

# HYDRAULIC MODELLING REPORT

GRAVEN HILL, BICESTER

HLEF 82785  
27<sup>th</sup> April 2022

## REPORT

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### Quality Management

Version	Status	Authored by	Reviewed by	Approved by	Review date
00	Draft	Minhaj Ahmed Mohammed Mamun	Anna Velkov		20.04.2022

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#### RPS Consulting Services Ltd. General Notes

1. This report contains available factual data for the site obtained only from the sources described in this report. The site location has been determined by the client and forms the basis of the assessment and associated data searches.
2. The assessment of the site is based on information supplied by the client. Relevant information was also obtained from other sources.
3. The report reflects both the information provided to RPS in documents made available for review and the results of observations and consultations by RPS staff.
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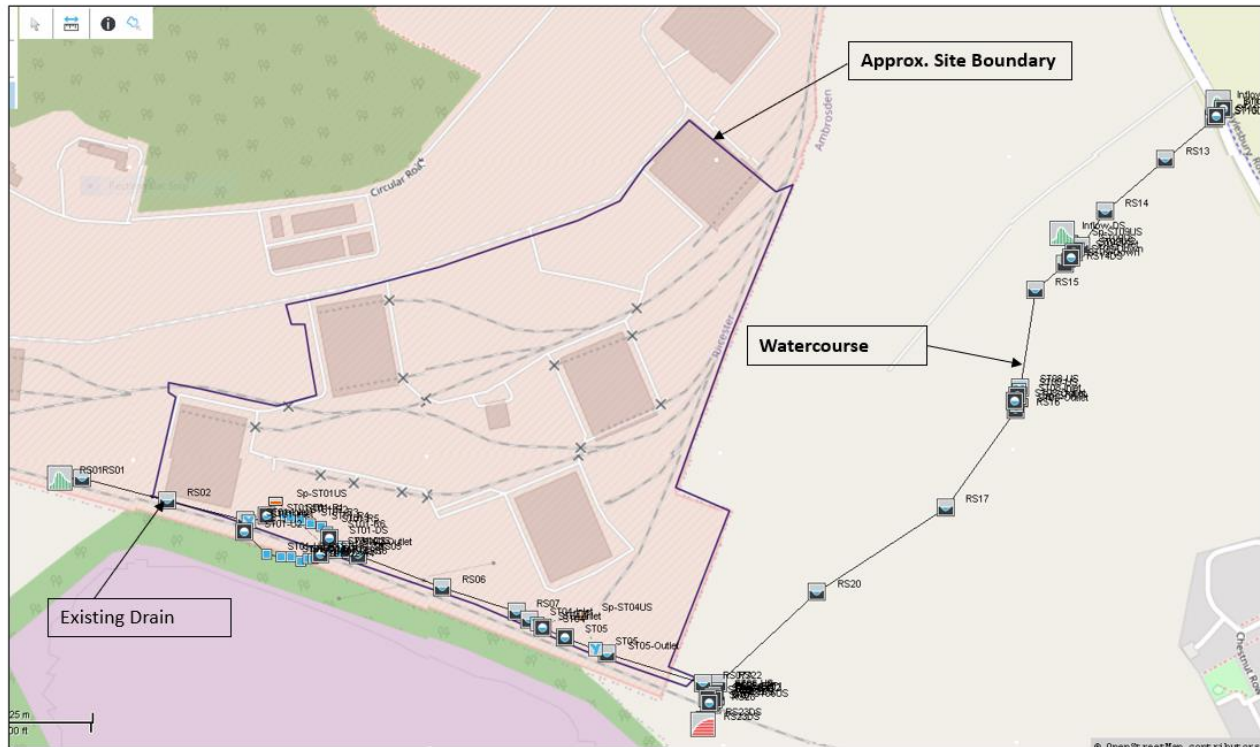
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# 1 INTRODUCTION AND BACKGROUND

- 1.1 RPS Consulting Services Ltd (RPS) was commissioned to undertake a hydraulic modelling exercise to assess the fluvial flood risk at Graven Hill, Bicester. The results of the modelling exercise will be used to support the Flood Risk Assessment (FRA) for the proposed development. The proposed model extends, along with the site boundary is shown in Figure 1.



**Figure 1: Hydraulic Model Extend**

- 1.2 The northern boundary of the site is located south of Aylesbury Road. The southern boundary is just north of the railway embankment. The Local Planning Authority (LPA) is Cherwell District Council, and the Lead Local Flood Authority (LLFA) is Oxfordshire County Council. The site is not located within an Internal Drainage Board (IDB) area.
- 1.3 The EA Flood Zone map shows that the proposed site is in Flood Zone 1, having a fluvial flood risk of greater than 0.1%, i.e., greater than 1 in 1000 year. However, the EA flood map did not consider the ordinary watercourse and the drain. The purpose of this modelling exercise is to investigate the impact of the ordinary watercourse and the drain on the flooding near the site.
- 1.4 EA flood zone map with respect to the site boundary and the cross section survey locations is shown in Figure 2

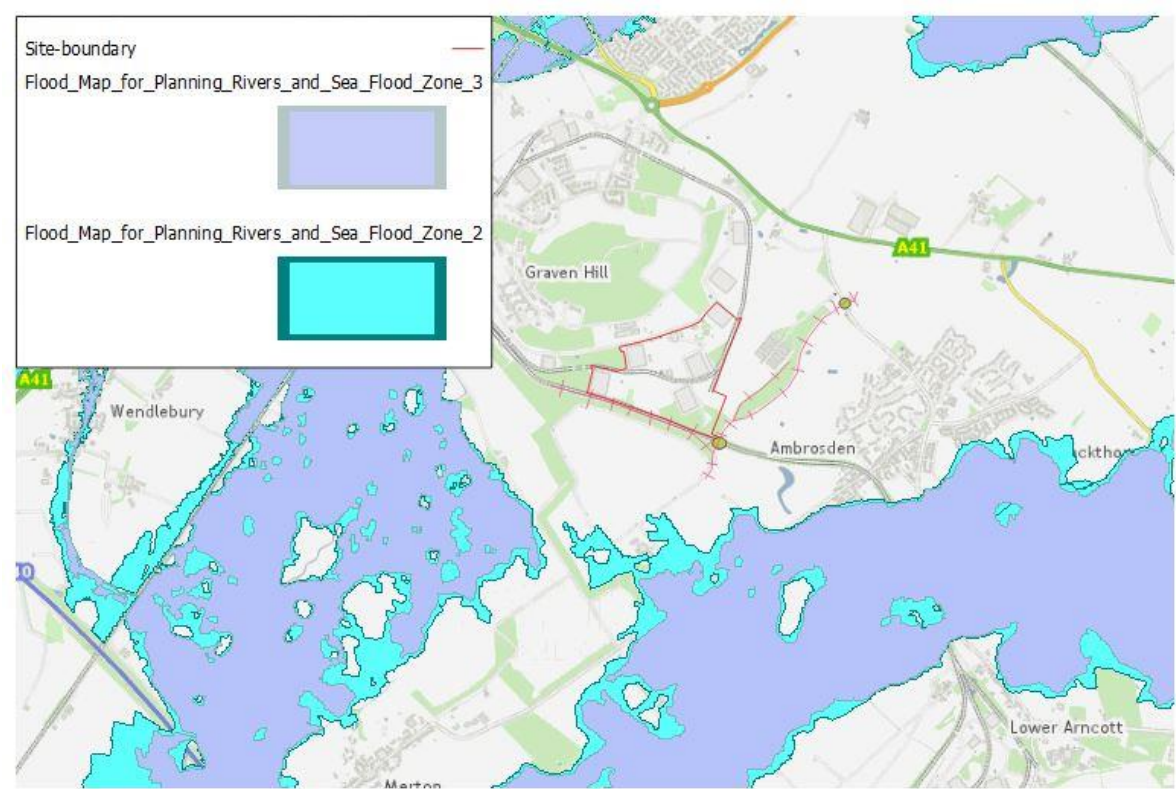


Figure 2: Environmental Agency flood map for planning

## 2 MODELLING APPROACH

- 2.1 Given the short length of channel required to be modelled adjacent to the site, it was considered that 1D Flood Modeller Pro (FMP) model would be suitable in order to simulate flood risk from the ordinary watercourse and the drain.
- 2.2 The 1D hydrodynamic model comprises a one-dimensional (FMP Version: 4.5.1.6163) open channel network model (based on surveyed channel cross-sections). The surveyed sections were extended using LiDAR data downloaded for this area.

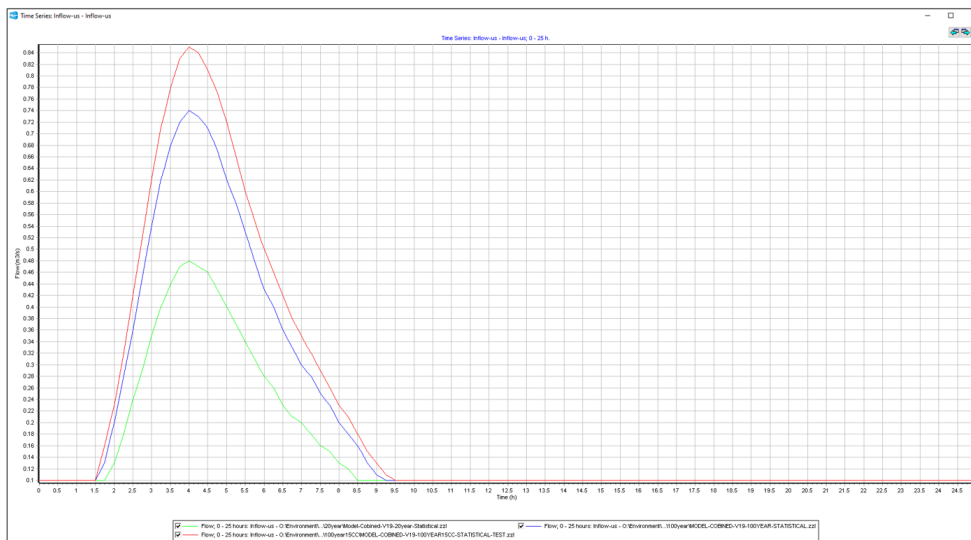
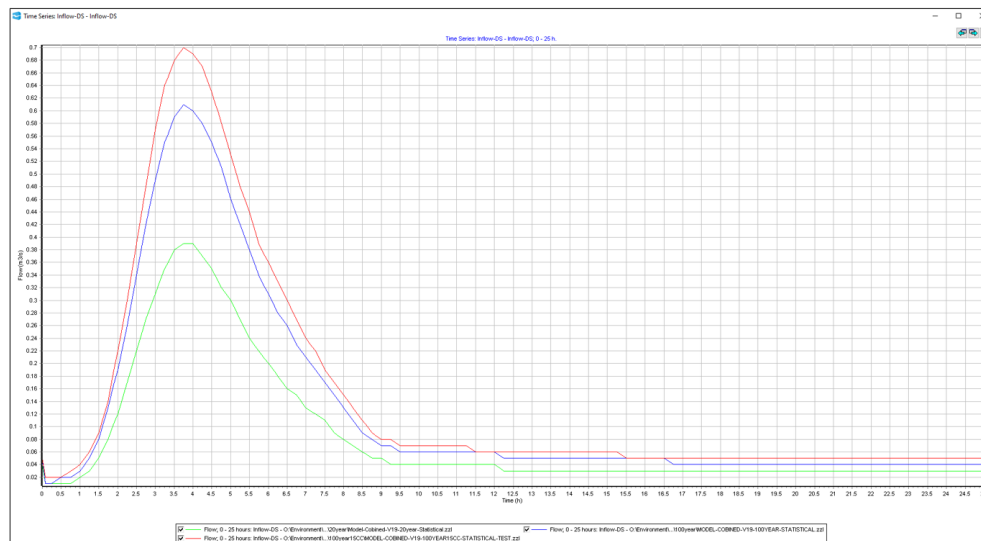
### ***Model extents and boundaries***

- 2.3 An approximate 995m length of the ordinary watercourse flowing from north to south and 838m of drains flowing from west to east have been represented within the model and can be seen in Figure 1. The upstream extent of the watercourse is located approximately 450m south from the Aylesbury Road just south of the footpath. The upstream extent of the drain is about 95 m west from the western side boundary. The drain joins the watercourse at the upstream of railway culvert.
- 2.4 However, the combined flow from the drain and the watercourse, passes through a small pond before entering the twin conduit under the Railway embankment. The survey section does not include this small pond. To include this storage in the model two additional cross sections have been added before the twin conduit under the railway embankment. The section data for this small reach has been copied from the upstream section.
- 2.5 A separate hydrology report (included as Appendix A) details the methodology adopted in deriving the inflow hydrographs for the hydraulic model. The model hydrology is based on the latest Environment agency (EA) Flood Estimation Guidelines v2 July 2020.
- 2.6 There are 3 Inflows applied to the model as point inflows. The inflow at the most upstream modelled extents of the watercourse is the inflow contributing from the northern catchment. The contribution from the southern catchment has been added as lateral point inflow about 286m downstream at structure 9. The inflow from the west has been added to the upstream end of the drain. The sub-catchment area for this inflow has been adjusted as per site boundary. The locations at which the point inflows are applied are shown on Figure 1.
- 2.7 The downstream boundary of the of the model is a normal depth unit (using a slope of 0.002).
- 2.8 There are six circular conduits within the model. Two of them are within the drain and the other four are within the watercourse. All the structures have been modelled as circular conduit. The diameters of the conduits have been taken from the survey section.
- 2.9 Manning's 'n' value coefficients have been used to represent the roughness of the open channel and floodplain. Established reference works (Chow, 1959) and experienced hydraulic modeller judgement has been used to select appropriate values. Estimates of the channel roughness coefficients were made using information from site visit and photographs from the channel survey undertaken for the commission. A manning's n value of 0.04 has been considered for the watercourse and the drain and 0.05 for the floodplain. It was considered as a conservative value.
- 2.10 Due to a lack of gauged data and limited anecdotal evidence it has not been possible to calibrate or validate the results of the hydraulic modelling against any recorded flood events.
- 2.11 The maximum inflow and the corresponding model nodes are shown in Table 1.

**Table 1: Maximum Flow in the model**

Hydrological Event	Maximum Flow m3/s		
	Inflow-us(East US)	Inflow-DS (EAST DS)	RS01(West)
20 year Event	0.48	0.39	0.41
100 year Event	0.74	0.61	0.63
100 year + 15%CC Event	0.85	0.70	0.72

The inflow hydrographs in the model are shown in Figure 3, Figure 4 and Figure 5.

**Figure 3 : Inflow at the upstream of Watercourse****Figure 4 : Inflow at the downstream of the watercourse**

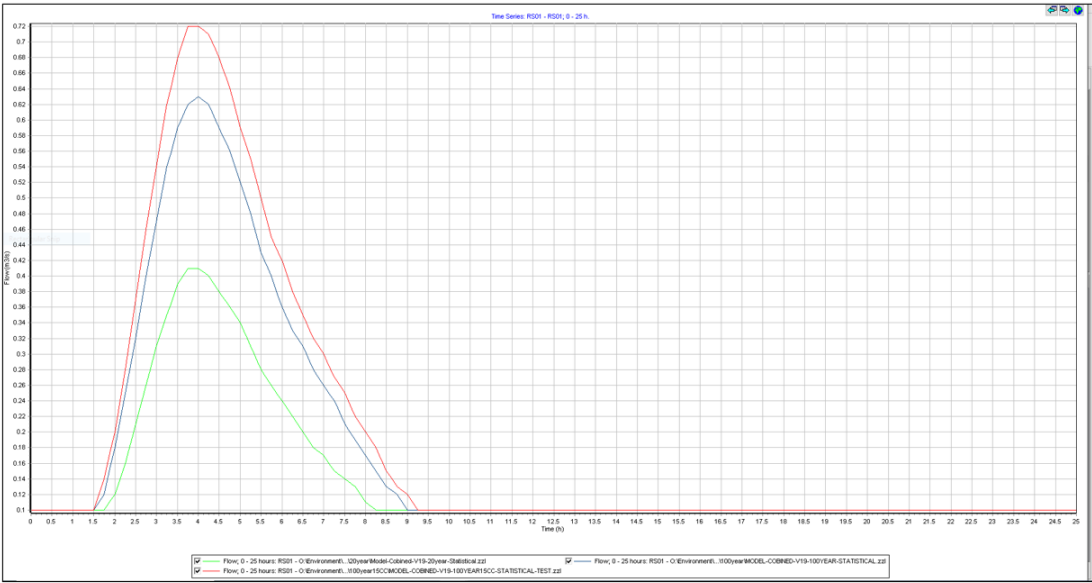


Figure 5 : Inflow at upstream end of the drain



### 3 MODEL RUNS AND PERFORMANCE

- 3.1 The model has been run for the following events:
- 1 in 20 year
  - 1 in 100 year
  - 1 in 100 year +15% Climate Change Allowance
  - 1 in 1000 year
- 3.2 The Climate Change Allowance scenario reflects Central scenario provided within the Environment Agency guidance for the Thames basin district.
- 3.3 The model shows acceptable stability and convergence in the 1D elements.
- 3.4 The 1D Flood Modeller convergence plots for all events show acceptable performance. Diagnostics plots are shown in Figure 6, Figure 7. There are no periods of non-convergence on the simulation.

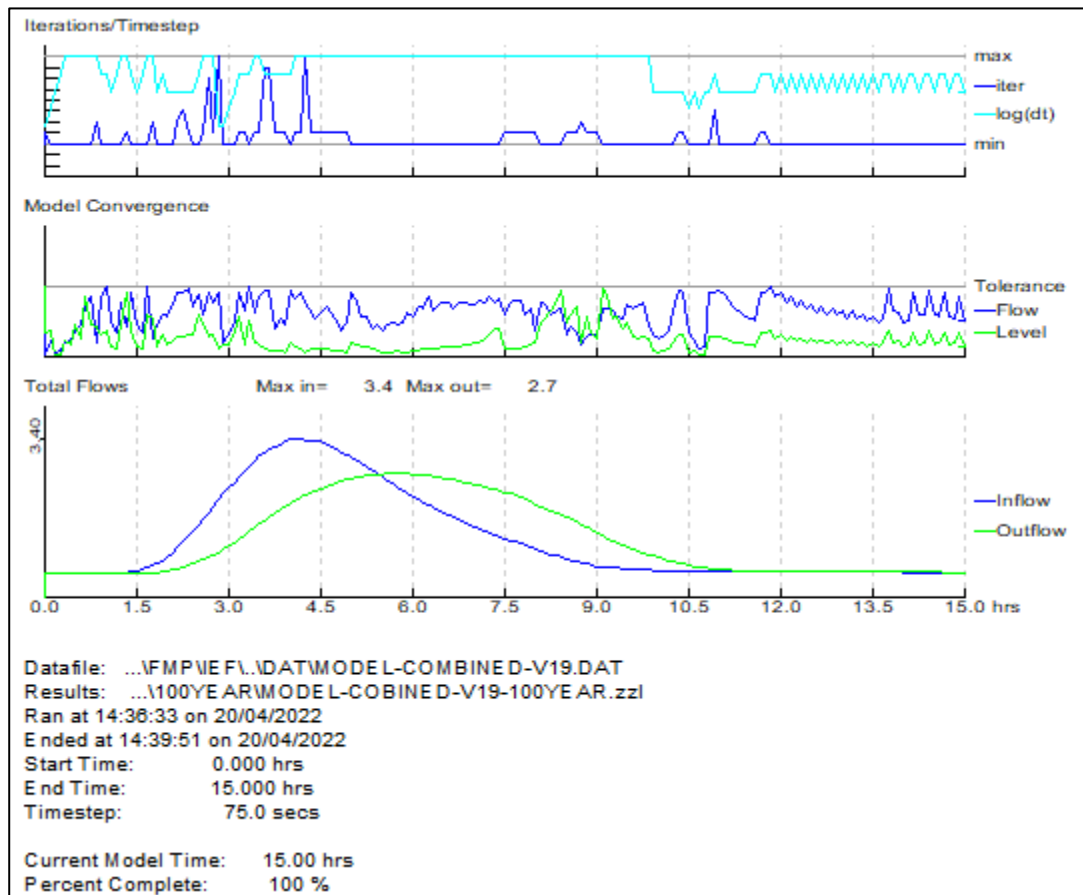


Figure 6: Convergence Plot for 100- year event run

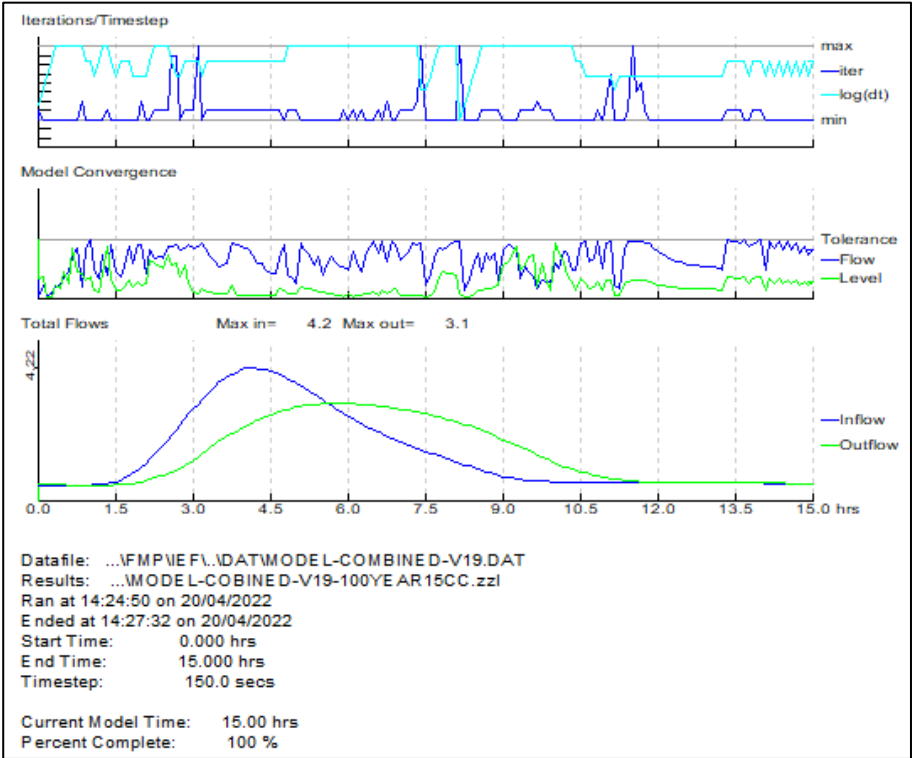


Figure 7: Convergence plot for 100 year +15%CC event

## 4 MODEL RESULTS

- 4.1 The output from the 1D model are water levels and flows at the model nodes. The water level profiles along the drain and the watercourse for different events are shown in Figure 9 and Figure 10. The maximum water levels at different cross sections along the reaches are shown in Table 2.

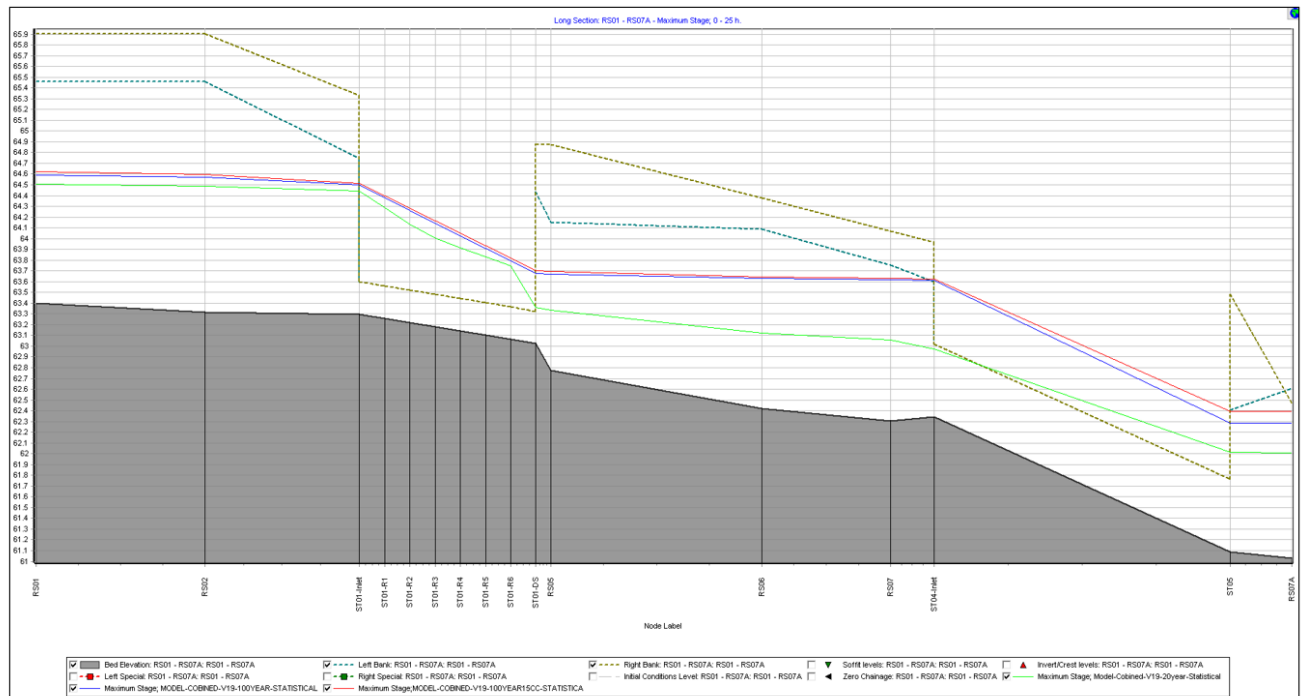


Figure 8: Long profile of maximum water level along the drain

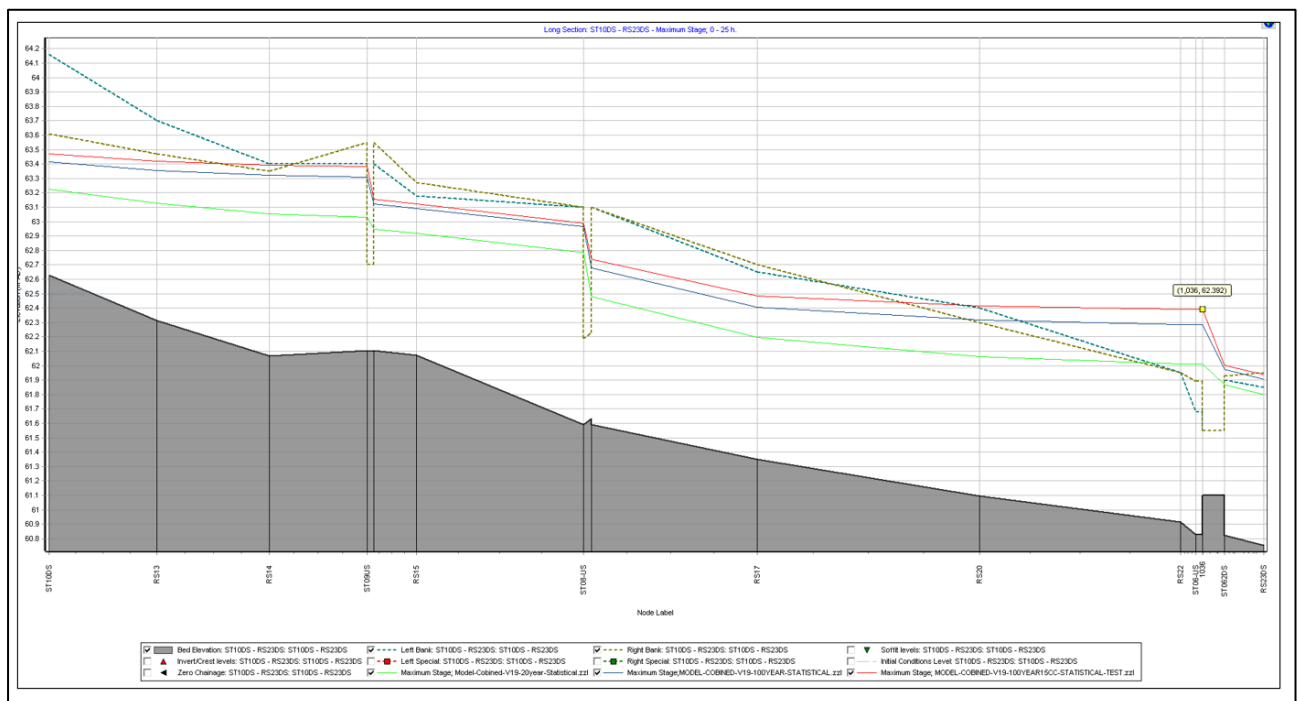


Figure 9: Long profile of maximum water level along the watercourse

- 4.2 A review of the modelling results revealed that there is “glass wall” effect along both the drain and the watercourse. In order to remove that, surveyed sections were extended using the Lidar data downloaded from Defra data service. However, The Lidar data shows that the ground levels along the watercourses are flat and extending the cross sections did not help in removing the “glass wall” effect. Thus, the “glass wall” effect still remains at the locations where the water levels exceed the bank level of the channel and for this reason the model results are considered to be conservative.
- 4.3 It is also observed that there is a back water effect due to the railway culvert. The water ponded at the upstream of the railway culvert. The water cannot spill over the railway up to 100 year +15%CC event.
- 4.4 The backwater effect diminishes at section RS05 in the drain and at RS13 in the watercourse.
- 4.5 The maximum water level at the upstream of the railway embankment are 62.011mAOD, 62.285mAOD and 62.394mAOD for 20year, 100year+15%CC and 100+15%CC year respectively. The railway embankment crest level is 63.354mAOD. It is observed that the water level does not exceeds the embankment crest level up to 100year+15%CC event.

**Table 2: Maximum water level from model**

Model nodes	Max Water level 20year	Max Water level 100 year	Max Water level 100 year+15%CC	Comments
ST10DS	63.226	63.413	63.471	Upstream of watercourse
RS13	63.126	63.352	63.417	
RS14	63.053	63.32	63.393	
ST09US	63.032	63.309	63.384	
ST09-Inlet	63.032	63.309	63.384	
Sp-ST09US	63.032	63.309	63.384	
Sp-ST09DS	62.949	63.122	63.154	
ST09-Down	62.949	63.122	63.154	
RS14DS	62.949	63.122	63.154	
RS15	62.921	63.093	63.125	
ST08-US	62.783	62.967	62.989	
ST08-Inlet	62.783	62.967	62.989	
ST08-Outlet	62.48	62.68	62.741	
RS16	62.48	62.68	62.741	
RS17	62.195	62.406	62.484	
RS20	62.065	62.318	62.417	
RS22	62.011	62.285	62.394	
ST06-US	62.011	62.285	62.394	
ST06	62.011	62.285	62.394	
ST07	61.868	61.973	62.004	
RS23	61.868	61.973	62.004	
RS23DS	61.801	61.907	61.938	
Inflow-us	63.226	63.413	63.471	Upstream end of drain
RS01	64.504	64.593	64.625	
RS02	64.486	64.568	64.598	
ST01-Inlet	64.444	64.498	64.519	

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ST01-U1	64.444	64.498	64.519	Junction with watercourse
ST01-U2	64.444	64.498	64.519	
Sp-ST01US	64.444	64.498	64.519	
Sp-ST01DS	63.358	63.675	63.704	
ST01-R1	64.288	64.376	64.397	
ST01-R2	64.131	64.259	64.282	
ST01-R3	64.002	64.142	64.166	
ST01-R4	63.916	64.025	64.051	
ST01-R5	63.83	63.908	63.935	
ST01-R6	63.745	63.791	63.82	
ST01-DS	63.358	63.675	63.704	
ST01-U2-R1	64.288	64.376	64.398	
ST01-U2-R2	64.131	64.259	64.282	
ST01-U2-R3	64.002	64.142	64.166	
ST01-U2-R4	63.916	64.025	64.051	
ST01-U2-R5	63.83	63.908	63.935	
ST01-U2-R6	63.745	63.791	63.82	
ST01-DS2	63.358	63.675	63.704	
ST02-Outlet	63.358	63.675	63.704	
RS05	63.332	63.672	63.702	
RS06	63.125	63.628	63.651	
RS07	63.054	63.618	63.639	
ST04-Inlet	62.975	63.609	63.629	
ST04	62.975	63.609	63.629	
Sp-ST04US	62.975	63.609	63.629	
Sp-ST04DS	62.014	62.286	62.394	
ST05	62.014	62.286	62.394	
ST05-Outlet	62.014	62.286	62.394	
RS07A	62.011	62.285	62.394	
Inflow-DS	62.949	63.122	63.154	
Sp-ST8US	62.783	62.967	62.989	
Sp-ST8DS	62.48	62.68	62.741	
ST062US	62.011	62.285	62.394	
ST062DS	61.868	61.973	62.004	
Sp-ST06US	62.011	62.285	62.394	
ST06-EXT1	62.011	62.285	62.394	
ST06-EXT2	62.011	62.285	62.394	
				Upstream of rail embankment

## 5 CONCLUSIONS

- 5.1 The purpose of this modelling exercise is to assess the water level for the Drain and the watercourse flowing near the site.
- 5.2 A 1D hydraulic model using industry standard Flood Modeller Pro- software has been used to simulate flood risk along drain and the watercourse.
- 5.3 Design peak flow estimates have been derived for the 1 in 20 year, 1 in 100 year, 1 in 100 year +15% climate change event. The flows are based on the latest Environment agency (EA) Flood Estimation Guidelines v2 July 2020.
- 5.4 The 1D element of the hydraulic model has been based upon 12 surveyed cross sections of the existing drain and 17 sections for the watercourse.
- 5.5 There are 6 circular conduits in the model. Two of them are in the drain and the other four are in the watercourse.
- 5.6 The depth of the model sections for the drain varies from 0.5m to 1.0m and the width of the drain is around 7m meters. The depth of the watercourse varies from 0.4m to 1.0m and the width is 5m to 10m.
- 5.7 The initial model runs showed there was “glass walling” at both the watercourse and the drain. Efforts were made to extend the cross section using Lidar data. However, the Lidar data demonstrates the floodplain is flat along these reaches and extending the cross sections did not result in removing this modelling artefact. The model results are still “glass walling” at certain locations. However, it was considered that the model results are conservative and still could be used for the purpose of the FRA.
- 5.8 No sensitivity runs were made for model. Roughness value was considered conservative and reasonable.

**Appendix A**

**Hydrology report**

# Flood estimation report: MOD Graven Hill

## Introduction

This report template is a supporting document to the Environment Agency's Flood Estimation Guidelines. It provides a record of the hydrological context, the method statement, the calculations and decisions made during flood estimation and the results. This document can be used for one site or multiple sites. If only one site is being assessed, analysts should remove superfluous rows from tables.

Guidance notes (in red text) are included throughout this document in column titles or above tables. These should be deleted before finalising the document. Where relevant, references to specific sections of the Flood Estimation Guidelines document are included to indicate where further useful information can be found.

Note: Column size / page layout can be adapted, where necessary, to best present relevant information, for example, maps do not need to be within the tables if they would be better as a separate page.

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## Approval

Revision stage	Analyst / Reviewer name & qualifications	Amendments	Date
Method statement preparation	Anna Velkov	N/A	N/A
Method statement sign-off			
Initial calculations preparation	Anna Velkov		N/A
Initial calculations sign-off			



## Abbreviations

AEP .....	annual exceedance probability
AM.....	Annual Maximum
AREA .....	Catchment area (km <sup>2</sup> )
BFI .....	Base Flow Index
BFIHOST .....	Base Flow Index derived using the HOST soil classification
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
OS.....	Ordnance Survey
POT.....	Peaks Over a Threshold
QMED .....	Median Annual Flood (with return period 2 years)
ReFH .....	Revitalised Flood Hydrograph method
ReFH2 .....	Revitalised Flood Hydrograph 2 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 SUMMARY OF ASSESSMENT

## 1.1 Summary

This table provides a summary of the key information contained within the detailed assessment in the following sections. The aim of the table is to enable quick and easy identification of the type of assessment undertaken. This should assist in identifying an appropriate reviewer and the ability to compare different studies more easily.

Catchment location	SP 59393 19484 at the downstream end
Purpose of study and scope e.g. for scope just include whether it is simple, routine, moderate, difficult, very difficult	To derive inflow hydrographs for input into the 1 D hydraulic model, to assess the fluvial flood risk from an unnamed watercourse and a drain which joins the watercourse just upstream a railway culvert.
Key catchment features e.g. permeable, urban, pumped, mined, reservoired	The catchment of the watercourse is predominantly rural with moderate permeability. The catchment of the drain covers the development site and is also moderately permeable. The catchment is not pumped.
Flooding mechanisms e.g. fluvial, surface water, groundwater	The flood risk is fluvial.
Gauged / ungauged State if there are flow or level gauges and a very brief indication of quality if there are	The catchment is ungauged.
Final choice of method	Statistical.
Key limitations / uncertainties in results	

## 1.2 Note on flood frequencies

The frequency of a flood can be quoted in terms of a return period, which is defined as the average time between years with at least one larger flood, or as an annual exceedance probability (AEP), which is the inverse of the return period.

Return periods are output by the Flood Estimation Handbook (FEH) software and can be expressed more succinctly than AEP. However, AEP can be helpful when presenting results to members of the public who may associate the concept of return period with a regular occurrence rather than an average recurrence interval. Results tables in this document contain both return period and AEP titles; both rows can be retained or the relevant row can be retained and the other removed, depending on the requirement of the study.

The table below is provided to enable quick conversion between return periods and annual exceedance probabilities.

**Annual exceedance probability (AEP) and related return period reference table**

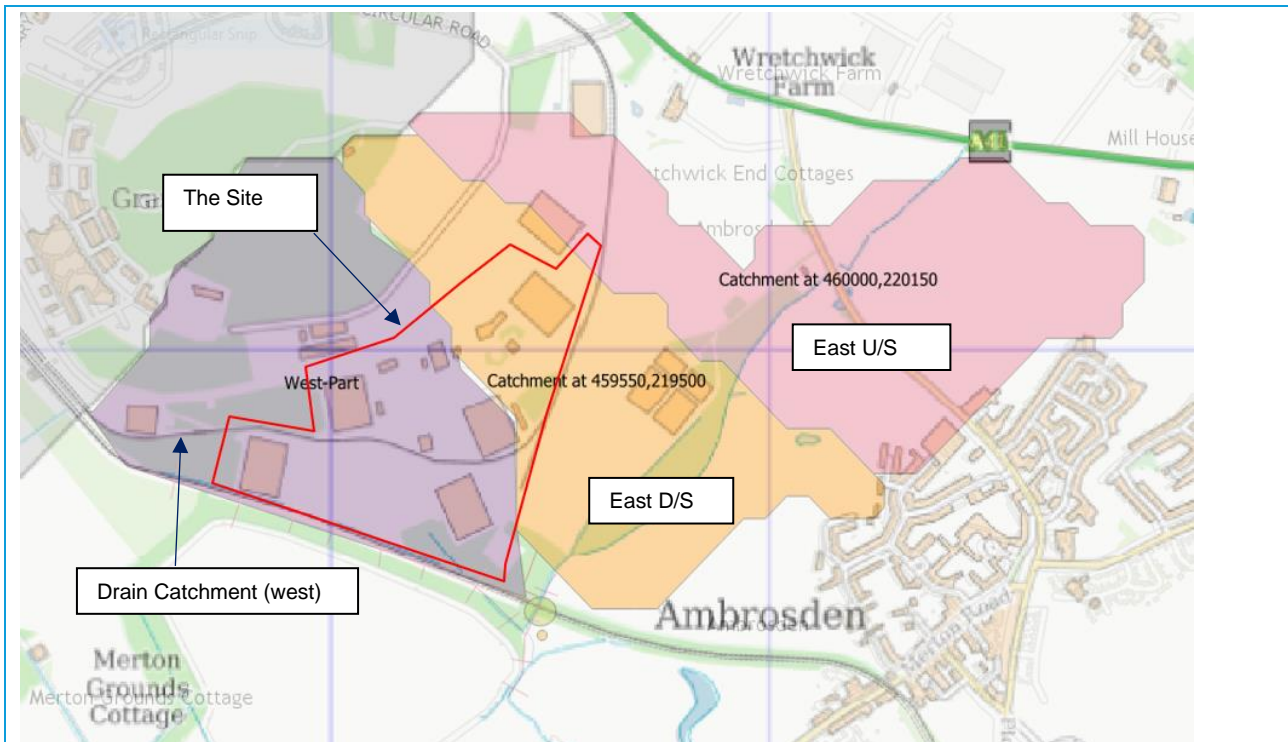
AEP (%)	50	20	10	5	3.33	2	1.33	1	0.5	0.1
AEP	0.5	0.2	0.1	0.05	0.033	0.02	0.0133	0.01	0.005	0.001
Return period (yrs)	2	5	10	20	30	50	75	100	200	1,000

## 2 METHOD STATEMENT

### 2.1 Requirements for flood estimates

<p><b>Overview</b></p> <p>The content and level of detail provided in this section will depend on the scope of the study. The following should be included as a minimum:</p> <ul style="list-style-type: none"> <li>• Purpose of study</li> <li>• Peak flows or hydrographs?</li> <li>• Design events for which flow estimates are to be made given as AEP (%)</li> <li>• Climate change allowances with reference to relevant guidance</li> <li>• Potential number of locations for flow estimation</li> <li>• The purpose of the document</li> </ul>	<p>The purpose of this study is to estimated peak flows and derive inflow hydrographs for input into the 1 D hydraulic model of the unnamed water course and the drain which run to the south east of the site and along the south western perimeter of the site respectively. The model will be used to assess the potential flood risk to a proposed development at MOD Graven Hill, (nearest Postcode OX25 2BA).</p> <p>Design peak flow estimates will be derived for the 5%, 1%, and 1%+Climate Change (CC) allowance and 0.1% AEP events (1 in 20, 100, 100 year+CC and 1 in 1000 return periods). The flow hydrographs will be estimated at three locations as explained further in this report.</p> <p>The latest EA Flood Estimation Guidelines v2 July 2020 and the Flood estimation: technical guidance of Natural Resource Wales has been used.</p>
<p><b>Project scope</b></p> <p>What is the complexity of the study – simple, routine, moderate, difficult, very difficult?</p> <p>What analyses need to be included within the study, for example:</p> <ul style="list-style-type: none"> <li>• Review of existing studies?</li> <li>• Rating reviews / updates?</li> <li>• Simple / detailed flood history review?</li> <li>• ReFH model parameter estimation?</li> <li>• Joint probability?</li> </ul>	<p>This is a routine study, which will include a simple flood history review and flood estimation based on the standard FEH methods – Statistical and ReFH2.</p>

## 2.2 The catchment



### Description

Include topography, climate, geology, soils, land use and any unusual features (e.g. reservoirs, historic mining) that may affect the flood hydrology. In some cases, it may be useful to include reference to things such as amount of modelled reach that is culverted but remember that this is not a hydraulic modelling report and detail on hydraulic features, such as weir and culvert sizes, is not required. Think about what features are going to affect runoff from the contributing catchment reaching the watercourse.

The subject site has an area of approximately 30.5ha. It is located approximately 3.5km south of Bicester Town Centre and 1 km to the north west of Ambrosden Centre and 500m south west of A41.

The study area and the contributing catchments are shown in the figure above. The Unnamed watercourse is about 1.5km long and drains the area to the south west of A41. The area to the north of A41 drains in northerly direction. The catchment of the drain to the south west of the site covers part of the development site. Both catchments are predominantly rural with some buildings which are part of the development site. The urbanisation level of the catchments is reflected in the FEH URBEXT2000 values which are 0.044, 0.053 (for the watercourse catchment) and 0.030 for the drain catchment.

It is noted that the FEH webservice divides the catchment of the watercourse in 2 parts as shown in the figure above. The catchment of the upstream part is 0.59km<sup>2</sup> and of the downstream part is 0.51km<sup>2</sup>. The catchment area of the drain is 0.56km<sup>2</sup>.

The FARL value for the catchment is 1.0. A revision of the OS mapping confirms that there are not major storages in the catchment, and the FARL value was deemed appropriate.

A review of the Soilsmap of the area has identified that the soil types across the catchment are predominantly *Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils*. The improved soils descriptor, BFIHOST19 for the U/S and D/S catchments is 0.26 and 0.319 respectively which indicate not very permeable catchment. The Catchment of the drain was not defined in the FEH website. Its catchment area was defined as the area between the neighbouring catchment to the north (in gray in the figure above), the catchment of the Unnamed watercourse and the railway which is on elevated embankment and acts as catchment boundary. The catchment descriptors for a small catchment further downstream the watercourse, which contain the area of the drain were used.

The value of the BFIHOST19 is outcome of a comprehensive revision of the BFIHOST calculation process, which provided a set of revised BFIHOST coefficients for each of the 29 HOST classes (Griffin and others, 2019). Some coefficients are very different from those in the original HOST classification. The guidance recommends the use of BFIHOST19 descriptor, as it has been found to improve the estimation of QMED. BFIHOST19 is also recommended for use in the ReFH 2.3 method, because it provides improved predictions of model parameters, particularly on some clay and peat catchments.

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## 2.3 Source of flood peak data

Source	NRFA peak flows dataset – Version 9 (September 2020).
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## 2.4 Gauging stations (flow or level)

Water-course	Station name	Gauging authority number	NRFA number	Catchment area (km <sup>2</sup> )	Type (rated / ultrasonic / level...)	Start of record and end if station closed
There are no gauges at or very near to the sites of flood estimates						

## 2.5 Data available at each flow gauging station in Table 2.4

N/A

## 2.6 Rating equations

N/A

## 2.7 Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available?	Source of data	Details
Check flow gaugings	No	No		
Historical flood data	Yes	No		
Flow or river level data for events	No	No		
Rainfall data for events	No	No		
Potential evaporation data	No	No		
Results from previous studies	Yes	No		
Other data or information	No	No		

## 2.8 Hydrological understanding of catchment

<p>Conceptual model</p> <p>Include information on factors such as:</p> <ul style="list-style-type: none"> <li>Where are the main sites of interest?</li> <li>What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides...)</li> <li>Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir?</li> <li>Is there a need to consider temporary debris dams that could collapse?</li> </ul>	<p>The main area of interest is the area of the study site, along the south west boundary, parallel to the drain and the south corner of the site, which is close to the junction of the two watercourses and the railway culvert .</p> <p>The main source of potential flooding is fluvial from overtopping of the banks of the drain and from water backing upstream of the railway culvert as a result of the culvert's restricted capacity or blockage. The high levels in the drain are most likely to be as a result of runoff from the site.</p>
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<p><b>Unusual catchment features</b></p> <p>Include information on factors such as:</p> <ul style="list-style-type: none"> <li>highly permeable</li> <li>heavily urbanised</li> <li>pumped watercourse</li> <li>major reservoir influence (FARL&lt;0.90)</li> <li>flood storage areas, particularly those which are normally dry</li> <li>historical mining or operational mining activities</li> </ul> <p>Guidance on methods for unusual catchments is contained in Section 7 of the Flood Estimation Guidelines</p>	<p>Both catchments are categorised as predominantly rural (URBEXT<sub>2000</sub> = 0.05 and 0.03 respectively).</p> <p>The catchments have moderate permeability (BFIHOST = 0.26 and 0.32 for the upstream watercourse catchment and the drain catchment respectively). The SPRHOST=50.7 and 48.3 respectively (&gt;20%) and no permeable adjustments were required.</p> <p>The watercourses are not pumped.</p> <p>The FARL value for the catchment upstream of the site is 1.0 which indicates that no reservoirs are present in the catchments. A review of the OS map confirms that.</p>
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## 2.9 Initial choice of approach

<p><b>Is FEH appropriate?</b> (it may not be for extremely heavily urbanised or complex catchments). If not, describe other methods to be used.</p>	<p>The catchment is not extremely urbanised or complex and it is suitable for both FEH methods (Statistical and ReFH2).</p>
<p><b>Initial choice of method(s) and reasons</b></p> <p>Think about: (i) the type of problem, (ii) the type of catchment, and (iii) the type of data available. Which methods are appropriate? If more than one method is appropriate will all be applied, and the results compared before a final decision is made?</p> <p>How will hydrograph shapes be derived if needed?</p> <p>e.g. ReFH1 / ReFH2 shapes, average hydrograph shape from gauge data</p> <p>Will the catchment be split into sub-catchments? If so, how?</p> <p>If the hydrological assessment is being undertaken to supply inflows to a hydraulic model, it is likely that a distributed approach will be taken, with the catchment split into sub-catchments and design flows routed from each sub-catchment.</p>	<p>The above information indicates that all factors are suitable for use of the FEH statistical method.</p> <p>A hybrid method will be used, where the ReFH2 will be used to generate design hydrographs and will be scaled to the FEH statistical (pooled analysis) peak flow.</p> <p>Flows will be derived for the catchment of the drain and applied as upstream boundary for this watercourse. Flows will also be derived for the upstream catchment of the Unnamed watercourse and applied as upstream boundary condition for this part of the model. In addition flows will be derived for the downstream part of this catchment (as defined in the FEH website) and applied as lateral flows.</p>
<p><b>Software to be used (with version numbers)</b></p> <p>Delete entries in the column on the right as appropriate</p>	<p>FEH Webservice</p> <p>WINFAP5</p> <p>ReFH2 Design Flood Modelling Software Version 2.3</p>



### 3 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.

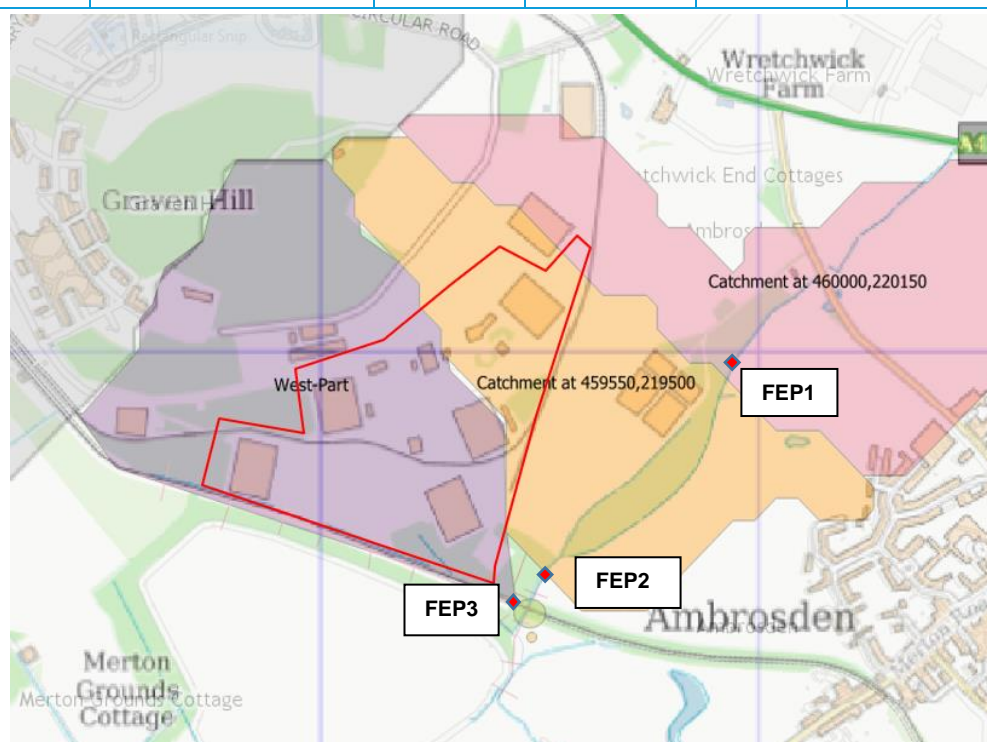
#### 3.1 Summary of subject sites

Site code	Type of estimate L: lumped catchment S: Sub-catchment	Watercourse	Name or description of site	Easting	Northing	AREA on FEH CD-ROM (km <sup>2</sup> )	Revised AREA if altered
FEP1 (East US)	L	Unnamed Tributary	Flows at the u/s end of the Unnamed watercourse. model. The flow was estimated at the downstream poin of the catchment as delineated in the FEH website. This is locate approximately in the middle of the watercourse. This flow was the applied at the upstream end of the model	460000	220150	0.59	Not revised
FEP2 (East DS)	L	Unnamed Tributary	Downstream catchment of the unnamed watercourse. Flows applied as laterat in the downstream section of the watercourse	459550	219500	0.515	Not revised
FEP3 (West)	L	The Drain	Cathcment area of the Drain			N/A	0.56

Note: Lumped catchments (L) are complete catchments draining to points at which design flows are required.

Sub-catchments (S) are catchments or intervening areas that are being used as inputs to a semi-distributed model of the river system. There is no need to report any design flows for sub-catchments, as they are not relevant: the relevant result is the hydrograph that the sub-catchment is expected to contribute to a design flood event at a point further downstream in the river system. This will be recorded within the hydraulic model output files. However, catchment descriptors and ReFH model parameters should be recorded for sub-catchments so that the results can be reproduced.

The schematic diagram illustrates the distinction between lumped and sub-catchment estimates.



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

Site code	FARL	PROPWET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	URBEXT 1990 Delete if not required	URBEXT 2000	FPEXT
FEP1	1.0	0.32	0.26	0.62	16.1	620		0.0446	0.116
FEP2	1.0	0.32	0.313	0.59	21.7	620		0.0534	0.0583
FEP3	1.0	0.32	0.328	0.73	26.0	620		0.0303	0.0964

### 3.3 Checking catchment descriptors

<p>Record how catchment boundary was checked and describe any changes</p> <p>Add maps if needed to aid explanation of any changes</p> <p>If changes are made to the catchment boundary (and hence AREA), identify if any other descriptors will be updated and how</p>	<p>Catchment boundary were checked using contour information from OS mapping and LiDAR data obtained from the EA's free data download service. No adjustment to the catchment boundary shown on the FEH CD-ROM for the Unnamed watercourse was considered necessary.</p> <p>As explained in Section 2.2 above, the catchment of the drain was not defined in the FEH website and therefore it was defined as the area between the neighbouring catchments and the railway embankment.</p>
<p>Record how other catchment descriptors were checked and describe any changes.</p> <p>Include before/after table if necessary.</p>	<p>The SAAR values are the same for all catchments and providing that the area of the catchments is very small is considered to be appropriate</p> <p>PROPWET seems suitable based on the <i>Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils</i>, which are present across the catchment.</p> <p>DPSBAR and DPLBAR seem appropriate based on topography of catchment.</p> <p>The catchment is characterised as moderately permeable.</p>
<p>Source of URBEXT</p> <p>Delete as needed. URBEXT1990 is only used for ReFH1</p> <p>An alternative is the URBAN50k method if URBEXT values need to be substantially revised due to discrepancies between the FEH urban extent layers and current mapping</p>	<p>URBEXT1990 / URBEXT2000</p>
<p>Method for updating of URBEXT</p> <p>Delete as needed (CPRE formula from FEH Volume 4 is for URBEXT1990)</p> <p>An update to the current year is not required when the URBAN50k method is used as it will be implicitly accounted for in the latest mapping</p>	<p>CPRE formula from FEH Volume 4 / CPRE formula from 2006 CEH report on URBEXT2000</p>



## 4 STATISTICAL METHOD

### 4.1 Application of Statistical method

<p>What is the purpose of applying this method?</p> <p>Brief summary of the reasons, specific to this study, for applying the method. For example, lumped estimates at key locations for the purpose of checking modelled peak flow estimates.</p>	<p>Estimates of peak flow at key locations and deriving growth curves for a range of return periods.</p>
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### 4.2 Overview of estimation of QMED at each subject site

Site code	QMED (rural) from CDs (m³/s)	Final method	Data transfer					Urban adjustment factor UAF	Final estimate of QMED (m³/s)
			NRFA numbers for donor sites used (see 4.3)	Distance between centroids d <sub>ij</sub> (km)	Moderated QMED adjustment factor, (A/B) <sup>a</sup>	If more than one donor			
						Weight	Weighted ave. adjustment		
FEP1	0.21	CD						1.033	0.217
FEP2	0.17	CD						1.047	0.178
FEP3	0.18	CD						1.030	0.183
Are the values of QMED spatially consistent?						Yes			
Method used for urban adjustment for subject and donor sites (delete method in the column to the right as needed)						Urban adjustment to QMED, using the Kjeldsen (2010).			
Parameters used for WINFAP v4 urban adjustment if applicable (these are 'standard' values and should be revised if alternative values have been applied)									
Impervious fraction for built-up areas, IF			Percentage runoff for impervious surfaces, PR <sub>imp</sub>			Method for calculating fractional urban cover, URBAN			
0.3			70%			From updated URBEXT2000			
Notes									
Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer (with urban adjustment); CD – Catchment descriptors alone (with urban adjustment); BCW – Catchment descriptors and bankfull channel width (add details); LF – Low flow statistics (add details).									
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. The final estimate of QMED is (A/B) <sup>a</sup> times the initial (rural) estimate from catchment descriptors.									
Important note on urban adjustment									
The method used to adjust QMED for urbanisation published in Kjeldsen (2010)Error! Bookmark not defined. in which PRUAF is calculated from BFIHOST is not correctly applied in WINFAP-FEH v3.0.003. Significant differences occur only on urban catchments that are highly permeable. This is discussed in Wallingford HydroSolutions (2016)Error! Bookmark not defined..									

### 4.3 Search for donor sites for QMED (if applicable)

<p>Comment on potential donor sites</p> <p>Provide details regarding how potential donors were selected and the reasons why they were chosen / rejected.</p> <p>Include a map if necessary, which shows the location of the study catchment and donor stations under consideration.</p> <p>Section 4 of the Flood Estimation Guidelines provides guidance on selecting a donor(s) for data transfer.</p>	<p>The catchments are very small and no suitable donor sites were available.</p>
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#### 4.4 Donor sites chosen and QMED adjustment factors

NRFA no.	Method (AM or POT)	Adjustment for climatic variation?	QMED from flow data (A)	QMED from catchment descriptors (B)	Adjustment ratio (A/B)

#### 4.5 Derivation of pooling groups

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged?	Changes made to default pooling group, with reasons	Weighted average L-moments L-CV and L-skew, (before urban adjustment)
MOD Pooling WINFAP5	D/S of FEP3 (grid reference SP 59450 19300) – the catchment from which the descriptors group was derived was a catchment to a point d/s of the railway culvert which includes the Unnamed watercourse catchment and the majority of the drain catchment.	no	Station 7011 (Black Burn @ Pluscarden Abbey) was removed since it has only 7 years of data. With this station removed, the total number of years was 544, and no other stations were added.	L-CV - 0.275 L-skew - 0.254

**Note:** Pooling groups were derived using the procedures from Science Report SC050050 (2008).

#### 4.6 Derivation of flood growth curves at subject sites

Site code	Method (SS, P, ESS, J)	If P, ESS or J, name of pooling group	Distribution used and reason for choice	Note any urban adjustment or permeable adjustment	Parameters of distribution	Growth factor for 100-year return period / 1% AEP
D/S FEP3	P	MOD Pooling WINFAP5	The GL distribution was selected with goodness of fit 0.1396. It has the best goodness of fit and in addition the GL distribution is the preferred distribution for the pooling analysis.	No permeable adjustments were made. No urban adjustment to the growth curves, only to QMED, using the Kjeldsen (2010).	L-CV - 0.275 L-skew - 0.254	3.421

##### Notes

Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis  
Urban adjustments are all carried out using the method of Kjeldsen (2010).  
Growth curves were derived using the procedures from Science Report SC050050 (2008).

#### 4.7 Flood estimates from the statistical method

Site code	Flood peak (m <sup>3</sup> /s) for the following return periods (in years)									
	2	5	10	20	50	100	200	1000		
	Flood peak (m <sup>3</sup> /s) for the following AEP (%) events									
	50	20	10	5	2	1	0.5	0.1		
FEP1 (U/S)	0.22	0.32	0.39	0.48	0.62	0.74	0.89	1.3		
FEP2 (D/S)	0.18	0.26	0.32	0.39	0.51	0.61	0.73	1.1		
FEP3 (West)	0.18	0.27	0.33	0.41	0.52	0.63	0.75	1.1		

## 5 REVITALISED FLOOD HYDROGRAPH (REFH) METHOD

N/A

## 6 REVITALISED FLOOD HYDROGRAPH 2 (REFH2) METHOD

### 6.1 Application of ReFH2 method

What is the purpose of applying this method?	Lumped estimates at key locations for the purpose of checking and comparing modelled peak flow estimates obtained from the Statistical method and deriving hydrograph shapes.
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### 6.2 Catchment sub-divisions for ReFH2 model

This section can be deleted if the catchment is essentially rural.

### 6.3 Parameters for ReFH2 model

Site code	Method	T <sub>p</sub> <sub>rural</sub> (hours)	T <sub>p</sub> <sub>urban</sub> (hours)	C <sub>max</sub> (mm)	PR <sub>imp</sub>	BL (hours)	BR
FEP1 (U/S)	CD	2.21		221.8		20.78	0.501
FEP2 (trib)	CD	1.95		258.53		23.27	0.912
FEP3 (West)	CD	2.08		267.41		24.98	1.016
Brief description of any flood event analysis carried out (further details should be given in the annex)							
Methods: OPT: Optimisation, BR: Baseflow recession fitting, CD: Catchment descriptors, DT: Data transfer (give details)							

### 6.4 Design events for ReFH2 method: Lumped catchments

This table can be deleted if ReFH2 is not being applied for lumped catchments. Note: ReFH2 may be applied for both lumped catchments and sub-catchments in a study; if this is the case both this table and the next should be completed.

Storm durations detailed here should be the values for the individual catchments. Lumped flows should be generated using the storm duration relevant to each lumped catchment for comparison with Statistical estimates.

Site code	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)
FEP1 (U/S)	Rural	Winter	3*
FEP2 (D/S)	Rural	Winter	3
*The critical duration was selected by estimating the time to peak using the Formula updated as per the "FEH Supplementary Report No1", pg 19, Sec 3.3.2.			

### 6.5 Design events for ReFH2 method: Sub-catchments and intervening areas

This table can be deleted if ReFH2 is not being applied for sub-catchments.

### 6.6 Flood estimates from the ReFH2 method

Note: This table is for recording results for lumped catchments. There is no need to record peak flows from sub-catchments or intervening areas that are being used as inputs to a semi-distributed model of the river system.

Site code	Flood peak (m <sup>3</sup> /s) for the following return periods (in years)									
	2	5	10	20	50	100	200	1000		
	Flood peak (m <sup>3</sup> /s) for the following AEP (%) events									
	50	20	10	5	2	1	0.5	0.1		
FEP1	0.39	0.56	0.69	0.81	0.99	1.14	1.32	1.85		
FEP2	0.30	0.43	0.53	0.61	0.77	0.89	1.03	1.45		
FEP3	0.29	0.43	0.52	0.62	0.76	0.87	1.00	1.42		

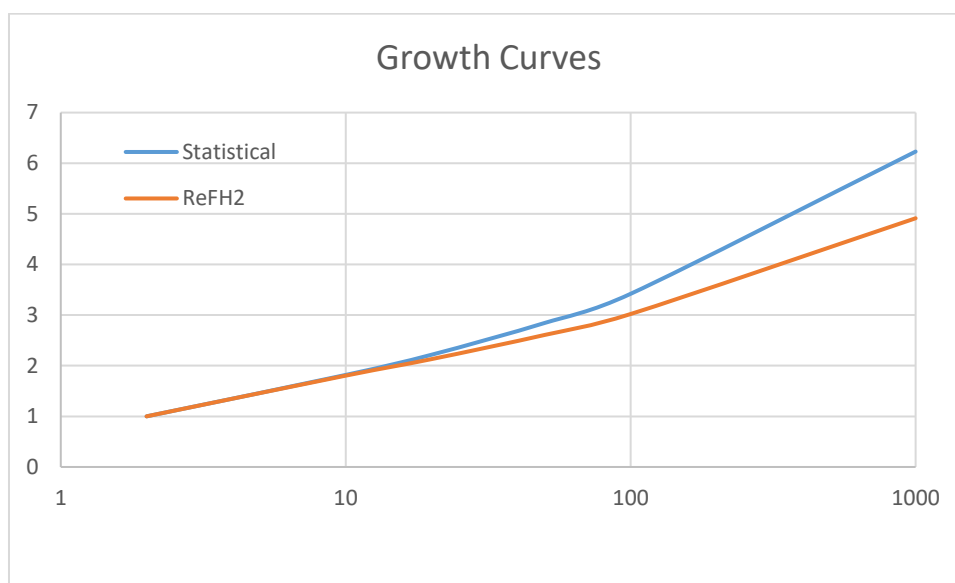
## 7 DISCUSSION AND SUMMARY OF RESULTS

### 7.1 Comparison of results from different methods

This table compares peak flows from various methods with those from the FEH Statistical method at example sites for two key return periods / AEP events. Delete columns which are not required.

Site code	Ratio of peak flow to FEH Statistical peak					
	Return period 2 years / 50% AEP			Return period 100 years / 1% AEP		
	ReFH	ReFH2	Statistical	ReFH	ReFH2	Statistical
FEP1		0.39	0.22		1.14	0.74
FEP2		0.30	0.18		0.89	0.61
FEP3		0.29	0.18		0.87	0.63

#### Growth Curves for the different methods investigated



### 7.2 Final choice of method

#### Choice of method and reasons

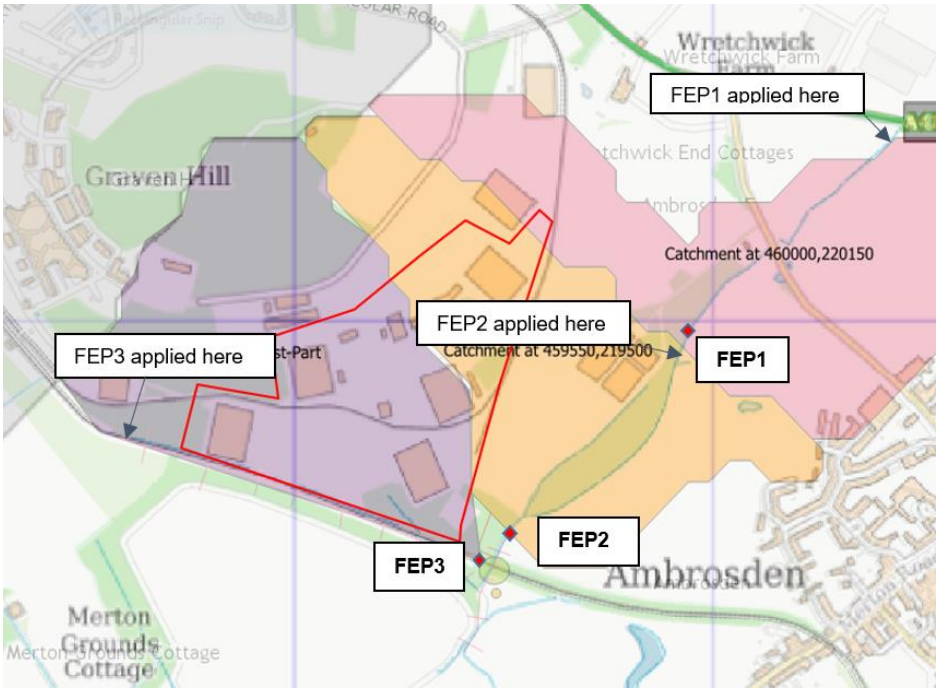
Include reference to type of study, nature of catchment and type of data available.

**Statistical method** – Moderate confidence can be placed on the QMED estimated using the Statistical method based on catchment descriptors only. The catchments are ungauged and there was no suitable donor gauge in a nearby catchment. In addition the catchment of the drain was not defined in the FEH website and it was delineated using the boundaries of the neighbouring catchments. However, the three catchment assessed are very small and next to each other and the catchment descriptors are similar, which give confidence in the used parameters.

**ReFH2** - Peak flows based on catchment descriptors alone produced growth curves similar in shape to the FEH statistical method (pooled analysis) growth curves for the low flows. But approximately around the 100 year event and towards the higher flows, the values decrease and the curve becomes flatter. At the same time the resulting peak flows are significantly higher in comparison to the Statistical method flows and are unrealistically big for such a small catchments.

#### Conclusion

The growth curves from the Statistical Method and the ReFH2 method follow a similar shape up to the 1 in 80 year return period events. However, the resulting peak flows from the ReFH2 method for all events are significantly higher in comparison to the Statistical method flows and are unrealistically big for such a small catchments. In addition the EA guidance advises that the FEH

	<p>statistical method is based on much larger database of flood events and has been more directly calibrated to reproduce flood frequency on UK catchments and is therefore preferred to other rainfall run-off approaches.</p> <p>A method was used for this study, where the peak flow from the statistical method was fit to a ReFH2 derived hydrograph shape.</p>
<p>How will the flows be applied to a hydraulic model?</p> <p>If relevant. Will model inflows be adjusted to achieve a match with lumped flow estimates, or will the model be allowed to route inflows?</p>	

### 7.3 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	<p>FEH Statistical estimates are derived using catchment descriptors and not from directly gauged flows/rainfall records. It is assumed that the catchment descriptors reflect the nature of the catchments and are reliable to be used for flow derivation.</p> <p>It is assumed that the empirical equations and the pooling groups derived from the catchment descriptors provide a good estimate of the flows in the subject watercourses.</p>
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed.	No gauged data for the study site was available and thus the accuracy of the calculations depends on the CD only.
<p>Provide information on the uncertainty in the design peak flow estimates and the methodology used</p> <p>Uncertainty in the peak flow estimates should always be provided. The default is the 95-percentile upper and lower bounds, but other estimates may need to be provided depending on the requirements of the study. Further information can be found in Section 5.4 of the Flood Estimation Guidelines.</p>	<p>It is almost always preferable to obtain Q<sub>med</sub> from flood data if at all possible; however, no such information was available for the study site.</p> <p>The degree of uncertainty for a design flow Q based on a Q<sub>MED</sub> estimated from catchment descriptors has a 95% confidence limit of 0.49Q, 2.04Q which in this case is 0.196 and 0.816 m<sup>3</sup>/sec for the combined upstream and downstream catchments of the Unnamed Watercourse.</p> <p>It is important to note that a wide confidence interval does not necessarily mean that the best estimate is wrong. It is much more likely to be correct than are the values at the upper and lower confidence limits.</p>
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes, would a project for scheme design require	The results from this study are consistent at different node locations and catchment areas.

additional detail, etc.	
Give any other comments on the study, e.g. suggestions for additional work, such as flow monitoring, rating reviews, etc.	It is considered that the distribution of the estimated flows within the model is appropriate and no adjustments are required.

## 7.4 Checks

Are the results consistent, for example at confluences? <i>This will not be relevant for a study where there is only a single flow estimation point.</i>	Yes
What do the results imply regarding the return periods / frequency of floods during the period of record? <i>This will only be relevant where there is flow gauge data.</i>	The results show that with increased return period there is increased flow, proportionally, according to the growth curves in which there is good confidence.
What is the range of 100-year / 1% AEP growth factors? Is this realistic?	Growth factors are: Statistical method – 3.4 ReFH2 method – 3.02 And they are considered realistic.
If 1000-year / 0.1% AEP flows have been derived, what is the range of ratios for 1000-year / 0.1% AEP flow over 100-year / 1% AEP flow?	Statistical method – 1.82 ReFH2 method – 1.62
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred. <i>This will not be relevant if there are no previous hydrological assessments.</i>	N/A
Are the results compatible with the longer-term flood history? <i>This will not be relevant if there is no flow gauge data or historical flooding information.</i>	N/A
Describe any other checks on the results, e.g. sense-checking hydraulic model results	No flood history for the study area was available.

## 7.5 Final results

Site code	Flood peak (m <sup>3</sup> /s) for the following return periods (in years)									
	2	5	10	20	50	100	200	1000		
	Flood peak (m <sup>3</sup> /s) for the following AEP (%) events									
	50	20	10	5	2	1	0.5	0.1		
FEP1 (U/S)	0.22	0.32	0.39	0.48	0.62	0.74	0.89	1.35		
FEP2 (D/S)	0.18	0.26	0.32	0.39	0.51	0.61	0.73	1.11		
FEP3 (West)	0.18	0.27	0.33	0.41	0.52	0.63	0.75	1.14		

## 7.6 Uncertainty bounds

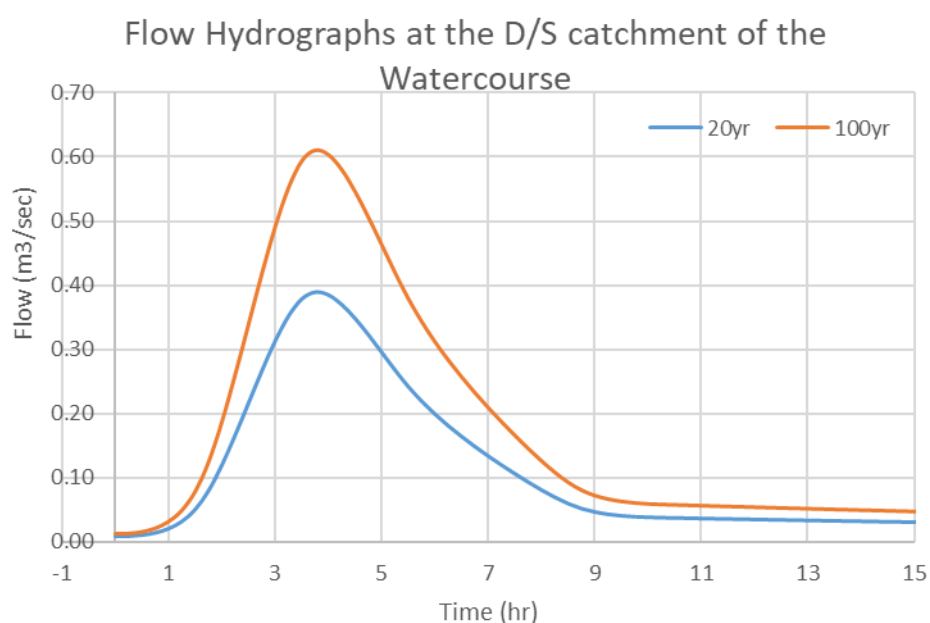
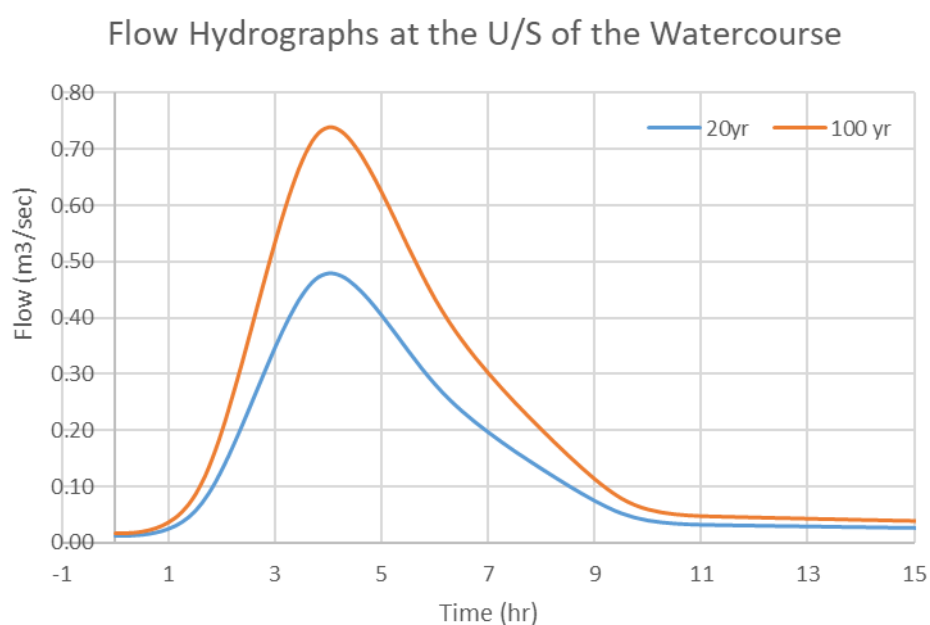
This table reports the flows derived from the uncertainty analysis detailed in Section 7.3. The 'true' value is more likely to be near the estimate reported in Section 7.5 than the bounds. However, it is possible that the 'true' value could still lie outside these bounds.



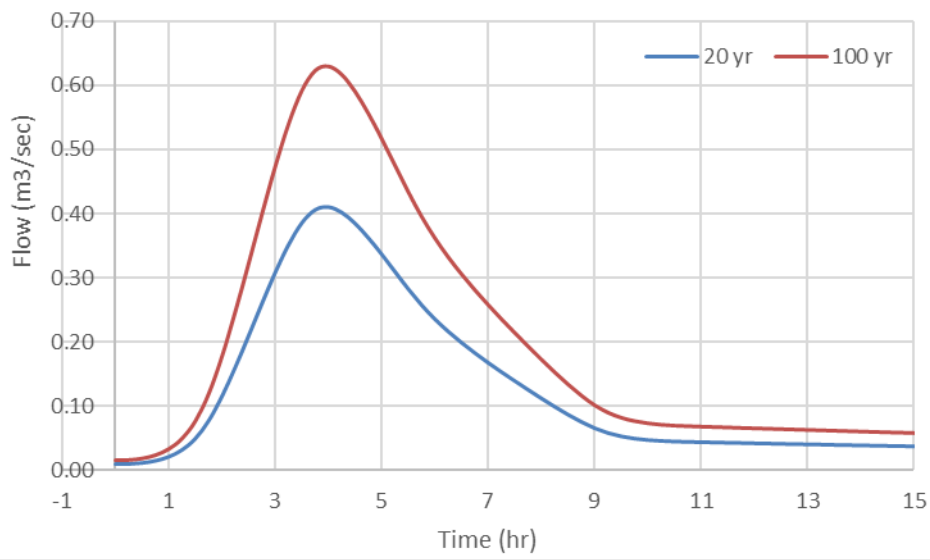
Complete this table with the flows from the uncertainty analysis. Some key design events have been added to the table, but these can be amended as required.

Site code	Flood peak (m³/s) or volumes (m³) for the following return periods (in years)							
	2		20		100		1,000	
	Flood peak (m³/s) or volumes (m³) for the following AEP (%) events							
	50		5		1		0.1	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
FEP1 (U/S)	0.11	0.44	0.24	0.98	0.36	1.51	0.66	2.75
FEP2 (D/S)	0.09	0.36	0.19	0.81	0.30	1.24	0.54	2.26
FEP3 (West)	0.09	0.37	0.20	0.83	0.31	1.28	0.56	2.32

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, hydraulic model, or reference to table below)



Flow Hydrographs at the U/S of the Drain

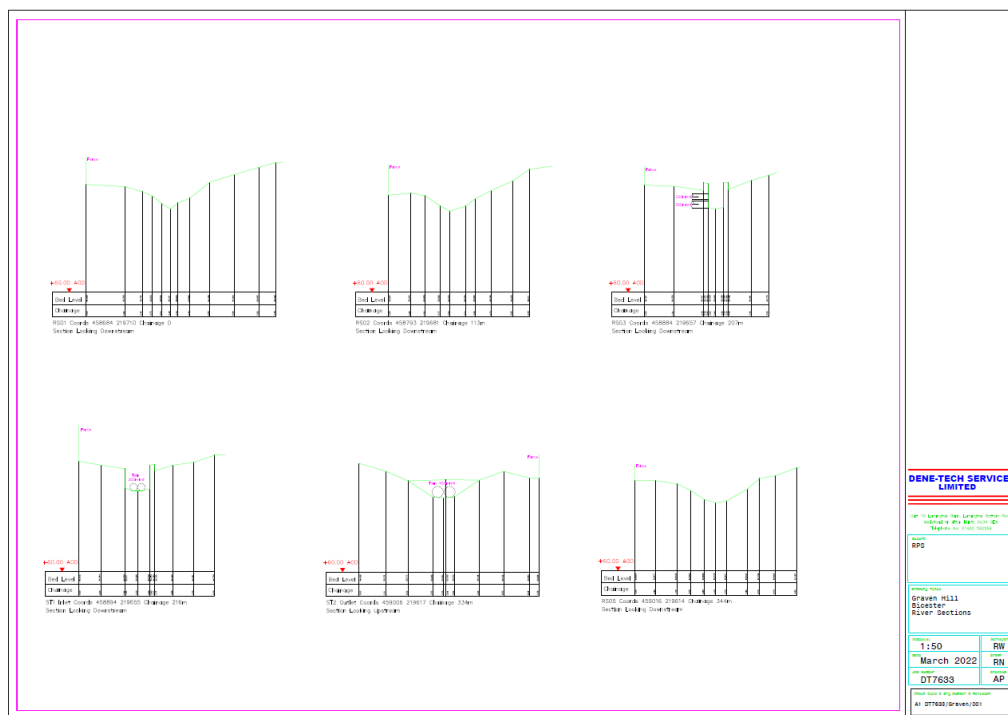


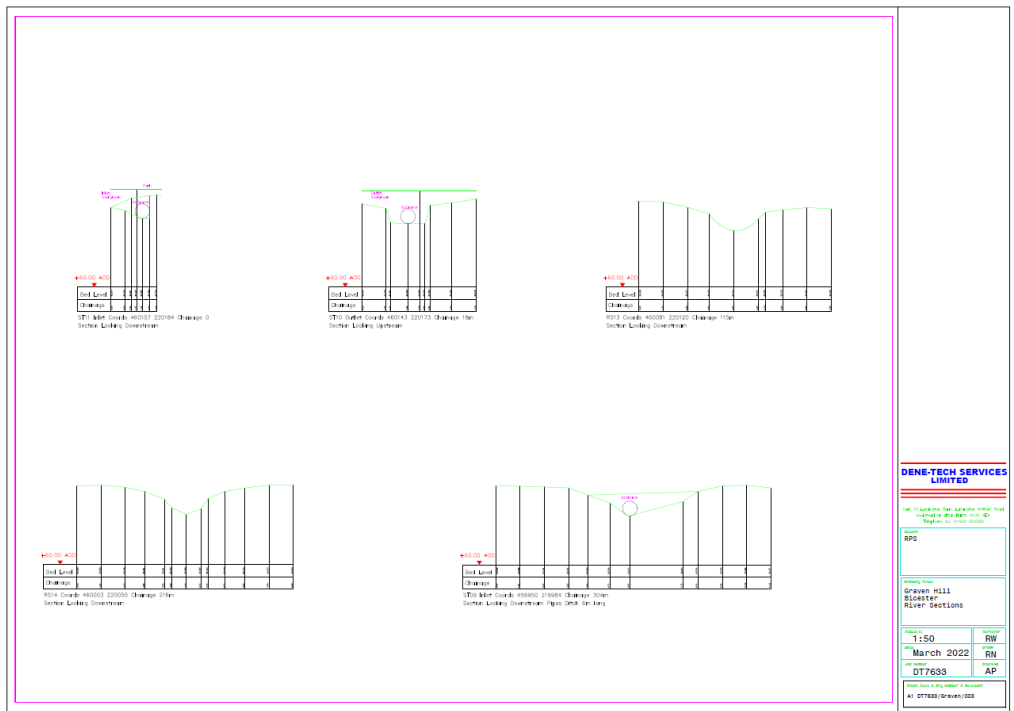
## 8 ANNEX

### Pooling Group Composition (MOD Pooling)

Site Number / Name	Distance	Initial Years of Data	QMED
76011 (Coal Burn @ Coalburn)	1.697	43	1.84
27073 (Brompton Beck @ Snainton Ings)	1.781	40	0.816
27051 (Crimple @ Burn Bridge)	1.968	48	4.544
26016 (Gypsy Race @ Kirby Grindalythe)	2.334	23	0.101
25019 (Leven @ Easby)	2.376	42	5.384
45816 (Haddeo @ Upton)	2.492	27	3.456
36010 (Bumpstead Brook @ Broad Green)	2.705	53	7.5
49005 (Bolingey Stream @ Bolingey Cocks Bridge)	2.721	10	5.972
27010 (Hodge Beck @ Bransdale Weir)	2.744	41	9.42
28033 (Dove @ Hollinsclough)	2.805	45	4.15
44008 (South Winterbourne @ Winterbourne Steepleton)	2.827	41	0.448
26014 (Water Forlornes @ Driffield)	2.862	22	0.431
41020 (Bevern Stream @ Clappers Bridge)	3.075	51	13.66
<b>Total</b>		<b>544</b>	

## Appendix B Surveyed Section





**DENE-TECH SERVICES LIMITED**

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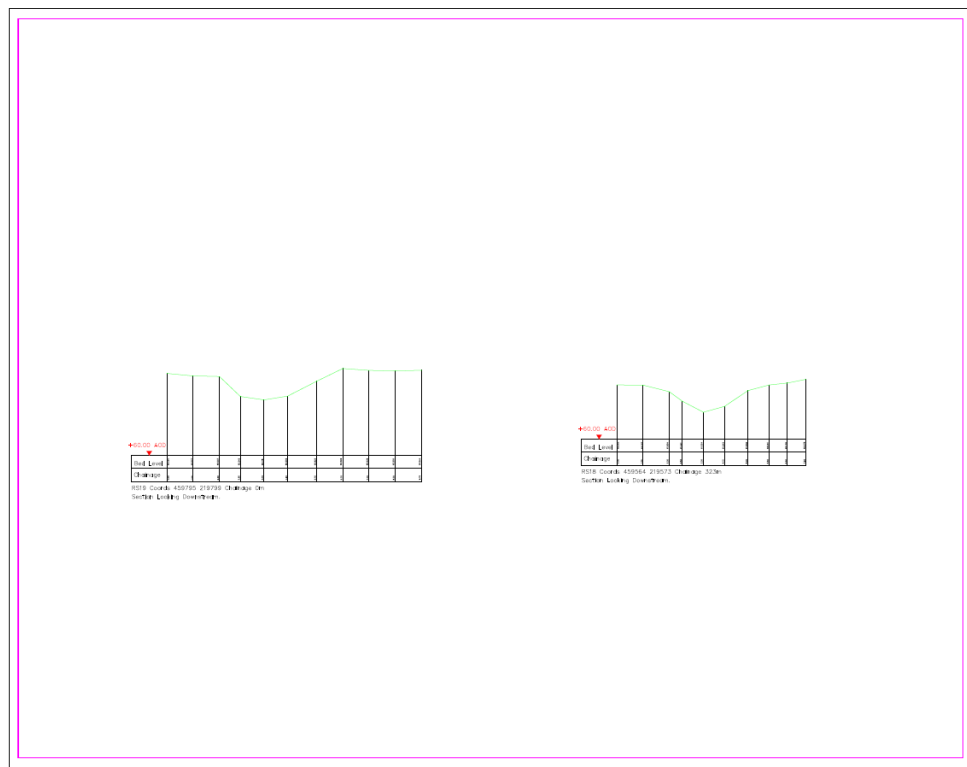
**DENE-TECH SERVICES LIMITED**

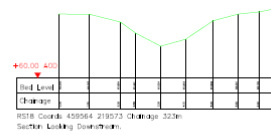
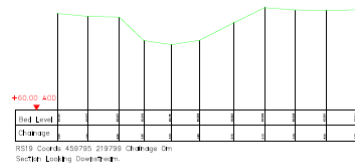
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1:50  
March 2022  
DT7633

RW  
RN  
AP

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10711000-10711000 Change 310  
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10711000-10711000 Change 30  
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**DENE-TECH SERVICES LIMITED**

Unit 10 Lexington Barn, Lexington 8  
 Medical 14 4th Regt 0334  
 Telephone No: 01420 5625

RPS

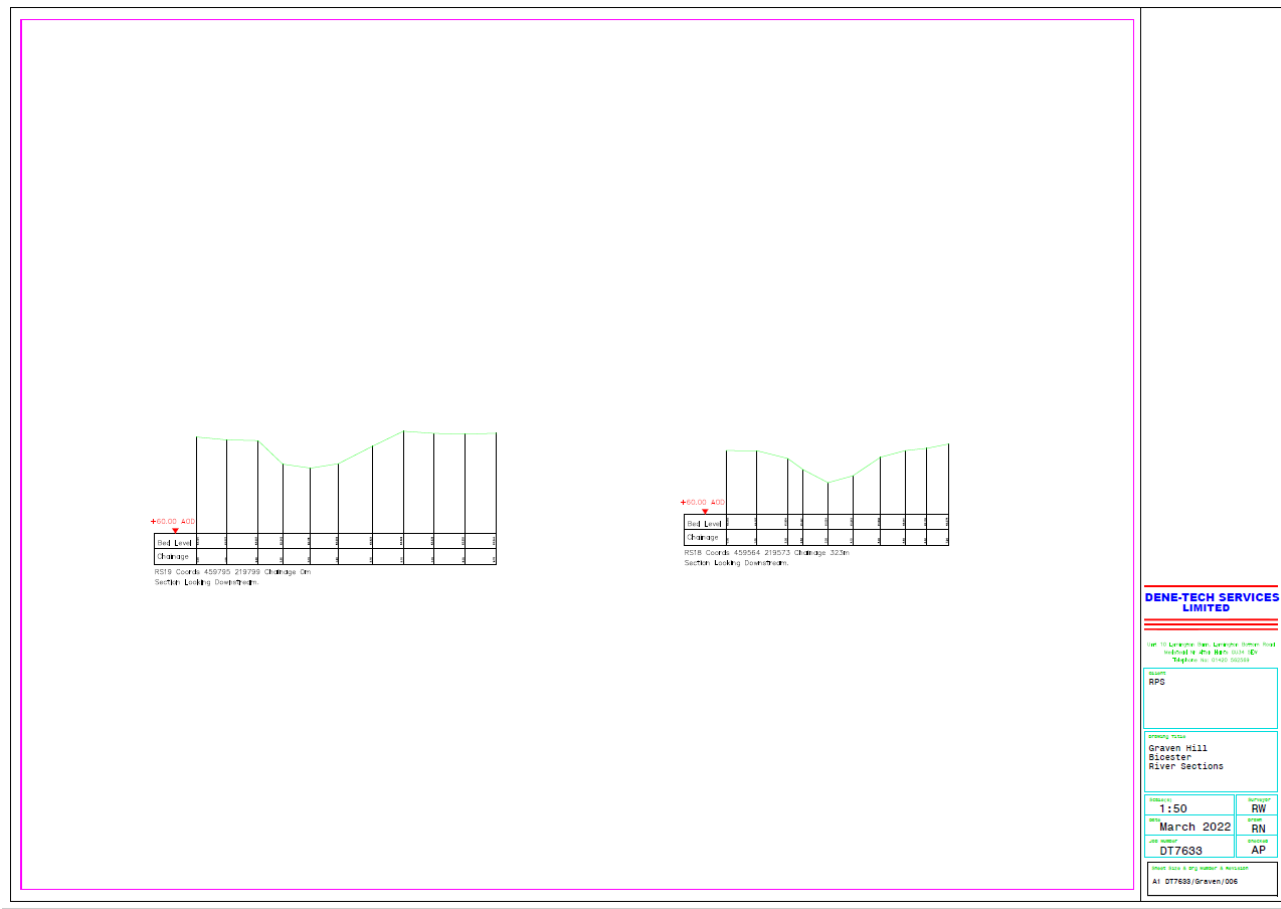
Graven Hill  
Bicester  
River Sections

1:50

March 2022

DT7633

A1 DT7633/Graven/006



**DENE-TECH SERVICES LIMITED**

Unit 10 Lonsdale Park, Lonsdale, Victoria 3190  
Australia & New South Wales, Australia  
Telephone: 03 9450 3000

**RPS**

**Graven Hill  
Bioester  
River Sections**

Scale	1:50	Author	RW
Date	March 2022	Drawn	RN
Job Number	DT7633	Checked	AP

Project: Graven Hill Bioester & River Sections  
At: DT7633/Graven/006



## Appendix C Photographs



Upstream Section of Drain



Section of Drain





Section upstream of twin culvert



Section 17 watercourse



Section Upstream railway culvert



**Section Downstream railway culvert**