great Ouse and if they were to occur at the same time flooding could become worse. Therefore, investigations will be undertaken on the lower, more frequent events:

- 1:5 year
- 1:20 year
- 1:75 year

4.1.5. This assessment will be undertaken using existing model results (i.e. hydrograph) from the Environment Agency's 2018 model to identify the onset of flooding at Newport Pagnell from the lower order (i.e. more frequent) flood events, associated with the River Ousel. This will allow us to identify what reduction in flow is required leaving the development site, to inform the testing of options for reducing flood risk from these events in Newport Pagnell, to be undertaken in the cut down model.

If this hydrograph analysis demonstrates the viability of an option, consideration will be given to testing this within the Environment Agency's 2018 model.

5 CONCLUSION

5.1.1. The Environment Agency's hydraulic models have been utilised to construct a 'cut down' hydraulic model for the scheme area. This model has been enhanced with site specific information to provide greater certainty of the flood levels in and around the site.

5.1.2. The modelling demonstrates the feasibility of constructing a new highway through the centre of the site with several openings across the flood plain, without having an impact elsewhere during the in 1 in 100 year event.

5.1.3. The most extreme event considered within the hydraulic model is the 1 in 100 year plus 65% climate change, for which the results demonstrate the proposed road will be safe and changes in flood levels elsewhere are within the bounds of model uncertainty.

5.1.4. Further works will be taken during detailed design to confirm the bridge and culvert numbers and location, which will be based on the options/feasibility outlined in this report, with the final design tested within the hydraulic model and submitted to the Environment Agency for approval.

5.1.5. As the scheme progresses other assessments will be undertaken to understand and manage the flood risk across the wider scheme extents.

Appendix A

CROSS SECTION UPDATES

.CSV ID	.CSV Width	.MIF Wwidth	Comments	new .csv ID	COMMENTS
BR_08_03_106_CH8.2.csv	28	33	No ZP points	BM_BR_08_03_106_CH8.2.csv	ZP points added XS file and model width corrected to match
BR_08_03_106_CH7.6.csv	33.5	33.2	No ZP points	File preserved	ZP points added
BR_08_03_106_CH7.4.csv	33.9	32	No ZP points	File preserved	ZP points added Width corrected to match XS file
BR_08_03_105_ch007_350.csv	47	47.3	No ZP points	File preserved	ZP points added
BR_08_03_105_ch7.2.csv	46.5	44.3	No ZP points	File preserved	ZP points added
BR_08_03_105_ch7.csv	42.4	43.6	No ZP points	File preserved	ZP points added Width corrected to match XS file
BR_08_03_105_ch6.834.csv	40	40	No ZP points	File preserved	ZP points added
BR_08_03_105_ch6.8.csv	36.8	37.5	No ZP points	File preserved	ZP points added Width corrected to match XS file
BR_08_03_104_ch6.6.csv	42.2	41.9	No ZP points	File preserved	ZP points added
BR_08_03_104_ch6.4.csv	43.1	42.9	No ZP points	File preserved	ZP points added
BR_08_03_104_ch6.2.csv	47	47.5	No ZP points	File preserved	ZP points added Width corrected to match XS file
BR_08_03_104_ch6.csv	34.4	38.2	No ZP points	BM_BR_08_03_104_ch6.csv	ZP points added XS file and model width corrected to match
BR_08_03_103_CH5.8.csv	50.5	54.9	No ZP points	BM_BR_08_03_103_CH5.8.csv	ZP points added XS file and model width corrected to match
BR_08_03_103_CH5.6.csv	48.1	48.9	No ZP points	File preserved	ZP points added Width corrected to match XS file
BR_08_03_101_ch5.45.csv	32.4	29	No ZP points	File preserved	ZP points added Width corrected to match XS file

.CSV ID	.CSV Width	.MIF Wwidth	Comments	new .csv ID	COMMENTS
BR_08_03_101_ch5.35.csv	30.8	25.2	-	BM_BR_08_03_101_ch5.35.csv	XS file and model width corrected to match
BR_08_02_106_ch5.2.csv	31.5	30	No ZP points	File preserved	ZP points added Width corrected to match XS file
BR_08_02_106_ch5.csv	31.6	24.5	No ZP points	BM_BR_08_02_106_ch5.csv	ZP points added XS corrected to match width
BR_08_02_105_ch4.79.csv	17.2	29	No ZP points	BM_BR_08_02_105_ch4.79.csv	ZP points added XS file and model width corrected to match 13.6 width which is the width between two M1 bridge piers where the actual channel is located. .
	-	-	-	BM_OZ_02413_01.csv	Channel DS of the M1 brodge. Included from 2008 WSP survey.
BR_08_02_105_ch4.6.csv	29	22.9	-	BM_BR_08_02_105_ch4.6.csv	ZP points added XS file and model width corrected to match
BR_08_02_105_ch4.4.csv	27	28.6		File preserved	Width corrected to match XS file
BR_08_02_104_ch4.36.csv	29	32.1	No ZP points	File preserved	ZP points added Width corrected to match XS file
BR_08_02_104_ch4.2.csv	26.9	28	No ZP points	File preserved	ZP points added Width corrected to match XS file
-	-	-	-	OZ_01875.csv	Included from 2008 WSP survey.
BR_08_02_104_ch4.csv	25.4	22.6	No ZP points	File preserved	ZP points added Width corrected to match XS file
BR_08_02_104_ch3.8.csv	23	22.2	No ZP points	File preserved	ZP points added Width corrected to match XS file
-	-	-	-	BM_OZ_01467.csv	Included from 2008 WSP survey.
BR_08_02_104_ch3.6.csv	26.3	25.9	No ZP points	File preserved	ZP points added Width corrected to match XS file

.CSV ID	.CSV Width	.MIF Wwidth	Comments	new .csv ID	COMMENTS
-	-	-	-	OZ_01237.csv	Included from 2008 WSP survey.
BR_08_02_103_ch3.4.csv	27.2	26.9	No ZP points	File preserved	ZP points added
BR_08_02_103_ch3.2.csv	36.3	30.1	No ZP points	BM_BR_08_02_103_ch3.2.csv	ZP points added XS file corrected to match the width
BR_08_02_103_ch3.csv	29.6	29.9	No ZP points	File preserved	ZP points added Width corrected to match XS file
BR_08_02_103_ch2.8.csv	17.9	17.2	No ZP points	File preserved	ZP points added Width corrected to match XS file
BR_08_01_105_ch2.6.csv	23	17.8	-	BM_BR_08_01_105_ch2.6.csv	ZP points corrected to match the xs Width corrected to match XS file
BR_08_01_105_ch2.59.csv	22.5	19.7	-	BM_BR_08_01_105_ch2.59.csv	ZP points added Width corrected to match XS file
-	-	-	-	OUZ_00268.csv	Included from 2008 WSP survey.
-	-	-	-	OUZ_00238.csv	Included from 2008 WSP survey.
BR_08_01_104_ch2.5_064.csv	37.8	37.43	-	File preserved	ZP points added
-	-	-	-	OZ_00172.csv	Included from 2008 WSP survey.
BR_08_01_103_ch002_400.csv	27.1	23.8	No ZP points	BM_BR_08_01_103_ch002_400.csv	ZP points added XS file corrected to match the width
BR_08_01_103_ch002_350_01.csv	45	22.4	No ZP points	BM_BR_08_01_103_ch002_350_01.csv	ZP points added XS file corrected to match the width

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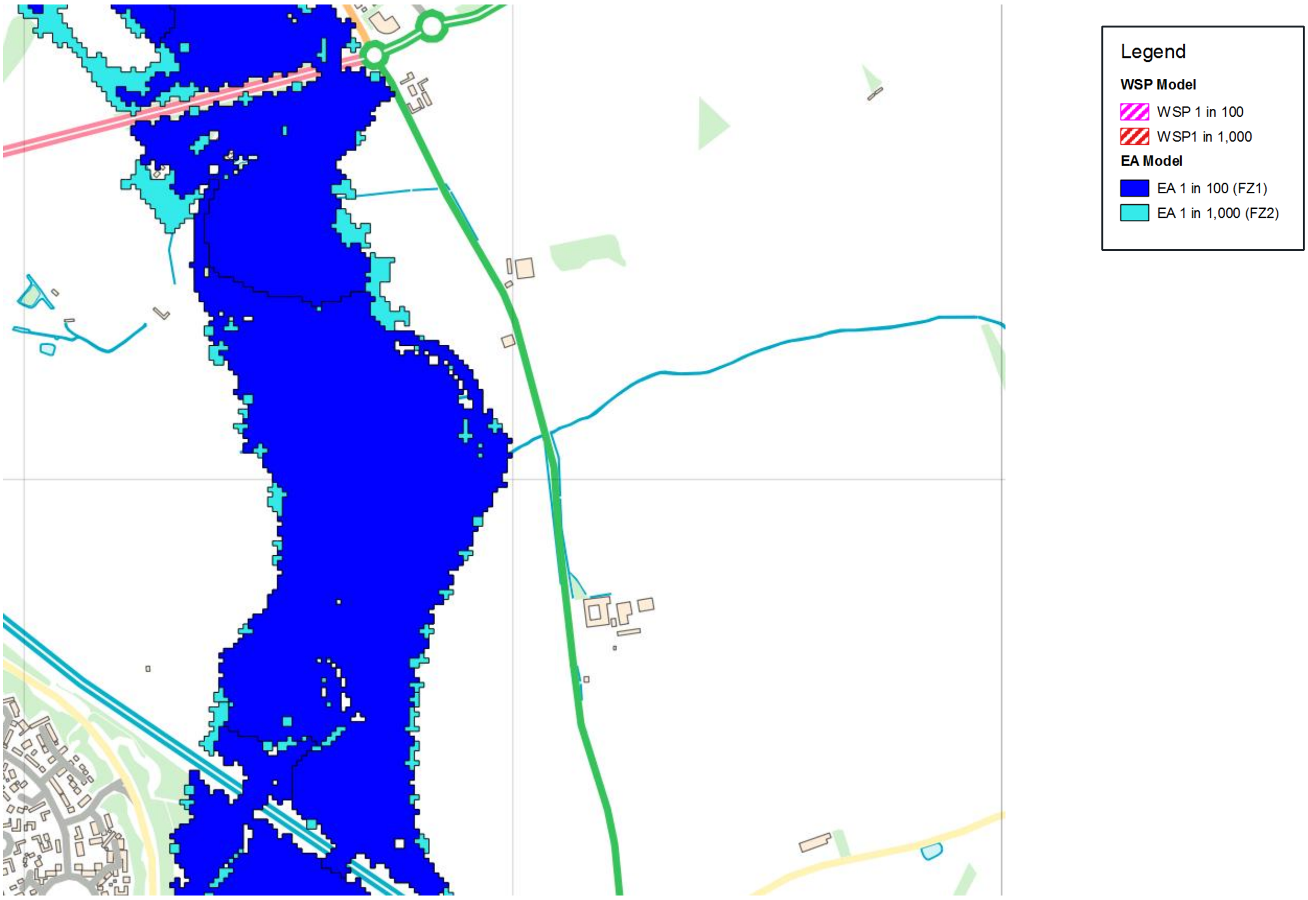
-	-	-	-	OZ_00000.csv	Included from 2008 WSP survey.
BR_08_01_103_ch002_200.csv	21.2	23.4	No ZP points	File preserved	ZP points added Width corrected to match XS file
BR_08_01_102_ch002_000.csv	23.4	21.9	No ZP points	File preserved	ZP points added Width corrected to match XS file
BR_08_01_102_ch001_800.csv	24	18.93	No ZP points	BM_BR_08_01_102_ch001_800.csv	ZP points added XS file corrected to match the width
BR_08_01_102_ch001_600.csv	22.8	17.7	No ZP points	File preserved	ZP points added Width corrected to match XS file
BR_08_01_102_ch001_400.csv	30.3	25	No ZP points	BM_BR_08_01_102_ch001_400.csv	ZP points added XS file corrected to match the width
BR_08_01_101_ch001_200.csv	39.3	26.9	-	BM_BR_08_01_101_ch001_200.csv	ZP points added XS file corrected to match the width
BR_08_01_101_ch001_140.csv	41	35.2	-	BM_BR_08_01_101_ch001_140.csv	ZP points added XS file corrected to match the width
BR_08_01_101_ch001_000.csv	40	25	-	BM_BR_08_01_101_ch001_000.csv	XS file corrected to match the width
BR_08_01_101_ch000_800.csv	24.7	24.5	-	File preserved	No changes

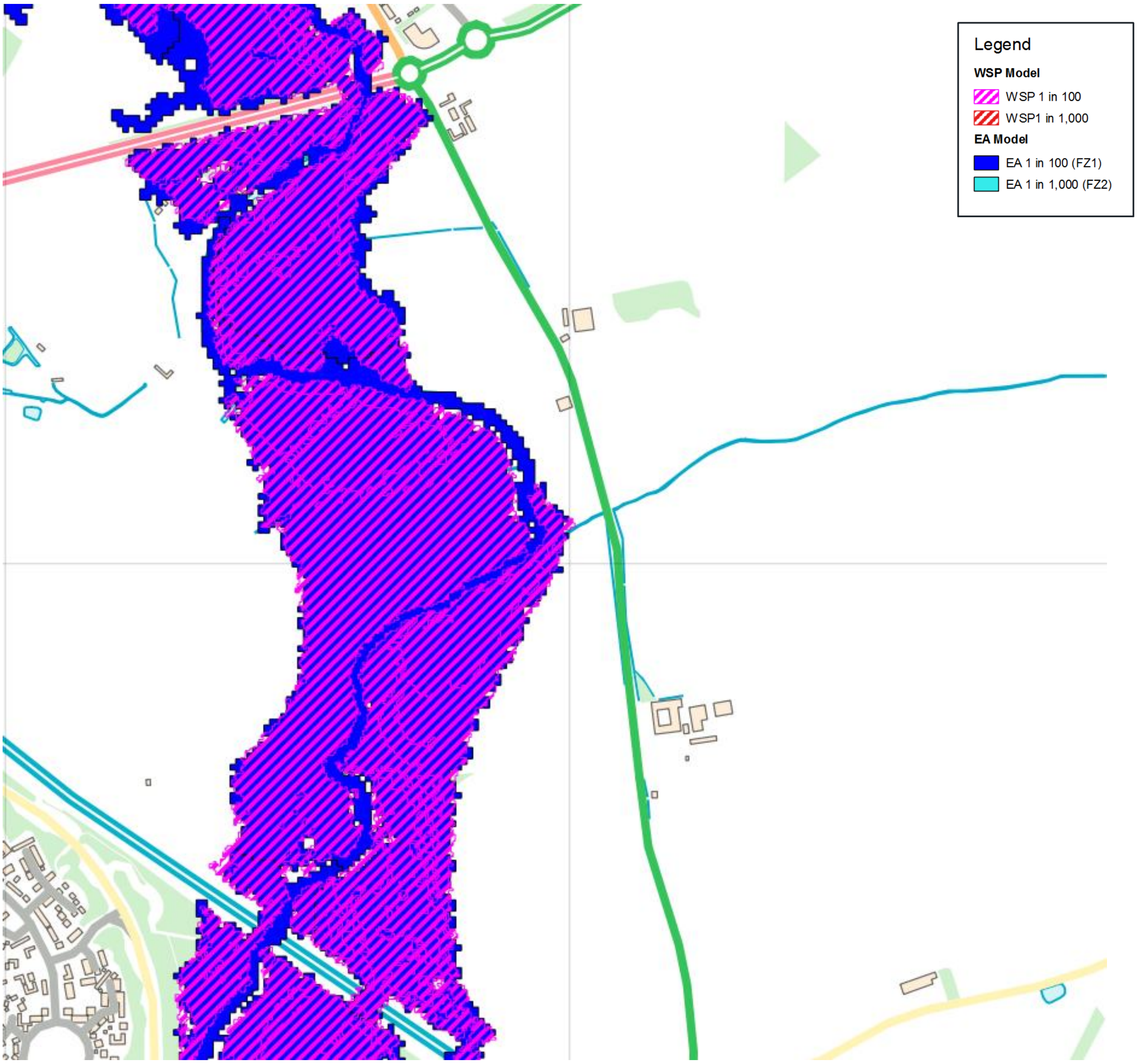
Appendix B

COMPARISON OF THE 2011 ENVIRONMENT AGENCY MODEL AND THE WSP ENHANCED MODEL

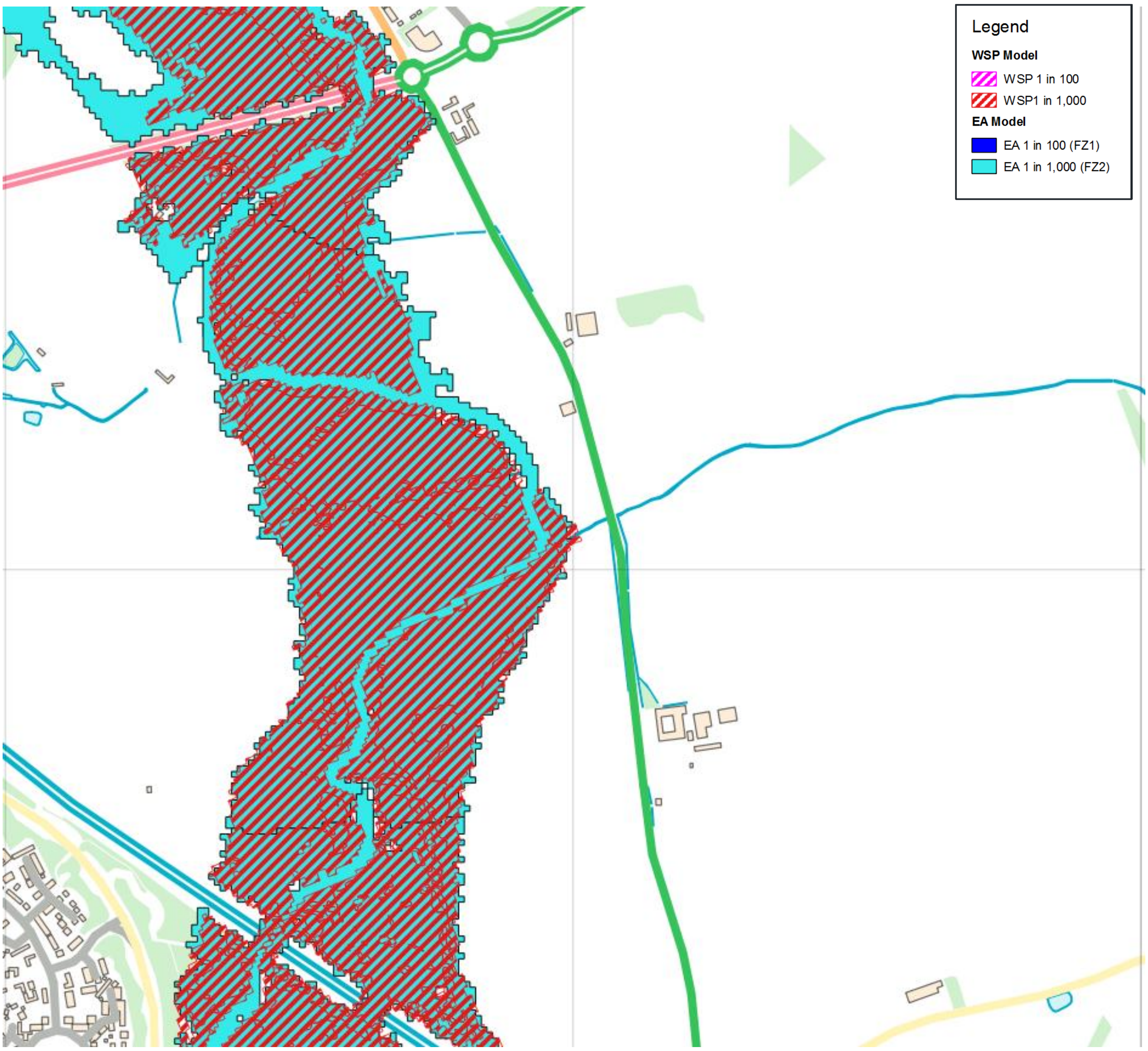
2011 ENVIRONMENT AGENCY FLOOD ZONES



COMPARISON OF ENVIRONMENT AGENCY 1 IN 100 & WSP 1 IN 100 YEAR MODEL



COMPARISON OF THE ENVIRONMENT AGENCY 1 IN 1000 & WSP 1 IN 1,000 YEAR MODEL



TECHNICAL NOTE

DATE:	11 May 2020	**CONFIDENTIALITY:**	Public
SUBJECT:	Milton Keynes East - St James - Revised baseline hydraulic modelling		
PROJECT:	700517078	**AUTHOR:**	Tom Ashby/Aidan Wilks-Daly
CHECKED:	Andy Smith	**APPROVED:**	Andy Smith

Introduction

This technical note has been prepared for issue alongside the revised baseline modelling for the Milton Keynes East – St James development and briefly describes the changes which have been made to the model following the previous review and approval by the Environment Agency.

Previous modelling, as detailed in the report (51078-HMR-001) issued February 2019

The modelling has been based on the existing ESTRY-TUFLOW model of the River Ouzel provided by the Environment Agency. The full Environment Agency model was run with output locations included to capture out of bank flows for input into a cut down version. The Environment Agency model was trimmed at an appropriate location upstream of the area of interest for this study and the 1D and 2D results from the full model used as inputs to the site specific trimmed model.

This site specific model was issued to the Environment Agency and approved for use and was discussed in our meeting on 16 January 2020.

Updated baseline modelling

During the development of options for the proposed River Ouzel highway crossing, some improvements were identified and included within the model. These are listed below and shown in Figure 1:

- Inclusion of the Broughton Brook as a 1D ESTRY channel element (green line in Figure 1);
- Inclusion of a small channel flowing adjacent to the Cotton Valley Sewage Treatment Works (STW), under the M1 through Pineham Nature Reserve (red line in Figure 1);
- Inclusion of an additional ordinary watercourse on the right bank of the River Ouzel upstream of the proposed highway crossing location as a point input (green triangle in Figure 1)
- Revised hydrology for the Broughton Brook and additional watercourses.

The two additional watercourses have been modelled based on cross section collected by Cartographical Surveys Ltd. using the same methods as the existing model. For instance the existing structures (i.e. those under the M1) have been modelled in line with the approach adopted by the Environment Agency for the existing model, this is as a 1D channel section through the embankment, as no interaction with the bridge deck is anticipated. Due to the peak flood levels for the 100yr event plus 65% climate change being 2m below the bridge soffit.

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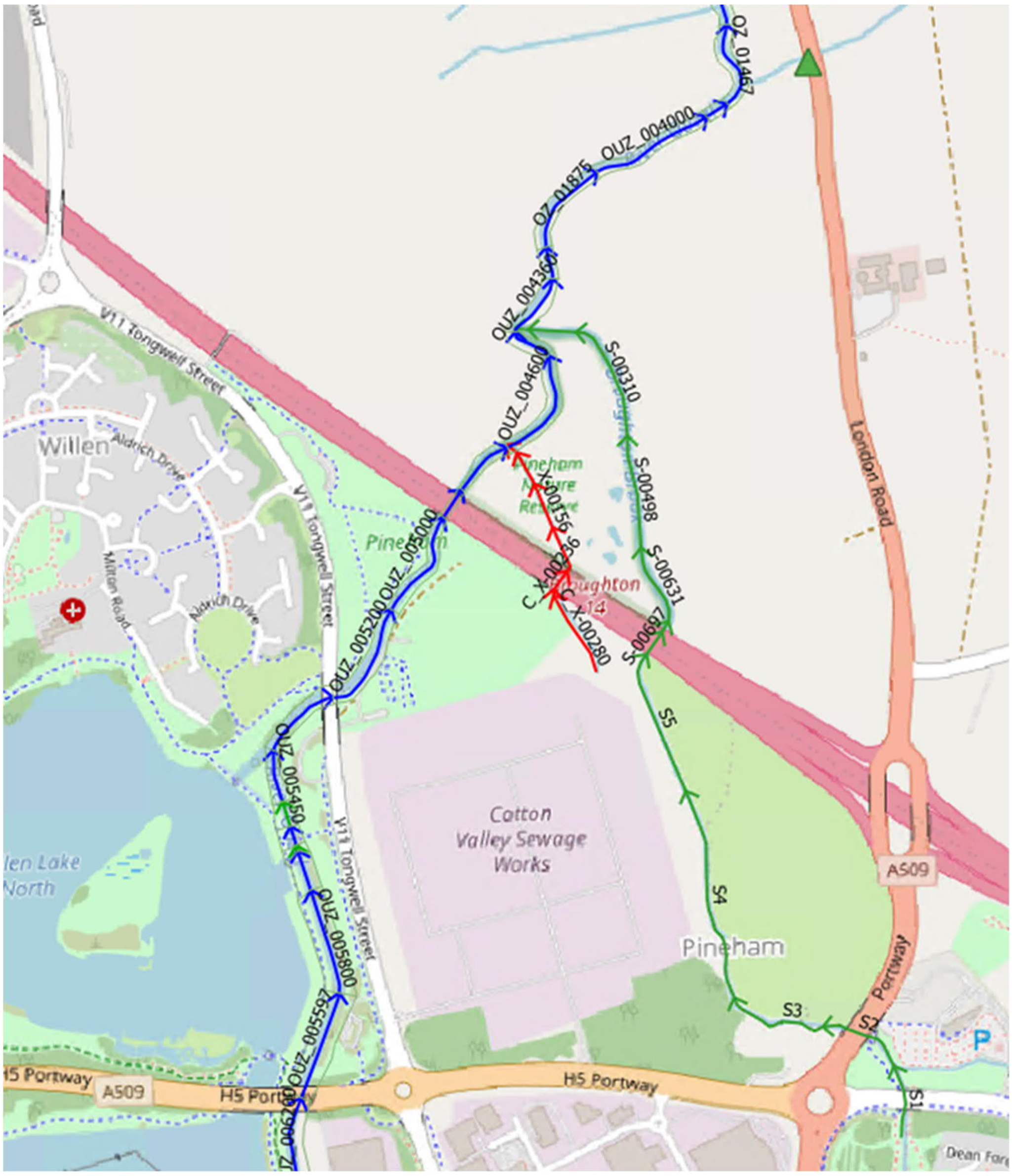

Figure 1: Revised baseline model elements

Updated hydrology - Broughton Brook

CATCHMENT OVERVIEW

The Broughton Brook is an IDB watercourse that drains the land to the east of Milton Keynes. It conveys water from a largely rural catchment in central Bedfordshire, flowing through the settlements of Ridgmont & Salford, before flowing through Broughton and towards the urban area of Milton Keynes, where it joins the River Ouzel to the north of Junction 14 of the M1 Motorway. The Broughton Brook is a gauged watercourse with an Environment Agency measuring station (no. 033031) located near to the Cotton Valley Sewage Treatment Works, at an approximate grid reference of 488850, 240950. The catchment draining to the flow gauge was downloaded from the FEH web service. Key catchment descriptors for this catchment are displayed in Table 1 below, the catchment descriptors which have been adjusted are shown in bold. A review of the catchment descriptors is provided in the FEH Calculation Record in Appendix A**.**

Table 1: Broughton Brook Key Catchment Descriptors

Descriptor	Broughton Brook at Broughton
AREA (km^2)	70.06
BFIHOST	0.482
DPLBAR	10.75
DPSBAR	29.10
FARL	0.9670
SPRHOST	40.87%
URBEXT1990	**0.0394**
URBEXT2000	**0.012**

CHOICE OF METHODS

The catchment is not highly permeable or heavily urbanised, nor does it have a major reservoir influence or any other unusual features. Therefore, in accordance with the Environment Agency's flood estimation guidelines, the FEH approach for flow estimation was considered appropriate, utilising the ReFH, ReFH2 and FEH Statistical methods. The Environment Agency model used hydrographs from ReFH analysis scaled to the peak flows from the FEH Statistical method as inputs into the hydraulic model.

FEH STATISTICAL METHOD

The FEH Statistical method was carried out using WINFAP-FEH v4.1 and based on the latest (Version 8) of the NRFA Peak Flow dataset, released in September 2019.

QMED

The Broughton Brook is a gauged watercourse (NRFA Station No. 33031), the estimate of QMED at this gauging station is 13.33 m^3/s. The estimate of QMED for the catchment using catchment descriptors was found to be 6.85 m^3/s. Station 33031 is included within the version 8 of the NRFA Peak Flow dataset as suitable for QMED, therefore, the gauged QMED value of 13.33 m^3/s was taken forwards.

POOLING GROUP

An enhanced single site (ESS) analysis was undertaken, making use of the at site data for the Broughton Brook using station 33031. The default pooling group suggested by WINFAP (PG1) is included in the Appendix of the Calculation Record, along with a modified pooling group (PG2) deemed more representative of the permeability of the subject site. The initial pooling group suggested by WINFAP included several highly permeable catchments (BFIHOST >0.8 & SPRHOST <20%) which were removed (33032, 26003, 34012, 33054, 26013 & 39042) and replaced by catchments with permeabilities more representative of the subject site (33011, 37016, 42003, 205005 & 37013).

FLOOD ESTIMATES

The flood estimates in Table 2 were calculated for the Broughton Brook using the FEH Statistical method following urban adjustment.

Table 2: FEH Statistical Method Flow Estimates

Site code	**Flood peak (m^3/s) for the following return periods (in years)**		
	2	**100**	**1,000**
33031 (ESS PG2)	13.30	35.07	50.34
Growth curve 33031 (ESS PG2)	*1.00*	*2.62*	*3.76*

REFH

The ReFH method was applied for the Broughton Brook catchment using the ReFH unit within version 4.3 of Flood Modeller Pro. The ReFH method utilises FEH 1999 rainfall and was run for a 14-hour design storm (representative of the critical duration) with a winter profile. The estimated peak flows from this method are displayed in

Site code	**Flood peak (m^3/s) for the following return periods (in years)**		
	2	**100**	**1,000**
33031	10.35	24.91	43.51
Growth curve 33031	*1.00*	*2.41*	*4.20*

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Table 3: ReFH Method Flow Estimates

Site code	**Flood peak (m^3/s) for the following return periods (in years)**		
	2	**100**	**1,000**
33031	10.35	24.91	43.51
Growth curve 33031	*1.00*	*2.41*	*4.20*

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REFH2

The Revitalised flood hydrograph 2 (ReFH2) method using Version 2.2 of the software and the FEH 2013 rainfall model was used. It was found that the critical storm duration for the catchment was 15 hours. Given the largely rural nature of the catchment, a winter rainfall profile has been used. The estimated peak flows based on this method are included in Table 4.

Table 4: ReFH2 Flow Estimates

Site code	Flood peak (m^3/s) for the following return periods (in years)		
	2	**100**	**1,000**
33031	9.24	22.48	41.04
Growth curve 33031	*1.00*	*2.43*	*4.44*

COMPARISON OF METHODS

Error! Reference source not found. displays the derived flood frequency curves for the Broughton Brook catchment for the three different flow estimation methods.

The flows from the FEH statistical method are higher for QMED than the ReFH and ReFH2 methods and subsequently for other return periods given that the three methods have similar growth factors. The site of interest has a small to medium catchment area, is not permeable, heavily urban or influenced significantly by the presence of reservoirs. As a result, there is not a clear choice of methods.

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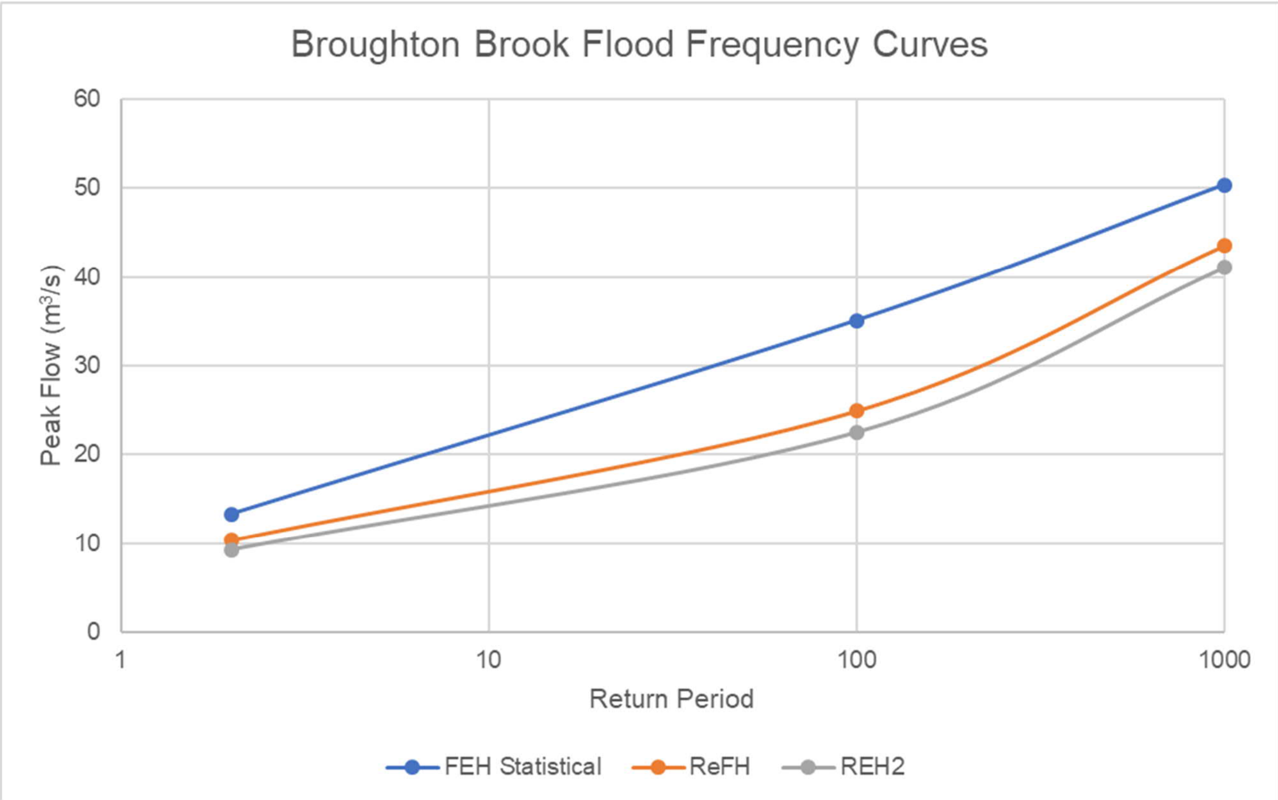

Figure 2: Broughton Brook Flood Frequency Curves

The FEH Statistical method flows have been selected for use in the model as this produces relatively conservative flows in comparison to ReFH and ReFH2. Furthermore, the FEH Statistical Method makes use of the at site gauging data and this method was used to derive the peak inflows in the existing ESTRY-TUFLOW model of the River Ouzel. The final results for the Broughton Brook are presented below in Table 5.

Table 5: Broughton Brook Final Flow Estimates

Site code	**Flood peak (m^3/s) for the following return periods (in years)**		
	2	**100**	**1000**
33031	13.30	35.07	50.34

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Hydrographs from the ReFH2 method were scaled to the peak flows from the FEH Statistical method to provide inputs into the hydraulic model.

ADDITIONAL WATERCOURSES

As mentioned at the start of this note, as well as the Broughton Brook, two additional small channels have been included in the updated baseline modelling:

- **London Road Tributary** - An additional watercourse upstream of the proposed road location, that flows under London Road and into the Ouzel; and
- **Channel adjacent to the STW** - A small channel flowing adjacent to Cotton Valley Sewage Works, under the M1 through Pineham Nature Reserve.

The hydrology for these watercourses was derived by means of an area ratio from the detailed hydrology carried out for the Broughton Brook.

LONDON ROAD TRIBUTARY

This small ordinary watercourse drains the land to the east of London Road (A509), flowing east to west from Tickford Park, towards and under the A509 where it joins the Ouzel. The catchment of the London Road tributary was found to be 1.57km^2, as derived from the FEH web service and is shown in Figure 3.

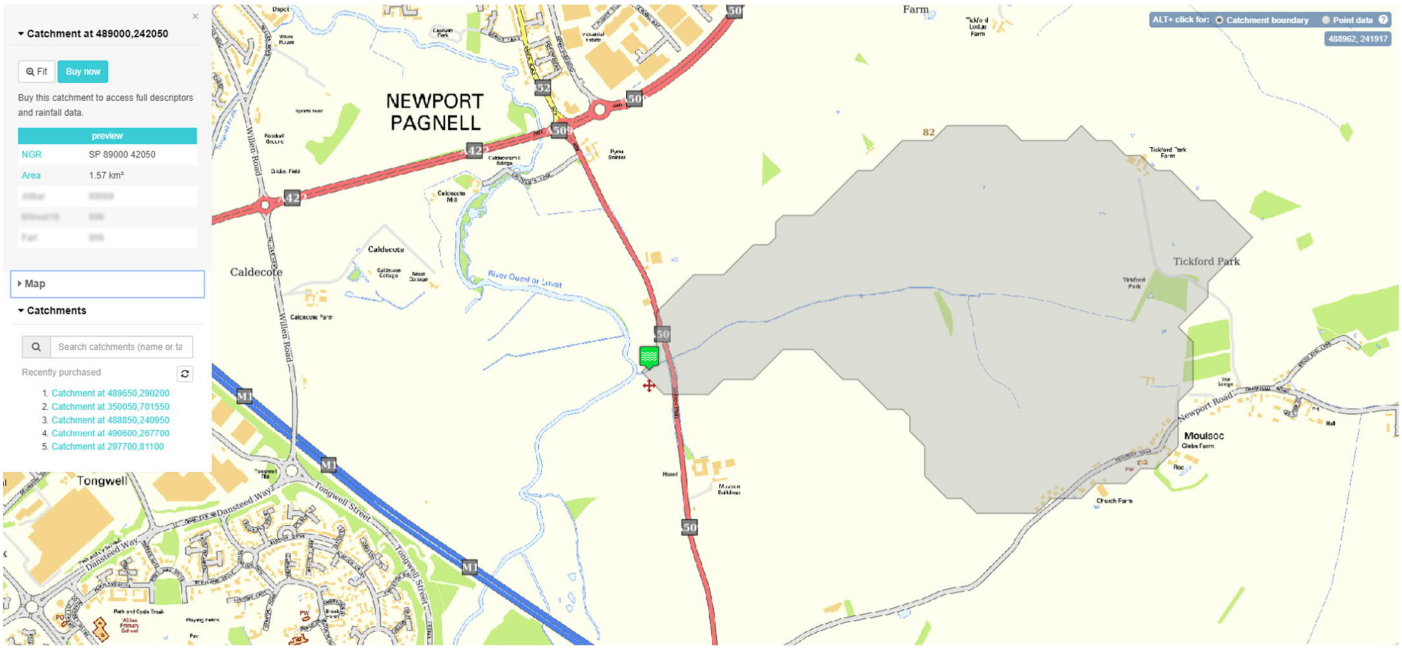

Figure 3: London Road Tributary Catchment Area

Given the proximity of this catchment to that of the Broughton Brook and the fact the catchments share the same underlying geology and soils, it was deemed appropriate to derive peak flow estimates for this watercourse by means of an area ratio from the detailed hydrology carried out for the Broughton Brook. The flow estimates for this watercourse are presented in Table 6.

Table 6:Flow Estimates for London Road Tributary

Site code	Flood peak (m^3/s) for the following return periods (in years)		
	2	**100**	**1,000**
London Road Tributary	0.30	0.79	1.13

Hydrographs for the London Road Tributary were derived by scaling the hydrographs from the Broughton Brook to match the peak flow estimates in Table 6.

Channel adjacent to the STW

This small channel conveys water from the STW, under the M1 through Pineham Nature Reserve and into the River Ouzel. The contributing area to this channel was estimated to be approximately 0.294km^2 based on a review of ordnance survey and satellite mapping. Given the very small size of this catchment it was not possible to acquire FEH catchment descriptors for this catchment, so flows for this channel were derived by means of an area ratio from the detailed hydrology carried out for the Broughton Brook. The peak flow estimates for this channel are presented in Table 7.

Table 7: Flow Estimates for the STW Channel

Site code	Flood peak (m^3/s) for the following return periods (in years)		
	2	**100**	**1000**
STW Channel	0.006	0.15	0.21

Given the size of the channel and the area it drains, peak constant inflows were applied to this channel in the hydraulic model, instead of full hydrographs.

From consultation with Anglian Water, it is understood that the majority of the water treated at the STW is discharged into a large pipe that runs under the River Ouzel and is ultimately pumped into the River Great Ouse, therefore, there is no need to consider the treated effluent in this model. The small channel adjacent to the STW is believed to convey water from the area surrounding the STW and potentially minor effluent discharges, which would not be significant when compared to the peak fluvial flows.

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River Ouzel Hydrology

In addition to undertaking a hydrological assessment of the Broughton Brook, the Environment Agency's hydrology for the River Ouzel was also reviewed. The hydrology of the existing ESTRY-TUFLOW model was based on 2011 the Upper Great Ouse Flood Risk mapping project, with model hydrographs based on the ReFH method and scaled to FEH Statistical Method Peaks. An enhanced single site analysis of the Ouzel at Bletchley was undertaken at this stage, this established that 100-year flow estimate (62.9 m^3/s) was comparable to the 100-year flow applied to Ouzel at Bletchley in the Environment Agency model (66.9m^3/s). Given that these flows are comparable and that the site of interest is located significantly downstream of this point, it was deemed appropriate to continue the use of the existing Environment Agency hydrology for the River Ouzel.

The Environment Agency study included a number of discrete inflow points along the River Ouzel, however after Willen Lake, no inflows are provided until just before the confluence of the River Ouzel with the River Great Ouse. No inflows were provided for the Broughton Brook, so the inclusion of inflow on the Broughton Brook is not considered to be a double counting of flows within the Scheme extents or the study area.

Timing of Hydrograph Peaks

To determine the likelihood of concurrent peaks on the River Ouzel and the Broughton Brook, a comparative analysis of recent flood events on these two watercourses was undertaken to understand the timing of their flood peaks. Data from GauageMap[1] was used to determine when significant peak flows occurred over the last 12 months, with potential flood events identified in October, November & December 2019 and in January & February 2020. Real time flood monitoring data for the River Ouzel at Bletchley and Willen and the Broughton Brook at Broughton was downloaded from the Environment Agency's flood monitoring archive[2] on the following dates:

- 14th – 15th October 2019
- 14th – 16th November 2019
- 20th – 22nd December 2019
- 14th – 17th January 2020.
- 15th – 18th February 2020.

For these events, hydrographs were plotted for the River Ouzel at Bletchley & Willen against the Broughton Brook at Broughton and these hydrographs can be seen in Appendix B. From these hydrographs it was found that the Broughton Brook was peaking at, or very close to, the same time as the River Ouzel.

It was therefore decided to match the peaks of the hydrographs of the Broughton Brook with those of the Ouzel within the hydraulic model. This is a conservative approach and is based on the publicly available

[1] https://www.gaugemap.co.uk/#!Map/Summary/1631/1773/2019-02-01/2020-02-29 (Accessed April 2020)
[2] https://environment.data.gov.uk/flood-monitoring/archive (Accessed April 2020).

flow data for these watercourses. The peak of the hydrograph on the London Road Tributary was also matched to the peaks of the Broughton Brook and main channel of the Ouzel within the model.

Conclusions

These relatively modest alterations to the existing model do not have a considerable impact on the model results. The additional inflows into the model matched to the peak of the main flow in the River Ouzel do result in a larger depth of flooding occurring, with a corresponding small increase in the flood extent.

Further work

Optioneering is being carried out for the proposed new road crossing the floodplain for the development. The baseline model described herein is the basis for the option modelling and the results will be used for comparison of flood levels.

Appendix A – Calculation Record

Flood estimation calculation record

Introduction

This document is a supporting document to the Environment Agency's flood estimation guidelines. It provides a record of the calculations and decisions made during flood estimation. It will often be complemented by more general hydrological information given in a project report. The information given here should enable the work to be reproduced in the future. This version of the record is for studies where flood estimates are needed at multiple locations.

Contents

Approval

	Signature	Name and qualifications
Calculations prepared by:		Aidan Wilks Daly, *MSc, Bsc (Hons) GradCIWEM*
Calculations checked by:		Rachel Ledger, *MPhys (Hons), C.WEM CEnv*
Calculations approved by:		Rachel Ledger, *MPhys (Hons), C.WEM CEnv*

Environment Agency competence levels are covered in Section 2.1 of the flood estimation guidelines:

¶ Level 1 – Hydrologist with minimum approved experience in flood estimation

¶ Level 2 – Senior Hydrologist

¶ Level 3 – Senior Hydrologist with extensive experience of flood estimation

ABBREVIATIONS

AM	Annual Maximum
AREA	Catchment area (km^2)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification
CFMP	Catchment Flood Management Plan
CPRE	Council for the Protection of Rural England
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FSR	Flood Studies Report
HOST	Hydrology of Soil Types
NRFA	National River Flow Archive
POT	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method
SAAR	Standard Average Annual Rainfall (mm)
SPR	Standard percentage runoff
SPRHOST	Standard percentage runoff derived using the HOST soil classification
Tp(0)	Time to peak of the instantaneous unit hydrograph
URBAN	Flood Studies Report index of fractional urban extent
URBEXT1990	FEH index of fractional urban extent
URBEXT2000	Revised index of urban extent, measured differently from URBEXT1990
WINFAP-FEH	Windows Frequency Analysis Package – used for FEH statistical method

1 Method statement

1.1 Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: ¶ Purpose of study ¶ Approx. no. of flood estimates required ¶ Peak flows or hydrographs? ¶ Range of return periods and locations ¶ Approx. time available	In 2011 hydraulic modelling and a hydrological assessment was undertaken by the Environment Agency of the River Ouzel and its tributaries as a part of the Upper Great Ouse Flood Risk mapping project. The ESTRY-TUFLOW model of the River Ouzel developed by the EA from this study does not include the Broughton Brook. This study will update the existing EA ESTRY-TUFLOW model of the River Ouzel by including the Broughton Brook as a 1D ESTRY channel element. The purpose of including the Broughton Brook in this model is to see how it impacts the flood risk at the site of a proposed mixed-use development adjacent to the River Ouzel. This hydrological assessment is required to derive a flow estimate for the Broughton Brook, where it flows into the River Ouzel, for inclusion into the updated hydraulic model of the Ouzel. Information as to how this fits with the wider hydrology is provided in the accompanying Technical Note. The Broughton Brook is a gauged watercourse with an Environment Agency gauging station (no. 033031) located near to the Broughton sewage treatment works. The 100-year and 1000-year return period flows will be estimated at this location. An assessment of the impacts of climate change will be made based on the Environment Agency's peak river flow allowances. The site is located within the Anglian River Basin District. The vulnerability classification of the proposed development is 'more vulnerable' and the site is located within Food Zones 2 & 3 therefore both the higher central upper end allowances should be assessed to understand the range of impact. For the '2080s' (2070 to 2115) for the Anglian RBD the higher central allowance is 35% and the upper end allowance is 65%.

1.2 Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	The Broughton Brook is an ordinary watercourse that drains the land to the east of Milton Keynes. It conveys water from a largely rural catchment in Central Bedfordshire, flowing through the settlements of Ridgmont & Salford, before flowing through Broughton and towards the urban area of Milton Keynes, where it joins the River Ouzel to the north of Junction 14 of the M1 Motorway. The Broughton Brook is a gauged watercourse with an Environment Agency measuring station (no. 033031) located near to the Broughton sewage treatment works, at an approximate grid reference of 488850, 240950.

1.3 Source of flood peak data

Was the HiFlows UK (NRFA Peak flow) dataset used? If so, which version? If not, why not? Record any changes made	Yes – Version 8, September 2019.

1.4 Gauging stations (flow or level)

(at the sites of flood estimates or nearby at potential donor sites)

Watercourse	Station name	Gauging authority number	NRFA number (used in FEH)	Grid reference	Catch-ment area (km²)	Type (rated / ultrasonic / level…)	Start and end of flow record
Broughton Brook	Broughton Brook at Brougton	Environment Agency – East Anglia (033031)	33031	SP888409	70.06	Flat V	11/1970 - N/A

1.5 Data available at each flow gauging station

Station name	Start and end of data in HiFlows-UK	Update for this study?	Suitable for QMED?	Suitable for pooling?	Data quality check needed?	**Other comments on station and flow data quality** – e.g. information from HiFlows-UK, trends in flood peaks, outliers.
33031	11/1970 – 12/2018	V8	Yes	Yes	No	N/a
Give link/reference to any further data quality checks carried out			**N/A**			

1.6 Rating equations

Station name	**Type of rating** e.g. theoretical, empirical; degree of extrapolation	Rating review needed?	**Reasons** – e.g. availability of recent flow gaugings, amount of scatter in the rating.
33031	Theoretical	No	All flows contained and theoretical rating expected to perform well. Flume was subject to drowning but flows were corrected. Current rating includes floodplain flow and accounts for drowning. One peak flow rating applied across period of record.
Give link/reference to any rating reviews carried out		**N/A**	

1.7 Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available?	Source of data and licence reference if from EA	Date obtained	Details
Check flow gaugings (if planned to review ratings)					
Historic flood data – give link to historic review if carried out.					
Flow data for events					
Rainfall data for events					
Potential evaporation data					
Results from previous studies					

Type of data	Data relevant to this study?	Data available?	Source of data and licence reference if from EA	Date obtained	Details
Other data or information (e.g. groundwater, tides)					

1.8 Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	The catchment descriptors and catchment mapping have been reviewed. The catchment is medium in size, is underlain by a mixture of acid loamy and clayey soils and acid sandy soils, situated above a bedrock of Mudstone and sandstone. The catchment is classified as slightly urbanised and has a minor influence from reservoirs and lakes. Based on this information and in accordance with the Environment Agency's flood estimation guidelines, the FEH approaches for flow estimation are considered appropriate. Peak flows are to be estimated using both FEH rainfall-runoff methods, i.e. ReFH and ReFH2, and the FEH Statistical Method for comparison.
Outline the conceptual model, addressing questions such as: ¶ Where are the main sites of interest? ¶ What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides…) ¶ Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir? ¶ Is there a need to consider temporary debris dams that could collapse?	The main area of interest is located just downstream of the confluence of the Broughton Brook and the River Ouzel where there is a proposed road crossing of the Ouzel.
Any unusual catchment features to take into account? e.g. ¶ highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20% ¶ highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments ¶ pumped watercourse – consider lowland catchment version of rainfall-runoff method ¶ major reservoir influence (FARL<0.90) – consider flood routing ¶ extensive floodplain storage – consider choice of method carefully	The catchment has low to medium permeability with a BFIHOST value of 0.482 and a SPRHOST value of 40.87%, accordingly there is no need to consider permeable catchment adjustments. The catchment is essentially rural, with an $URBEXT_{2000}$ value of 0.0394 (adjusted for 2020). There are several small lakes in the south of the catchment by Woburn Abbey and it is understood that these lakes are hydraulically connected to the Broughton Brook. The FARL value for the catchment is 0.9670. The catchment is not pumped nor is there extensive floodplain storage.
Initial choice of method(s) and reasons Will the catchment be split into subcatchments? If so, how?	Based on the information above, flows estimation will be undertaken using the following methods:

	¶ The Statistical method using WINFAP-FEH v4.1 and based on the latest (Version 8) of the NRFA Peak Flow dataset, released in September 2019; ¶ The Revitalised flood hydrograph (ReFH) method using the unit within Version 4.3 of FMP based on the FEH1999 rainfall model, and ¶ The Revitalised flood hydrograph 2 (ReFH2) method using Version 2.2 of the software based on the FEH 2013 rainfall model.
Software to be used (with version numbers)	FEH Web Service WINFAP-FEH v4.1[1] ReFH unit within v4.3 of FMP FEH unit within v4.3 of FMP ReFH2 2.2 software

[1] WINFAP-FEH v4.1 © Wallingford HydroSolutions Limited and NERC (CEH) 2016.

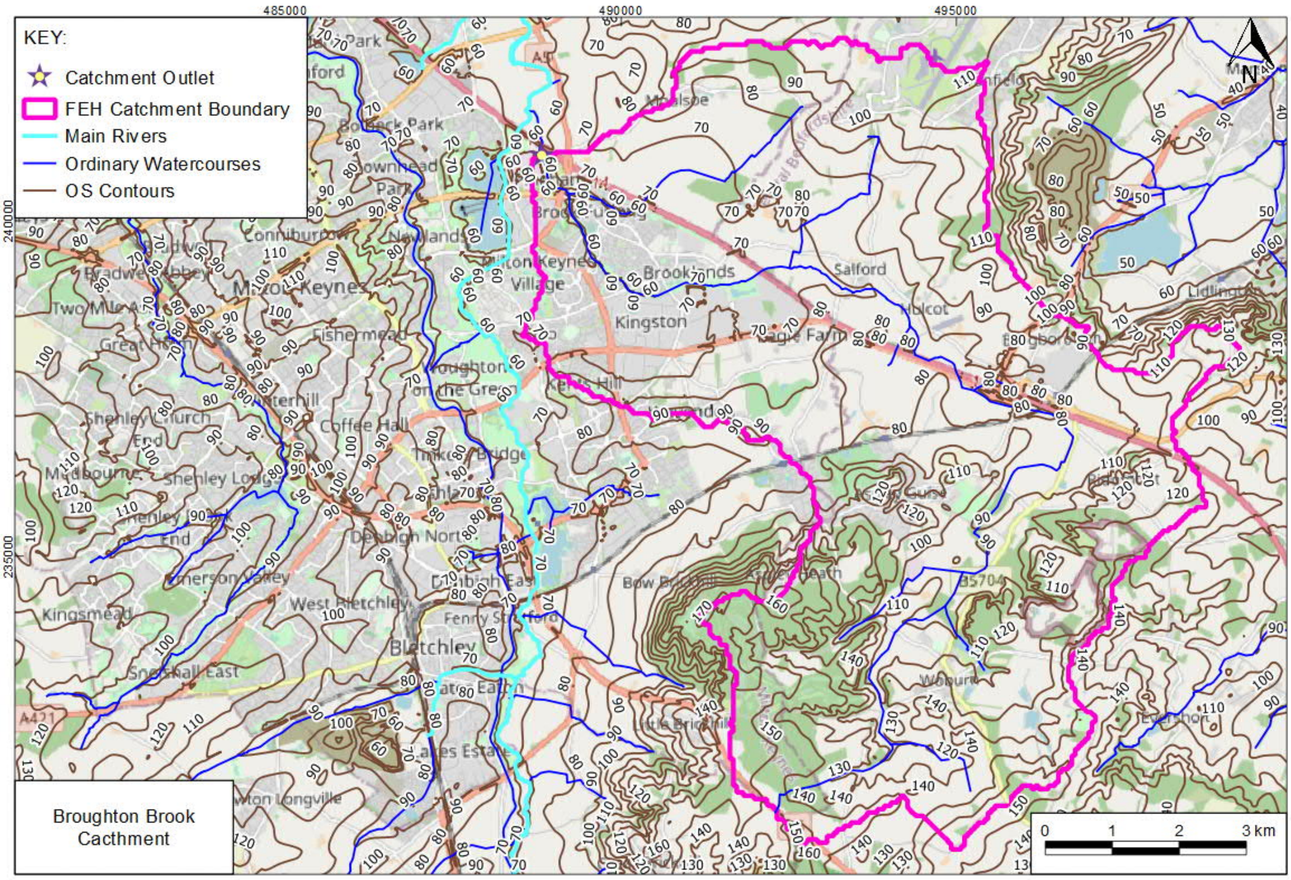
2 Locations where flood estimates required

The table below lists the locations of subject sites. The site codes listed below are used in all subsequent tables to save space.

2.1 Summary of subject sites

Site code	Watercourse	Easting	Northing	AREA on FEH Web Service (km^2)	AREA estimated using LiDAR (km^2)
Broughton_01	Broughton Brook	488850	240950	70.06	N/A
Reasons for choosing above locations	This is the location of the EA gauging station on the Broughton Brook.				

Figure 1: Catchment Boundary



2.2 Important catchment descriptors at each subject site (incorporating any changes made)

Amended catchment descriptors are shown in red and bold text.

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT2000	FPEXT
Broughton_01	0.967	0.31	0.482	10.75	29.1	629	40.87	**0.0394**	0.1439

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	The FEH Catchment boundary was checked using Ordnance Survey contours and mapping, as shown in Figure 1. A review of the catchment boundary found that it followed the OS contours well and was reflective of the drainage patterns in the area. It was decided to take the FEH catchment boundary forwards without any modifications. The use of the FEH catchment boundary also facilitates the use of the gauged data that is available for the catchment.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	Soils – the catchment has a low to medium permeability reflected by a BFIHOST value of 0.482 and a SPRHOST value 40.87%. The catchment is underlain by a mixture of acid loamy and clayey soils and acid sandy soils, situated above a bedrock of Mudstone and sandstone. As the catchment boundary was not changed it was not necessary to update the BFIHOST & SPRHOST value. The DPLBAR value was not altered as the catchment boundary was not changed. FARL values were checked by a review of online mapping and desk-based research. There are several small lakes in the south of the catchment by Woburn Abbey and it is understood that these lakes are hydraulically connected to the Harrowden Brook. The FARL value for the catchment is 0.9670 and this was not altered. Urbanisation – the catchment has an URBEXT1990 value of 0.012 which reflects that of an essentially rural catchment. The URBEXT2000 value for the catchment is 0.0394 which reflects that of a slightly urbanised catchment. The catchment boundary has not been modified there it was not necessary to alter these URBEXT values, other than updating their values to the present day (2020) using urban expansion factors.
Source of URBEXT	Catchment descriptors (URBEXT 1990 & 2000), checked against Ordnance Survey Mapping and satellite mapping.
Method for updating of URBEXT	CPRE formula (6.8) from FEH Volume 5 on URBEXT1999/ Formula 5.5 from 2007 EA/Defra R&D Technical Report FD1919/TR on URBEXT2000.

3 Statistical method

3.1 Search for donor sites for QMED (if applicable)

Comment on potential donor sites Mention: ¶ Number of potential donor sites available ¶ Distances from subject site ¶ Similarity in terms of AREA, BFIHOST, FARL and other catchment descriptors ¶ Quality of flood peak data Include a map if necessary. Note that donor catchments should usually be rural.	The Broughton Brook is a gauged watercourse (NRFA Station No. 33031) that is included within the version 8 of the NRFA Peak Flow dataset as suitable for QMED. The estimate of QMED at this gauging station is 13.30 m^3/s, based on Annual Maxima. An urbanisation factor is not required in this instance as the QMED is based on observed data. The estimate of QMED for the catchment using catchment descriptors was found to be 6.85 m^3/s. The gauged QMED value of 13.30 m^3/s was taken forwards as that is based on observed data.

3.2 Donor sites chosen and QMED adjustment factors

NRFA no.	Reasons for choosing or rejecting	Method (AM or POT)	Adjustment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjust-ment ratio (A/B)	Power term, a	Moderated QMED adjustment factor, (A/B)[a]
33031	The site is gauged	AM	No	13.298	6.847	1.94	n/a	n/a

Which version of the urban adjustment was used for QMED at donor sites, and why?	QMED from AM used directly as it was at the subject site.

Notes

The data transfer procedure is from Science Report SC050050. The QMED adjustment factor A/B for each donor site is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment.

3.3 Overview of estimation of QMED at each subject site

Site code	Method	Initial estimate of QMED (m^3/s) (exc. urban adj)	Data transfer: NRFA numbers for donor sites used (see 3.2)	Data transfer: Distance between centroids dij (km)	Data transfer: Weight	UAF	Final estimate of QMED (inc. urban adj) (m^3/s)
Broughton_01	CD	6.85	n/a	n/a	n/a	1.045	7.15
Broughton_01	AM	13.30	33031	n/a	n/a	n/a	13.30

Are the values of QMED consistent, for example at successive points along the watercourse and at confluences?	There is a single flow estimation point.
Which version of the urban adjustment was used for QMED, and why (describe any changes to the parameters, such as Primp% and Impervious Factor, used to calculate the urban adjustment)?	Default parameters were used.

Notes

Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer; CD – Catchment descriptors alone; CDCW – Catchment descriptors and channel width

3.4 Derivation of pooling groups

The full composition of the pooling group is given in the Annex

Name of group	**Site code from whose descriptors group was derived**	**Subject site treated as gauged?** (enhanced single site analysis)	**Changes made to default pooling group, with reasons**	**Weighted average L-moments**, L-CV and L-skew, (before urban adjustment)
PG0	Broughton_01	NO	None	L-CV 0.263 L-SKEW 0.045
PG1	Broughton_01	YES (ESS)	None	L-CV 0.275 L-SKEW 0.045
PG2	Broughton_01	YES (ESS)	Removed stations 33032, 26003, 34012, 33054, 26013 & 39042 due to significant differences in catchment permeability (SPRHOST <17.6% & BFIHOST >0.81) compared to subject site (SPRHOST 40.9% & BFIHOST 0.48). Added in stations 33011, 37016, 42003, 205005 & 37013 which have permeabilities more similar to the subject site.	L-CV 0.280 L-SKEW 0.092

3.5 Derivation of flood growth curves at subject sites

Site code	**Method** (SS, P, ESS, J)	**If P, ESS or J, name of pooling group (3.4)**	**Distribution used and reason for choice**	**Note any urban adjustment or permeable adjustment**	**Parameters of distribution** (location, scale and shape) after adjustments	**Growth factor for 100-year return period**
Broughton_01	P	PG0	The Generalised Logistic distribution is the recommended distribution for flood frequency analysis in the UK and has been applied to all pooling groups in this study	Urban adjustment made	LOC 1.000; SCALE 0.262; SHAPE -0.051; BOUND -4.174	2.35
Broughton_01	ESS	PG1			LOC 1.000; SCALE 0.274; SHAPE -0.051; BOUND -4.343	2.42
Broughton_01	ESS	PG2			LOC 1.000; SCALE 0.282; SHAPE -0.098; BOUND -1.875	2.64

Notes

Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis

A pooling group (or ESS analysis) derived at one gauge can be applied to estimate growth curves at a number of ungauged sites. Each site may have a different urban adjustment, and therefore different growth curve parameters.

3.6 Flood estimates from the statistical method

	Flood peak (m^3/s) for the following return periods (in years)		
Site code	**2**	**100**	**1000**
Broughton_01_PG0	13.30	31.30	42.07
Broughton_01_PG0	*1.00*	*2.35*	*3.16*
Broughton_01_PG1	13.30	32.16	43.47
Broughton_01_PG1	*1.00*	*2.42*	*3.27*
Broughton_01_PG2	13.30	35.07	50.34
Broughton_01_PG2	*1.00*	*2.64*	*3.78*

4 Revitalised flood hydrograph (ReFH) method – FEH1999 rainfall model

4.1 Parameters for ReFH model – FEH1999 rainfall

Note: If parameters are estimated from catchment descriptors, they are easily reproducible so it is not essential to enter them in the table.

The ReFH outputs for the 1 in 100 year event are provided in the Annex.

Site code	**Method:** OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	**Tp (hours)** Time to peak	**C_{max} (mm)** Maximum storage capacity	**BL (hours)** Baseflow lag	**BR** Baseflow recharge
Broughton_01	CD	8.710	395.115	53.412	1.119
Brief description of any flood event analysis carried out (further details should be given below or in a project report)			No flood event analysis was undertaken as the catchment is ungauged.		

4.2 Design events for ReFH method

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
Broughton_01	urban	Winter	14	-

4.3 Flood estimates from the ReFH method

Site code	**Flood peak (m^3/s) for the following return periods (in years)**		
	2	**100**	**1000**
Broughton_01	10.35	24.91	43.51
Growth Curve Broughton_01	*1.00*	*2.41*	*4.20*

5 Revitalised flood hydrograph 2 (ReFH2) method – FEH2013 rainfall model

5.1 Parameters for ReFH2 model – FEH2013 rainfall

Note: If parameters are estimated from catchment descriptors, they are easily reproducible so it is not essential to enter them in the table.

The ReFH2 outputs for the 1 in 100 year event are provided in the Annex.

Site code	**Method:** OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	**Tp (hours)** Time to peak	**C_{max} (mm)** Maximum storage capacity	**BL (hours)** Baseflow lag	**BR** Baseflow recharge
Broughton_01	CD	9.71	397.47	57.11	1.14
Brief description of any flood event analysis carried out (further details should be given below or in a project report)			No flood event analysis was undertaken as the catchment is ungauged.		

5.2 Design events for ReFH2 method

Site code	**Urban or rural**	**Season of design event (summer or winter)**	**Storm duration (hours)**	**Storm area for ARF** (if not catchment area)
Broughton_01	Urban	Winter	15:00:00	-
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?				No further analysis proposed at this stage
Any changes to the parameters used to estimate the impact of urbanisation in the catchment?				Catchment is essentially rural

5.3 Flood estimates from the ReFH2 method

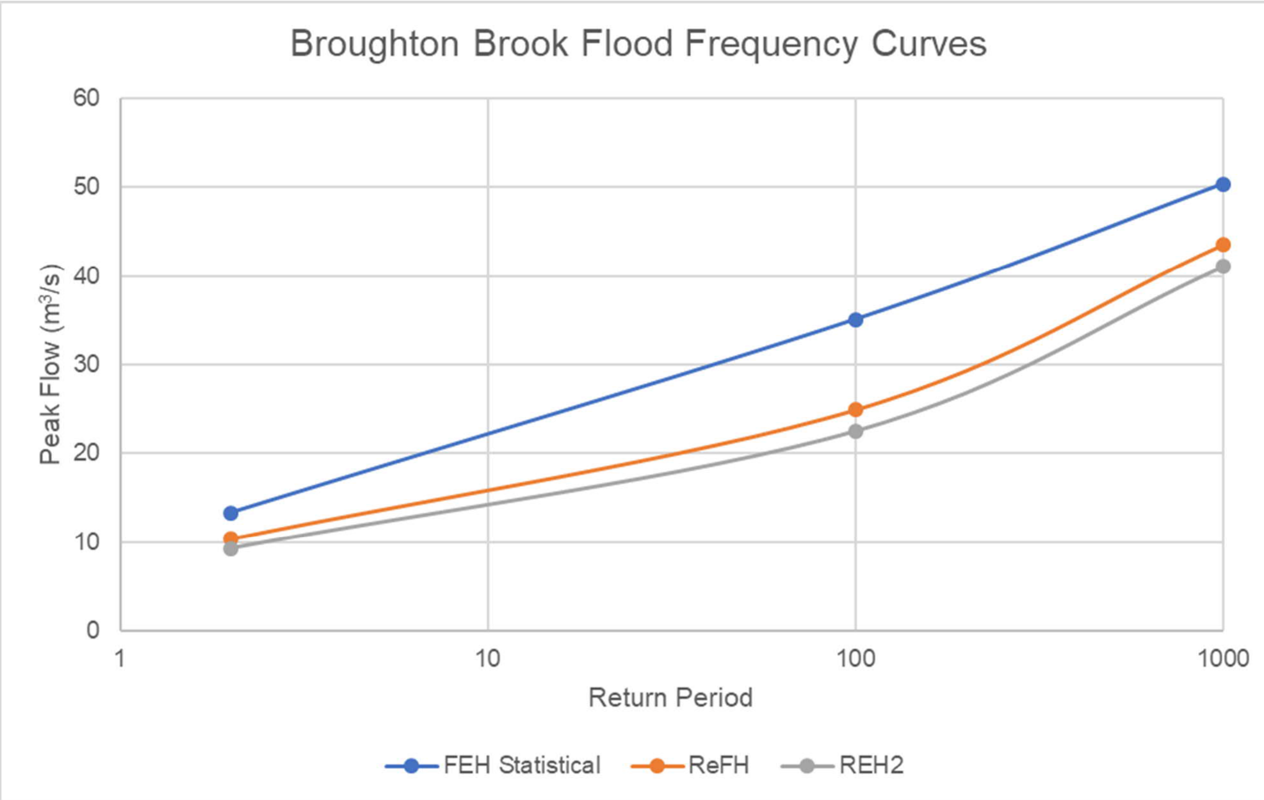
Site code	**Flood peak (m^3/s) for the following return periods (in years)**		
	2	**100**	**1000**
Broughton_01	9.24	22.48	41.04
Growth curve Broughton_01	*1.00*	*2.43*	*4.44*

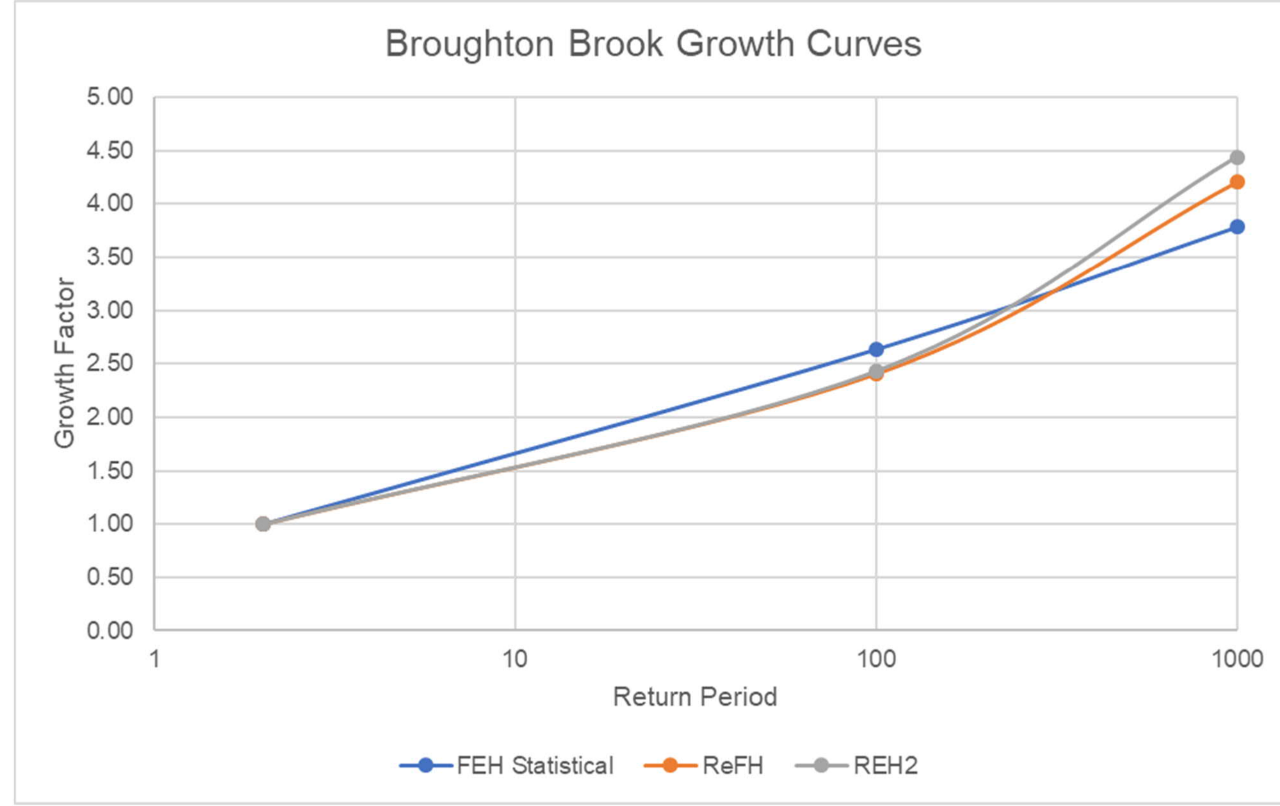
6 Discussion and summary of results

6.1 Comparison of results from different methods

This table compares peak flows from ReFH, ReFH2 and the FEH Rainfall-Runoff and Statistical method at the subject site for three key return periods.

Method	Return Period		
	2 years	100 years	1000 years
FEH Statistical	13.30m^3/s	35.07m^3/s	50.34 m^3/s
ReFH	10.35m^3/s	24.91m^3/s	43.51m^3/s
REH2	9.24m^3/s	22.48m^3/s	41.04m^3/s





6.2 Final choice of method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	The growth curves for the Statistical, ReFH and ReFH2 methods are comparable. The flows from the FEH statistical method are higher for QMED than the ReFH and ReFH2 methods and subsequently for other return periods given the similar growth factors. The FEH Statistical QMED is based on observed data at the subject site whereas ReFH and ReFH2 use catchment descriptors only. There is therefore more confidence in the Statistical QMED estimate. The FEH Statistical method flows are selected for use in the model as this produces relatively conservative flows in comparison to ReFH and ReFH2 and makes use of the at site historic gauging data.

6.3 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	It has been assumed that the catchment descriptors reflect the site conditions. Appropriate checks have been made against available mapping data to confirm this. It is also assumed that the gauged data is correct and suitable for QMED estimates – this is assessed as part of the HiFlows dataset review.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed	The catchment is not highly permeable or heavily urbanised. Consequently, the FEH methods are considered appropriate for flow estimation at the subject site.
Give what information you can on uncertainty in the results – e.g. confidence limits for the QMED estimates using FEH **3** 12.5 or the factorial standard error from Science Report SC050050 (2008).	The estimate of QMED based on gauged data is for Broughton_01 is 13.30m^3/s. For the 68% confidence interval QMED is expected to be in the range of 9.29 – 19.03m^3/s. For the 95% confidence interval QMED is expected to be in the range of 6.49 – 27.23m^3/s.

Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	Peak flow estimates have been considered at the subject site against the aims of this study. Consequently, it is not recommended that they are adopted at different locations for different purposes.
Give any other comments on the study, for example suggestions for additional work.	No further analysis is recommended.

6.4 Checks

Are the results consistent, for example at confluences?	Flow estimation only carried out at one point.
What do the results imply regarding the return periods of floods during the period of record?	No historic fluvial flood information is available for this site.
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	The 100-year growth factor for the statistical method is 2.64 which sits in a typical range, and therefore is appropriate.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	The 1000/100-year ratio for the Broughton Brook is 1.44, which sits in a typical range, and therefore is appropriate.
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	The specific runoff at Broughton_01 is 1.90 l/s/ha for the 1 in 2-year event and 5.01 l/s/ha for the 1 in 100-year event.
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	N/A
Are the results compatible with the longer-term flood history?	No flood history is available for the subject site.
Describe any other checks on the results	No additional checks have been undertaken as part of this assessment.

6.5 Final results

Site code	Flood peak (m^3/s) for the following return periods (in years)		
	2	100	1000
Broughton_01	13.30	35.07	50.34

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, name of ISIS model, or reference to table below)	Flow hydrographs provided for the sub-catchments in excel spreadsheets for inclusion in the hydraulic model.

7 Annex - supporting information

7.1 ReFH outputs for the 1 in 100 year event

```
ROZ_BS_001
 ** beginning of data read warnings **

 ReFH dll is not being used - calculations are performed using the published
report.
 Calculations may therefore not be the latest recognised standard.
 URBEXT = 0.012; Season set to WINTER

 ***** end of data read warnings *****


FILE=12C.dat Flood Modeller VER=4.5.1.6163
 ************************************************************
 Flood Modeller
 ************************************************************

 HYDROLOGICAL DATA

 Catchment: ROZ_BS_001
 ************************************************************
 Catchment Characteristics
 ************************************************************
 Easting         :    488850 Northing       :    240950
 Area            :    70.062 km2
 DPLBAR          :    10.750 km
 DPSBAR          :    29.100 m/km
 PROPWET         :     0.310
 BFIHOST         :     0.482
 SAAR            :   629.000 mm
 Urban Extent    :     0.012
 c               :    -0.027
 d1              :     0.331
 d2              :     0.280
 d3              :     0.290
 e               :     0.316
 f               :     2.425

********************************************************************************
 Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
 Calculations from ReFH published report (2005)

********************************************************************************
 Estimation of T-year flood
 ==========================
 Season                         :    WINTER
 (Seasonality determined by URBEXT = 0.012)
 ==========================================
 Rainfall
 ==========================================
 Event rainfall flag            :    DESIGN
 Rainfall profile flag          :    DESIGN
 Flood return period            :   100.000 years
 Data interval                  :     2.000 hours
```

```
Design storm duration          :    14.000 hours
Critical storm duration        :    14.189 hours
ARF flag                       : ReFH Design Standard
Areal reduction factor (ARF)   :     0.938
SCF flag                       : ReFH Design Standard
Seasonal correction factor     :     0.682
DDF storm depth                :    82.208 mm
Design storm depth             :    52.628 mm
Peak rainfall [design]         :    17.890 mm
==========================================
Loss model
==========================================
Cmax flag                      : Catchment descriptors
Cmax donor correction factor   :     1.000
Cmax value                     :   395.115
Cini flag                      : ReFH Design Standard
Cini value                     :   125.410
alpha_T flag                   : ReFH Design Standard
alpha_T value                  :     0.830
Maximum runoff                 :      39.4%
Minimum runoff                 :      26.6%
==========================================
Routing model
==========================================
Time-to-peak (Tp) flag         : Catchment descriptors
Tp donor correction factor     :     1.000
Instantaneous UH time to peak  :     8.710 hours
Up flag                        : ReFH Design Standard
Dimensionless UH peak          :     0.650
Uk flag                        : ReFH Design Standard
Uk value used                  :     0.800
Dimensionless UH kink ordinate :     0.270
UH ordinate multiplier         :     2.234
Unit hydrograph kink abscissa  :    17.420 hours
Unit hydrograph time base      :    31.323 hours
==========================================
Baseflow model
==========================================
Baseflow lag (BL) flag         : Catchment descriptors
BL donor correction factor     :     1.000
BL value                       :    53.412
Baseflow recharge (BR) flag    : Catchment descriptors
BR donor correction factor     :     1.000
BR value                       :     1.119
Initial Baseflow (BF0) flag    : ReFH Design Standard
BF0 value                      :     2.648
Maximum Baseflow               :     6.699 m3/s
==========================================
Output summary
==========================================
Direct runoff hydrograph peak  :    20.249 m3/s
Minimum allowable flow         :     0.000 m3/s
Total flow hydrograph peak     :    24.913 m3/s
Hydrograph scaling factor      :     1.000
```

Simulation results using   : Full hydrograph

****

7.2 ReFH2 outputs for the 1 in 100 year event

UK Design Flood Estimation

Generated on Thursday, February 13, 2020 2:44:21 PM by UKAMW009
Printed from the ReFH Flood Modelling software package, version 2.2.6589.25305

Summary of estimate using the Flood Estimation Handbook revitalised flood hydrograph method (ReFH)

Site details

Checksum: C081-8ED2

Site name: Broughton_Brook_UpdatedCatchment_Descriptors

Easting: 488850

Northing: 240950

Country: England, Wales or Northern Ireland

Catchment Area (km²): 70.06

Using plot scale calculations: No

Site description: None

Model run: 100 year

Summary of results

Rainfall - FEH 2013 (mm):	75.47	Total runoff (ML):	1222.20
Total Rainfall (mm):	48.46	Total flow (ML):	2504.90
Peak Rainfall (mm):	8.27	Peak flow (m³/s):	22.48

Parameters

Where the user has overriden a system-generated value, this original value is shown in square brackets after the value used.
** Indicates that the user locked the duration/timestep*

Rainfall parameters (Rainfall - FEH 2013 model)

Name	Value	User-defined?
Duration (hh:mm:ss)	15:00:00	No
Timestep (hh:mm:ss)	01:00:00	No
SCF (Seasonal correction factor)	0.68	No
ARF (Areal reduction factor)	0.94	No
Seasonality	Winter	n/a

Loss model parameters

Name	Value	User-defined?
Cini (mm)	116.29	No
Cmax (mm)	397.47	No
Use alpha correction factor	No	No
Alpha correction factor	n/a	No

Routing model parameters

Name	Value	User-defined?
Tp (hr)	9.71	No
Up	0.65	No
Uk	0.8	No

Baseflow model parameters

Name	Value	User-defined?
BF0 (m^3/s)	2.24	No
BL (hr)	57.11	No
BR	1.14	No

Urbanisation parameters

Name	Value	User-defined?
Urban area (km^2)	4.33	No
Urbext 2000	0.04	No
Impervious runoff factor	0.7	No
Imperviousness factor	0.3	No
Tp scaling factor	0.5	No
Sewered area (km^2)	0.00	Yes
Sewer capacity (m^3/s)	0.00	Yes

Time series data

Time (hh:mm:ss)	Rain (mm)	Sewer Loss (mm)	Net Rain (mm)	Runoff (m^3/s)	Baseflow (m^3/s)	Total Flow (m^3/s)
00:00:00	0.724	0.000	0.218	0.000	2.241	2.241
01:00:00	1.059	0.000	0.321	0.018	2.202	2.220
02:00:00	1.543	0.000	0.473	0.082	2.164	2.246
03:00:00	2.243	0.000	0.698	0.213	2.129	2.341
04:00:00	3.246	0.000	1.032	0.441	2.097	2.538
05:00:00	4.666	0.000	1.529	0.815	2.069	2.884
06:00:00	6.616	0.000	2.260	1.392	2.049	3.442
07:00:00	8.269	0.000	2.976	2.265	2.041	4.306
08:00:00	6.616	0.000	2.503	3.542	2.049	5.591
09:00:00	4.666	0.000	1.830	5.228	2.079	7.307
10:00:00	3.246	0.000	1.305	7.204	2.138	9.342
11:00:00	2.243	0.000	0.917	9.314	2.229	11.543
12:00:00	1.543	0.000	0.638	11.414	2.354	13.768
13:00:00	1.059	0.000	0.441	13.381	2.513	15.894
14:00:00	0.724	0.000	0.303	15.142	2.705	17.847
15:00:00	0.000	0.000	0.000	16.655	2.928	19.583
16:00:00	0.000	0.000	0.000	17.839	3.177	21.016
17:00:00	0.000	0.000	0.000	18.574	3.444	22.019
18:00:00	0.000	0.000	0.000	18.758	3.721	22.479
19:00:00	0.000	0.000	0.000	18.438	3.997	22.435
20:00:00	0.000	0.000	0.000	17.739	4.262	22.001
21:00:00	0.000	0.000	0.000	16.786	4.510	21.297
22:00:00	0.000	0.000	0.000	15.671	4.738	20.409
23:00:00	0.000	0.000	0.000	14.459	4.942	19.401
24:00:00	0.000	0.000	0.000	13.205	5.122	18.327
25:00:00	0.000	0.000	0.000	11.959	5.276	17.236
26:00:00	0.000	0.000	0.000	10.795	5.406	16.201
27:00:00	0.000	0.000	0.000	9.750	5.513	15.263
28:00:00	0.000	0.000	0.000	8.838	5.600	14.437
29:00:00	0.000	0.000	0.000	8.037	5.669	13.706
30:00:00	0.000	0.000	0.000	7.319	5.722	13.041
31:00:00	0.000	0.000	0.000	6.660	5.760	12.420
32:00:00	0.000	0.000	0.000	6.042	5.786	11.827
33:00:00	0.000	0.000	0.000	5.452	5.799	11.251
34:00:00	0.000	0.000	0.000	4.879	5.801	10.680

Time (hh:mm:ss)	Rain (mm)	Sewer Loss (mm)	Net Rain (mm)	Runoff (m^3/s)	Baseflow (m^3/s)	Total Flow (m^3/s)
35:00:00	0.000	0.000	0.000	4.318	5.791	10.109
36:00:00	0.000	0.000	0.000	3.762	5.770	9.532
37:00:00	0.000	0.000	0.000	3.215	5.739	8.954
38:00:00	0.000	0.000	0.000	2.680	5.698	8.378
39:00:00	0.000	0.000	0.000	2.165	5.647	7.812
40:00:00	0.000	0.000	0.000	1.678	5.587	7.265
41:00:00	0.000	0.000	0.000	1.234	5.518	6.752
42:00:00	0.000	0.000	0.000	0.851	5.443	6.294
43:00:00	0.000	0.000	0.000	0.554	5.363	5.917
44:00:00	0.000	0.000	0.000	0.344	5.279	5.623
45:00:00	0.000	0.000	0.000	0.203	5.192	5.395
46:00:00	0.000	0.000	0.000	0.110	5.105	5.216
47:00:00	0.000	0.000	0.000	0.053	5.018	5.071
48:00:00	0.000	0.000	0.000	0.020	4.932	4.952
49:00:00	0.000	0.000	0.000	0.004	4.847	4.851
50:00:00	0.000	0.000	0.000	0.000	4.762	4.762
51:00:00	0.000	0.000	0.000	0.000	4.680	4.680
52:00:00	0.000	0.000	0.000	0.000	4.599	4.599
53:00:00	0.000	0.000	0.000	0.000	4.519	4.519
54:00:00	0.000	0.000	0.000	0.000	4.440	4.440
55:00:00	0.000	0.000	0.000	0.000	4.363	4.363
56:00:00	0.000	0.000	0.000	0.000	4.287	4.287
57:00:00	0.000	0.000	0.000	0.000	4.213	4.213
58:00:00	0.000	0.000	0.000	0.000	4.140	4.140
59:00:00	0.000	0.000	0.000	0.000	4.068	4.068
60:00:00	0.000	0.000	0.000	0.000	3.997	3.997
61:00:00	0.000	0.000	0.000	0.000	3.928	3.928
62:00:00	0.000	0.000	0.000	0.000	3.860	3.860
63:00:00	0.000	0.000	0.000	0.000	3.793	3.793
64:00:00	0.000	0.000	0.000	0.000	3.727	3.727
65:00:00	0.000	0.000	0.000	0.000	3.662	3.662
66:00:00	0.000	0.000	0.000	0.000	3.599	3.599
67:00:00	0.000	0.000	0.000	0.000	3.536	3.536
68:00:00	0.000	0.000	0.000	0.000	3.475	3.475
69:00:00	0.000	0.000	0.000	0.000	3.415	3.415
70:00:00	0.000	0.000	0.000	0.000	3.355	3.355

Printed from the ReFH Flood Modelling software package, version 2.2.6589.25305

Time (hh:mm:ss)	Rain (mm)	Sewer Loss (mm)	Net Rain (mm)	Runoff (m³/s)	Baseflow (m³/s)	Total Flow (m³/s)
71:00:00	0.000	0.000	0.000	0.000	3.297	3.297
72:00:00	0.000	0.000	0.000	0.000	3.240	3.240
73:00:00	0.000	0.000	0.000	0.000	3.184	3.184
74:00:00	0.000	0.000	0.000	0.000	3.128	3.128
75:00:00	0.000	0.000	0.000	0.000	3.074	3.074
76:00:00	0.000	0.000	0.000	0.000	3.021	3.021
77:00:00	0.000	0.000	0.000	0.000	2.968	2.968
78:00:00	0.000	0.000	0.000	0.000	2.917	2.917
79:00:00	0.000	0.000	0.000	0.000	2.866	2.866
80:00:00	0.000	0.000	0.000	0.000	2.816	2.816
81:00:00	0.000	0.000	0.000	0.000	2.768	2.768
82:00:00	0.000	0.000	0.000	0.000	2.719	2.719
83:00:00	0.000	0.000	0.000	0.000	2.672	2.672
84:00:00	0.000	0.000	0.000	0.000	2.626	2.626
85:00:00	0.000	0.000	0.000	0.000	2.580	2.580
86:00:00	0.000	0.000	0.000	0.000	2.536	2.536
87:00:00	0.000	0.000	0.000	0.000	2.492	2.492
88:00:00	0.000	0.000	0.000	0.000	2.448	2.448
89:00:00	0.000	0.000	0.000	0.000	2.406	2.406
90:00:00	0.000	0.000	0.000	0.000	2.364	2.364
91:00:00	0.000	0.000	0.000	0.000	2.323	2.323
92:00:00	0.000	0.000	0.000	0.000	2.283	2.283

Printed from the ReFH Flood Modelling software package, version 2.2.6589.25305

Appendix

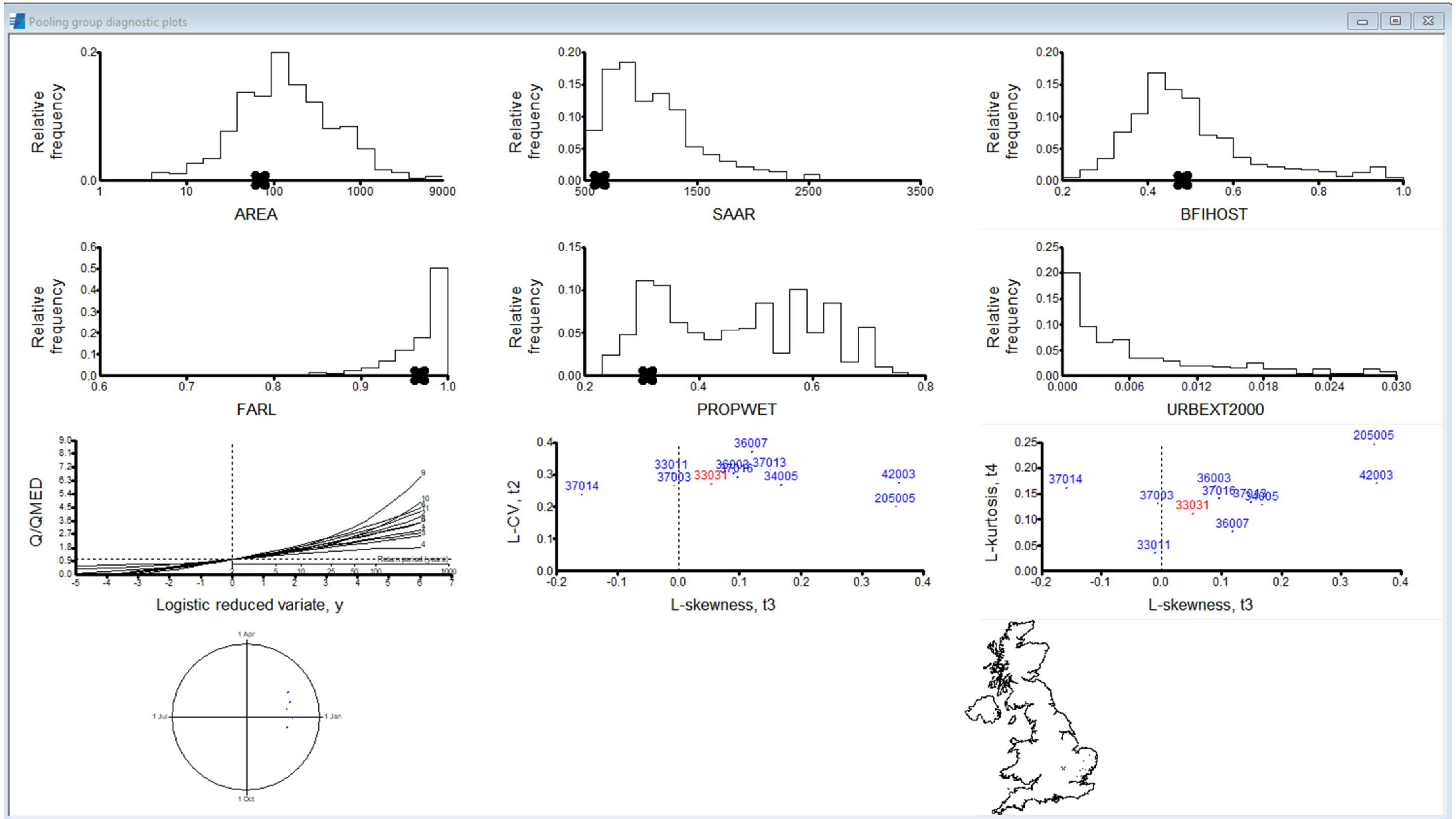
Catchment descriptors

Name	Value	User-defined value used?
Area (km²)	70.06	No
ALTBAR	98	No
ASPBAR	307	No
ASPVAR	0.17	No
BFIHOST	0.48	No
DPLBAR (km)	10.75	No
DPSBAR (mkm-¹)	29.1	No
FARL	0.97	No
LDP	21.62	No
PROPWET (mm)	0.31	No
RMED1H	10.4	No
RMED1D	29.1	No
RMED2D	37.4	No
SAAR (mm)	629	No
SAAR4170 (mm)	621	No
SPRHOST	40.87	No
Urbext2000	0.04	No
Urbext1990	0.01	No
URBCONC	0.79	No
URBLOC	0.79	No
Urban Area (km²)	4.33	No
DDF parameter C	-0.03	No
DDF parameter D1	0.33	No
DDF parameter D2	0.28	No
DDF parameter D3	0.29	No
DDF parameter E	0.32	No
DDF parameter F	2.43	No
DDF parameter C (1km grid value)	-0.03	No
DDF parameter D1 (1km grid value)	0.34	No
DDF parameter D2 (1km grid value)	0.26	No
DDF parameter D3 (1km grid value)	0.29	No
DDF parameter E (1km grid value)	0.31	No
DDF parameter F (1km grid value)	2.43	No

7.3 Pooling group composition

Station	Distance	Years of data	QMED AM	AREA	SAAR	FPEXT	FARL	URBEXT 2000	SPRHOST	BFIHOST	PG0	PG1_ESS	PG2_ESS
33031 (Broughton Brook @ Broughton)	0	45	13.298	70.06	629	0.144	0.967	0.038	40.87	0.482	NO	YES	YES
34005 (Tud @ Costessey Park)	0.175	57	3.146	72.11	649	0.158	0.973	0.029	32.65	0.598	YES	YES	YES
37003 (Ter @ Crabbs Bridge)	0.434	53	5.43	77.76	570	0.115	0.994	0.012	41.76	0.461	YES	YES	YES
33032 (Heacham @ Heacham)	0.482	50	0.442	56.16	688	0.116	0.983	0.006	6.01	0.968	YES	YES	NO
26003 (Foston Beck @ Foston Mill)	0.533	57	1.76	59.59	698	0.106	0.987	0.004	10.43	0.878	YES	YES	NO
37014 (Roding @ High Ongar)	0.588	54	10.928	92.65	597	0.107	0.986	0.008	43.46	0.403	YES	YES	YES
34012 (Burn @ Burnham Overy)	0.61	52	1.038	83.87	668	0.098	0.997	0.005	6.29	0.965	YES	YES	NO
33054 (Babingley @ Castle Rising)	0.627	42	1.132	48.53	686	0.118	0.944	0.005	9.74	0.906	YES	YES	NO
36003 (Box @ Polstead)	0.687	57	3.91	56.72	566	0.093	0.993	0.012	37.7	0.555	YES	YES	YES
26013 (Driffield Trout Stream @ Driffield)	0.729	8	2.78	53.33	690	0.093	0.997	0.006	17.61	0.807	YES	YES	NO
39042 (Leach @ Priory Mill Lechlade)	0.76	46	3.085	77.62	736	0.083	0.971	0.003	12.21	0.865	YES	YES	NO
36007 (Belchamp Brook @ Bardfield Bridge)	0.824	53	4.63	58.16	560	0.079	0.996	0.004	36.21	0.523	YES	YES	YES
33011 (Little Ouse @ County Bridge Euston)	0.871	57	3.926	129.35	596	0.146	0.985	0.008	26.08	0.652	NO	NO	YES
37016 (Pant @ Copford Hall)	0.876	54	7.24	63.8	588	0.069	0.997	0.009	43.6	0.404	NO	NO	YES
42003 (Lymington @ Brockenhurst)	0.89	23	27.4	99.87	854	0.107	0.997	0.013	39.18	0.387	NO	NO	YES
205005 (Ravernet @ Ravernet)	0.912	44	15.066	73.72	946	0.106	0.934	0	44.85	0.422	NO	NO	YES
37013 (Sandon Brook @ Sandon Bridge)	0.937	52	8.99	74.7	575	0.092	0.855	0.026	46.7	0.275	NO	NO	YES

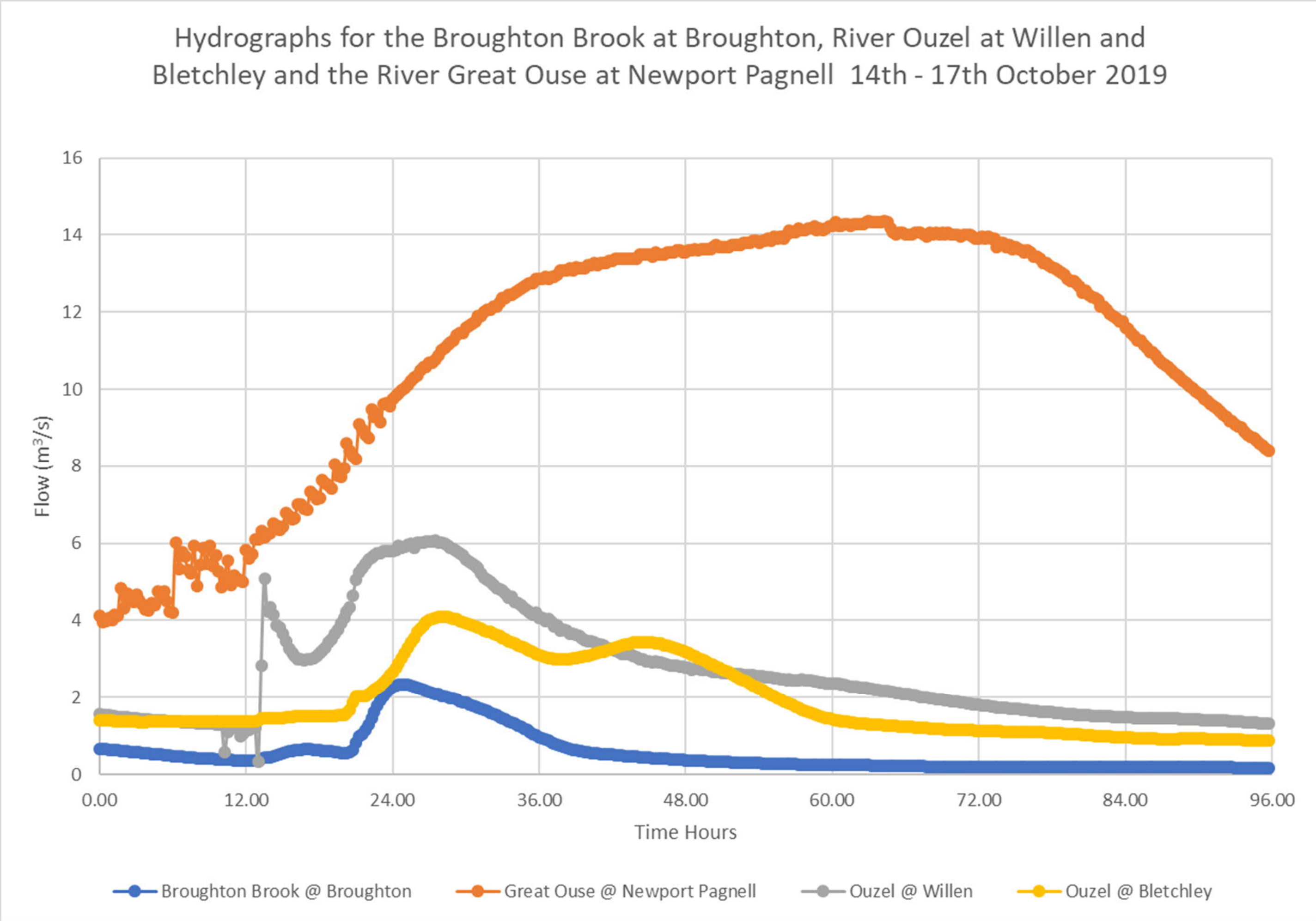
7.4 Pooling group graphs (PG2)

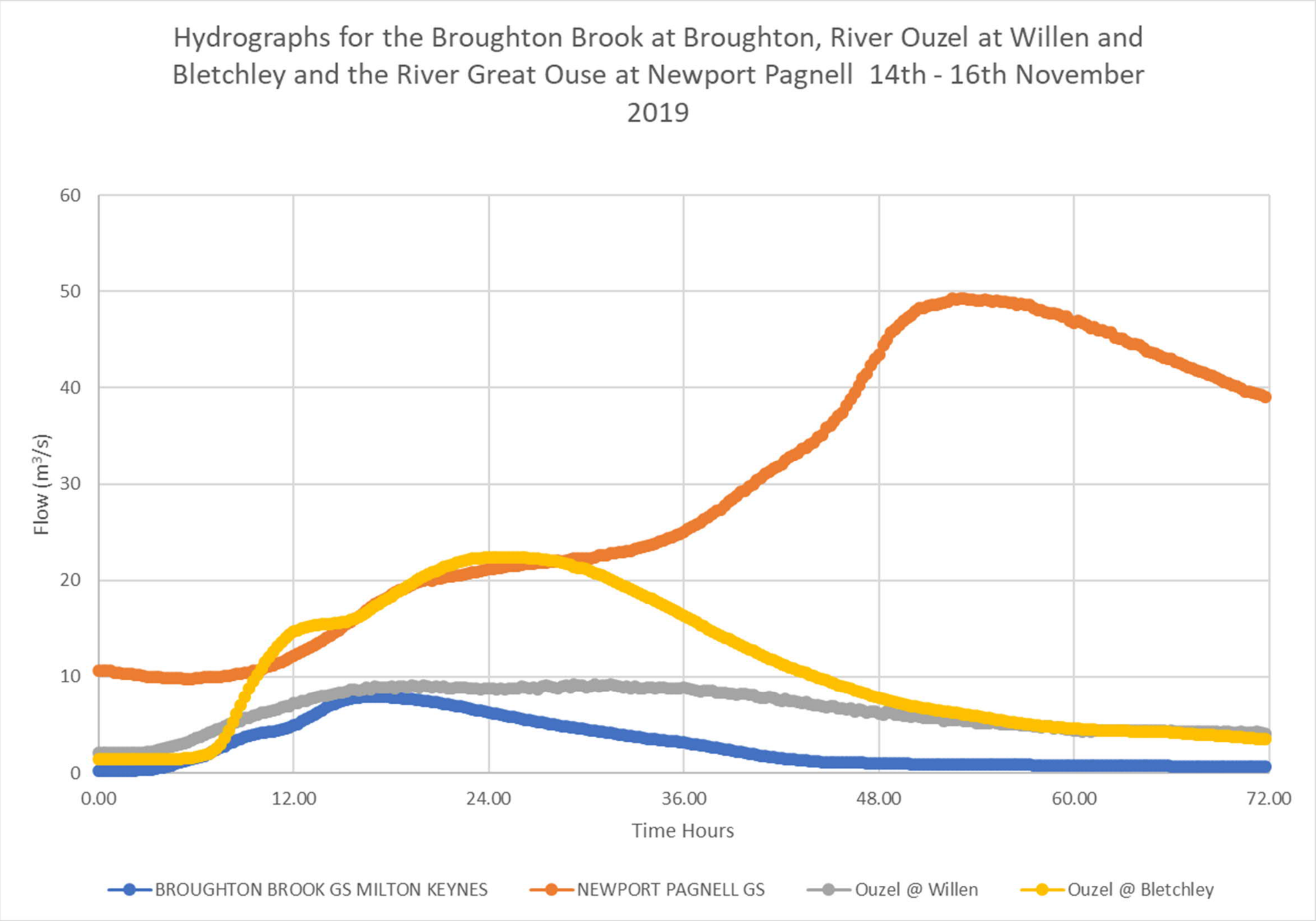


DATE:	11 May 2020	**CONFIDENTIALITY:**	Public
SUBJECT:	Milton Keynes East - St James - Revised baseline hydraulic modelling		
PROJECT:	700517078	**AUTHOR:**	Tom Ashby/Aidan Wilks-Daly
CHECKED:	Andy Smith	**APPROVED:**	Andy Smith

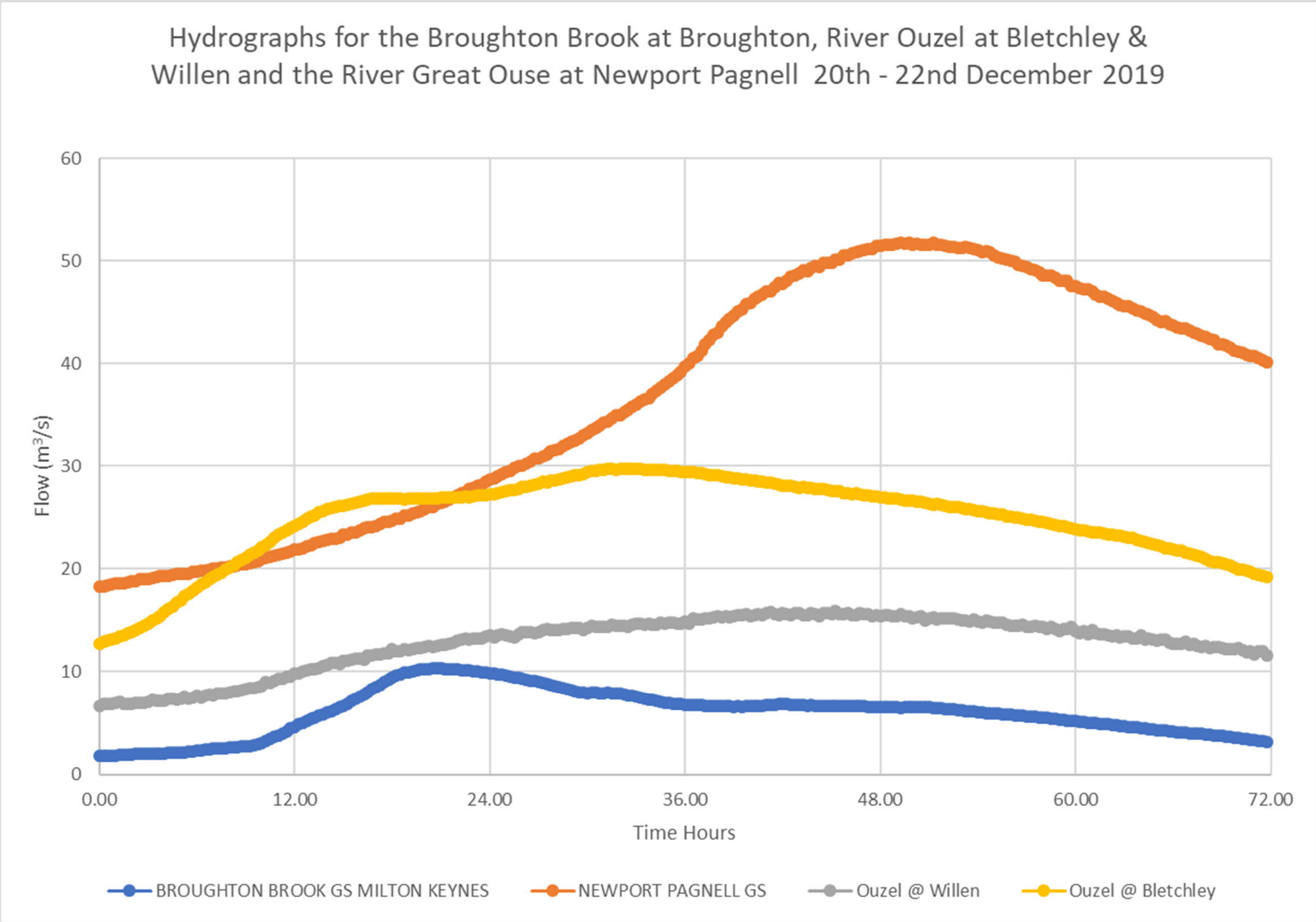
Appendix B – Flood Peak Comparison

Milton Keynes East - St James - Revised baseline hydraulic modeling: Appendix B – Flood Hydrographes

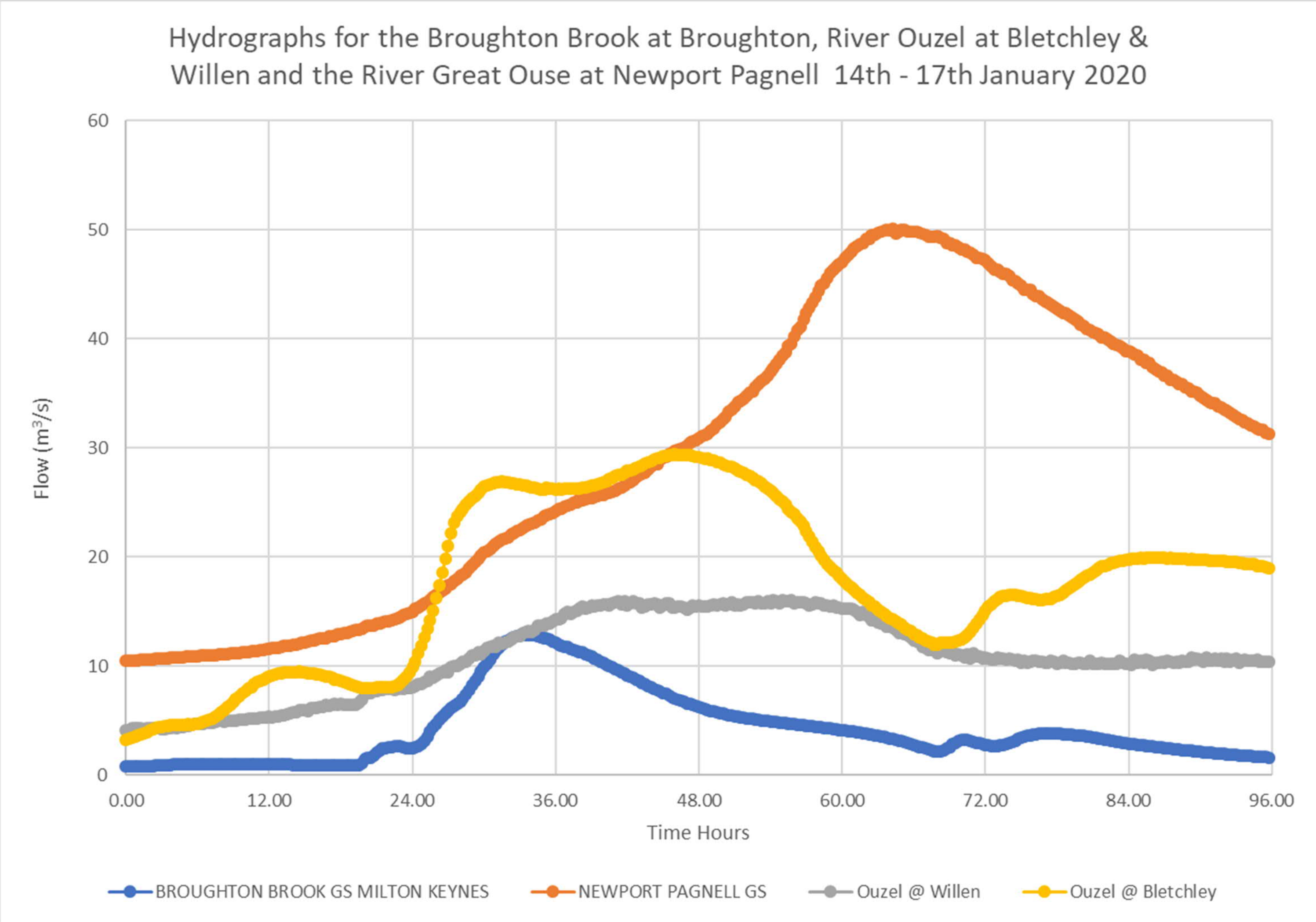




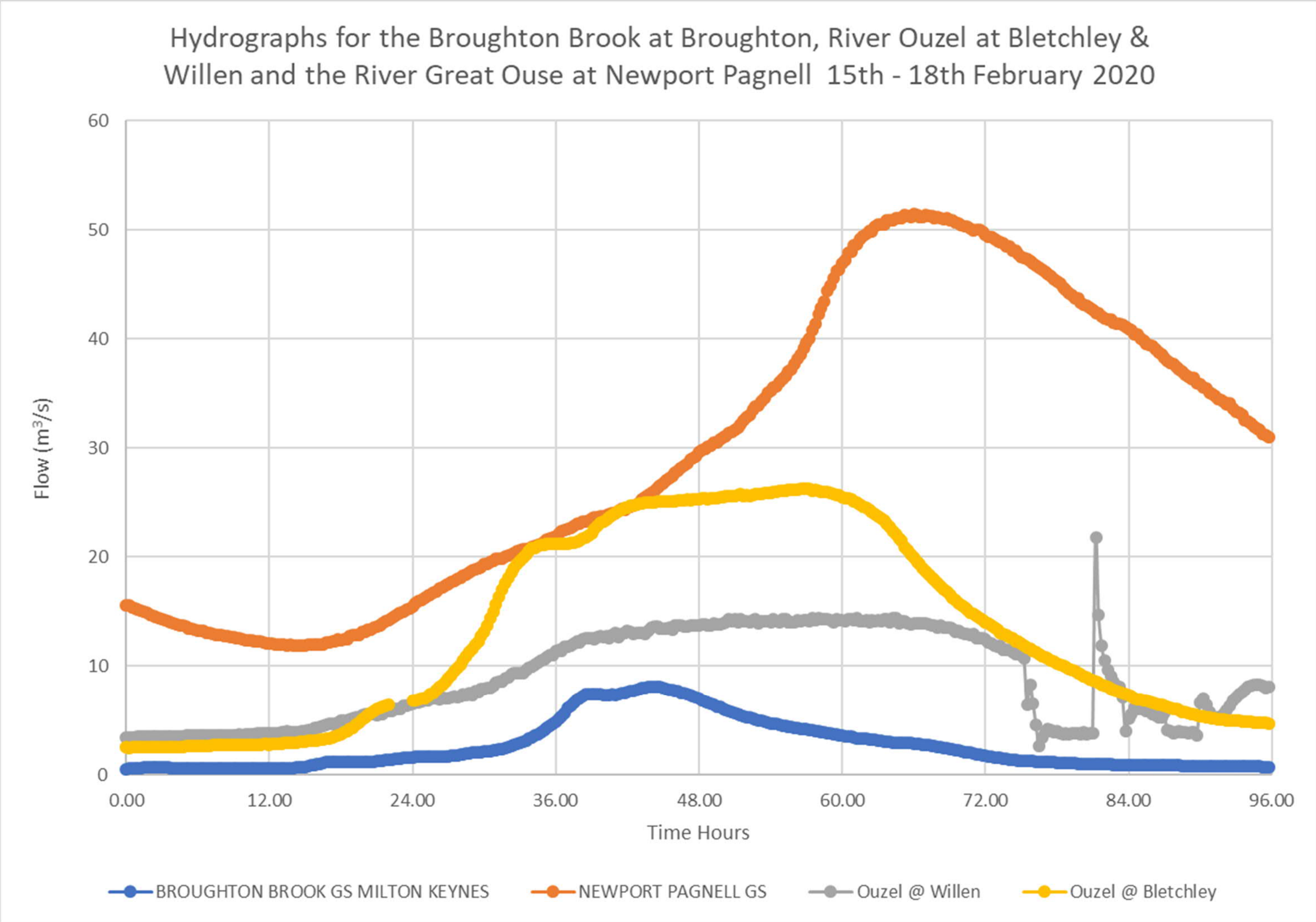
Hydrographs for the Broughton Brook at Broughton, River Ouzel at Willen and Bletchley and the River Great Ouse at Newport Pagnell 14th - 16th November 2019
60
50
40
30
20
10
0
Flow (m³/s)
0.00
12.00
24.00
36.00
48.00
60.00
72.00
Time Hours
BROUGHTON BROOK GS MILTON KEYNES
NEWPORT PAGNELL GS
Ouzel @ Willen
Ouzel @ Bletchley



Hydrographs for the Broughton Brook at Broughton, River Ouzel at Bletchley & Willen and the River Great Ouse at Newport Pagnell 20th - 22nd December 2019
60
50
40
30
20
10
0
Flow (m3/s)
0.00
12.00
24.00
36.00
48.00
60.00
72.00
Time Hours
BROUGHTON BROOK GS MILTON KEYNES
NEWPORT PAGNELL GS
Ouzel @ Willen
Ouzel @ Bletchley



Hydrographs for the Broughton Brook at Broughton, River Ouzel at Bletchley & Willen and the River Great Ouse at Newport Pagnell 14th - 17th January 2020
Flow (m3/s)
60
50
40
30
20
10
0
0.00
12.00
24.00
36.00
48.00
60.00
72.00
84.00
96.00
Time Hours
BROUGHTON BROOK GS MILTON KEYNES
NEWPORT PAGNELL GS
Ouzel @ Willen
Ouzel @ Bletchley


Hydrographs for the Broughton Brook at Broughton, River Ouzel at Bletchley & Willen and the River Great Ouse at Newport Pagnell 15th - 18th February 2020
Flow (m³/s)
60
50
40
30
20
10
0
0.00
12.00
24.00
36.00
48.00
60.00
72.00
84.00
96.00
Time Hours
BROUGHTON BROOK GS MILTON KEYNES
NEWPORT PAGNELL GS
Ouzel @ Willen
Ouzel @ Bletchley

TECHNICAL NOTE

DATE:	30 October 2020	**CONFIDENTIALITY:**	Public
SUBJECT:	Response to Environment Agency Queries on Baseline Flood Modelling		
PROJECT:	70057521 - Milton Keynes East	**AUTHOR:**	Andy Smith
CHECKED:	Tom Ashby	**APPROVED:**	Doug Barker

INTRODUCTION

The Environment Agency provided comments (dated 5 October 2020) in relation to the refined baseline hydraulic model submitted by WSP (on 7 May 2020) to support the Milton Keynes development. Where appropriate this Technical Note references the Revised Baseline Hydraulic Modelling Technical Note dated 7 May 2020 (Revised Baseline Note).

Approval is sought for the baseline model which has been modified since it was approved for use in the Scheme in a meeting between WSP and the Environment Agency on 16 January 2020. The improvements to the baseline model are:

§ Inclusion of the Broughton Brook as a 1D ESTRY channel element (green line in Figure 1);
§ Inclusion of a small channel flowing adjacent to the Cotton Valley Sewage Treatment Works (STW), under the M1 through Pineham Nature Reserve (red line in Figure 1);
§ Inclusion of an additional ordinary watercourse on the right bank of the River Ouzel upstream of the proposed highway crossing location as a point input (green triangle in Figure 1)
§ Revised hydrology for the Broughton Brook and additional watercourses.

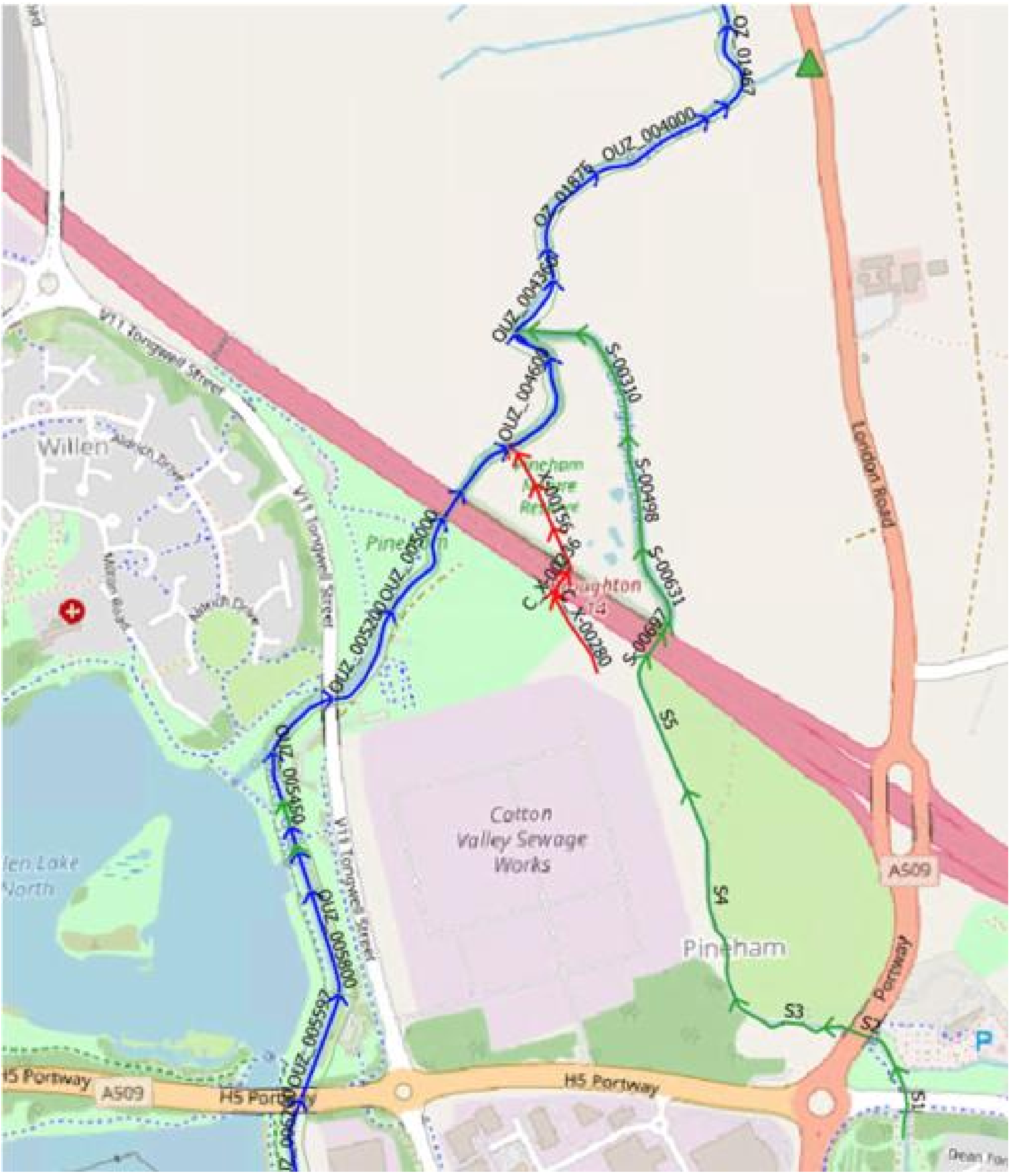


Figure 1 Map showing location of alterations to previous Environment Agency model

The Environment Agency has requested further information on both the hydrology estimates and the hydraulics as part of their review of this model, these queries and the associated responses are provided below:

HYDROLOGY:

Environment Agency: Broughton Brook has a long gauged record (nearly 50 years). There are no apparent attempts to use the observed record to inform hydrograph shape, time to peak or reconcile peak flow estimates with flood history. It is strongly recommended that the observed record is used in this way to add confidence to peak flow estimates and inflow hydrographs.

WSP: As outlined in the "*Timing of Hydrograph Peaks*" section of the Revised Baseline Note observed data was used within the study, this part of the assessment utilised the publicly available data from the

Environment Agency's flood monitoring archive[1], which limits the available data to the previous 12 months. The minutes of the meeting between WSP and the Environment Agency on 7 January 2020 outline that the Environment Agency were to undertake an assessment of the alignment of peaks utilising their information, however, this was not provided, therefore, checks with the publicly available information were undertaken. Within the period of available record there were several reasonable high flow events that could be used to inform the hydrological aspects of the study, these occurred on:

- 14th – 15th October 2019;
- 14th – 16th November 2019;
- 20th – 22nd December 2019;
- 14th – 17th January 2020; and
- 15th – 18th February 2020.

Since the preparation of the previous Technical Note the Environment Agency, through a Freedom of Information Request have provided gauged flow data for the Broughton Brook at Broughton and Ouzel at Willen for the period since the 2 January 2003 (earlier data was requested but was not forthcoming). This gauged flow data has been used to assess the alignment of flood peaks on the River Ouzel and the Broughton Brook for corresponding AMAX events since 2003. Hydrographs for the following high flow events were compared; 10 January 2007, 16 of January 2008 and the 7/8 January 2014, as shown in Appendix 2. These hydrographs showed that at higher magnitude events the peak on the River Ouzel is delayed compared to the peak on the Broughton Brook.

Hydrograph Shape

The hydrographs presented in Appendix B of the Revised Baseline Note do not show a consistent clear shape, therefore, given the uncertainties with the catchment response it was considered that the most appropriate approach to the construction of the hydrographs was to scale the ReFH2 hydrographs. Whilst these inflows were added to the upstream of the model, the hydrograph shape changes once the M1 embankment is reached due to out of bank flow, backwater effects and interaction with Willen Lake. Therefore, the shape of the input hydrograph is not overly critical at the area of interest.

Time to peak

This confirmed that the Broughton Brook peaks at, or very close to the River Ouzel, therefore the time to peaks for the two watercourses at the upstream end of the model were aligned.

Reconcile peak flow estimates with flood history

The Flood Estimation Calculation Record has been updated to include the estimates for the low magnitude events (2yr, 5yr, 10yr & 20yr) only, as these were not previously submitted for approval. However, given the final Scheme design it was considered appropriate to consider the implications on the functional floodplain within the hydraulic model. The revised Flood Estimation Calculation Record is in Appendix 1 of this Technical Note.

[1] https://environment.data.gov.uk/flood-monitoring/archive (Accessed April 2020)

The flows for the low magnitude events (2yr, 5yr, 10yr & 20yr) have all been calculated based on the observed data using a single site estimate within WINFAP.

However, there was insufficient data (49 years) to come up with single site estimates for the 1 in 100 year and 1 in 1,000 year events. Therefore, the flow estimates were based on an enhanced single site analysis using pooled data, which included the gauge on the Broughton Brook, which was at the top of the pooling group thereby strongly influencing the flows. The 1 in 100 year estimate is 35.1m^3/s and the 1 in 1000 year flow estimate is 50.3m^3/s. This compares to single site estimates of 32.6m^3/s and 44.2m^3/s for the 100 year and 1000 year respectively. The pooled estimates are higher than the single site estimates, with the ratio of the pooled flood estimates compared to single site estimates of 1.08 for the 100 year event and 1.14 for the 1000 year event.

The graphs in Figure 2 and Figure 3 below show how the pooled data compares to the single site gauged data for the Broughton Brook, for both the flood frequency curve and the growth curve.

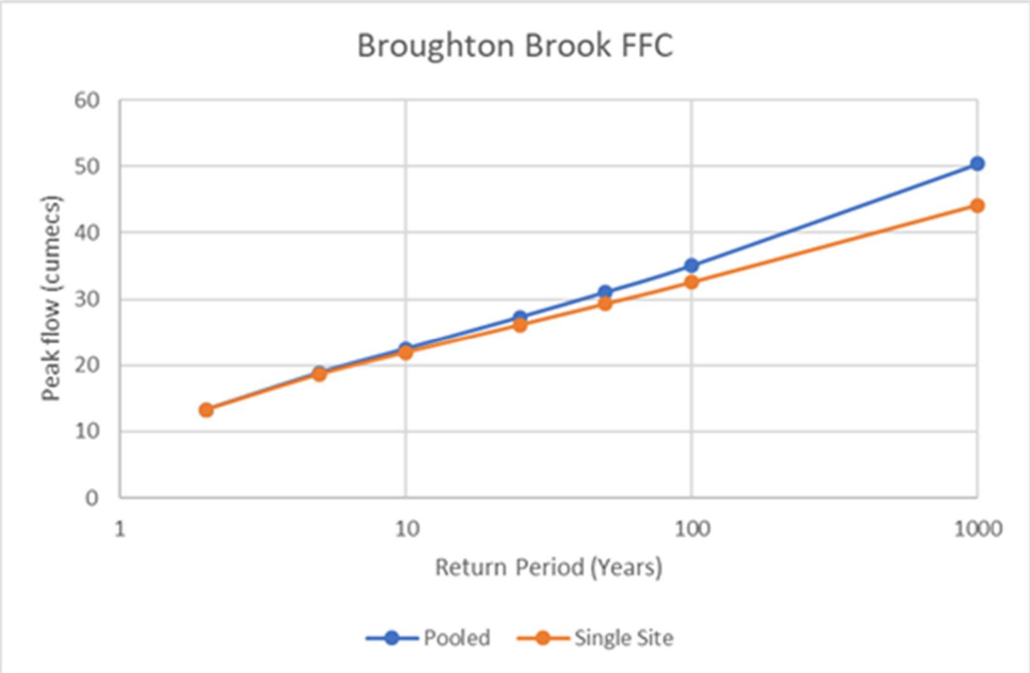


Figure 2 - Broughton Brook Flood Frequency Curve

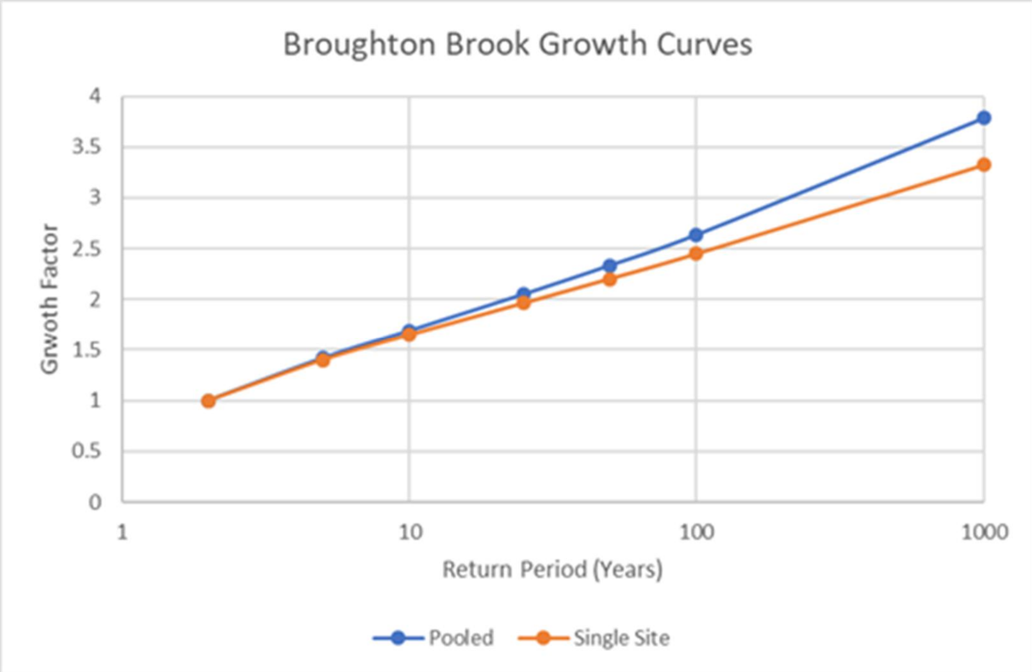


Figure 3 - Broughton Brook Growth Curve

It is therefore demonstrated that at the low magnitude events, where the gauged data is sufficiently robust to enable a single site analysis the pooled analysis fits extremely well, giving sufficient confidence in the flow estimates and demonstrating that the gauged data has adequately been incorporated into the hydrological estimates.

HYDRAULICS:

Environment Agency: There has been no apparent attempt to calibrate Broughton Brook to the rating or observed data at Broughton gauge. Calibration should be carried out and any change needed to the rating curve should be fed back into the hydrology. Calibration may change model parameters and therefore results.

WSP: The National River Flow Archive demonstrates that there is only one rating curve for the Broughton Brook at Broughton (33031) which has been in use since it has been installed. However, gauging to confirm this rating curve has only been undertaken since 2001, with the gauging fitting the theoretical plot well below 0.4m / 1.3 m^3/s, above which there appears to be a disconnection between the gauging data and the curve. This is shown in Figure 4 and only demonstrates a good fit at very low flow events which are approximately 10-20% of QMED and it is therefore not a suitable approach to high flow calibration of the model with any certainty.

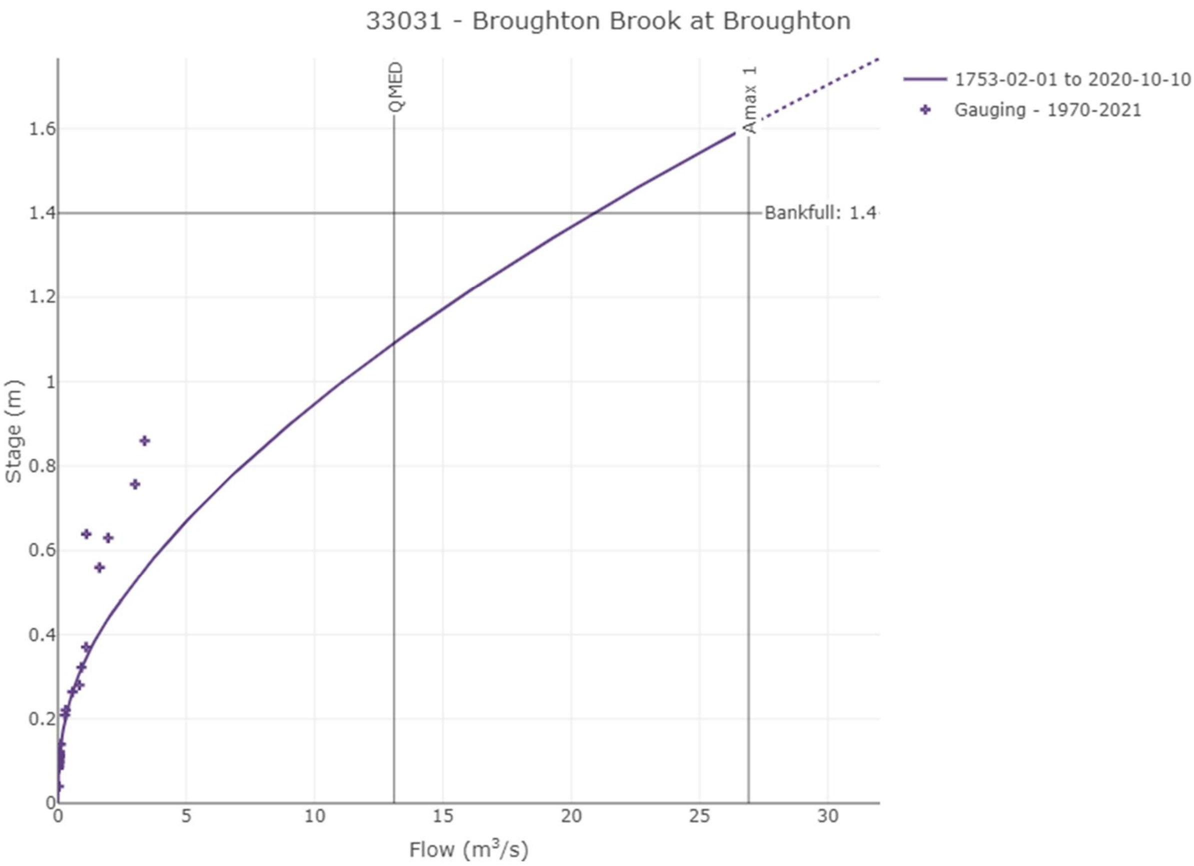


Figure 4 - Rating Curve for the Broughton Brook

In terms of verification of the model this has been undertaken at the Broughton gauge by comparing the model results against the rating curve. Whilst the model does not include a surveyed cross section at the gauge itself, there is a cross section (Section S5) in close proximity upstream. The location of this cross section is shown in Figure 5, this cross section is considered a suitable location for calibration of the model.

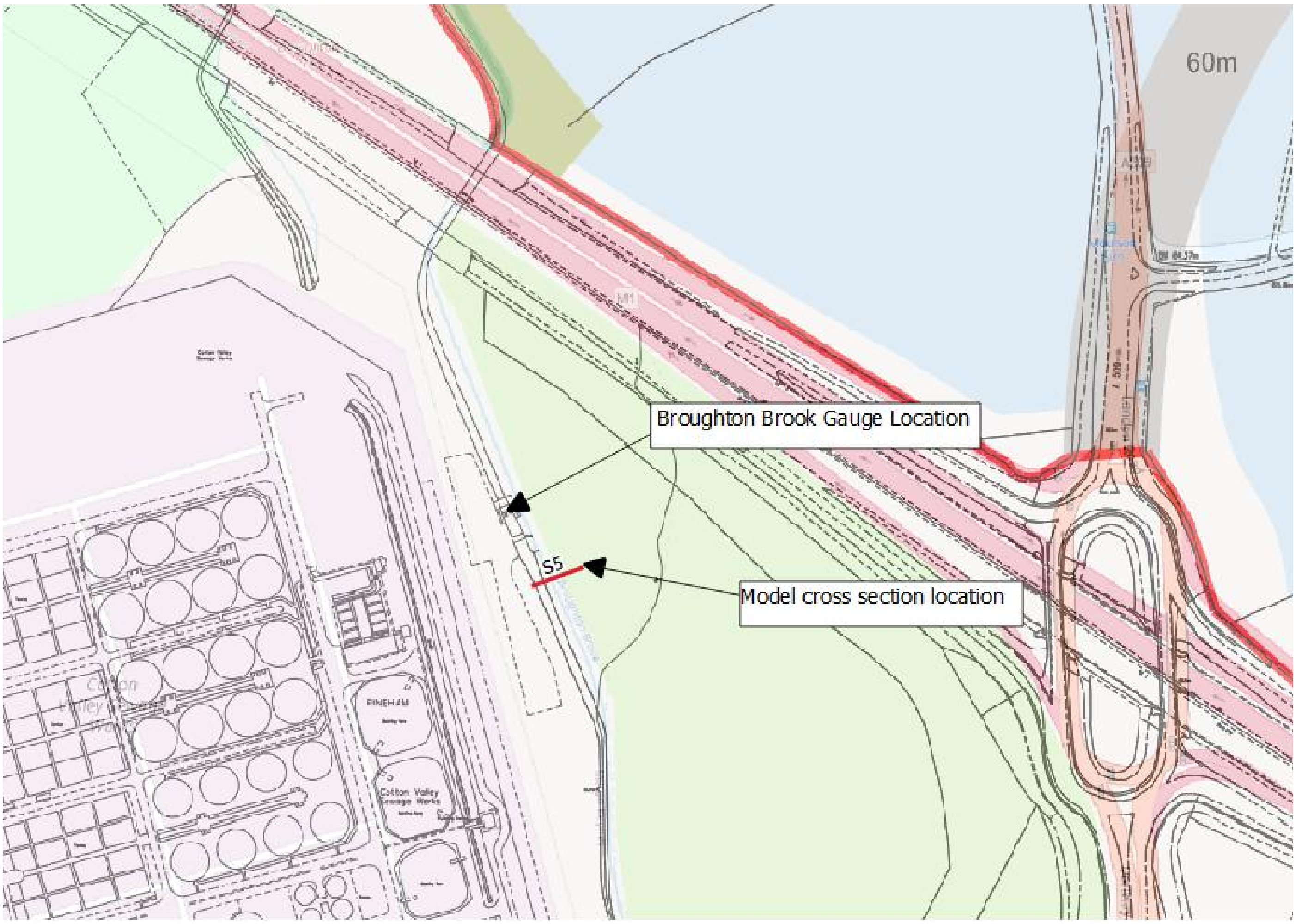


Figure 5 - Location of Cross Section S5 in relation to the Broughton Brook gauge

The comparison of the model predictions with the gauge rating, shown in Figure 6, demonstrates that the model is within 225mm of the rating curve. This shows a good fit between the model predictions and the gauge rating, which suggests there is high confidence in the model performance for this modelling exercise and no further changes are required to the hydraulics or hydrology.

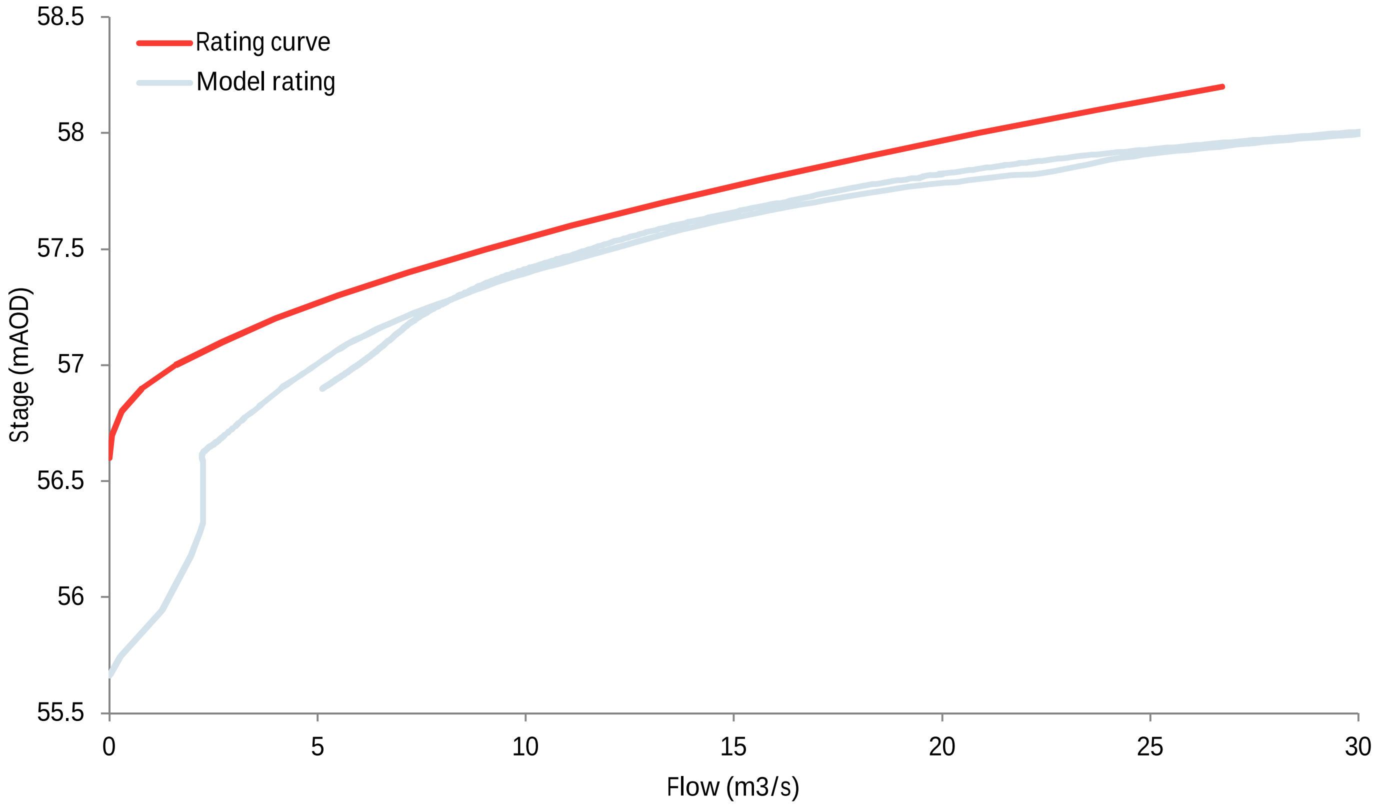


Figure 6 - Rating curve comparison at model cross section S5

Environment Agency: Representation of flow routes should also be checked, particularly around road crossings. The M1 is represented as a solid barrier to floodplain flows however there is some evidence to suggest it is raised on piers. No survey or site photos provided to help confirm this.

WSP: The model provides a good representation of flow routes in and around the site and the representation of key structures and floodplain features has been validated in the model. The representation of the M1 embankment is accurate and is described in further detail below.

The hydraulic modelling adopted the same approach to the representation of the M1 and other key highway embankments as that within the Environment Agency's model, as these were determined to reflect the conditions at these locations. Topographical / Channel Survey was collected in 2008 as part of the initial phases of the Scheme and was used to confirm the suitability of the approach of this representation as well as to refine it. This survey was used to inform the model build for the new reaches.

Tongwell Street Bridge

We have not been provided with the topographical survey used to inform the Environment Agency's model, therefore, the best representation of the Tongwell Street crossing is shown on the Birds eye view in Bing maps, which clearly shows the opening and the associated embankment. This is not re-produced here due to licence constrictions, but the link is in the footnotes[2]. Whilst there are two piers in the floodplain, these are relatively small when compared to the model 8m grid size and therefore are considered not to have a

[2] https://www.bing.com/maps?osid=54ecb569-8208-4be8-a467-3f67a2182ccd&cp=52.060029~-0.714186&lvl=19&dir=90&style=g&v=2&sV=2&form=S00027

significant impact. This has been tested through the use of flow constriction shapes to represent the bridge piers in this location. The inclusion of the piers made a very minor difference to the water levels in this area. The only existing highway crossing that will be modified as part of the scheme is the Tongwell Street bridge. This will include the modification of the bridge piers and therefore sensitivity testing of the impact of the additional piers within the model is required, which was best achieved via the use of flow constriction shapes.

M1

The OS Mastermap demonstrates that there are three openings beneath the M1 for the River Ouzel, the channel adjacent to the STW and the Broughton Brook (west to east respectively) to pass through, this is shown in Figure 7. This is also clearly shown in the birds eye view of the crossing in Bing Maps (this is not re-produced here due to licence constrictions, but the link in the footnotes[3]).

Figure 7 - M1 Crossing OS Mastermap

The M1 crossing of the River Ouzel is shown in Figure 8 and Figure 9, noting that the piers are substantially smaller than the 8m cell size within the model. The piers which are located on the left and right bank of the river channel have been represented using a high Manning's roughness value. As outlined in the Tongwell Street bridge section, the impact of including piers in the floodplain was negligible and therefore not required at this location, particularly given the very small width of the piers when compared to the opening.

[3] https://www.bing.com/maps?osid=331677b4-2e6b-450f-b3d4-e1c05835e3f6&cp=52.061996~-0.709124&lvl=19&style=g&v=2&sV=2&form=S00027

Figure 8 - River Ouzel beneath the M1, showing tie into highway embankment (downstream – left bank)

Figure 9 - River Ouzel beneath the M1, showing tie into highway embankment (downstream – right bank)

A422

The A422 is on an embankment as it crosses the northern boundary of the site, with three openings (supoort by piers) across the floodplain, this is shown in Figure 10 and Figure 11. The pier which is located on the left bank of the channel has been represented using a high Manning's roughness value. As outlined in the Tongwell Street bridge section, the impact of including piers in the floodplain was negligible and therefore not required at this location, given the number of openings and size of the piers relative to the floodplain.

In conclusion it is considered that the modelling represenation of these structures is suitable for the modelling assessment undertaken.

Figure 10 - A422 Floodplain Opening (distant view)

Figure 11 - A422 Floodplain Opening (close view)

Environment Agency: Recommendations for clarifications to reporting to aid any future reviews including sensitivity testing to new reaches added in the model, explanation of parameter choices, and differences in phasing of inflows between events. Other recommendations include addressing glass-walling and stability issues but unlikely to affect maximum flood extents in areas of interest.

WSP:

Sensitivity Tests

A number of sensitivity tests have been undertaken to understand the sensitivity of the model to changes in various model parameters throughout the model. This includes:

- Manning's roughness values for the watercourse channel and floodplain (+/- 20%)
- Structure co-efficient values (+/-20%)
- Variation in inflow values (+20%)
- Downstream boundary depths (+/-20%)

All sensitivity scenarios have been run using the 1 in 100 year return period event. The scenarios, and the impact on the model results, are discussed in more detail below. Maximum water depths have been extracted from the results to undertake comparisons at the locations shown in Figure 14. During the sensitivity tests, the largest change in depth observed was 140mm. However, this is within the freeboard allowance for the Scheme which will be discussed in the post development model technical note.

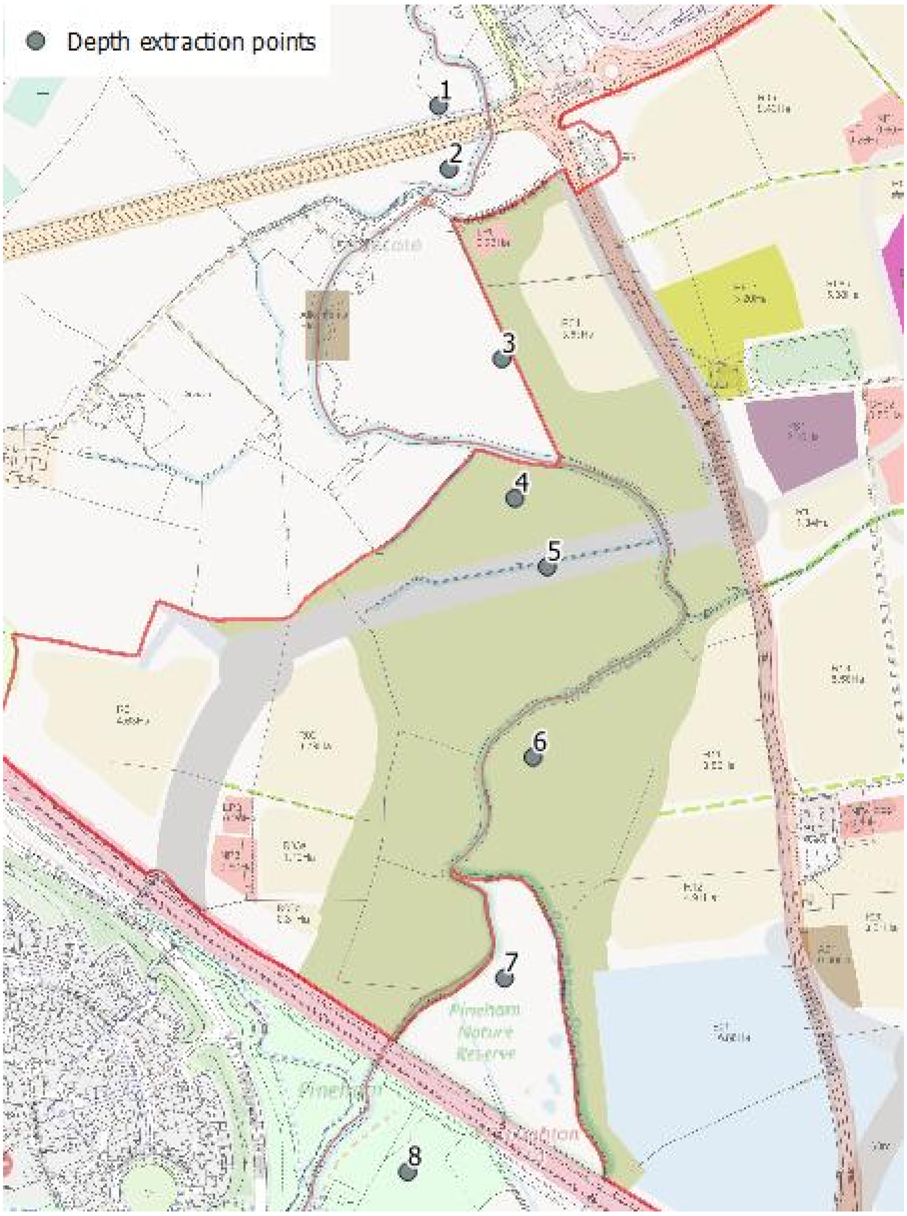


Figure 12 Depth extraction locations for sensitivity test comparison

Roughness sensitivity

Manning's roughness values in both the in channel and floodplain model have been increased and decreased by 20%. Table 1 shows the point depth comparison between the baseline and roughness sensitivity scenarios.

Table 1 Maximum depth difference during Manning's roughness sensitivity analysis

Point number	Baseline depth (m)	Depth difference (m) – Roughness + 20%	Depth difference (m) – Roughness - 20%
1	0.63	0.10	-0.11
2	0.84	0.12	-0.14
3	0.27	0.09	-0.11
4	0.60	0.06	-0.07
5	0.52	0.07	-0.09
6	0.60	0.06	-0.06
7	0.82	0.07	-0.07
8	0.33	0.10	-0.11

The model follows typical behaviour when Manning’s roughness is varied. When it is increased, water depths also increase as water is held up in the channel and floodplain. Conversely, when the Manning’s roughness value is decreased, water levels also decrease as it can flow more easily downstream. Changes to the flood extent in both roughness sensitivity scenarios are also relatively minor, with no new areas shown to flood or removed from the flood extent. The largest depth difference is 0.14m, which is not considered to be significant as the original water depth in this location is 0.84m, and therefore this depth difference is unlikely to change the overall assessment of flood risk and is within typical model tolerances.

Structure co-efficient sensitivity

The Manning’s roughness co-efficient of the ESTRY structures within the channel model have been increased and decreased by 20%. Table 2 shows the point depth comparison between the baseline and sensitivity models.

Table 2 Maximum depth difference during structure co-efficient sensitivity analysis

Point number	Baseline depth (m)	Depth difference (m) – Structure co-efficients + 20%	Depth difference (m) – Structure co-efficients - 20%
1	0.63	0.00	0.00
2	0.86	0.00	0.00
3	0.27	0.00	0.00
4	0.69	0.00	0.00
5	0.60	0.00	0.00
6	0.63	0.00	0.00
7	0.84	0.00	0.00
8	0.34	0.00	0.00

The structures in the model are primarily located on the Tongwell Brook, a tributary of the River Ouzel. The majority of structures on the River Ouzel have been represented as open channel due to the large size of the bridges over the watercourse. There are only two culvert structures on the River Ouzel, located approximately 200m and 300m upstream of the A422 road crossing. Therefore, changes to the structure co-efficient values are unlikely to have a significant impact on the River Ouzel due to the small number of structures on the watercourse particularly in the vicinity of the development area. The comparison indicates that variation to the structure co-efficient parameters does not result in a significant change in floodplain water levels throughout the model. Therefore, any change in water level is likely to be localised to the channel adjacent to the structures only.

Inflow sensitivity

All inflows in the model have been scaled by 20% to assess the model behaviour when inflows are increased. Table 3 shows the point depth comparison between the baseline and inflow sensitivity model.

Table 3 Maximum depth difference during flow sensitivity analysis

Point number	Baseline depth (m)	Depth difference (m) – Inflow + 20%
1	0.63	0.10
2	0.84	0.13
3	0.27	0.11
4	0.60	0.07
5	0.52	0.08
6	0.60	0.06
7	0.82	0.07
8	0.33	0.11

When the inflows are increased by 20%, the water level increases appropriately through the model domain resulting in higher water levels / depths. The increase in flows results in a relatively modest increase in flood depths of between 0.06m and 0.13m showing that this does not significantly impact the model results. Similarly, the flood extent throughout the model increases, with an additional flow path shown on the grassland downstream of the A422. However, the increase in flow does not increase the flood risk to critical receptors in the study area.

Downstream boundary sensitivity

The downstream boundary in the model is a HQ boundary, with levels and flows extracted from the Environment Agency's strategic model. As this strategic model study does not specifically include inflows from the Broughton Brook (instead the flows were added in further downstream), the range of flows at the point the model was cut is not sufficient to provide a boundary condition for the larger flows in the updated model. Therefore, the flow and levels have been extrapolated from the available flow and level relationship. Figure 13 shows the flow and stage relationship that has been set at the downstream boundary. This approach is considered appropriate for the scope of the study and area of interest, and this has been tested using a robust sensitivity analysis. Furthermore, it was not possible to re-run the Environment Agency's strategic model with adjusted inflows, due to unrelated error messages combined with the findings detailed within the original model reports that outline the downstream boundary on the River Ouse is sensitive to the River Ouzel flows and re-calibration of the River Ouse model is beyond the scope of the current study and not proportionate to the scale and nature of the flood risk to or from the Scheme.

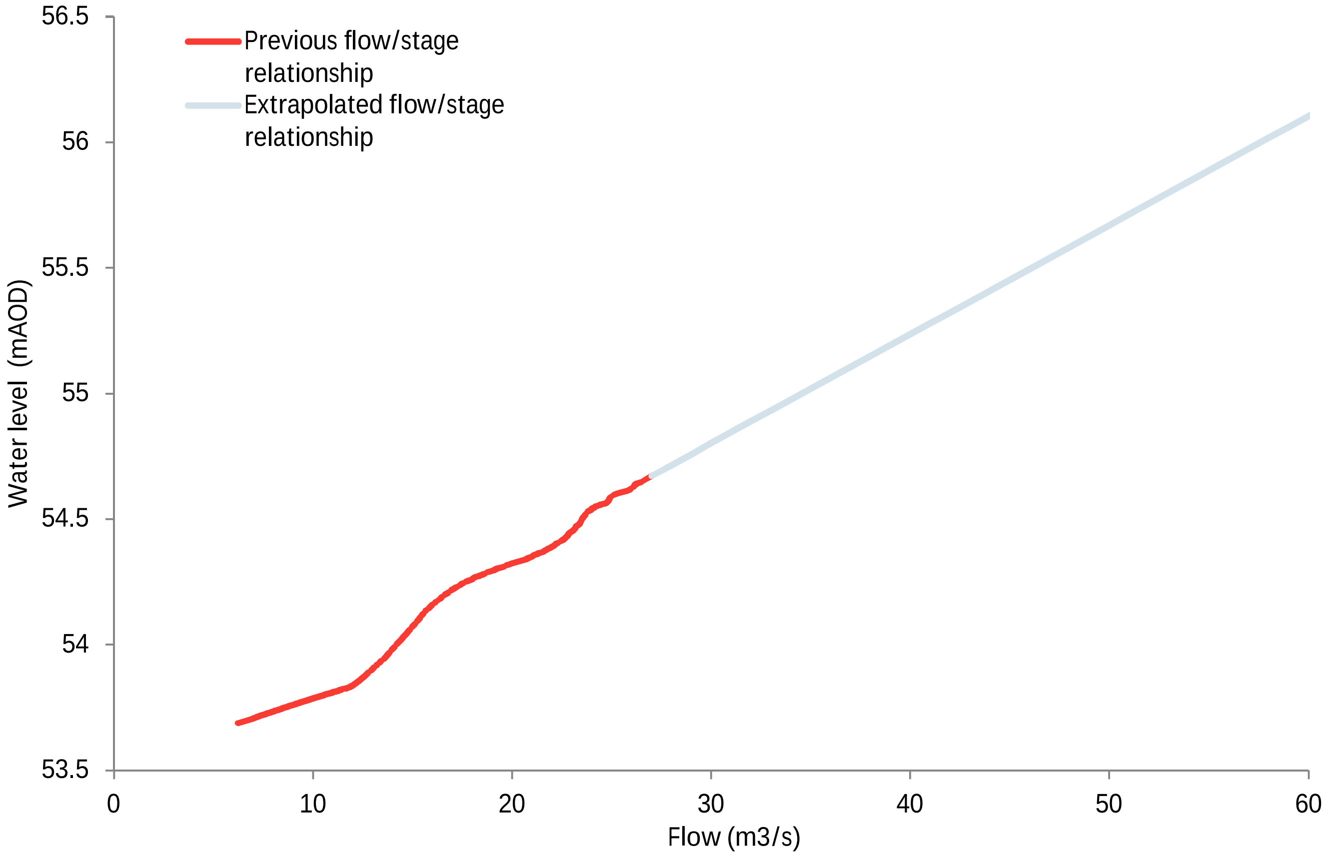


Figure 13 Final combined flow/stage relationship used in the downstream boundary of the model

The water depth in this boundary has been increased and decreased by 20% for the same flow during the sensitivity analysis. Figure 14 shows a maximum water level comparison on a long section beginning directly upstream of the A422 crossing, with the A422 essentially being the most downstream part of the redline boundary, with the most downstream impacts within / adjacent to the floodplain being further upstream.

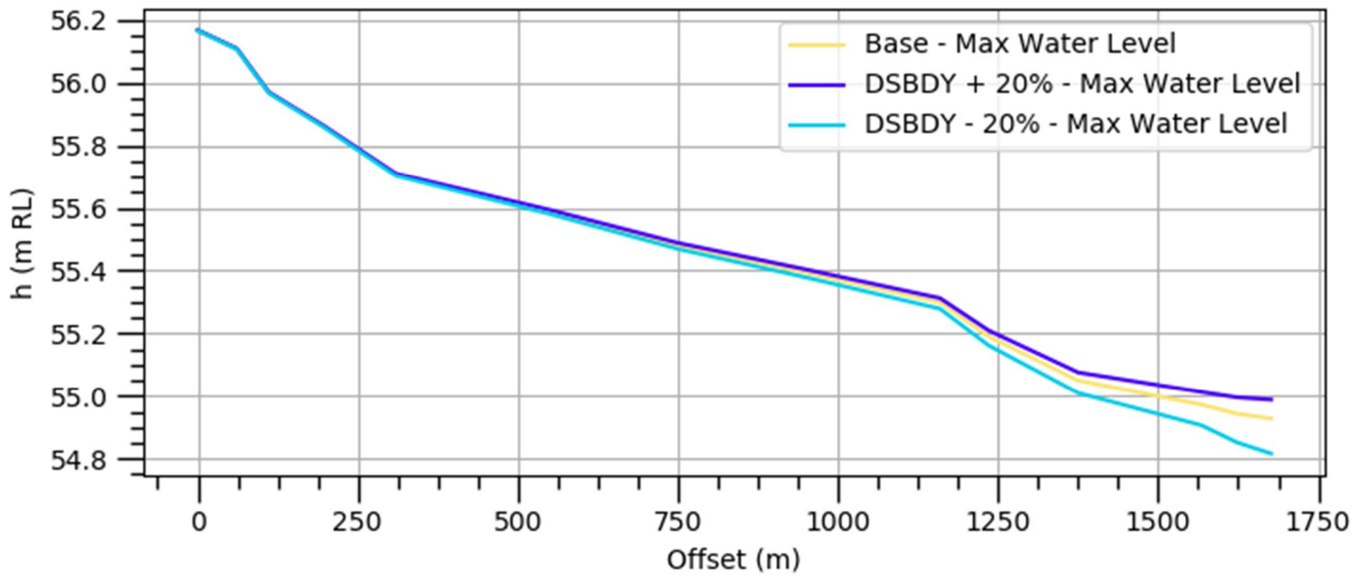


Figure 14 Maximum water level comparison long section, beginning directly upstream of the A422 crossing

The sensitivity test indicates that changes to the downstream boundary cause a change in water level in the downstream part of the model. However, the change in water level becomes <1mm once upstream of the A422 road crossing. The main area of interest (the River Ouzel highway crossing) in the post-development model is approximately 2700m upstream of the downstream boundary. Therefore, a change in the downstream boundary would be unlikely to have a significant influence on the assessment of the scheme.

Parameter Choices

As part of the construction of the additional reaches the original Environment Agency model was reviewed and the parameters confirmed as being suitable, these same parameters were used within the new reaches for consistency and based on the observations from survey photos and site visits.

Inflow Phasing

As discussed in the hydrology section above, the peaks of the Broughton Brook and the River Ouzel were aligned based upon the available gauged data. The model includes two other inflows:

1. The London Road Tributary, the stream that joins the River Ouzel upstream of the proposed road location; and
2. The channel adjacent to the STW - A small channel flowing adjacent to Cotton Valley Sewage Works, under the M1 through Pineham Nature Reserve.

These flows were also conservatively aligned as no further information on their time to peak was available. The peak flow in the London Road Tributary is based upon the current (undeveloped) peak flow estimates for both the baseline and post development scenarios. However, given that much of its catchment will become developed with the impermeable areas attenuated back to QBAR, the impact of this is considered to be negligible.

Whereas the peak flows in the channel adjacent to the STW are estimated at 0.15 m^3/s for the 1 in 100-year event which is considered negligible when compared to those in the River Ouzel (66.9m^3/s) and the Broughton Brook (35.07m^3/s) for the same event.

Glass-walling

During the Environment Agency review, a comment was made stating that glass walling occurs at the upstream boundary on the Broughton Brook in the 1 in 100 year climate change event. Checking of the 1d channel in this area indicates that water comes out of bank and enters the 2d domain appropriately. Back flow from the first section on this watercourse is observed, which causes water to pool against the edge of the 2d boundary. However, as indicated in the review this is unlikely to affect the results further downstream and at the area of interest, thus no further action is required.

Warning messages

The review documents Warning message 2073, which relates to null objects ignored in shapefiles 2d_zln_BM_087_02_002_L and 2d_bc_HX_S_Channel_002_L.shp. These files are a new addition added to the model by WSP as part of the previously agreed baseline model. The model geometry has been checked, and banklines and boundary lines are being applied appropriately. Therefore, the presence of null shape objects does not impact the application of the model files.

An additional Warning message, 2218, relating to the use of a High Manning's n value of 1 was also flagged in the review. This warning relates to the high Manning's n value that has been used to represent the impact of piers directly adjacent to the watercourse channel at the M1 and A422 road crossing. Therefore, this warning concerns a feature of the model that was applied deliberately, as detailed in a previous section.

Stability

Within the review, high miss balance errors within the 2d domain during the initial 30 hours of the model run were flagged. These errors are attributed to the very small inflows to the 2d domain from the new right bank point inflow, and were therefore unlikely to affect peak flows. Figure 15 shows the cumulative mass balance error during the model run in the climate change event.

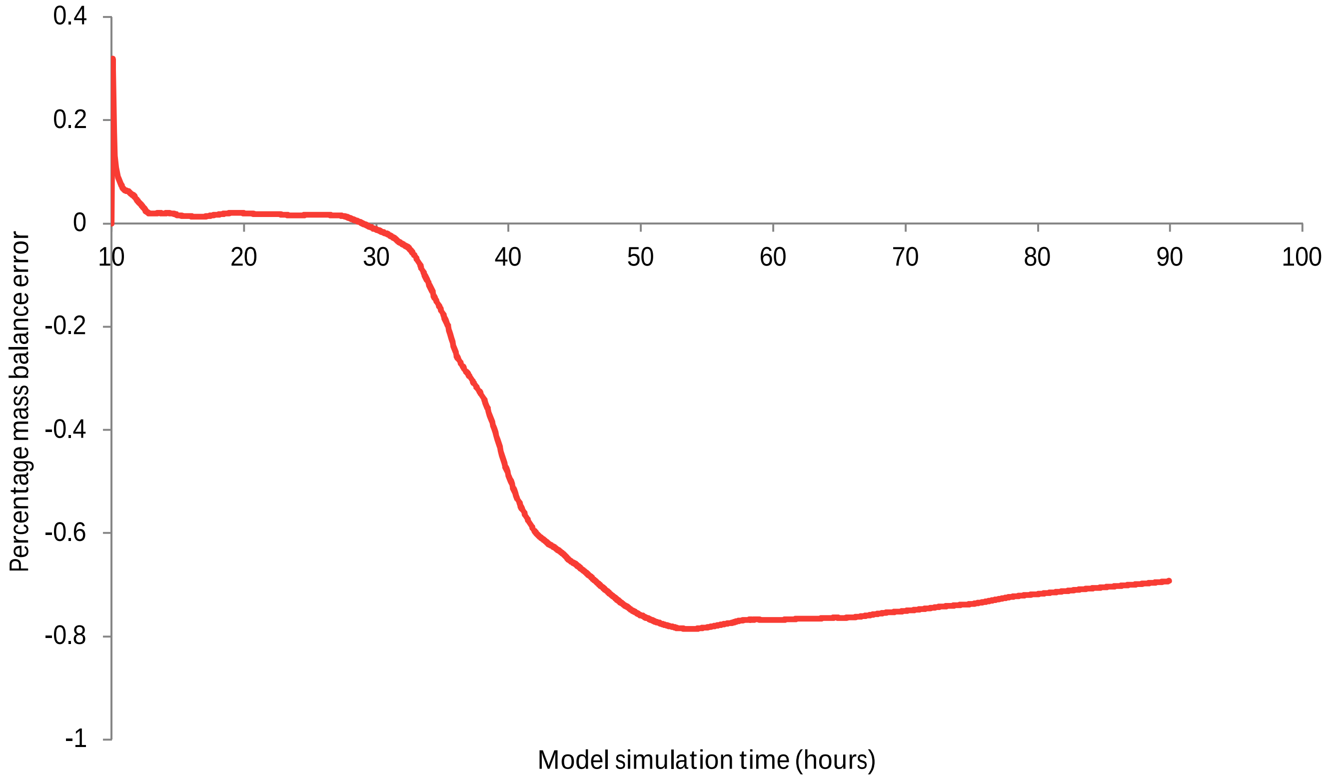


Figure 15 Mass balance error during the climate change model simulation

This indicates that the model remains within the accepted mass balance tolerance of +/- 1% during the simulation. The mass balance errors within the 2d domain appear to be of very localised extent, persisting for relatively short durations. It is not considered that the mass balance fluctuations will impact the peak flows significantly, and therefore will not affect the maximum flood extents in areas of interest.

CONCLUSIONS

This Technical Note provides comprehensive responses to the Environment Agency's comments on the Milton Keynes East baseline model and demonstrates that the model is a suitable representation of the baseline conditions in this location without the requirement for further refinement.

APPENDIX 1 – UPDATED FLOOD ESTIMATION CALCULATION RECORD

Flood estimation calculation record

Introduction

This document is a supporting document to the Environment Agency's flood estimation guidelines. It provides a record of the calculations and decisions made during flood estimation. It will often be complemented by more general hydrological information given in a project report. The information given here should enable the work to be reproduced in the future. This version of the record is for studies where flood estimates are needed at multiple locations.

Contents

Approval

	Signature	Name and qualifications
Calculations prepared by:		Aidan Wilks Daly, *MSc, Bsc (Hons) GradCIWEM*
Calculations checked by:		Rachel Ledger, *MPhys (Hons), C.WEM CEnv*
Calculations approved by:		Rachel Ledger, *MPhys (Hons), C.WEM CEnv*

Environment Agency competence levels are covered in Section 2.1 of the flood estimation guidelines:

- Level 1 – Hydrologist with minimum approved experience in flood estimation
- Level 2 – Senior Hydrologist
- Level 3 – Senior Hydrologist with extensive experience of flood estimation

ABBREVIATIONS

AM	Annual Maximum
AREA	Catchment area (km^2)
BFI	Base Flow Index
BFIHOST	Base Flow Index derived using the HOST soil classification
CFMP	Catchment Flood Management Plan
CPRE	Council for the Protection of Rural England
FARL	FEH index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook
FSR	Flood Studies Report
HOST	Hydrology of Soil Types
NRFA	National River Flow Archive
POT	Peaks Over a Threshold
QMED	Median Annual Flood (with return period 2 years)
ReFH	Revitalised Flood Hydrograph method
SAAR	Standard Average Annual Rainfall (mm)
SPR	Standard percentage runoff
SPRHOST	Standard percentage runoff derived using the HOST soil classification
Tp(0)	Time to peak of the instantaneous unit hydrograph
URBAN	Flood Studies Report index of fractional urban extent
URBEXT1990	FEH index of fractional urban extent
URBEXT2000	Revised index of urban extent, measured differently from URBEXT1990
WINFAP-FEH	Windows Frequency Analysis Package – used for FEH statistical method

1 Method statement

1.1 Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: • Purpose of study • Approx. no. of flood estimates required • Peak flows or hydrographs? • Range of return periods and locations • Approx. time available	In 2011 hydraulic modelling and a hydrological assessment was undertaken by the Environment Agency of the River Ouzel and its tributaries as a part of the Upper Great Ouse Flood Risk mapping project. The ESTRY-TUFLOW model of the River Ouzel developed by the EA from this study does not include the Broughton Brook. This study will update the existing EA ESTRY-TUFLOW model of the River Ouzel by including the Broughton Brook as a 1D ESTRY channel element. The purpose of including the Broughton Brook in this model is to see how it impacts the flood risk at the site of a proposed mixed-use development adjacent to the River Ouzel. This hydrological assessment is required to derive a flow estimate for the Broughton Brook, where it flows into the River Ouzel, for inclusion into the updated hydraulic model of the Ouzel. Information as to how this fits with the wider hydrology is provided in the accompanying Technical Note. The Broughton Brook is a gauged watercourse with an Environment Agency gauging station (no. 033031) located near to the Broughton sewage treatment works. Flow estimates for the 2-year, 5-year, 10-year, 20-year, 100-year and 1000-year return events will be estimated at this location. An assessment of the impacts of climate change will be made based on the Environment Agency's peak river flow allowances. The site is located within the Anglian River Basin District. The vulnerability classification of the proposed development is 'more vulnerable' and the site is located within Food Zones 2 & 3 therefore both the higher central upper end allowances should be assessed to understand the range of impact. For the '2080s' (2070 to 2115) for the Anglian RBD the higher central allowance is 35% and the upper end allowance is 65%.

1.2 Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	The Broughton Brook is an ordinary watercourse that drains the land to the east of Milton Keynes. It conveys water from a largely rural catchment in Central Bedfordshire, flowing through the settlements of Ridgmont & Salford, before flowing through Broughton and towards the urban area of Milton Keynes, where it joins the River Ouzel to the north of Junction 14 of the M1 Motorway. The Broughton Brook is a gauged watercourse with an Environment Agency measuring station (no. 033031) located near to the Broughton sewage treatment works, at an approximate grid reference of 488850, 240950.

1.3 Source of flood peak data

Was the HiFlows UK (NRFA Peak flow) dataset used? If so, which version? If not, why not? Record any changes made	Yes – Version 8, September 2019.

1.4 Gauging stations (flow or level)

(at the sites of flood estimates or nearby at potential donor sites)

Watercourse	Station name	Gauging authority number	NRFA number (used in FEH)	Grid reference	Catchment area (km²)	Type (rated / ultrasonic / level…)	Start and end of flow record
Broughton Brook	Broughton Brook at Broughton	Environment Agency – East Anglia (033031)	33031	SP888409	70.06	Flat V	11/1970 - N/A

1.5 Data available at each flow gauging station

Station name	Start and end of data in HiFlows-UK	Update for this study?	Suitable for QMED?	Suitable for pooling?	Data quality check needed?	Other comments on station and flow data quality – e.g. information from HiFlows-UK, trends in flood peaks, outliers.
33031	11/1970 – 12/2018	V8	Yes	Yes	No	N/a
Give link/reference to any further data quality checks carried out			**N/A**			

1.6 Rating equations

Station name	Type of rating e.g. theoretical, empirical; degree of extrapolation	Rating review needed?	Reasons – e.g. availability of recent flow gaugings, amount of scatter in the rating.
33031	Theoretical	No	All flows contained and theoretical rating expected to perform well. Flume was subject to drowning but flows were corrected. Current rating includes floodplain flow and accounts for drowning. One peak flow rating applied across period of record.
Give link/reference to any rating reviews carried out		**N/A**	

1.7 Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available?	Source of data and licence reference if from EA	Date obtained	Details
Check flow gaugings (if planned to review ratings)					
Historic flood data – give link to historic review if carried out.					
Flow data for events					
Rainfall data for events					
Potential evaporation data					
Results from previous studies					

Type of data	Data relevant to this study?	Data available?	Source of data and licence reference if from EA	Date obtained	Details
Other data or information (e.g. groundwater, tides)					

1.8 Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	The catchment descriptors and catchment mapping have been reviewed. The catchment is medium in size, is underlain by a mixture of acid loamy and clayey soils and acid sandy soils, situated above a bedrock of Mudstone and sandstone. The catchment is classified as slightly urbanised and has a minor influence from reservoirs and lakes. Based on this information and in accordance with the Environment Agency's flood estimation guidelines, the FEH approaches for flow estimation are considered appropriate. Peak flows are to be estimated using both FEH rainfall-runoff methods, i.e. ReFH and ReFH2, and the FEH Statistical Method for comparison.
Outline the conceptual model, addressing questions such as: • Where are the main sites of interest? • What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides…) • Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir? • Is there a need to consider temporary debris dams that could collapse?	The main area of interest is located just downstream of the confluence of the Broughton Brook and the River Ouzel where there is a proposed road crossing of the Ouzel.
Any unusual catchment features to take into account? e.g. • highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20% • highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments • pumped watercourse – consider lowland catchment version of rainfall-runoff method • major reservoir influence (FARL<0.90) – consider flood routing • extensive floodplain storage – consider choice of method carefully	The catchment has low to medium permeability with a BFIHOST value of 0.482 and a SPRHOST value of 40.87%, accordingly there is no need to consider permeable catchment adjustments. The catchment is essentially rural, with an $URBEXT_{2000}$ value of 0.0394 (adjusted for 2020). There are several small lakes in the south of the catchment by Woburn Abbey and it is understood that these lakes are hydraulically connected to the Broughton Brook. The FARL value for the catchment is 0.9670. The catchment is not pumped nor is there extensive floodplain storage.
Initial choice of method(s) and reasons Will the catchment be split into subcatchments? If so, how?	Based on the information above, flows estimation will be undertaken using the following methods:

	• The Statistical method using WINFAP-FEH v4.1 and based on the latest (Version 8) of the NRFA Peak Flow dataset, released in September 2019; • The Revitalised flood hydrograph (ReFH) method using the unit within Version 4.3 of FMP based on the FEH1999 rainfall model, and • The Revitalised flood hydrograph 2 (ReFH2) method using Version 2.2 of the software based on the FEH 2013 rainfall model.
Software to be used (with version numbers)	FEH Web Service WINFAP-FEH v4.1[1] ReFH unit within v4.3 of FMP FEH unit within v4.3 of FMP ReFH2 2.2 software

[1] WINFAP-FEH v4.1 © Wallingford HydroSolutions Limited and NERC (CEH) 2016.

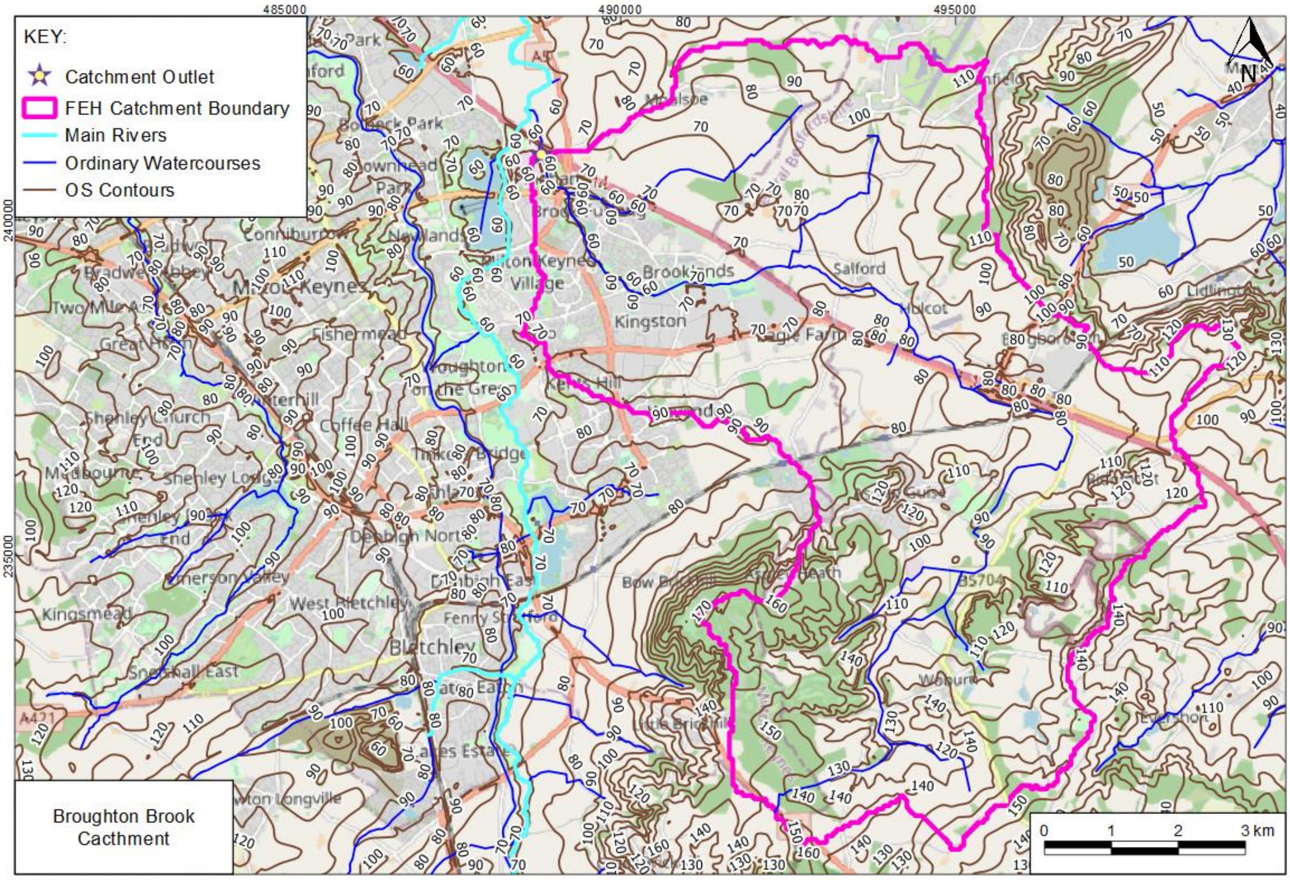
2 Locations where flood estimates required

The table below lists the locations of subject sites. The site codes listed below are used in all subsequent tables to save space.

2.1 Summary of subject sites

Site code	Watercourse	Easting	Northing	AREA on FEH Web Service (km^2)	AREA estimated using LiDAR (km^2)
Broughton_01	Broughton Brook	488850	240950	70.06	N/A
Reasons for choosing above locations	This is the location of the EA gauging station on the Broughton Brook.				

Figure 1: Catchment Boundary



2.2 Important catchment descriptors at each subject site (incorporating any changes made)

Amended catchment descriptors are shown in red and bold text.

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRHOST	URBEXT2000	FPEXT
Broughton_01	0.967	0.31	0.482	10.75	29.1	629	40.87	**0.0394**	0.1439

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	The FEH Catchment boundary was checked using Ordnance Survey contours and mapping, as shown in Figure 1. A review of the catchment boundary found that it followed the OS contours well and was reflective of the drainage patterns in the area. It was decided to take the FEH catchment boundary forwards without any modifications. The use of the FEH catchment boundary also facilitates the use of the gauged data that is available for the catchment.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	Soils – the catchment has a low to medium permeability reflected by a BFIHOST value of 0.482 and a SPRHOST value 40.87%. The catchment is underlain by a mixture of acid loamy and clayey soils and acid sandy soils, situated above a bedrock of Mudstone and sandstone. As the catchment boundary was not changed it was not necessary to update the BFIHOST & SPRHOST value. The DPLBAR value was not altered as the catchment boundary was not changed. FARL values were checked by a review of online mapping and desk-based research. There are several small lakes in the south of the catchment by Woburn Abbey and it is understood that these lakes are hydraulically connected to the Harrowden Brook. The FARL value for the catchment is 0.9670 and this was not altered. Urbanisation – the catchment has an URBEXT1990 value of 0.012 which reflects that of an essentially rural catchment. The URBEXT2000 value for the catchment is 0.0394 which reflects that of a slightly urbanised catchment. The catchment boundary has not been modified there it was not necessary to alter these URBEXT values, other than updating their values to the present day (2020) using urban expansion factors.
Source of URBEXT	Catchment descriptors (URBEXT 1990 & 2000), checked against Ordnance Survey Mapping and satellite mapping.
Method for updating of URBEXT	CPRE formula (6.8) from FEH Volume 5 on URBEXT1999/ Formula 5.5 from 2007 EA/Defra R&D Technical Report FD1919/TR on URBEXT2000.

3 Statistical method

3.1 Search for donor sites for QMED (if applicable)

Comment on potential donor sites Mention: • Number of potential donor sites available • Distances from subject site • Similarity in terms of AREA, BFIHOST, FARL and other catchment descriptors • Quality of flood peak data Include a map if necessary. Note that donor catchments should usually be rural.	The Broughton Brook is a gauged watercourse (NRFA Station No. 33031) that is included within the version 8 of the NRFA Peak Flow dataset as suitable for QMED. The estimate of QMED at this gauging station is 13.30 m^3/s, based on Annual Maxima. An urbanisation factor is not required in this instance as the QMED is based on observed data. The estimate of QMED for the catchment using catchment descriptors was found to be 6.85 m^3/s. The gauged QMED value of 13.30 m^3/s was taken forwards as that is based on observed data.

3.2 Donor sites chosen and QMED adjustment factors

NRFA no.	Reasons for choosing or rejecting	Method (AM or POT)	Adjustment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjust-ment ratio (A/B)	Power term, a	Moderated QMED adjustment factor, (A/B)^a
33031	The site is gauged	AM	No	13.298	6.847	1.94	n/a	n/a
Which version of the urban adjustment was used for QMED at donor sites, and why?				QMED from AM used directly as it was at the subject site.				

Notes

The data transfer procedure is from Science Report SC050050. The QMED adjustment factor A/B for each donor site is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment.

3.3 Overview of estimation of QMED at each subject site

Site code	Method	Initial estimate of QMED (m^3/s) (exc. urban adj)	Data transfer			UAF	Final estimate of QMED (inc. urban adj) (m^3/s)
			NRFA numbers for donor sites used (see 3.2)	Distance between centroids dij (km)	Weight		
Broughton_01	CD	6.85	n/a	n/a	n/a	1.045	7.15
Broughton_01	AM	13.30	33031	n/a	n/a	n/a	13.30
Are the values of QMED consistent, for example at successive points along the watercourse and at confluences?				There is a single flow estimation point.			
Which version of the urban adjustment was used for QMED, and why (describe any changes to the parameters, such as Primp% and Impervious Factor, used to calculate the urban adjustment)?				Default parameters were used.			

Notes

Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer; CD – Catchment descriptors alone; CDCW – Catchment descriptors and channel width

3.4 Derivation of pooling groups

The full composition of the pooling group is given in the Annex

Name of group	**Site code from whose descriptors group was derived**	**Subject site treated as gauged?** (enhanced single site analysis)	**Changes made to default pooling group, with reasons**	**Weighted average L-moments**, L-CV and L-skew, (before urban adjustment)
PG0	Broughton_01	NO	None	L-CV 0.263 L-SKEW 0.045
PG1	Broughton_01	YES (ESS)	None	L-CV 0.275 L-SKEW 0.045
PG2	Broughton_01	YES (ESS)	Removed stations 33032, 26003, 34012, 33054, 26013 & 39042 due to significant differences in catchment permeability (SPRHOST <17.6% & BFIHOST >0.81) compared to subject site (SPRHOST 40.9% & BFIHOST 0.48). Added in stations 33011, 37016, 42003, 205005 & 37013 which have permeabilities more similar to the subject site.	L-CV 0.280 L-SKEW 0.092

3.5 Derivation of flood growth curves at subject sites

Site code	**Method** (SS, P, ESS, J)	**If P, ESS or J, name of pooling group (3.4)**	**Distribution used and reason for choice**	**Note any urban adjustment or permeable adjustment**	**Parameters of distribution** (location, scale and shape) after adjustments	**Growth factor for 100-year return period**
Broughton_01	P	PG0	The Generalised Logistic distribution is the recommended distribution for flood frequency analysis in the UK and has been applied to all the growth curves in this study.	UAF: 1.045.	LOC 1.000; SCALE 0.262; SHAPE -0.051; BOUND -4.174	2.35
Broughton_01	ESS	PG1		UAF: 1.045. Deurbanised at-site L-moments	LOC 1.000; SCALE 0.274; SHAPE -0.051; BOUND -4.343	2.42
Broughton_01	ESS	PG2			LOC 1.000; SCALE 0.282; SHAPE -0.098; BOUND -1.875	2.64
Broughton_01	SS	N/A		N/A	LOC 1.000; SCALE 0.278; SHAPE -0.053; BOUND -4.248	2.45

Notes

Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis

A pooling group (or ESS analysis) derived at one gauge can be applied to estimate growth curves at a number of ungauged sites. Each site may have a different urban adjustment, and therefore different growth curve parameters.

3.6 Flood estimates from the statistical method

	Flood peak (m^3/s) for the following return periods (in years)					
Site code	**2**	**5**	**10**	**20**	**100**	**1000**
Broughton_01_PG0	13.30	18.30	21.39	24.35	31.30	42.07
Broughton_01_PG0_GrowthCurve	*1.00*	*1.38*	*1.61*	*1.83*	*2.35*	*3.16*
Broughton_01_PG1	13.30	18.53	21.77	24.87	32.16	43.47
Broughton_01_PG1_Growth_Curve	*1.00*	*1.39*	*1.64*	*1.87*	*2.42*	*3.27*
Broughton_01_PG2	13.30	18.87	22.49	26.10	35.07	50.34
Broughton_01_PG2_Growth_Curve	*1.00*	*1.42*	*1.69*	*1.96*	*2.64*	*3.78*
Broughton_01_SS	13.30	18.62	21.92	25.09	32.56	44.18
Broughton_01_SS_GrowthCurve	*1.00*	*1.4*	*1.65*	*1.89*	*2.45*	*3.32*

4 Revitalised flood hydrograph (ReFH) method – FEH1999 rainfall model

4.1 Parameters for ReFH model – FEH1999 rainfall

Note: If parameters are estimated from catchment descriptors, they are easily reproducible, so it is not essential to enter them in the table.

The ReFH outputs for the 1 in 100 year event are provided in the Annex.

Site code	Method: OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	Tp (hours) Time to peak	C_{max} (mm) Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
Broughton_01	CD	8.710	395.115	53.412	1.119
Brief description of any flood event analysis carried out (further details should be given below or in a project report)		No flood event analysis was undertaken as the catchment is ungauged.			

4.2 Design events for ReFH method

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
Broughton_01	urban	Winter	14	-

4.3 Flood estimates from the ReFH method

Site code	Flood peak (m^3/s) for the following return periods (in years)					
	2	5	10	20	100	1000
Broughton_01	10.35	13.29	15.58	17.96	24.91	43.51
Growth Curve Broughton_01	*1.00*	*1.28*	*1.51*	*1.74*	*2.41*	*4.20*

5 Revitalised flood hydrograph 2 (ReFH2) method – FEH2013 rainfall model

5.1 Parameters for ReFH2 model – FEH2013 rainfall

Note: If parameters are estimated from catchment descriptors, they are easily reproducible, so it is not essential to enter them in the table.

The ReFH2 outputs for the 1 in 100 year event are provided in the Annex.

Site code	Method: OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	Tp (hours) Time to peak	C_{max} (mm) Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
Broughton_01	CD	9.71	397.47	57.11	1.14
Brief description of any flood event analysis carried out (further details should be given below or in a project report)		No flood event analysis was undertaken as the catchment is ungauged.			

5.2 Design events for ReFH2 method

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
Broughton_01	Urban	Winter	15:00:00	-
Are the storm durations likely to be changed in the next stage of the study, e.g. by optimisation within a hydraulic model?			No further analysis proposed at this stage	
Any changes to the parameters used to estimate the impact of urbanisation in the catchment?			Catchment is essentially rural	

5.3 Flood estimates from the ReFH2 method

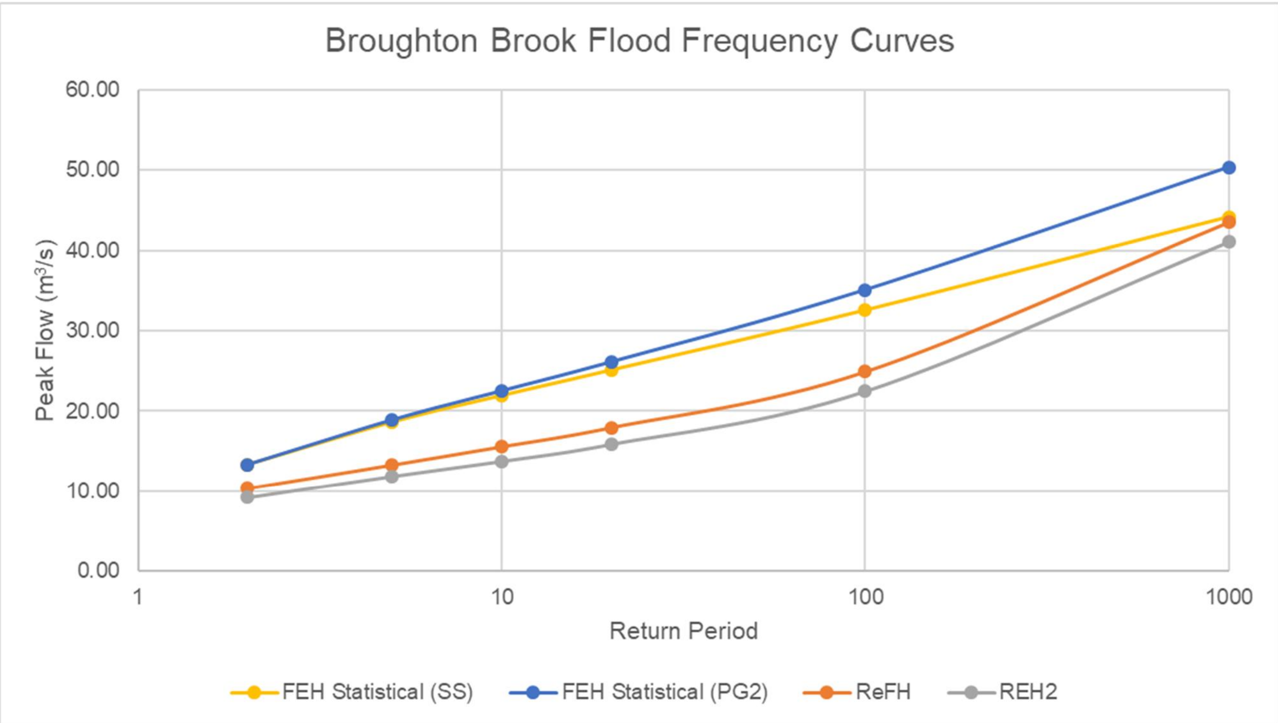
Site code	Flood peak (m^3/s) for the following return periods (in years)					
	2	**5**	**10**	**20**	**100**	**1000**
Broughton_01	9.24	11.90	13.79	15.80	22.48	41.04
Growth curve Broughton_01	*1.00*	*1.29*	*1.49*	*1.71*	*2.43*	*4.44*

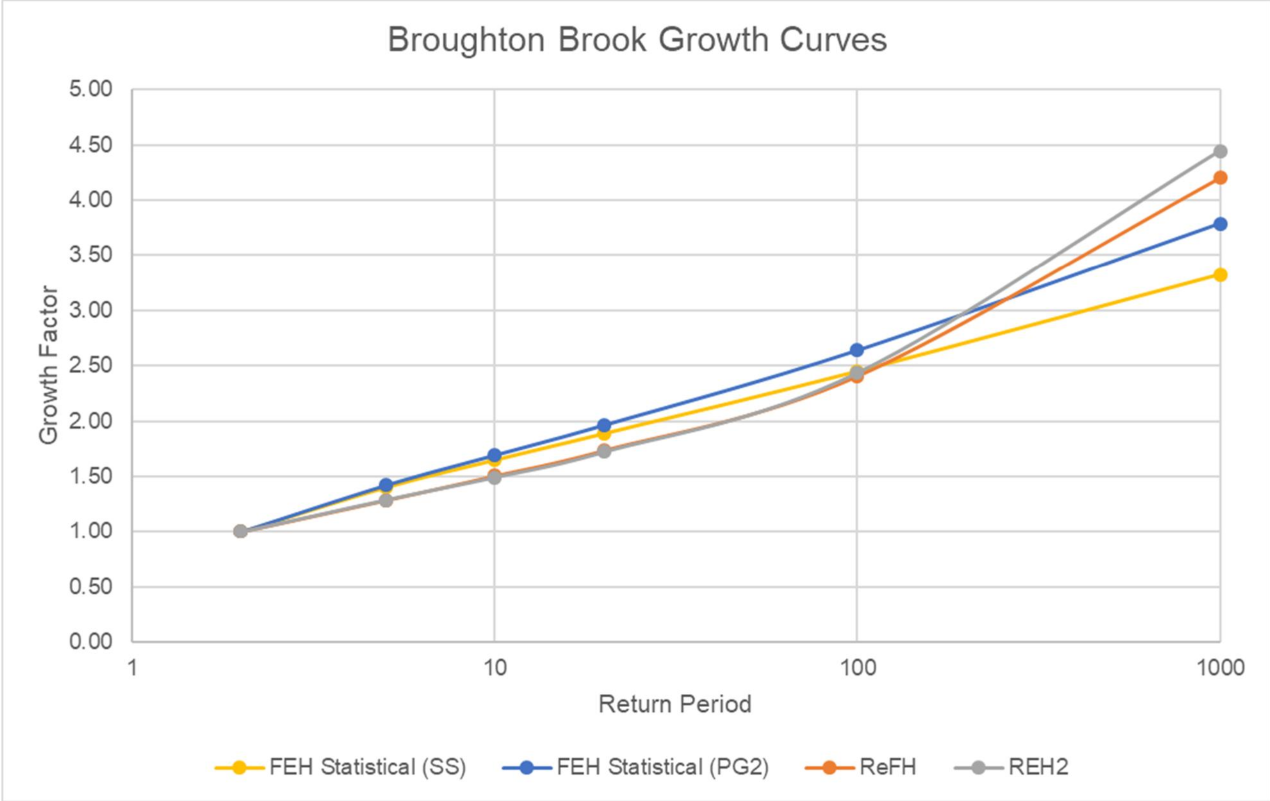
6 Discussion and summary of results

6.1 Comparison of results from different methods

This table compares peak flows from ReFH, ReFH2 and the FEH Rainfall-Runoff and Statistical method at the subject site for three key return periods.

Method	Flood peak (m^3/s) for the following return periods (in years)					
	2	5	10	20	100	1000
FEH Statistical (PG2)	13.30	18.87	22.49	26.10	35.07	50.34
FEH Statistical (Single site)	13.30	18.62	21.92	25.09	32.56	44.18
ReFH	10.35	13.29	15.58	17.96	24.91	43.51
REH2	9.24	11.90	13.79	15.80	22.48	41.04





6.2 Final choice of method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	The growth curves for the single site Statistical, pooled statistical and ReFH and ReFH2 methods are comparable. The flows from both the single site and pooled FEH statistical methods are higher for QMED than the ReFH and ReFH2 methods and subsequently for other return periods given the similar growth factors. The FEH Statistical QMED is based on observed data at the subject site whereas ReFH and ReFH2 use catchment descriptors only. There is therefore more confidence in the Statistical QMED estimate. The FEH Statistical method flows are selected for use in the model as this produces relatively conservative flows in comparison to ReFH and ReFH2 and makes use of the at site historic gauging data. The single site statistical method flows will be used for the lower magnitude events (Ò 20 years) as there is sufficient gauged data (49 years) at the site to be confident in these estimates. For the 100 and 1000 year return period flow estimates the pooled statistical method estimates (using PG2) will be used. Where the gauged data is sufficiently robust to enable a single site analysis the pooled analysis fits extremely well, giving confidence in the pooled flow estimates for the 100 year and 1000 year events.

6.3 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	It has been assumed that the catchment descriptors reflect the site conditions. Appropriate checks have been made against available mapping data to confirm this. It is also assumed that the gauged data is correct and suitable for QMED estimates – this is assessed as part of the HiFlows dataset review.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed	The catchment is not highly permeable or heavily urbanised. Consequently, the FEH methods are considered appropriate for flow estimation at the subject site.

Give what information you can on uncertainty in the results – e.g. confidence limits for the QMED estimates using FEH **3** 12.5 or the factorial standard error from Science Report SC050050 (2008).	The estimate of QMED based on gauged data is for Broughton_01 is 13.30m^3/s. For the 68% confidence interval QMED is expected to be in the range of 9.29 – 19.03m^3/s. For the 95% confidence interval QMED is expected to be in the range of 6.49 – 27.23m^3/s.
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	Peak flow estimates have been considered at the subject site against the aims of this study. Consequently, it is not recommended that they are adopted at different locations for different purposes.
Give any other comments on the study, for example suggestions for additional work.	No further analysis is recommended.

6.4 Checks

Are the results consistent, for example at confluences?	Flow estimation only carried out at one point.
What do the results imply regarding the return periods of floods during the period of record?	No historic fluvial flood information is available for this site.
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	The 100-year growth factor for the statistical method is 2.64 which sits in a typical range, and therefore is appropriate.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	The 1000/100-year ratio for the Broughton Brook is 1.44, which sits in a typical range, and therefore is appropriate.
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	The specific runoff at Broughton_01 is 1.90 l/s/ha for the 1 in 2-year event and 5.01 l/s/ha for the 1 in 100-year event.
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	N/A
Are the results compatible with the longer-term flood history?	No flood history is available for the subject site.
Describe any other checks on the results	No additional checks have been undertaken as part of this assessment.

6.5 Final results

Site code	**Flood peak (m^3/s) for the following return periods (in years)**					
	2	**5**	**10**	**20**	**100**	**1000**
Broughton_01	13.30	18.62	21.92	25.09	35.07	50.34

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, name of ISIS model, or reference to table below)	Flow hydrographs provided for the sub-catchments in excel spreadsheets for inclusion in the hydraulic model.

7 Annex - supporting information

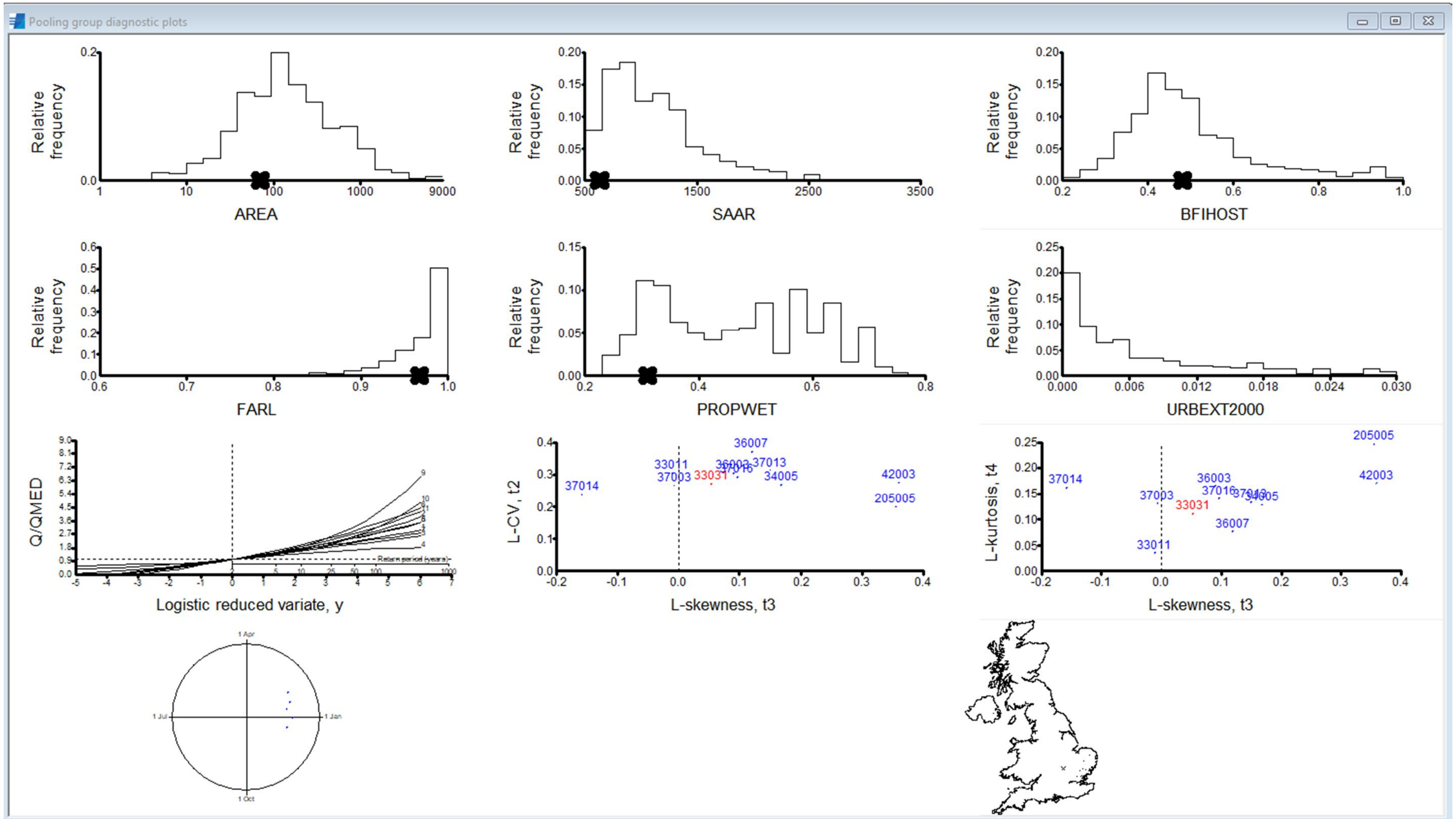
7.1 ReFH outputs for the 1 in 100 year event

7.2 ReFH2 outputs for the 1 in 100 year event

7.3 Pooling group composition

Station	Distance	Years of data	QMED AM	AREA	SAAR	FPEXT	FARL	URBEXT 2000	SPRHOST	BFIHOST	PG0	PG1_ESS	PG2_ESS
33031 (Broughton Brook @ Broughton)	0	45	13.298	70.06	629	0.144	0.967	0.038	40.87	0.482	NO	YES	YES
34005 (Tud @ Costessey Park)	0.175	57	3.146	72.11	649	0.158	0.973	0.029	32.65	0.598	YES	YES	YES
37003 (Ter @ Crabbs Bridge)	0.434	53	5.43	77.76	570	0.115	0.994	0.012	41.76	0.461	YES	YES	YES
33032 (Heacham @ Heacham)	0.482	50	0.442	56.16	688	0.116	0.983	0.006	6.01	0.968	YES	YES	NO
26003 (Foston Beck @ Foston Mill)	0.533	57	1.76	59.59	698	0.106	0.987	0.004	10.43	0.878	YES	YES	NO
37014 (Roding @ High Ongar)	0.588	54	10.928	92.65	597	0.107	0.986	0.008	43.46	0.403	YES	YES	YES
34012 (Burn @ Burnham Overy)	0.61	52	1.038	83.87	668	0.098	0.997	0.005	6.29	0.965	YES	YES	NO
33054 (Babingley @ Castle Rising)	0.627	42	1.132	48.53	686	0.118	0.944	0.005	9.74	0.906	YES	YES	NO
36003 (Box @ Polstead)	0.687	57	3.91	56.72	566	0.093	0.993	0.012	37.7	0.555	YES	YES	YES
26013 (Driffield Trout Stream @ Driffield)	0.729	8	2.78	53.33	690	0.093	0.997	0.006	17.61	0.807	YES	YES	NO
39042 (Leach @ Priory Mill Lechlade)	0.76	46	3.085	77.62	736	0.083	0.971	0.003	12.21	0.865	YES	YES	NO
36007 (Belchamp Brook @ Bardfield Bridge)	0.824	53	4.63	58.16	560	0.079	0.996	0.004	36.21	0.523	YES	YES	YES
33011 (Little Ouse @ County Bridge Euston)	0.871	57	3.926	129.35	596	0.146	0.985	0.008	26.08	0.652	NO	NO	YES
37016 (Pant @ Copford Hall)	0.876	54	7.24	63.8	588	0.069	0.997	0.009	43.6	0.404	NO	NO	YES
42003 (Lymington @ Brockenhurst)	0.89	23	27.4	99.87	854	0.107	0.997	0.013	39.18	0.387	NO	NO	YES
205005 (Ravernet @ Ravernet)	0.912	44	15.066	73.72	946	0.106	0.934	0	44.85	0.422	NO	NO	YES
37013 (Sandon Brook @ Sandon Bridge)	0.937	52	8.99	74.7	575	0.092	0.855	0.026	46.7	0.275	NO	NO	YES

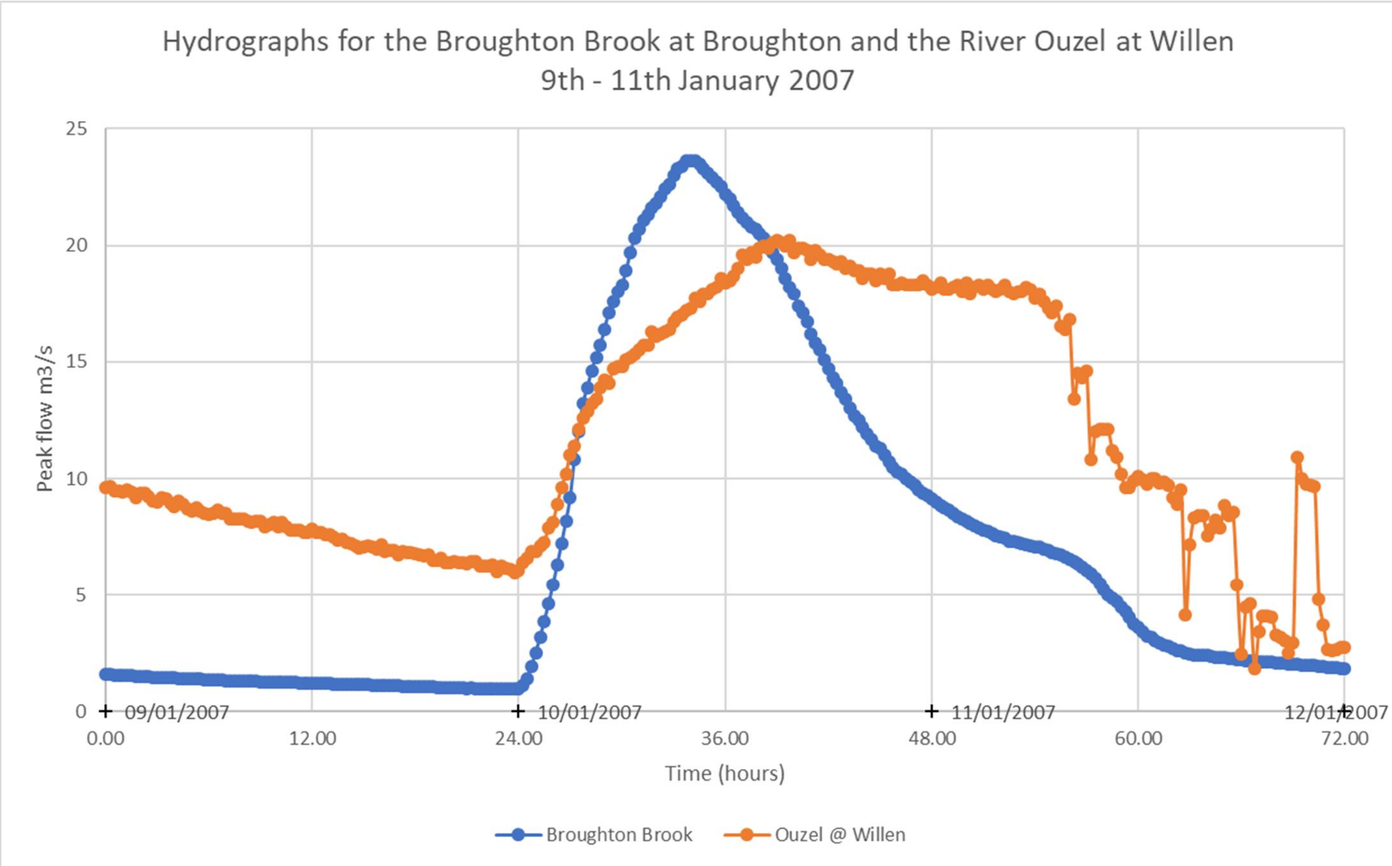
7.4 Pooling group graphs (PG2)



APPENDIX 2 – UPDATED FLOOD PEAK COMPARISON

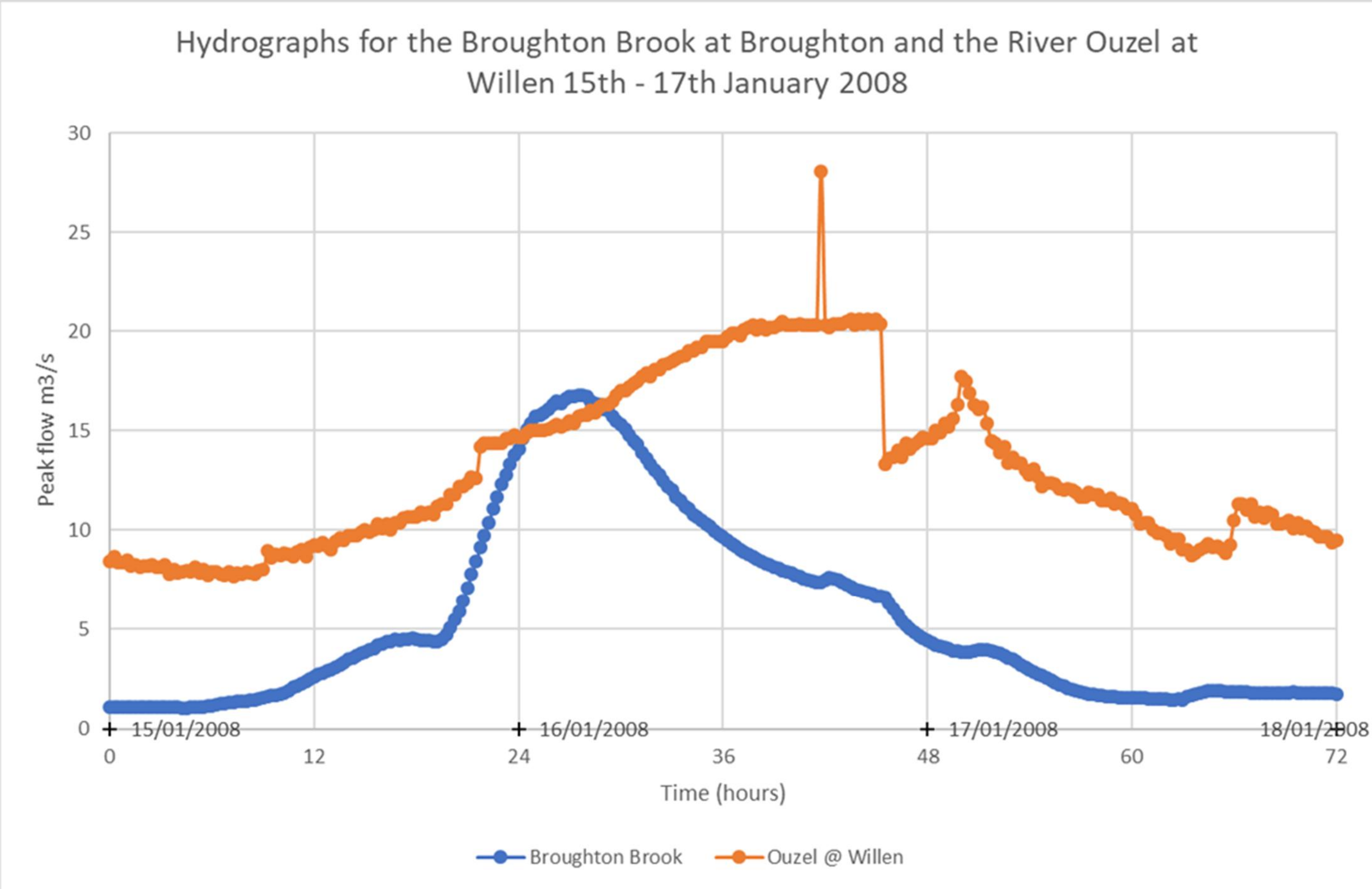
10 JANUARY 2007

- Ranked 5th on AMAX list for the Broughton Brook at Broughton, peaked at 10:15 on the 10th of January 2007
- Ranked 25th on AMAX list for the River Ouzel at Willen, peaked at 15:00 on the 10th of January 2007.



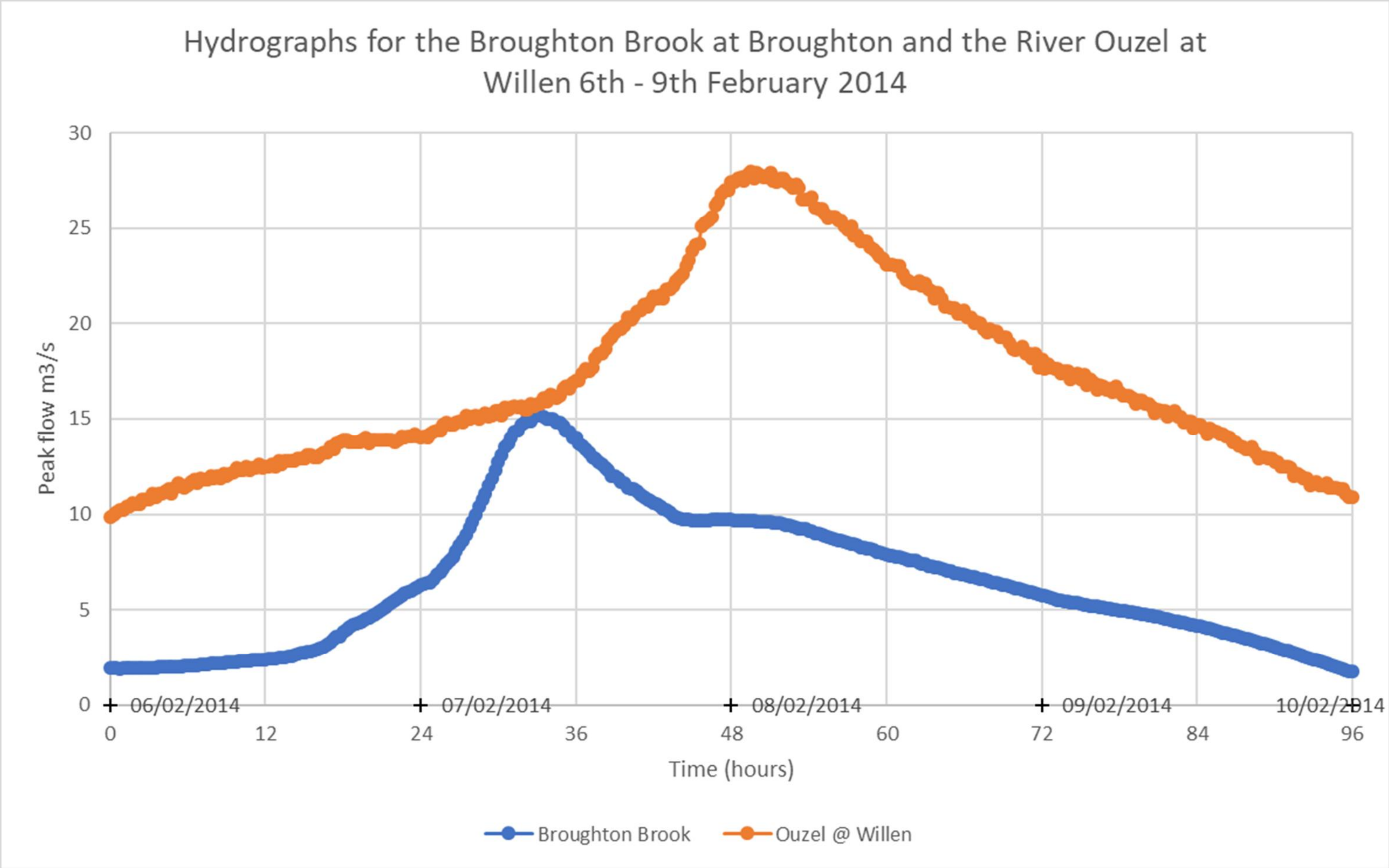
16 JANUARY 2008

- Ranked 13th on AMAX list for the Broughton Brook at Broughton, peaked at 03:45 on the 16th of February 2008
- Ranked 8th on the AMAX list for the River Ouzel at Willen, peaked at 17:45 on the 16th of February 2008



7 / 8 FEBRUARY 2014

- Ranked 14th on AMAX list for the Broughton Brook at Broughton, peaked at 09:15 on the 7 February 2014
- Ranked 9th on AMAX list for the River Ouzel at Willen, peaked at 01:30 on the 8 February 2014.

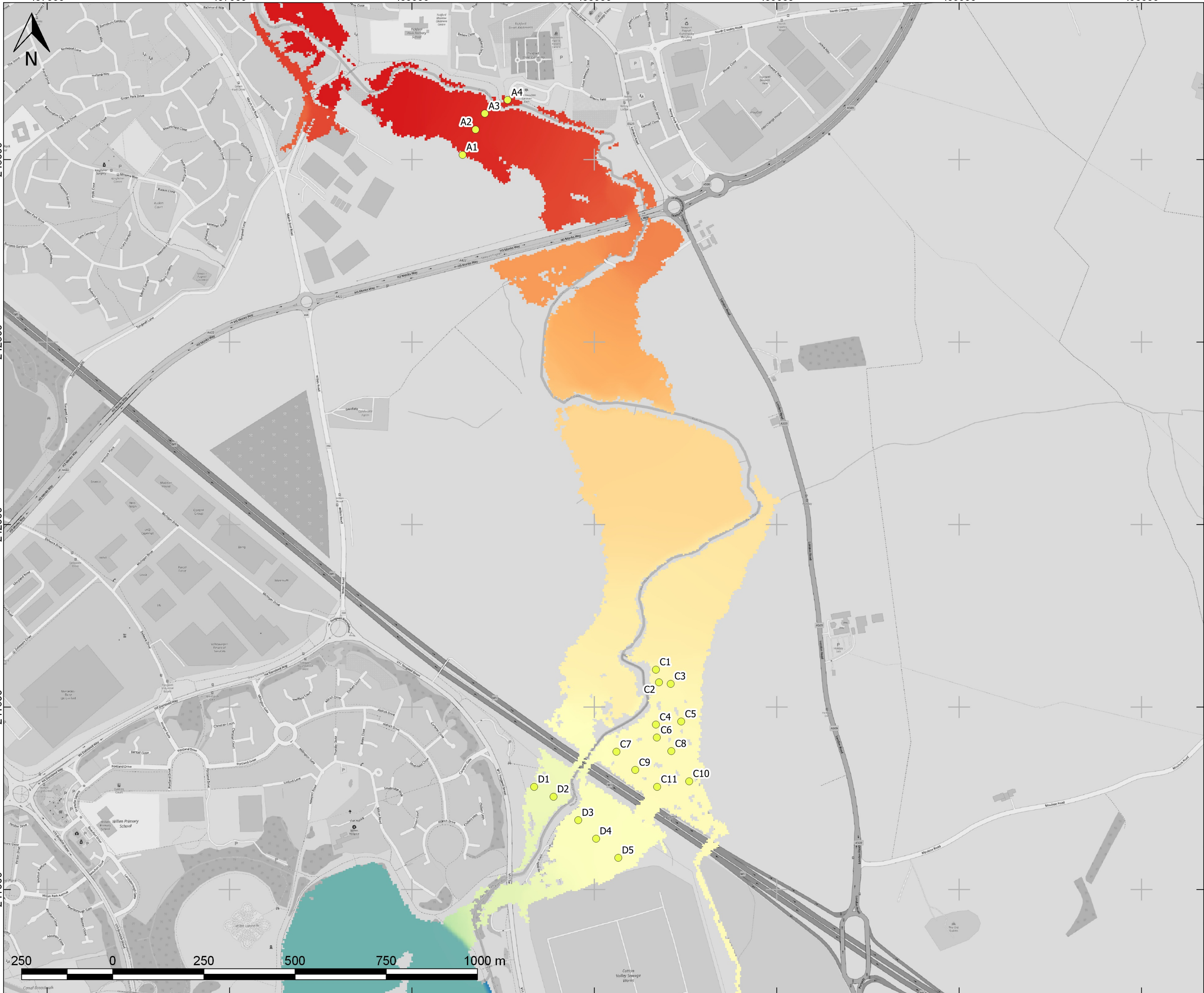


Appendix C

PROPOSED HIGHWAY DRAWINGS

Appendix D

FLOOD DEPTH PLANS



KEY:

Point Location

Flood Elevation (mODN)

(red)	55
(orange)	56.25
(pale yellow)	57.5
(light green)	58.75
(blue)	60

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TITLE:

Flood Elevation
Base
Q100

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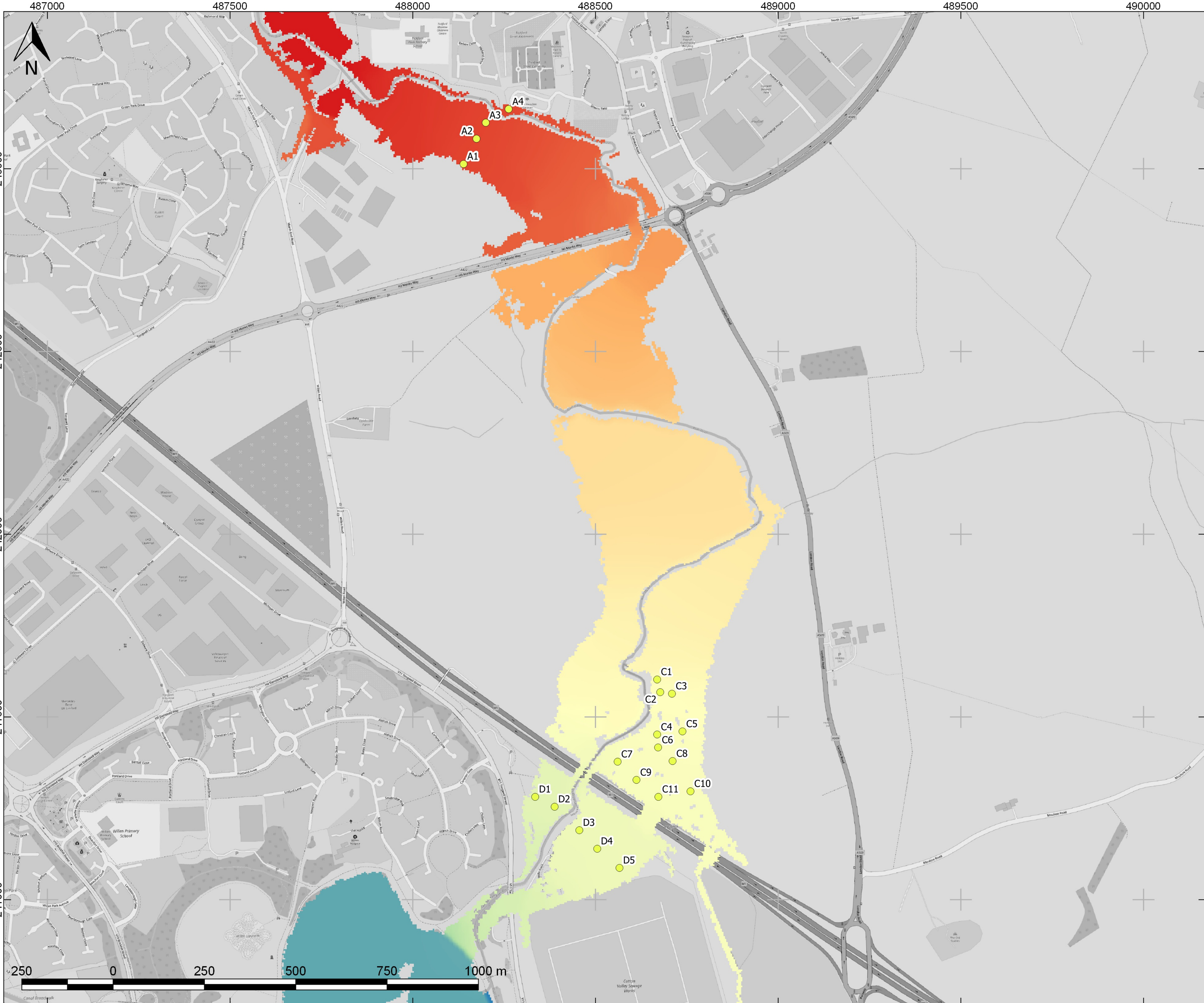

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- 57.5
- 58.75
- 60

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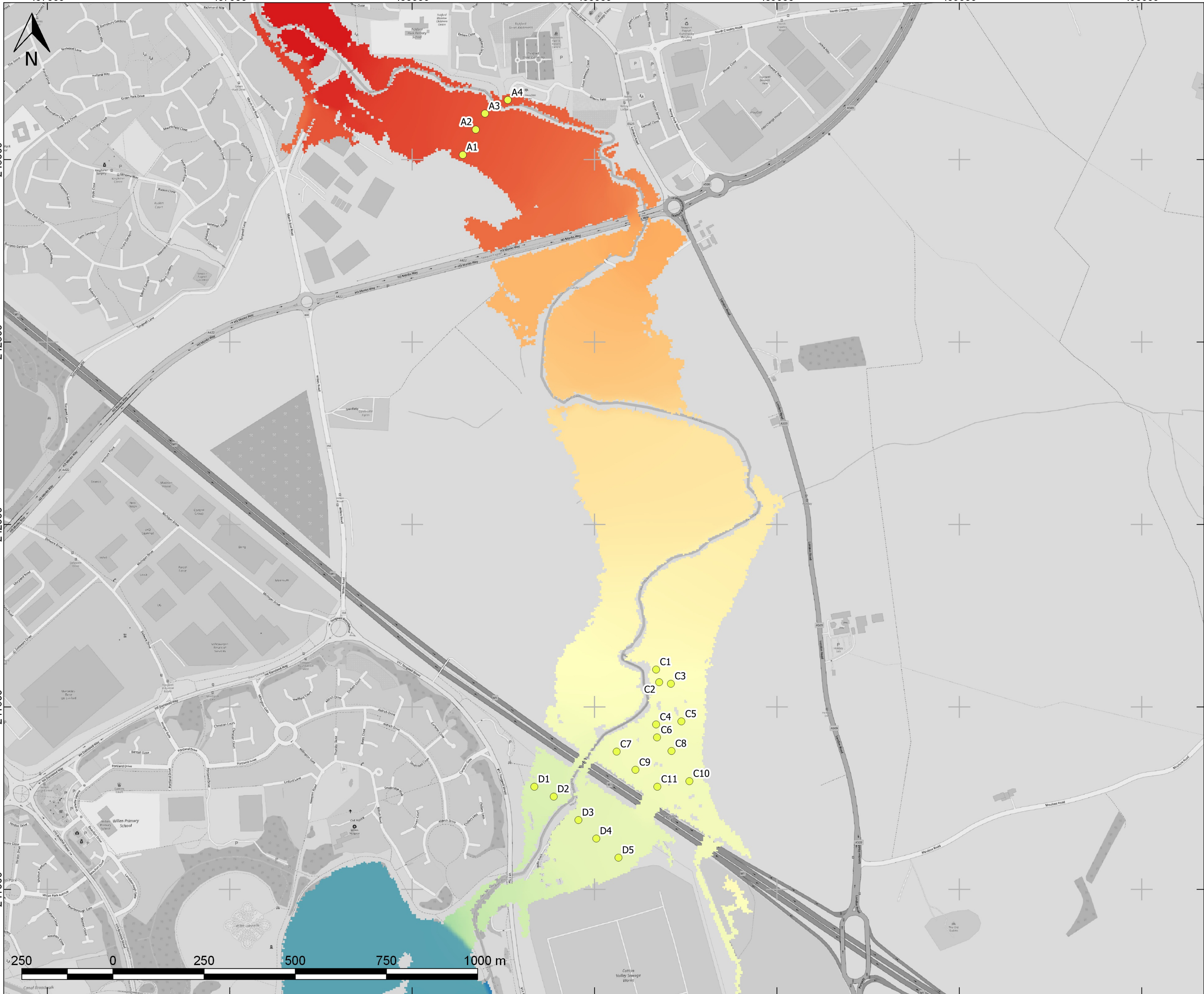

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- 58.75
- 60

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TITLE:

Flood Elevation
Base
Q100 + 65CC

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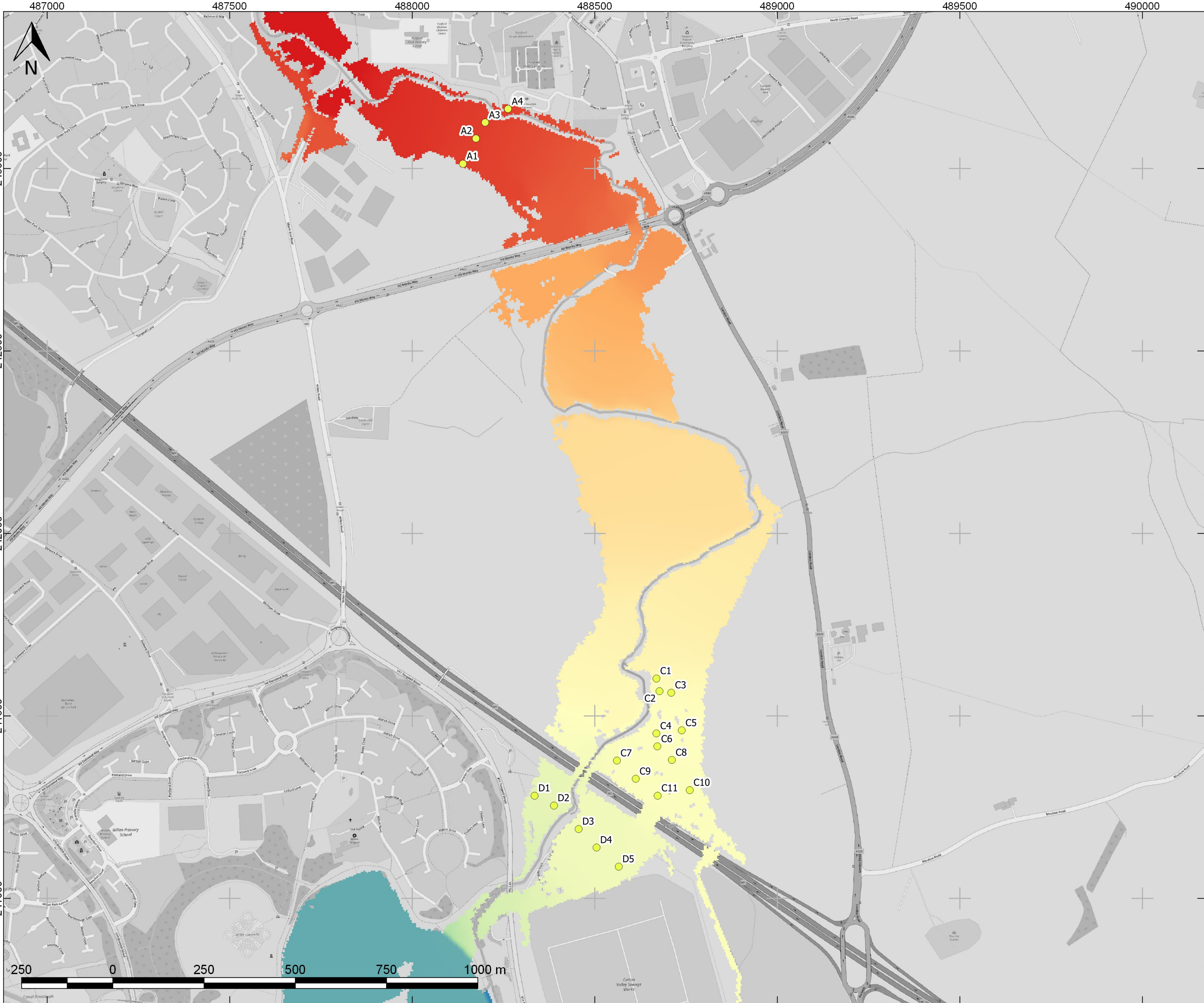

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TITLE:

Flood Elevation (mODN)
Base
Q1000

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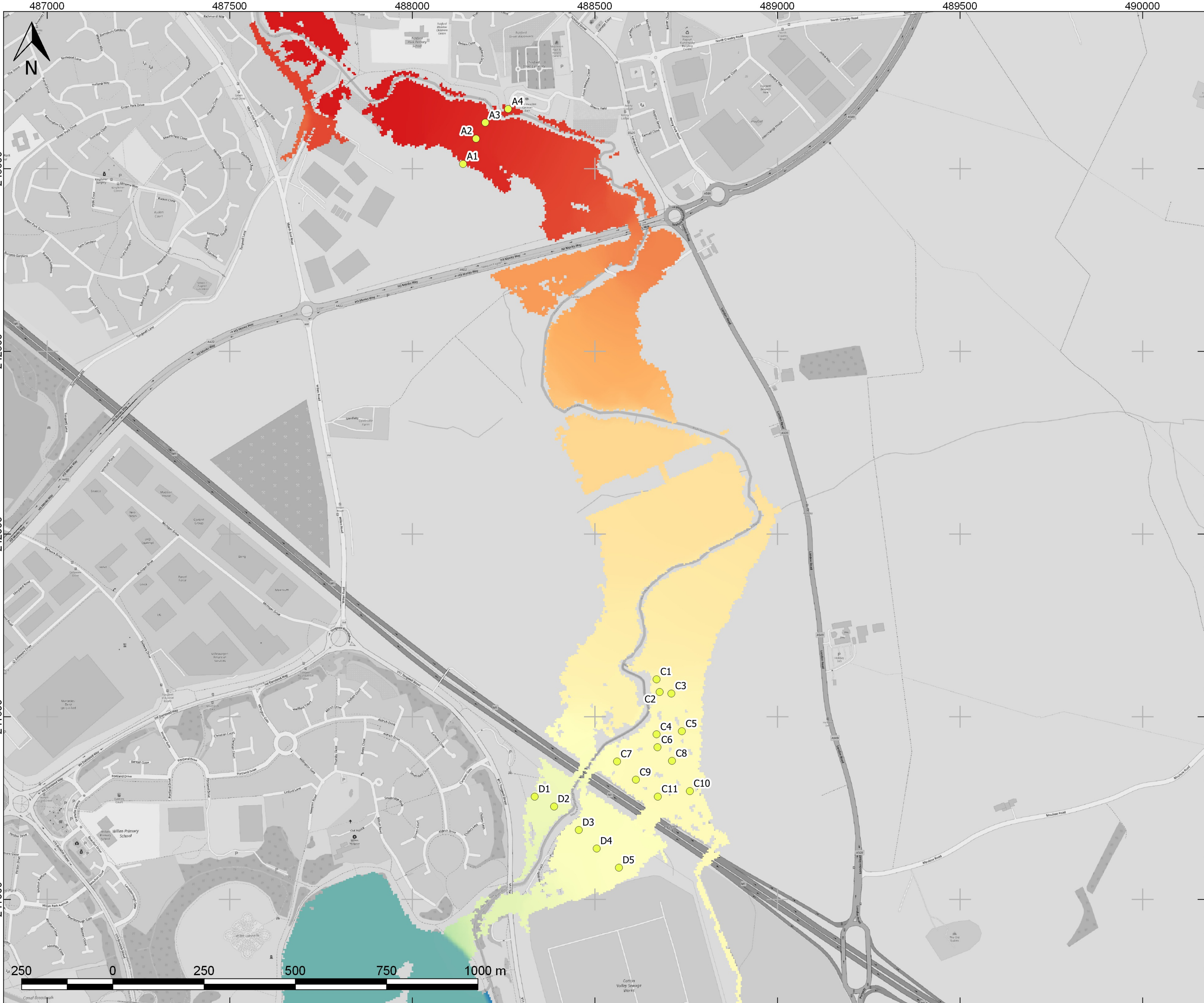

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Option 1
Q100

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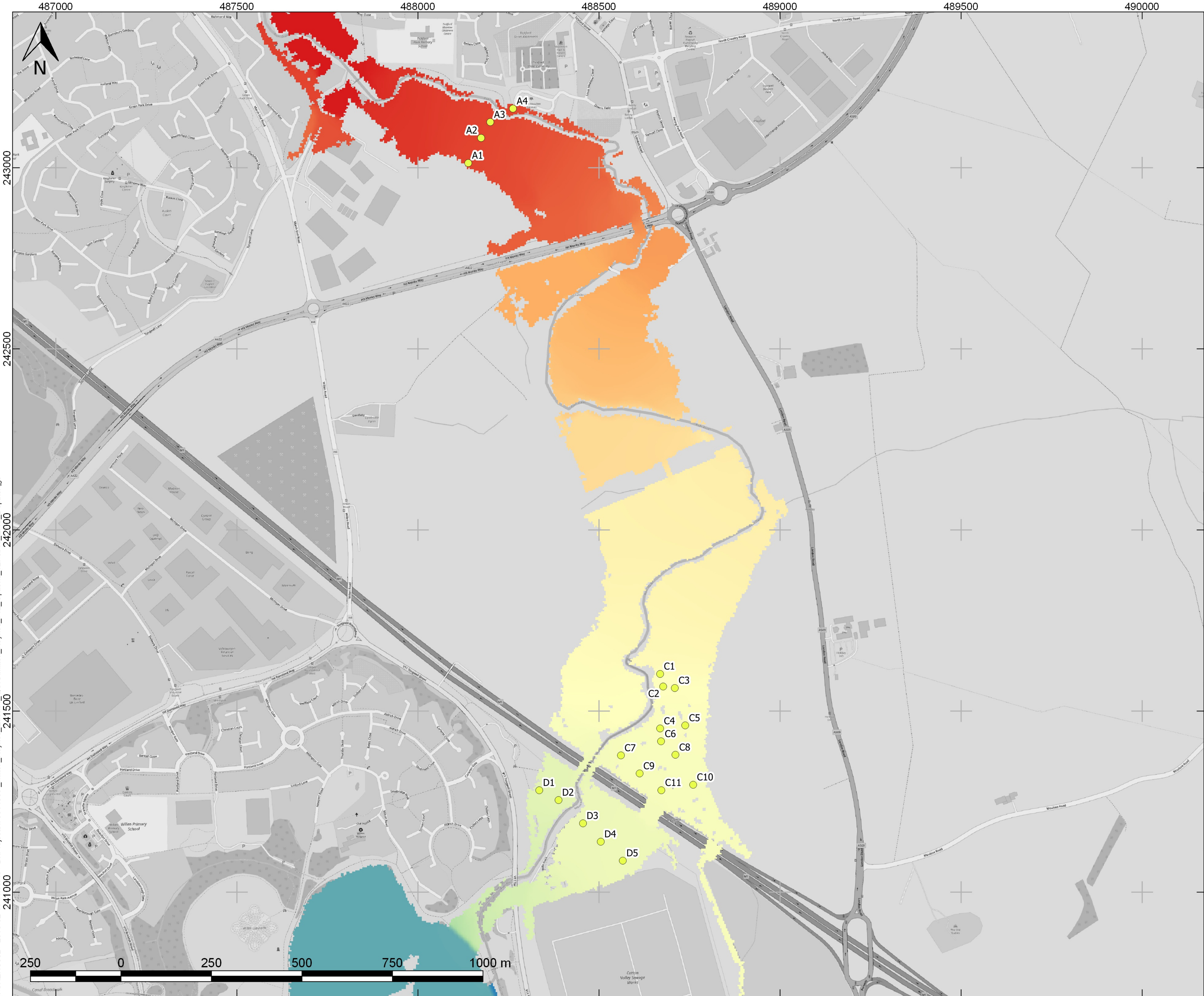

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- 58.75
- 60

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TITLE:

Flood Elevation
Option 1
Q100 + 35CC

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EHC	AS	AS

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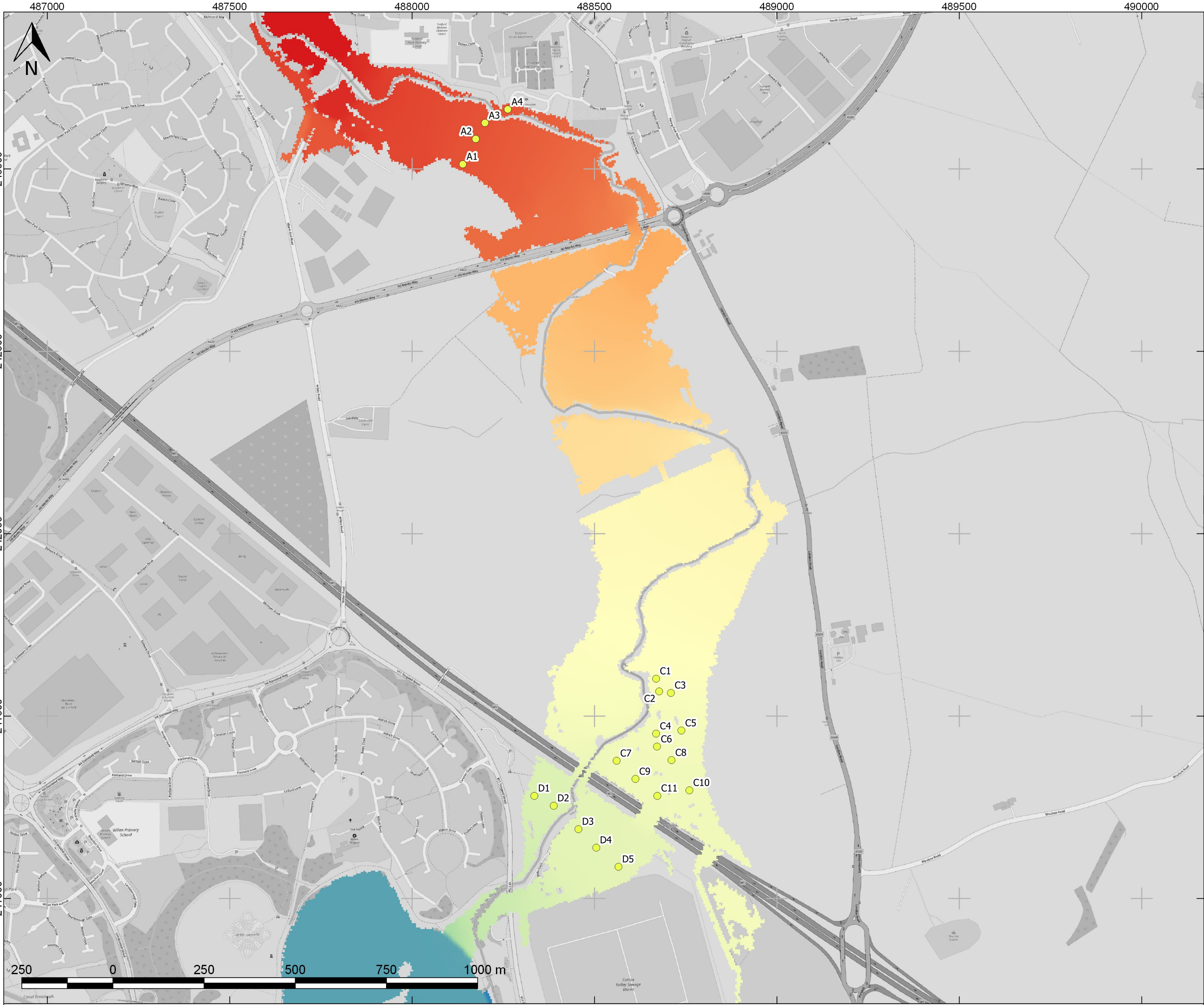

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TITLE:
Flood Elevation
Option 1
Q100 + 65CC

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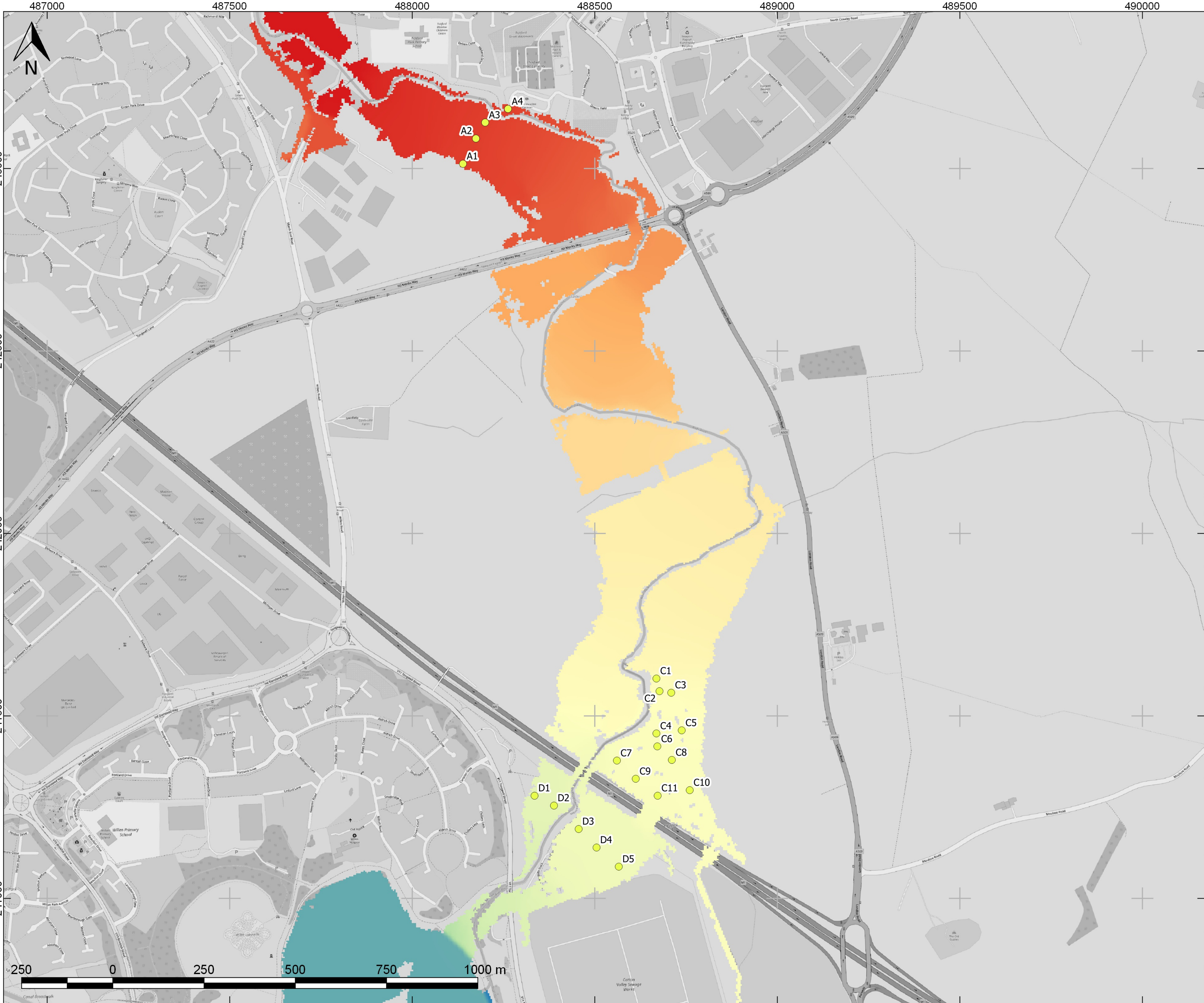

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PROJECT: MILTON KEYNES EAST

TITLE: Flood Elevation Option 1 Q1000

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EHC	AS	AS
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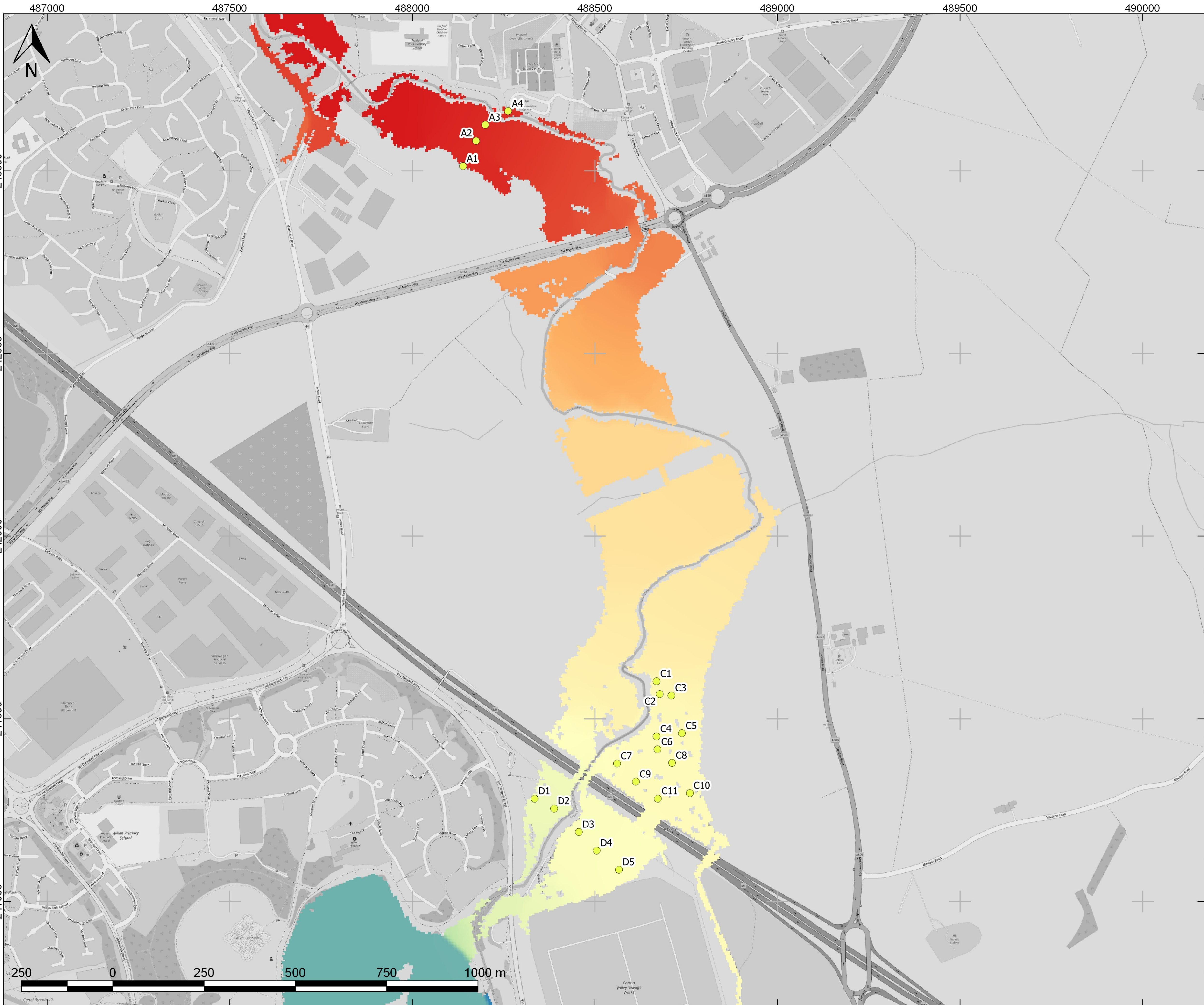

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Flood Elevation (mODN)

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- 57.5
- 58.75
- 60

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TITLE:

Flood Elevation
Option 2
Q100

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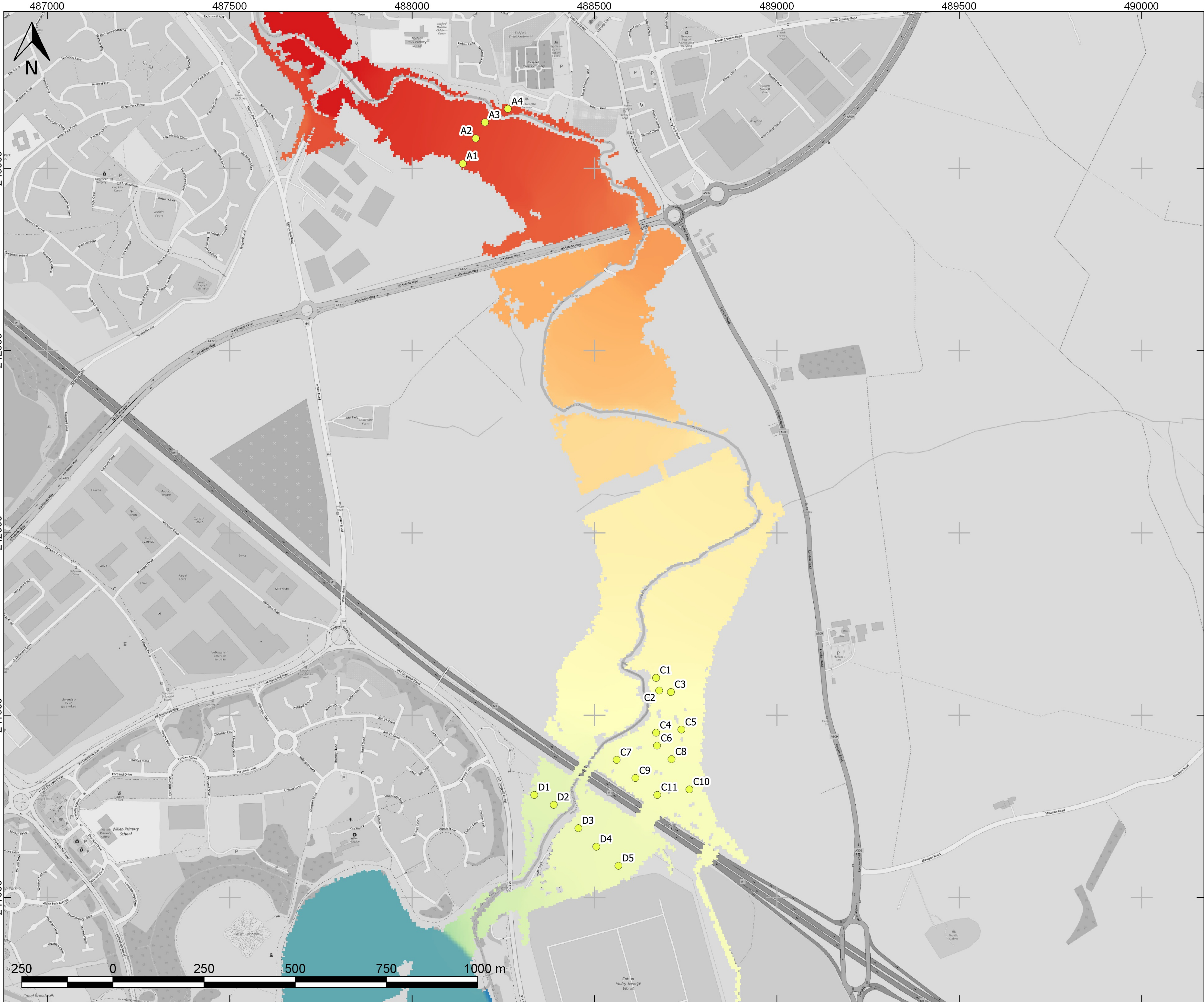

KEY:

- Point Location

Flood Elevation (mODN)

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- 56.25
- 57.5
- 58.75
- 60

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A	15/02/19	EHC	FIRST ISSUE	AS	AS

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ARCHITECT:

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PROJECT:

MILTON KEYNES EAST

TITLE:

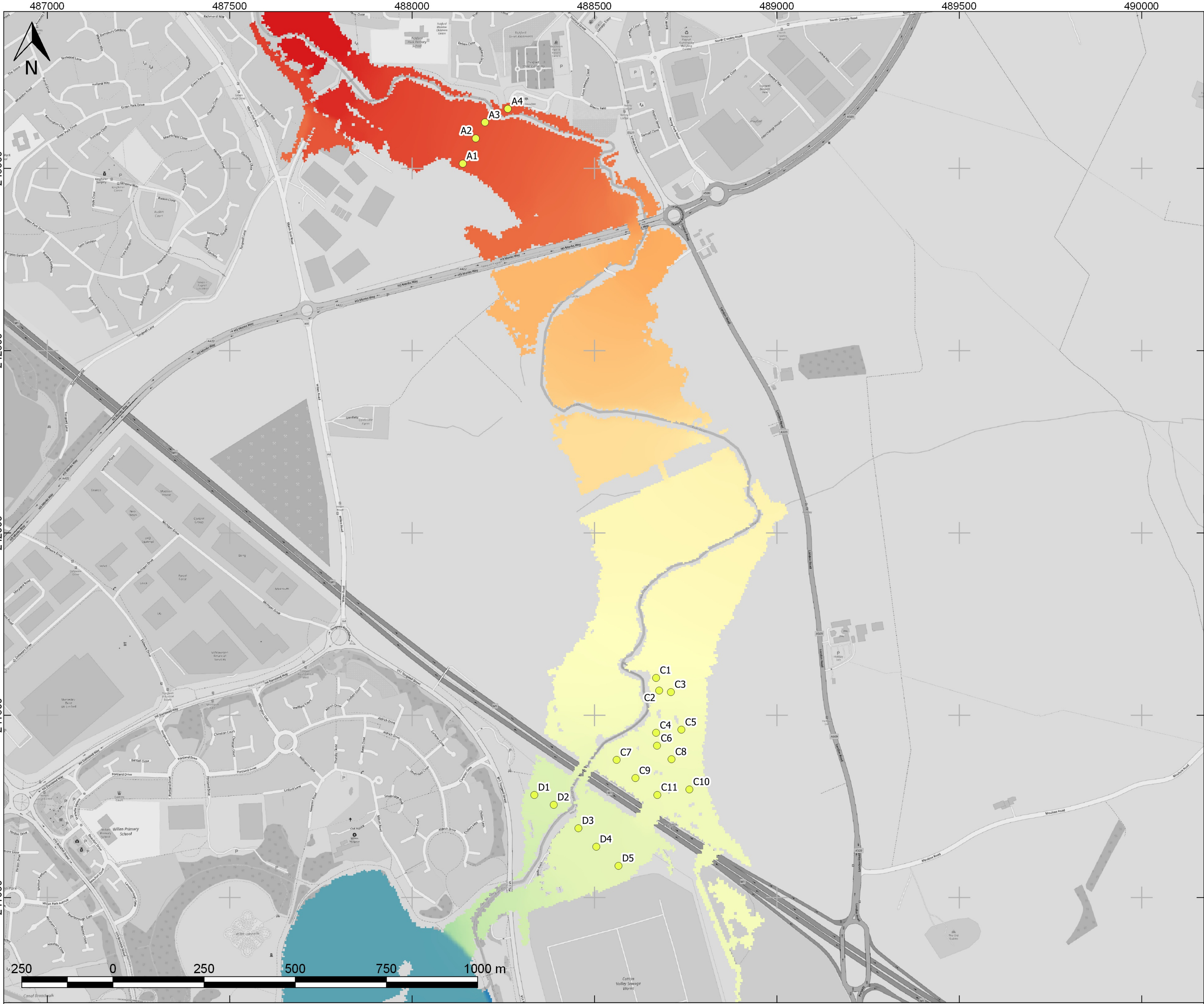
Flood Elevation
Option 2
Q100 + 35CC

DRAWN:	CHECKED:	APPROVED:
EHC	AS	AS

QGIS FILE:	SCALE @A3:	DATE:
/12_Options_12Feb19_E	1:10,000	19/02/19

PROJECT No:	DRAWING No:	REV:
70014859	FE-O2-02	A

Created by: UKEHC002 - 2019-02-19 11:44:04 - D:\Projects\70014859_Milton_Keynes_East\01_QGIS\Milton_Keynes_v12_Options_12Feb19_EHC_Depths.qgs



KEY:

- Point Location

Flood Elevation (mODN)

- 55
- 56.25
- 57.5
- 58.75
- 60

REV	DATE	DRW	DESCRIPTION	CHK	APP
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PROJECT:

MILTON KEYNES EAST

TITLE:

Flood Elevation
Option 2
Q100 + 65CC

DRAWN:	CHECKED:	APPROVED:
EHC	AS	AS

QGIS FILE:	SCALE @A3:	DATE:
/12_Options_12Feb19_E	1:10,000	19/02/19

PROJECT No:	DRAWING No:	REV:
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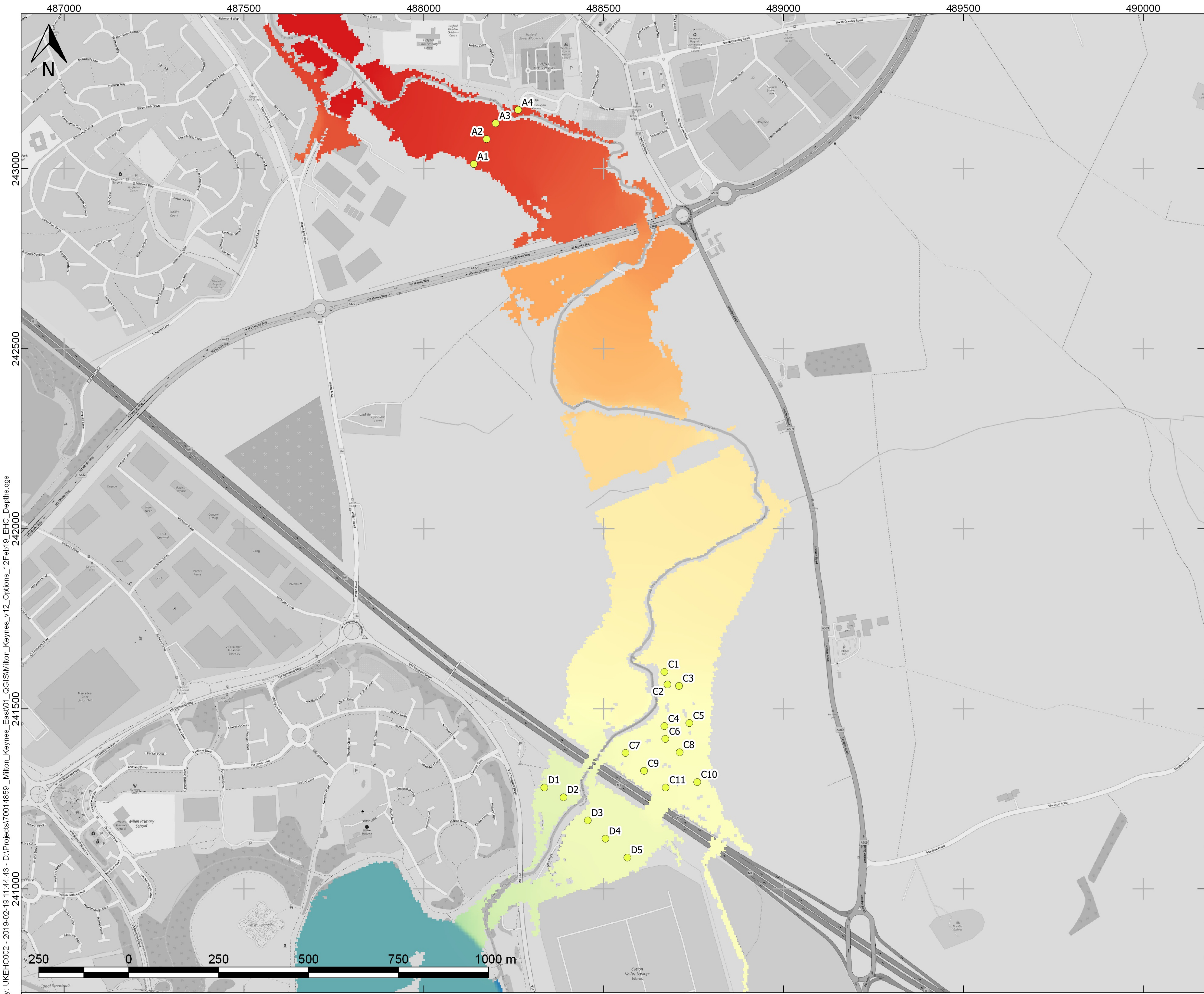

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Point Location

Flood Elevation (mODN)

- 55
- 56.25
- 57.5
- 58.75
- 60

REV	DATE	DRW	DESCRIPTION	CHK	APP
A	15/02/19	EHC	FIRST ISSUE	AS	AS

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PROJECT:

MILTON KEYNES EAST

TITLE:

Flood Elevation Option 2 Q1000

DRAWN:	CHECKED:	APPROVED:
EHC	AS	AS

QGIS FILE:	SCALE @A3:	DATE:
/12_Options_12Feb19_E	1:10,000	19/02/19

PROJECT No:	DRAWING No:	REV:
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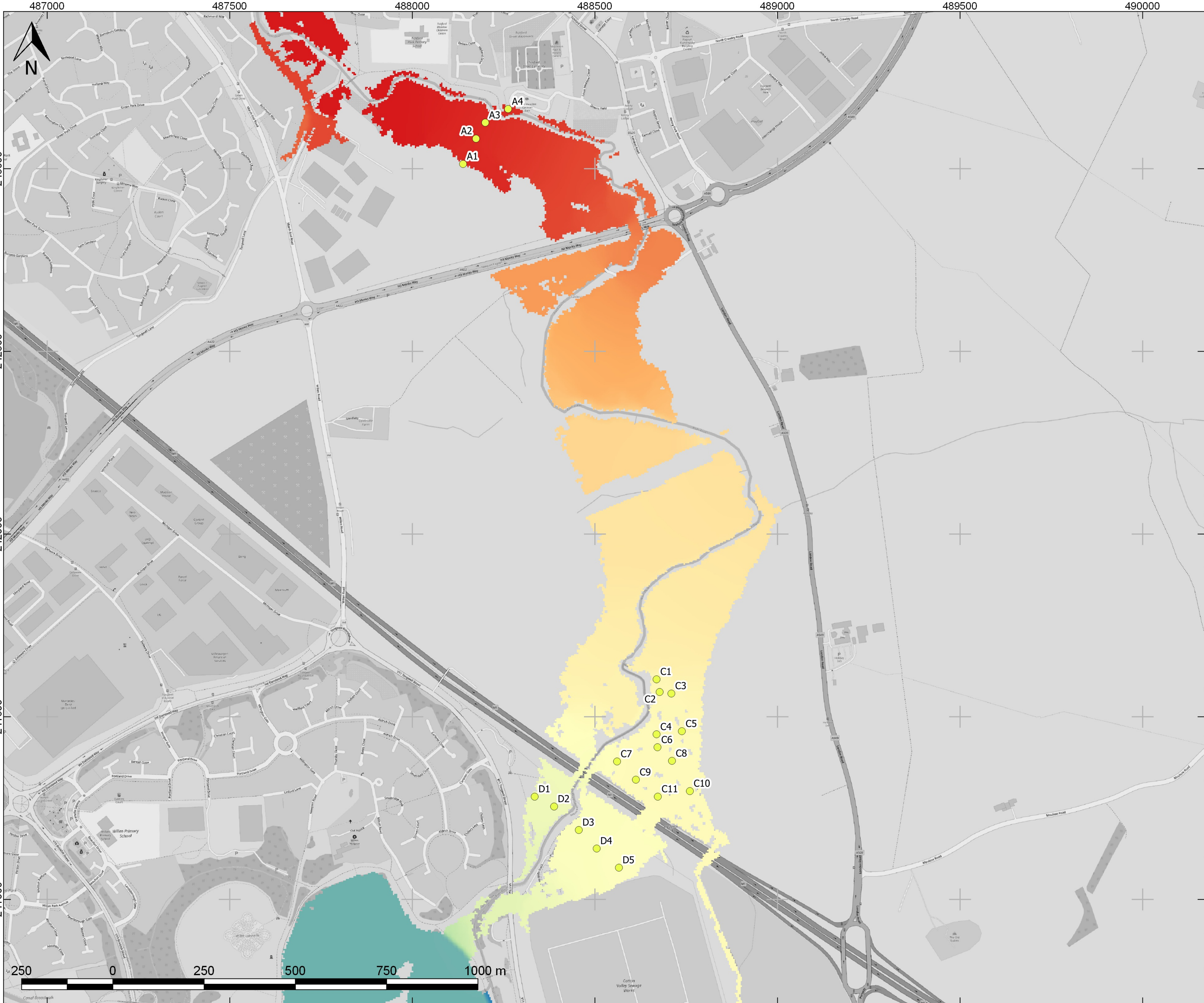

KEY:

- Point Location

Flood Elevation (mODN)

- 55
- 56.25
- 57.5
- 58.75
- 60

REV	DATE	DRW	DESCRIPTION	CHK	APP
A	15/02/19	EHC	FIRST ISSUE	AS	AS

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PROJECT:

MILTON KEYNES EAST

TITLE:

Flood Elevation
Option 3
Q100

DRAWN:	CHECKED:	APPROVED:
EHC	AS	AS

QGIS FILE:	SCALE @A3:	DATE:
/12_Options_12Feb19_E	1:10,000	19/02/19

PROJECT No:	DRAWING No:	REV:
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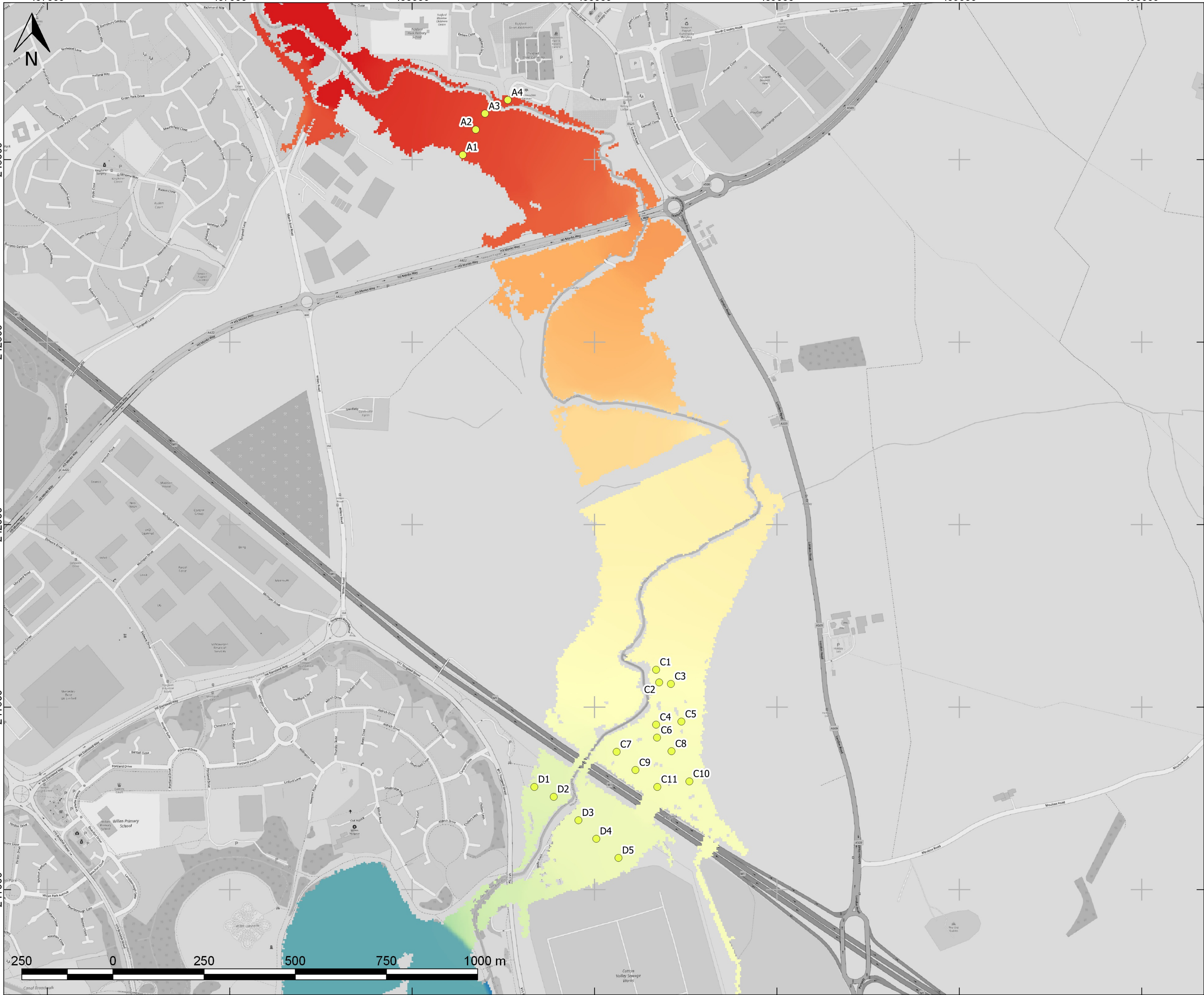

KEY:

Point Location

Flood Elevation (mODN)

- 55
- 56.25
- 57.5
- 58.75
- 60

REV	DATE	DRW	DESCRIPTION	CHK	APP
A	15/02/19	EHC	FIRST ISSUE	AS	AS

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PROJECT:

MILTON KEYNES EAST

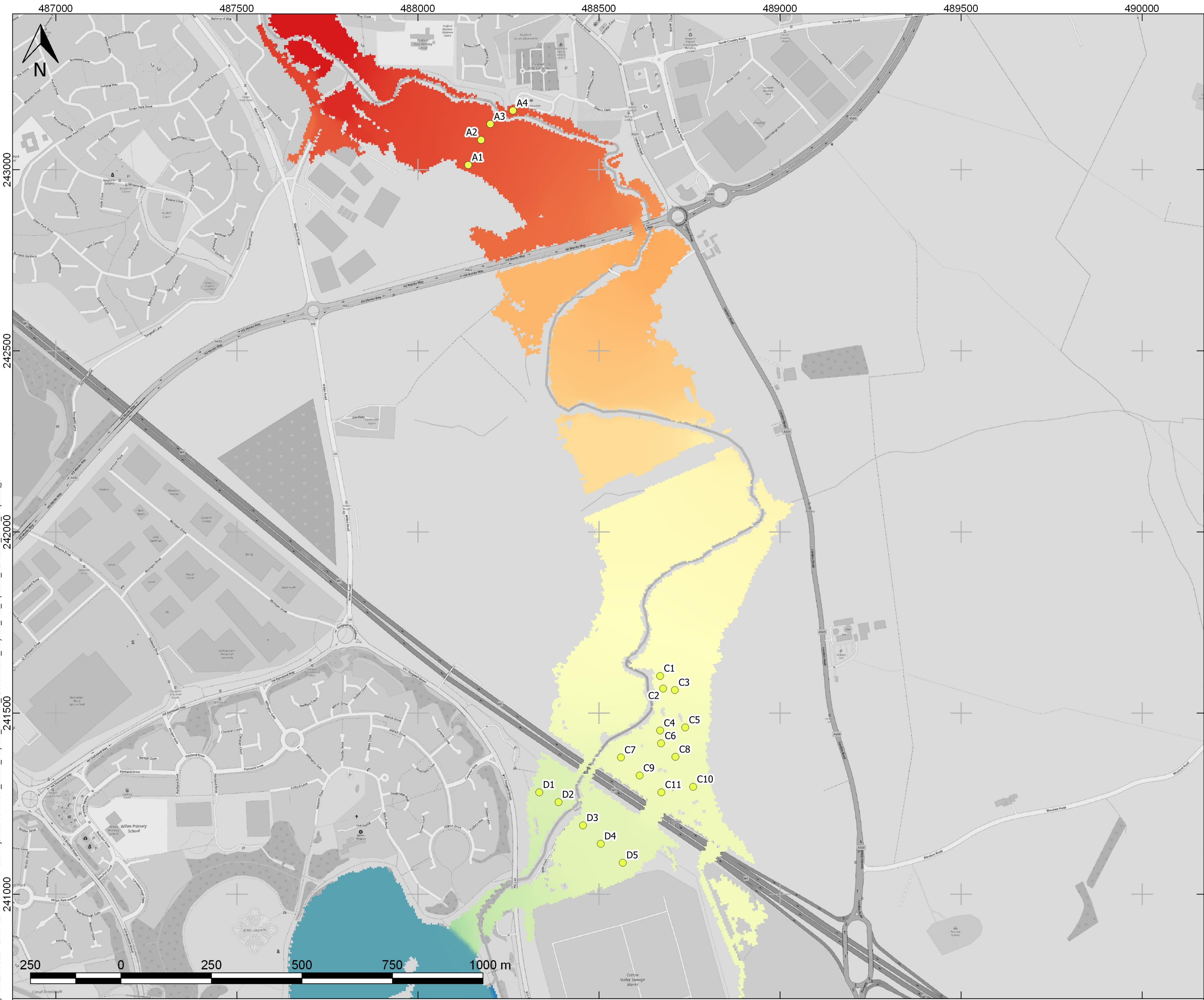
TITLE:

Flood Elevation
Option 3
Q100 + 35CC

DRAWN:	CHECKED:	APPROVED:
EHC	AS	AS

QGIS FILE:	SCALE @A3:	DATE:
/12_Options_12Feb19_E	1:10,000	19/02/19

PROJECT No:	DRAWING No:	REV:
70014859	FE-O3-02	A



KEY:

- Point Location

Flood Elevation (mODN)

- 55
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- 58.75
- 60

REV	DATE	DRW	DESCRIPTION	CHK	APP
A	15/02/19	EHC	FIRST ISSUE	AS	AS

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PROJECT:

MILTON KEYNES EAST

TITLE:

Flood Elevation
Option 3
Q100 + 65CC

DRAWN:	CHECKED:	APPROVED:
EHC	AS	AS

QGIS FILE:	SCALE @A3:	DATE:
/12_Options_12Feb19_E	1:10,000	19/02/19

PROJECT No:	DRAWING No:	REV:
70014859	FE-O3-03	A

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