APPENDIX C

FLOOD RISK INFORMATION

Date:

Flood Risk Modelling

Project: Wixam Woods, Bedford

Client: Wates Developments Ltd.

Reference: C86343-JNP-XX-XX-RP-C-1002

Date: July 2020

JNP GROUP
CONSULTING ENGINEERS

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1 INTRODUCTION

1.1.1 This report presents the results of the preliminary hydraulic modelling work undertaken by JNP Group for the development site at Wixams Woods, Bedford (National Grid Reference TL 05680 43460).

1.1.2 The objective of the work undertaken by JNP Group was to improve understanding of fluvial flooding at the development site from the ordinary watercourses along its southern and northern boundaries and to define the fluvial flood risk constraints necessary to implement a sequential approach to master planning in line with the National Planning Policy Framework.

1.1.3 This preliminary hydraulic modelling work is limited by the absence of LiDAR coverage of the area of interest, which restricted the modelled extent to the area covered by the bespoke topographical survey of the development site. Further survey of key off-site areas and features will be required to address the model's limitations and conservative assumptions.

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2 HYDROLOGICAL ASSESSMENT

2.1 Overview

2.1.1 The aim of the hydrological assessment was to derive inflow hydrographs for the hydraulic model using the FEH Statistical and ReFH methods, estimating flows for the ordinary watercourses along the development site's southern and northern boundaries.

2.1.2 The areas of interest (Appendix A) are the ungauged catchments of the ordinary watercourses flowing west to east along the development site's southern and northern boundaries.

2.1.3 The 2.98 km² (southern watercourse) and 0.82 km² (northern watercourse) catchment areas are essentially rural and do not comprise any significant reservoirs or lakes.

2.1.4 In accordance with British Geological Survey's *GeoIndex*, the catchments comprise superficial deposits of clay, silt, sand, and gravel (near the watercourses) underlain by mudstone bedrock.

2.2 Catchment Descriptors

2.2.1 Catchment descriptors were obtained from the FEH *Web Service* for the larger catchment area (southern watercourse). While all catchment descriptors provide useful hydrological information, the ten descriptors included in Table 2.1 are key for flood estimation.

2.2.2 The key descriptors are within normal ranges and having been reviewed against available information are deemed representative of the catchments' characteristics

Table 2.1: Key Catchment Descriptors (FEH *Web Service*)

Watercourse	OS Easting	OS Northing	AREA
Unnamed	505950	243500	2.9775 km²

BFIHOST	DPLBAR	DPSBAR	FARL	FPEXT	PROPWET	SAAR	SPRHOST	URBEXT
0.308	2.14	39.8	1.000	0.1167	0.24	574	55.28	0.0000

2.3 Flood Estimation Handbook (FEH) Statistical Method

2.3.1 WINFAP 4 was used to implement the FEH Statistical method using the key catchment descriptors summarised in Table 2.1.

2.3.2 A rural QMED of 0.601 m³/s was derived from catchment descriptors and the pooling group of gauged catchments used in the statistical analysis is shown in Appendix A and summarised in Table 2.2.

Table 2.2: Pooling Group Summary

Parameter	Value
Years of Data	514
Similarity Distance	1.572~3.166
L-CV	0.239
L-Skew	0.212

2.3.3 The pooling group did not contain any anomalous stations, and, despite the strongly heterogeneous pooling group, the generalised logistic distribution gives an acceptable goodness of fit.

2.3.4 The (rural) peak flows estimated using the FEH Statistical method are presented in Table 2.3.

Table 2.3: Peak Flows (FEH Statistical Method)

Return Period (Annual Exceedance Probability)	Peak Flow (m³/s)	
	Southern Watercourse	Northern Watercourse†
1 in 2 year (50.0%) (QMED)	0.601	0.162
1 in 30 year (3.3%)	1.315	0.355
1 in 100 year (1.0%)	1.731	0.467
1 in 1000 year (0.1%)	2.881	0.778

2.4 Revitalised Flood Hydrograph (ReFH) Method

2.4.1 ReFH 2 was used to implement the ReFH method using the key catchment descriptors summarised in Table 2.1.

2.4.2 Table 2.4 shows the key parameters of the ReFH model. Peak flows and hydrographs were derived for the winter rainfall profile using the recommended critical storm duration of 7.5 hours.

Table 2.4: ReFH Model Parameters

Cmax (mm)	Cini (mm)	Tp (hours)	BL	BR
264.887	165.574	4.673	34.186	0.608

2.4.3 The (rural) peak flows estimated using the ReFH method are presented in Table 2.5

Table 2.5: Peak Flows (ReFH Method)

Return Period (Annual Exceedance Probability)	Peak Flow (m³/s)	
	Southern Watercourse	Northern Watercourse
1 in 2 year (50.0%) (QMED)	1.216	0.328
1 in 30 year (3.3%)	2.406	0.650
1 in 100 year (1.0%)	3.292	0.889
1 in 1000 year (0.1%)	6.191	1.672

2.5 Conclusions

2.5.1 As shown in Table 2.3 and Table 2.5, the methods produce very disparate results, with the ReFH method rendering much higher peak flows for all return periods considered.

2.5.2 For a small rural catchment with key descriptors well within normal ranges and an acceptable fit to a distribution function, the FEH Statistical method (which is based on a large sample of gauged data from hydrologically similar catchments) is expected to produce the more accurate flow estimates and the (much higher) ReFH method flows are deemed to be overestimated.

† Flows for the northern watercourse were estimated by scaling flows for the southern watercourse proportionally to the respective catchment areas (i.e. northern watercourse = 0.27 x southern watercourse).

2.5.3 Nevertheless, this study follows the precautionary principle recommended for the assessment of flood risk and, in addition to the baseline scenario based on the FEH Statistical method peak flows, includes a conservative scenario with flows increased by 50% (i.e. midway between the FEH and ReFH peak flow estimates).

3 HYDRAULIC MODEL

3.1 Overview

3.1.1 ESTRY-TUFLOW was used to develop the hydraulic model. ESTRY-TUFLOW is a 1D-2D hydrodynamic simulator for modelling flows in urban waterways, rivers, floodplains, estuaries, and coastlines. It can model complex hydraulic systems comprising all the features present within the area of interest, namely the hydraulic structures (i.e. bridges / culverts), open channels and overland flow paths that would otherwise be difficult and less accurate to represent using simpler 1D or quasi-2D models.

3.1.2 In the absence of LiDAR coverage of the area of interest, the hydraulic model is exclusively based on the bespoke topographical survey of the development site undertaken by CD Surveys Ltd. in January 2020.

3.2 Model Description

3.2.1 The model covers a total area of 22.9 hectare comprising 270 m of the southern watercourse and 370 m of the northern watercourse.

3.2.2 The model includes four existing culverts (1D domain) based on the invert levels and dimensions surveyed by CD Surveys Ltd. in January 2020. These are:

- **EC1**: 2 x Ø900 mm culvert of the southern watercourse under the access track parallel to the A6.
- **EC2**: Ø1800 mm culvert of the southern watercourse under the A6.
- **EC3**: Ø225 mm outlet of the drainage ditch along the site's north-eastern boundary into the northern watercourse.
- **EC4**: Ø1000 mm culvert of the northern watercourse under access path near the site's north-eastern corner.

3.2.3 The watercourses' main channels and out-of-bank flow paths were modelled in the 2D domain using the top and bottom-of-bank lines (3D break lines) and spot levels surveyed by CD Surveys Ltd. in January 2020.

3.2.4 The 2D domain uses a 1 m grid which is compatible with the key features present within the area of interest and provides a good representation of in-bank flows for both the southern and northern watercourses.

3.2.5 The preliminary hydraulic model is schematically represented in Map 1 in Appendix C.

3.3 Modelling Coefficients

3.3.1 Roughness coefficients (Manning's 'n') are estimated to range between 0.020 and 0.060 in the main channel (and culverts) and 0.040 in the floodplains, as summarised in Table 3.1.

3.3.2 Roughness coefficients were attributed in accordance with CHOW (1959), based on site observations and aerial images.

Table 3.1: Roughness Coefficients (Manning's 'n')

Location	Description	Manning's 'n' ($m^{1/3}s$)
Main Channel	Bed: clean and straight channel with stones and weeds	0.035
	Banks: light brush and trees	0.060
	Culverts: concrete pipes	0.020
Floodplain	Cultivated area: mature field crop	0.040

3.3.3 All other modelling coefficients (e.g. contraction and headloss coefficients at culverts) used TUFLOW's default / recommended values.

3.4 Boundary Conditions

3.4.1 The following boundary conditions were used in the hydraulic model:

- *Southern and Northern Watercourses' Upstream Boundary Conditions (2D domain)*. Hydrographs for the 3.3%, 1.0% and 0.1% AEP events (Appendix A), established using the FEH Statistical method, as summarised in Section 2. Climate change allowances of 35% (higher central) and 65% (upper end) were added to the 1.0% AEP event in line with current EA guidance for the Anglian River Basin District (2070 to 2115).
- *Southern Watercourse's Downstream Boundary Condition (1D domain)*. In the absence of any topographical information (LiDAR or bespoke survey) downstream of the culvert under the A6, this normal-depth boundary assumes that the key characteristics of the channel (i.e. cross-section geometry, roughness and 1:167 m/m longitudinal bed slope) downstream of the A6 match those surveyed upstream. While a preliminary sensitivity test indicates that this assumption has little impact on results, **a bespoke survey of the southern watercourse downstream of the A6 is recommended to address this uncertainty.**
- *Northern Watercourse's Downstream Boundary Condition (2D domain)*. Normal-Depth boundary based on a conservative channel bed slope of 1:500 m/m.

4 MODEL PREDICTIONS

4.1 Flood Estimation Handbook (FEH) Statistical Method Flows

4.1.1 Maximum flood depths for the FEH Statistical method flows are shown in Map 2 (3.3% AEP), Map 3 (1.0% AEP), Map 4 (1.0% AEP + 35%), Map 5 (1.0% AEP + 65%) and Map 6 (1.0% AEP + (0.1% AEP) in Appendix C.

4.1.2 Results show some overtopping of the southern watercourse around the 2 x Ø900 mm culvert under the access track parallel to the A6, with out-of-bank flows barely affecting the total developable area for all storm events considered.

4.1.3 No overtopping of the northern watercourse is predicted for the FEH Statistical method flows and storm events considered.

4.2 Conservative Flows (FEH + 50%)

4.2.1 Maximum flood depths for the FEH + 50% flows are shown in Map 7 (50.0% AEP), Map 8 (5.0% AEP), Map 9 (1.0% AEP + 35%), Map 10 (1.0% AEP + 65%) and Map 11 (0.1% AEP) in Appendix C.

4.2.2 Results show limited overtopping of the southern watercourse around the 2 x Ø900 mm culvert under the access track parallel to the A6 for the 3.3%, 1.0% and 1.0% AEP + 35% storm events, with out-of-bank flows barely affecting the site's developable area.

4.2.3 For the 1.0% AEP + 65% and 0.1% AEP storm events, the impact on the site's developable area becomes noticeable, but still restricted to the south-eastern corner of the site (i.e. low-lying area adjacent to the A6).

4.2.4 No overtopping of the northern watercourse is predicted for the FEH + 50% flows and storm events considered.

5 MODEL STABILITY

5.1.1 The proposed hydraulic model uses a 2D timestep of 0.5 seconds, within the 0.2 to 0.5 seconds range recommended for a 1 m grid. The 1D timestep is also 0.5 seconds.

5.1.2 All scenarios ran without unexpected warnings, errors or negative depths for all storm events considered. Mass balance errors are generally within the desired range of ±2.0% and Qi, Qo and dV values are stable throughout all simulations, indicating a healthy hydraulic model.

5.1.3 1D and 2D outputs have been reviewed and also indicate a healthy model.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1.1 The preliminary hydraulic modelling work is limited by the absence of LiDAR coverage of the area of interest, which restricted the modelled extent to the area covered by the bespoke topographical survey of the development site.

6.1.2 Inflow hydrographs for the hydraulic model were derived using the FEH Statistical and ReFH methods. For a small rural catchment with key descriptors well within normal ranges and an acceptable fit to a distribution function, the FEH Statistical method (which is based on a large sample of gauged data from hydrologically similar catchments) is expected to produce the more accurate flow estimates and the (much higher) ReFH method flows are deemed to be overestimated. Nevertheless, this study follows the precautionary principle recommended for the assessment of flood risk and, in addition to the baseline scenario based on the FEH Statistical method peak flows, includes a conservative scenario with flows increased by 50% (i.e. midway between the FEH and ReFH peak flow estimates).

6.1.3 In the absence of any topographical information (LiDAR or bespoke survey) downstream of the culvert under the A6, a normal depth boundary assuming that the key characteristics of the channel (i.e. cross section geometry, roughness and longitudinal bed slope) downstream of the A6 match those surveyed upstream has been adopted. While a preliminary sensitivity test indicates that this assumption has little impact on results, a bespoke survey of the southern watercourse downstream of the A6 is recommended to address this uncertainty.

6.1.4 Results for the FEH Statistical method flows show some overtopping of the southern watercourse around the 2 x Ø900 mm culvert under the access track parallel to the A6, with out-of-bank flows barely affecting the total developable area for all storm events considered. No overtopping of the northern watercourse is predicted for the FEH Statistical method flows and storm events considered.

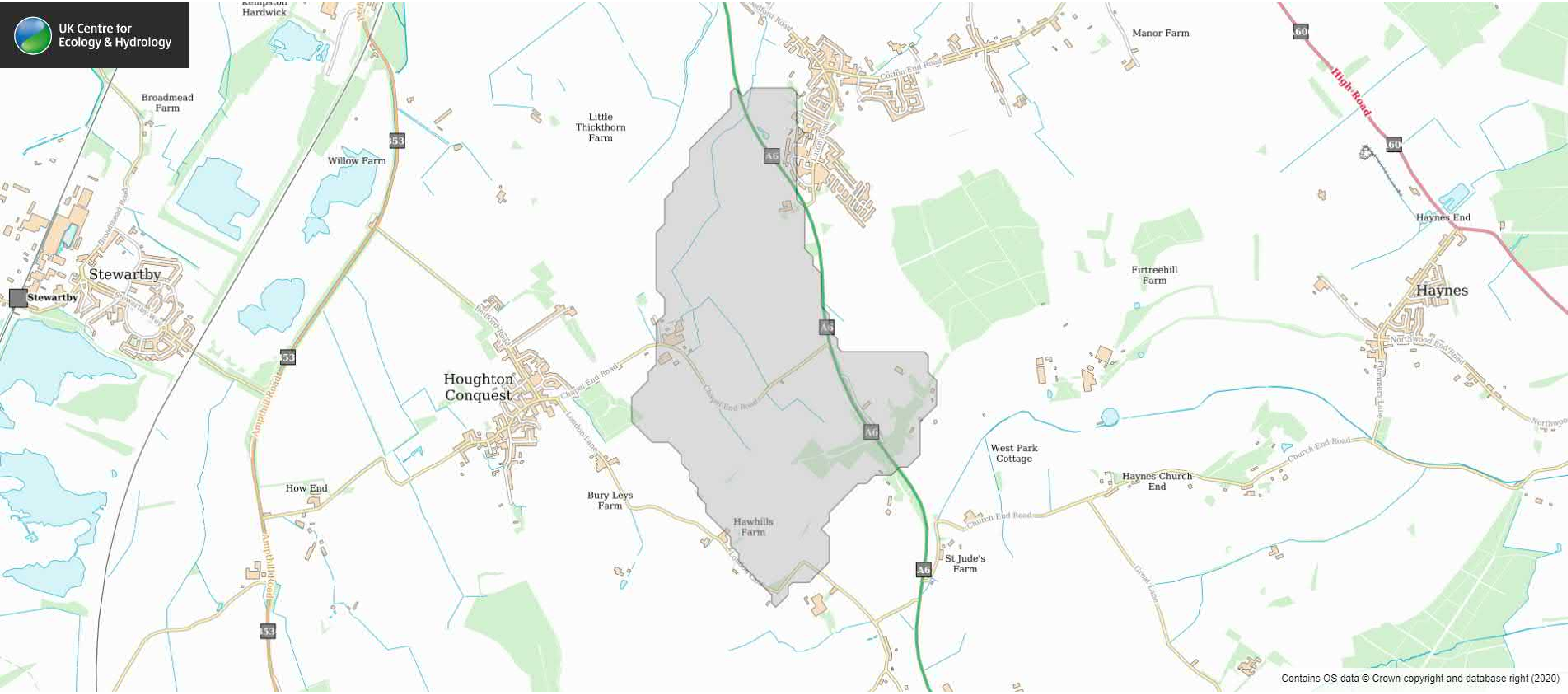
6.1.5 Results for the FEH + 50% flows also show some overtopping of the southern watercourse around the 2 x Ø900 mm culvert under the access track parallel to the A6 for the 3.3%, 1.0% and 1.0% AEP + 35% storm events, with out-of-bank flows still barely affecting the site's developable area.

6.1.6 For the 1.0% AEP + 65% and 0.1% storm events (FEH + 50%), the impact on the site's developable area becomes noticeable, but still restricted to the south-eastern corner of the site (i.e. low-lying area adjacent to the A6).

6.1.7 No overtopping of the northern watercourse is predicted for the FEH + 50% flows and storm events considered.

APPENDIX A

HYDROLOGICAL ASSESSMENT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Hawhills Farm
West Park Cottage
Haynes Church End
St Jude's Farm
Firtreehill Farm
Haynes
Haynes End
High Road
Cotton End Road
Chapel End Road
London Lane
Bedford Road
Ampthill Road
Church End Road
Northwood End Road
Plummers Lane
Great Lane
A6
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Willow Farm
Stewartby
Stewartby
Firtreehill Farm
Houghton Conquest
West Park Cottage
Haynes Church End
How End
Bury Leys Farm
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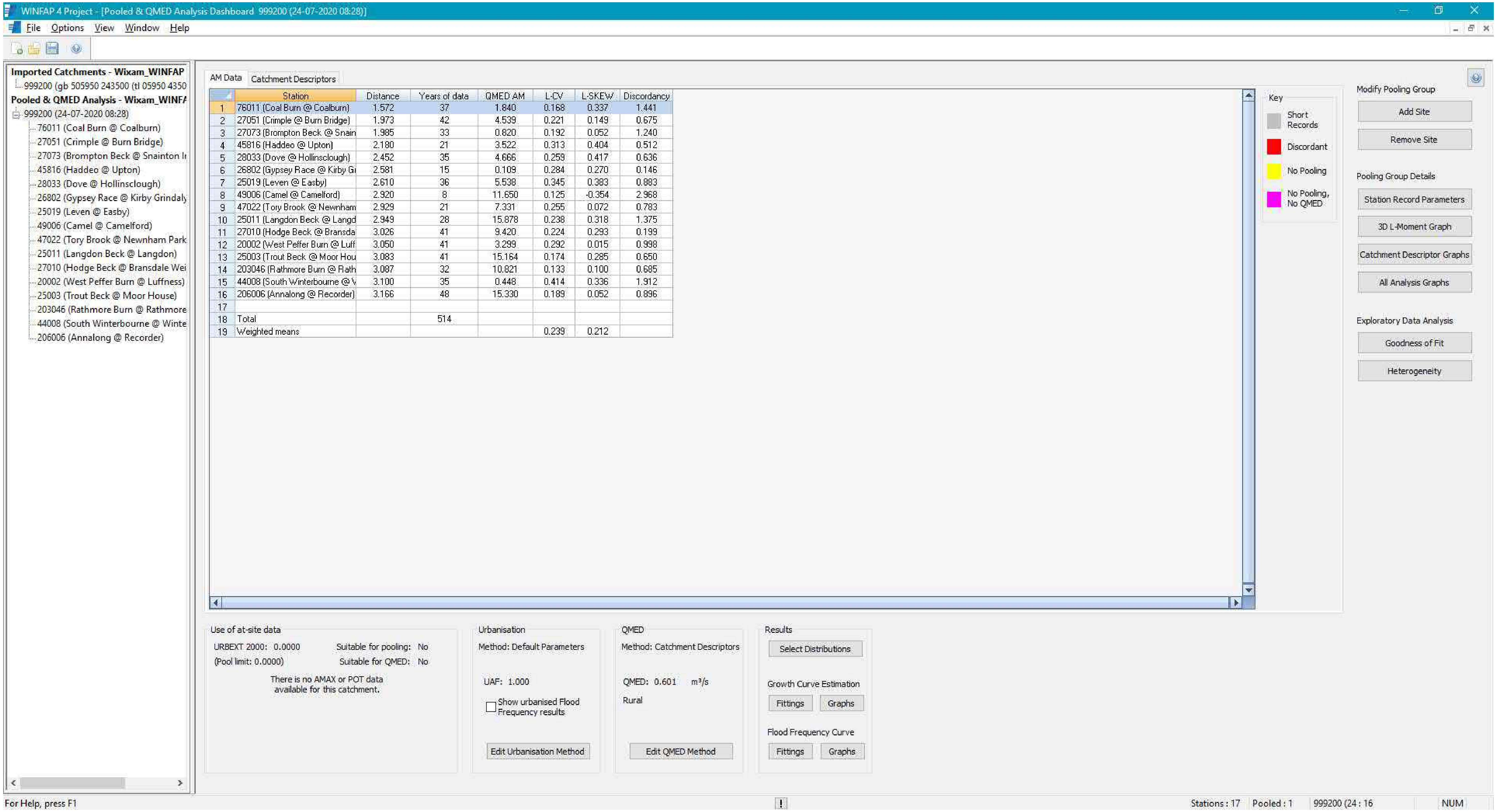

	Station	Distance	Years of data	QMED AM	L-CV	L-SKEW	Discordancy
1	76011 (Coal Burn @ Coalburn)	1.572	37	1.840	0.168	0.337	1.441
2	27051 (Crimple @ Burn Bridge)	1.973	42	4.539	0.221	0.149	0.675
3	27073 (Brompton Beck @ Snain	1.985	33	0.820	0.192	0.052	1.240
4	45816 (Haddeo @ Upton)	2.180	21	3.522	0.313	0.404	0.512
5	28033 (Dove @ Hollinsclough)	2.452	35	4.666	0.259	0.417	0.636
6	26802 (Gypsey Race @ Kirby Gi	2.581	15	0.109	0.284	0.270	0.146
7	25019 (Leven @ Easby)	2.610	36	5.538	0.345	0.383	0.883
8	49006 (Camel @ Camelford)	2.920	8	11.650	0.125	-0.354	2.968
9	47022 (Tory Brook @ Newnham	2.929	21	7.331	0.255	0.072	0.783
10	25011 (Langdon Beck @ Langd	2.949	28	15.878	0.238	0.318	1.375
11	27010 (Hodge Beck @ Bransda	3.026	41	9.420	0.224	0.293	0.199
12	20002 (West Peffer Burn @ Luff	3.050	41	3.299	0.292	0.015	0.998
13	25003 (Trout Beck @ Moor Hou	3.083	41	15.164	0.174	0.285	0.650
14	203046 (Rathmore Burn @ Rath	3.087	32	10.821	0.133	0.100	0.685
15	44008 (South Winterbourne @ V	3.100	35	0.448	0.414	0.336	1.912
16	206006 (Annalong @ Recorder)	3.166	48	15.330	0.189	0.052	0.896
17							
18	Total		514				
19	Weighted means				0.239	0.212	

APPENDIX B

TOPOGRAPHICAL SURVEY

APPENDIX C
FLOOD RISK MAPS

Map 1: Model Schematic

Map 2: FEH Statistical Method Flows. Maximum Flood Depths (3.3% AEP)

Map 3: FEH Statistical Method Flows. Maximum Flood Depths (1.0% AEP)

Map 4: FEH Statistical Method Flows. Maximum Flood Depths (1.0% AEP + 35% Climate Change Allowance)

Map 5: FEH Statistical Method Flows. Maximum Flood Depths (1.0% AEP + 65% Climate Change Allowance)

Map 6: FEH Statistical Method Flows. Maximum Flood Depths (0.1% AEP)

Map 7: FEH + 50% Flows. Maximum Flood Depths (3.3% AEP)

Map 8: FEH + 50% Flows. Maximum Flood Depths (1.0% AEP)

Map 9: FEH + 50% Flows. Maximum Flood Depths (1.0% AEP + 35% Climate Change Allowance)

Map 10: FEH + 50% Flows. Maximum Flood Depths (1.0% AEP + 65% Climate Change Allowance)

Map 11: FEH + 50% Flows. Maximum Flood Depths (0.1% AEP)