APPENDIX 04

Hydraulic Modelling Report

PROPOSED ANAEROBIC DIGESTION FACILITY AT SPRING GROVE FARM, SUFFOLK

Hydraulic Modelling Appendix

Prepared for: Acorn Bioenergy Limited

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1.0 INTRODUCTION

1.1 Flood Risk Assessment

This hydraulic modelling report forms part of the Spring Grove Farm Anaerobic Digestion Facility *Flood Risk Assessment and Surface Water Drainage Strategy* and should therefore be read in conjunction with this document for full context.

1.2 Terms of Reference

With reference to the *Flood Map for Planning (Rivers and Sea)* the main Site lies partly within an area considered to be at risk of fluvial or tidal flooding. A preliminary flood risk assessment confirms that the main Site is partly at risk of fluvial and pluvial flooding. Fluvial flooding is typically defined as water that overtops the river bank and flows onto the surrounding area. Whereas pluvial flooding occurs when rainfall saturates the soils and/or exceeds the urban drainage system resulting in overland runoff.

In response to a flood data request, the Environment Agency confirmed that they hold no detailed site-specific flood information for the main Site. In addition, it was noted that the existing Environment Agency fluvial mapping was likely missing key topographic features in comparison to the pluvial mapping. SLR Consulting Limited was therefore instructed to construct a hydraulic model to represent, assess the impact of the proposed development on flood risk at the main Site and elsewhere, and, if required, identify and assess suitable mitigation options.

1.3 Scope

Carry out hydraulic modelling to inform the emerging proposed layout including:

i. Define baseline flood mechanism against which the impact of the proposed scheme and mitigation measure(s) can be assessed

ii. Examine changes in the flood mechanism(s) compared to the baseline as a result of the proposed development to identify if/what issues need to be mitigated

iii. Outline suitable options that may mitigate increase in peak water levels or flood extent

iv. Test and refine mitigations options

v. Identify set of mitigations to implement into the proposed development

vi. Determine whether further model justification is likely to be required by Environment Agency and/or Lead Local Flood Authority (LLFA)

vii. Prepare deliverable as a summary in Flood Risk Assessment (FRA)

viii. Prepare a modelling report to explain modelling process that was undertaken.

2.0 HYDRAULIC MODELLING

2.1 Modelling Scenarios

The impact of proposed development, with a range of mitigation options, was compared to the baseline scenario under a range of Annual Exceedance Probability (AEP) rainfall events and Manning's n values for the 1D (one dimensional) elements as set out within Table 1.

Details of each mitigation scenario, and the baseline conditions against which the impact was assessed, are detailed in the below section. However, a summary of the baseline and mitigation measures modelled are included within Table A4 - 1**.**

Table A4 - 1 Hydraulic Parameters between Scenarios

Category	Modelled Options	Hydrological Conditions	Railway culvert Manning's n
Baseline	• Existing access and railway culverts	• 1% AEP • 1% AEP +8% • 0.1% AEP	• 0.030
Mitigation	• Flood relief culverts • Increased bridge conveyance • Improvement on railway culvert		• 0.015

2.2 Acceptance Scenario

For a proposed development, with or without mitigation measures, to be deemed acceptable in terms of its impact on flood risk elsewhere, the following criteria need to be met:

i. National Planning Policy Framework (NPPF Clause 52) requires there to be no adverse impact to 'others', which includes those upstream or downstream of the main Site.

ii. Environment Agency criteria usually requires proposed scheme peak water levels to be within +/- 5mm of baseline conditions.

It should be noted that, if the proposed development results in an increase in flood risk within the site boundary, the criteria is to demonstrate that the flood risk can be managed over the lifetime of the scheme with or without flood mitigation measures.

2.3 Methodology

Following instruction on 21st July 2022 a linked 1D/2D hydraulic model was developed to quantify the extent and depth of flooding at the main Site, as this type of model is better able to represent the expected 'out of banks' flows than a 1D model.

The dynamically linked hydraulic model has been constructed using the latest commercially available ESTRY – TUFLOW (HPC) 2020-10-AD build, widely used in the UK. The High-Performance Compute (HPC) version solves the full 2D shallow water equations including inertia and turbulence, and is suited to floodplain, open channel and pipe hydraulics. The HPC enables adaptive time-stepping in conjunction with smaller grid resolutions for greater granularity.

2.3.1 Hydrological Analysis

Standard UK methods for deriving flood flows for watercourses are described in the Flood Estimation Handbook[1] (FEH). The FEH offers two principal methods of flood flow estimation; a Statistical Method and a Rainfall-Runoff model method. The most recent form of the Rainfall-Runoff Method is termed the Revitalised Flood Hydrograph Method.

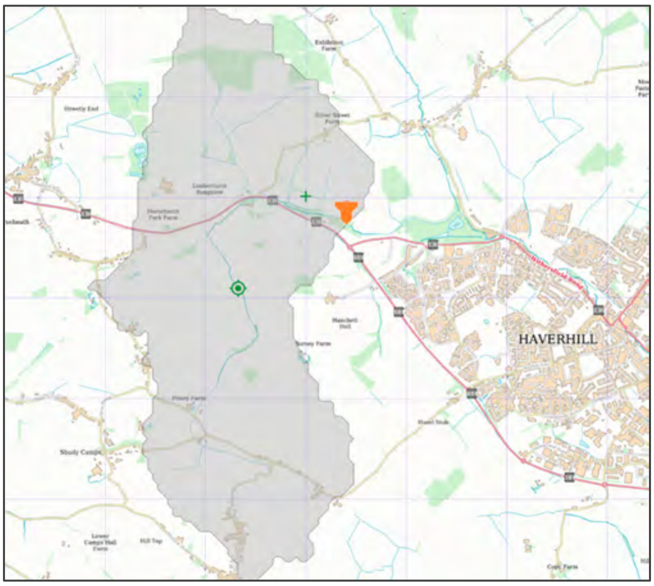
1. The **Statistical Method** estimates peak flow for a catchment for a given Annual Exceedance Probability (AEP) event using historical gauging station data from analogous catchments that are selected based on catchment descriptors.
2. The **Revitalised Flood Hydrograph Method** uses catchment descriptors to estimate the response of a catchment to a rainfall event of a given AEP to generate a corresponding flood flow hydrograph.

The FEH methodologies are supported by WINFAP-*FEH (WINFAP Version: 5.0.7947 supported by Peak Flow Dataset 10.0.0)* and the Revitalised Flood Hydrograph (ReFH2) software applications *(version 3.2.7650.24314)* which are used in combination with the catchment descriptors obtained from the FEH Web Service.

The WINFAP-FEH software supports the Statistical Method for flood frequency estimation, using historical annual maxima data alongside catchment descriptors.

2.3.2 Catchment

Figure A4 - 1 FEH Webservice Downstream Boundary Condition Lumped Catchment



Shown above is the FEH Webservice delineation the catchment for the lumped downstream boundary of the model at coordinates: X 564400, Y 246750. This catchment includes two small tributary watercourses identified on Ordnance Survey mapping that join the main modelled watercourse along the model reach. This lumped catchment has a watershed basin contributing area of 9.47km^2. No edits have been made to this watershed boundary. The v4 XML file has been exported from the FEH Webservice and used in ReFH2 and WINFAP software packages. No edits have been made to the FEH catchment descriptors.

[1] Institute of Hydrology, Flood Estimation Handbook, 1999

2.3.3 FEH Rainfall-runoff Model

ReFH2 has been used to apply the FEH rainfall-runoff model to the downstream boundary condition catchment. The FEH2013 DDF model has been used to generate the synthetic hydrograph. The critical storm duration of 9 hours with 1 hour timestep has been estimation based upon FEH catchment descriptors and used with the FEH2013 DDF model to generate the input hyetograph. No edits have been made to the ReFH2 model parameters. Full ReFH2 model reports for the 100yr and 1000yr events can be found at the end of this report.

2.3.3.1 FEH statistical Model

QMED

2022 FEH guidance states for small catchments (<25km2) to: *"Use the standard FEH regression for QMED. Adjust QMED using a single donor catchment, chosen on the basis of proximity."*[2] However, for this catchment, this would mean applying a QMED adjustment based solely upon NRFA 36010 - Bumpstead Brook at Broad Green. This gauging station has a very high ratio of observed ($QMED^{obs}$) to catchment descriptor derived estimate for QMED ($QMED^{cds}$). This is likely due to the gauge being location on *"Chalk and glacial gravel in the catchment completely overlain with Boulder Clay. Rural, predominantly arable land."* Having a highly porous bedrock overlain by clay and gravels can allow for large variation locally in low flows, and therefore would not be suitable as a sole donor adjustment site. Gauging station 36011 on the same catchment and most local of all to the main Site (http://nrfa.ceh.ac.uk/data/station/info/36011) is not included in the NRFA suitable for QMED dataset, potentially due to the high artificial abstractions.

Due to the considerations above, the standard method of six donor QMED sites has been applied.

Permeable Adjustment method applicable

SPR and BFI HOST for the study catchment are below the threshold for applying the Permeable Adjustment method despite the catchment being underlain by chalk/highly permeable bedrock. This could be due to impermeable superficial top soils.

"Permeable catchments are defined in the FEH Statistical method using an arbitrary threshold of SPRHOST<20%, which corresponds roughly to BFIHOST>0.75." [1]

Pooling Group and Growth Curves

Pooling group sites have been selected based upon NRFA Peak Flow dataset 10.0 which was the most current version at the time of calculation. Growth curves and Pooling Groups has been selected based upon the similarity distance measure (SDM) within small catchments as per Stewart et. al., 2019[3]. No at site data or User Defined gauging station data has been utilised. The Generalized Logistic (GL) growth curves gives a good fit and therefore has been selected. The pooling group is identified as heterogenous but has not been edited.

Full WINFAP 5 pooling group details can be found at the end of this report.

Climate change

Climate change uplift has been applied to the results flows from the rainfall-runoff model, and not to the input rainfall.

Method Selection

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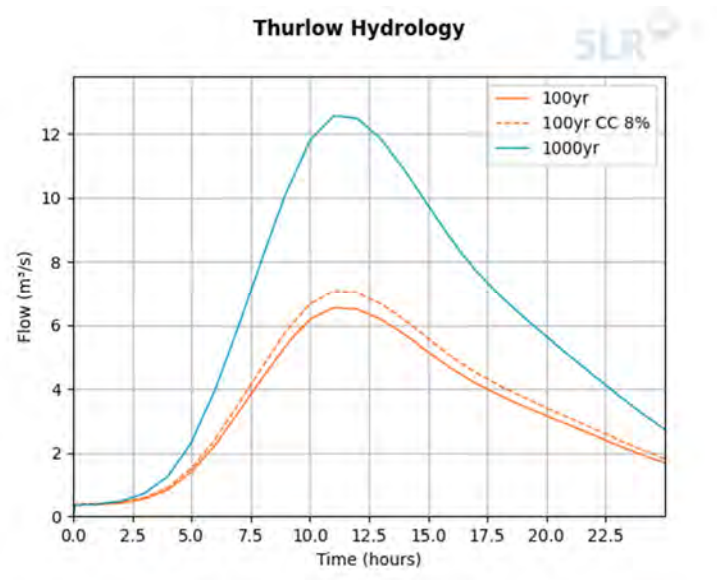
[2]Environment Agency, 2022. LIT-11832-Flood-estimation-guidelines
[3]Environment Agency, 2019. Report SC090031/R0 - Estimating flood peaks and hydrograph for small catchments (Phase 2).

Due to the issues with QMED donors and the heterogenous pooling group, it has been decided not to scale down the hydrographs to match the peak flows of the statistical method analysis. The final hydrographs used in the hydraulic modelling are therefore the raw ReFH2 outputs (Figure A4 - 2).

Table A4 - 2 Hydrological Peak Flow Comparison

Return Period	WINFAP		REFH2	
	RURAL	URBAN	RURAL	URBAN
2	1.98	1.99	2.47	2.47
5	3.00	3.01	3.35	3.36
10	3.73	3.74	3.95	3.96
30	5.01	5.03	4.97	4.98
50	5.68	5.70	5.53	5.55
75	6.26	6.28	6.07	6.09
100	6.69	6.72	6.54	6.55
200	7.84	7.87	8.05	8.07
1000	11.16	11.20	12.54	12.57

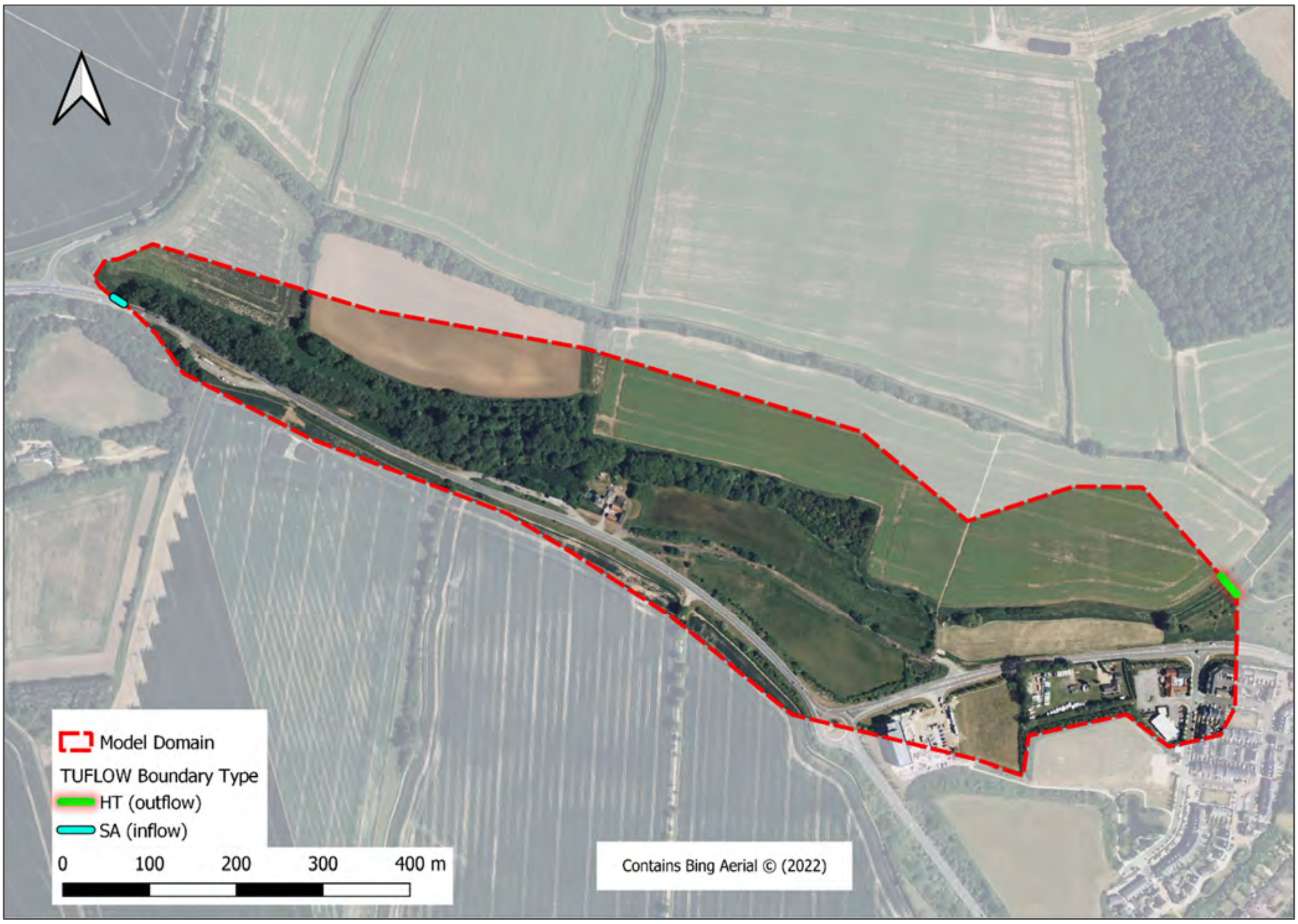
Figure A4 - 2 Thurlow hydrological inflows



2.3.4 Extent

The active hydraulic model domain extends from the intersection of the A1307 and Silver Street to the West to the roundabout at A1017 and A1307 as shown on Figure A4 - 3 below. To eliminate any backwater effects from the downstream boundary, the 2D domain was extended further east parallel with the A1307 to the intersection of the A1307 and Three Counties Way, approximately 500m downstream of the main Site.

Figure A4 - 3 Model External Boundaries



2.3.5 Topography

A Digital Terrain Model (DTM) of the study area has been generated from 1m resolution Light Detection and Ranging (LiDAR) aerial photogrammetric data, downloaded from the Environment Agency open data website[4]. The LIDAR-DTM-1m-2020-TL64nw Composite DTM tile covers the entire modelled domain and forms the 2-Dimensional (2D) element of the hydraulic model, across which floodwater propagates. Minor modifications were made to underlying topography 'within channel' to cut through areas of poor triangulation as a result of vegetation. These cuts were common between the baseline and mitigation scenarios to ensure a continuous flow path for fluvial flooding.

The only additional modification to the topography is a result of the proposed design scenario which applies an elevated access road, as a 2D topographic amendment, to represent the embankment obstruction across the flood plain.

2.3.6 Cell Size

The flood hazard predictions in urban environments with complex flow paths can be sensitive to model grid resolution. Typically, three to five grid cells are required across key flow paths (i.e. a road or channel). The Spring Grove Farm model domain covers an area of approximately 0.308 km² and comprises a uniform grid of 2m

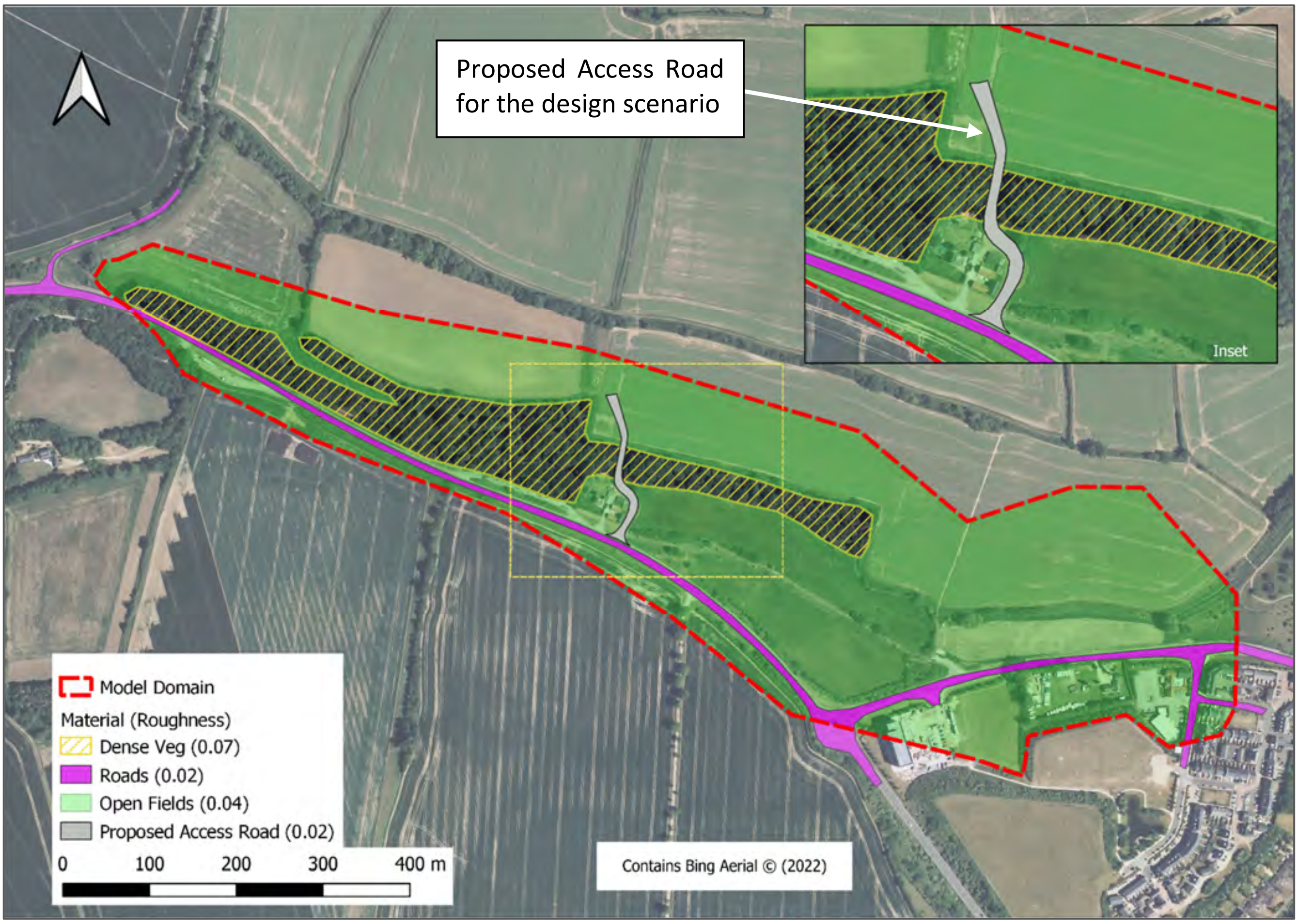
[4] https://environment.data.gov.uk/DefraDataDownload/?Mode=survey

resolution square cells. This resolution was used to best define the finer scale channel features whilst also representing reasonable simulation times. Each grid cell contains information on ground topography and the surface resistance to flow (Manning's 'n' value) sampled from the DTM at 1.0m spacing. As the open channel in the Spring Grove Farm model was sufficiently resolved in the 2D domain, there was no need to utilise a 1D representation with cross-sections.

2.3.7 Land-use

The Manning's n coefficient represents the roughness of the land surface, or river channel, in the hydraulic model. Delineation of land-use within the model domain utilises aerial imagery and a corresponding Manning's n coefficient values were then applied to each of these land-uses (Figure A4 - 4). Areas of dense vegetation were applied a Manning's n roughness coefficient of 0.07 which equates to medium to dense brush. Whereas all other areas, excluding the roadway, utilised a roughness of 0.04 that corresponds to weedy open fields. In addition, the design scenario incorporates a material modification along the proposed access road to lower the Manning's roughness.

Figure A4 - 4 Land-use Roughness



2.3.8 Structures

The 1-Dimensional (1D) elements in the model are limited to several discrete structures, namely:

- The existing (baseline scenario) and proposed (mitigation scenario) culverts underneath the access road; and
- The railway bridge culvert downstream of the main Site (baseline and mitigation scenarios).

The structures have been modelled using topographic site information provided by Mitcham Survey Department (11the March 2022) and by site observations carried out on 10th May 2022.

2.3.9 Mitigations

The proposed access road that is to connect the A1307 through to the main Site, past an existing property, consists of an elevated roadway over the Stour Brook. The small existing culvert (assumed to be a 600mm circular culvert) is to be replaced by a 10m wide x 2m high bridge to improve flow conveyance and ensure proposed works do not adversely impact the floodplain.

As a result of installing the elevated access road, the road embankment obstructs the propagation of flow downstream for larger AEP events. To reduce the attenuation upstream of the road embankment, and any further downstream detriment, the following two mitigation measures have been optioneered (see Figure A4 - 5):

- a series of 10 flood relief culverts (each 600mm diameter) are proposed between the bridge and the main Site; and
- improvement works on the existing downstream culvert (assumed 920mm diameter) underneath the old railway embankment.

The flood relief culverts are designed to convey the attenuated floodwaters from the western woodland area through to Spring Grove Farm to the east.

It is proposed that the existing railway culvert be repaired and lined to improve flow through the culvert, in order to ensure that flows do not unacceptably out-flank the railway embankment to the east. The improvement works to the existing culvert at the downstream railway embankment have been modelled as a reduction in the Manning's roughness from 0.03 to 0.015.

The provision of additional storage within the Spring Grove Field and the area immediately upstream of the flood relief culverts was shown to have little to no benefit on the overall peak depths and was excluded from consideration.

Figure A4 - 5 Proposed Flood Risk Management Measure

2.4 Preferred Option

To establish the flood risk and, consequently, the Flood Zone(s) at the main Site, the hydraulic model was used to evaluate the flood extent of the proposals across the main Site as a result of a 1% and 0.1% AEP rainfall event.

The proposed access road that connects the A1307 through to the main Site, past an existing property, consists of an elevated roadway over the Stour Brook. A small existing culvert will be replaced by a 10m wide x 2m high bridge to improve conveyance of flow.

As a result of installing the elevated access road, the road embankment obstructs the propagation of flow downstream for larger AEP events. In order to reduce the attenuation upstream of the road embankment, and any further downstream detriment, a series of 10 flood relief culverts (each 600mm diameter) are proposed between the bridge and the main Site; and improvement works on the existing downstream culvert underneath the old railway embankment.

The flood relief culverts are designed to convey the attenuated floodwaters from the western woodland area through to Spring Grove Field to the east.

In contrast, improvement in flow conveyance on the existing railway culvert helps offset the increase water levels around the proposed bridge area.

The predicted peak differences in flood depths due the proposed access road and mitigation measures are considered acceptable. The inclusion of the elevated access road blocks a previous flow route in the baseline scenario which results in an area of benefit in a downstream field adjacent to the downstream watercourse.

However, by decreasing flow conveyance downstream of the access road, higher water levels of approximately 30mm are predicted. The mitigation measures alleviate some of the extent of detriment to the west of the access road. However, there is a limited area within the woodland to the south west of the main Site where flood risk is marginally increased.

3.0 CONCLUSIONS

SLR Consulting Limited (SLR) was appointed by Acorn Bioenergy Limited. (the Client) to prepare a hydraulic model to inform the Flood Risk Assessment (FRA) to support a planning application for the proposed Anaerobic Digestion (AD) Plant at Spring Grove Farm, Withersfield, North West of Haverhill, Suffolk, CB9 7SW (the 'Site').

The constructed hydraulic model successfully represents the obstruction caused by the existing railway embankment and the granularity of the culverted structures. The updated hydraulic model incorporates topographic and hydrological details which was not present in the current Environment Agency fluvial flood mapping.

The hydraulic model was used to optioneer and compare a series of options to mitigate upstream and downstream effects as a result of placing an access bridge and road across the Stour Brook.

The proposed development has incorporated the preferred mitigation of flood culverts beneath the access road and improvements to the railway culvert, that ensures that there is no unacceptable effect to others both upstream and downstream of the proposed development. The hydraulic model indicates an increase in the predicted peak water levels within the woodland, primarily to the west of the proposed access road. Further, the model also predicts no measurable increase in flood risk to residents and property downstream in Haverhill.

ANNEX 01

Model Operation

Annex 01 – Model Operation

The hydraulic model was simulated using the HPC Solver for TUFLOW build 2020-10-AD single precision (iSP). Initialisation of the TUFLOW model utilised a standard Windows Batch file linking the TUFLOW executable, model TUFLOW control file (.tcf) and relevant event and scenario logic.

Table A4 - 3 Baseline Model Scenario

Run Reference:	Thurlow_~e1~_~s1~_016.tcf
Scenario Description (-s1)	EXG (Existing/baseline)
Return Periods (-e1)	1% AEP, 1% AEP + 8% allowance for climate change and 0.1% AEP
Run Settings:	No changes in default settings

Table A4 - 4 Mitigation Model Scenario

Run Reference:	Thurlow_~e1~_~s1~_016.tcf
Scenario Description (-s1)	DES (Design mitigation)
Return Periods (-e1)	1% AEP, 1% AEP + 8% allowance for climate change and 0.1% AEP
Run Settings:	No changes in default settings

All simulations were executed using a Windows batch file (.bat). Batch files are text files which contain a series of commands and allow for a large degree of flexibility in starting TUFLOW simulations. Due to the number of variables being modelled, event and scenario management wildcards (e.g. ~s1, ~e1) were utilised within the batch file to easily run simulations in series or concurrently.

Example batch file configuration for the Baseline and Mitigation runs are given below:

```
set TUFLOWEXEiSP="C:\TUFLOW\Release\TUFLOW.2020-10-AD\2020-10-AD\TUFLOW_iSP_w64.exe"
set RUN=start "TUFLOW" /wait "%TUFLOWEXEiSP%" -b

:: Runs - Baseline
%RUN% -e1 100R -s1 EXG Thurlow_~e1~_~s1~_016.tcf
%RUN% -e1 1000R -s1 EXG Thurlow_~e1~_~s1~_016.tcf
%RUN% -e1 100R_CC08 -s1 EXG Thurlow_~e1~_~s1~_016.tcf

:: Runs - Mitigation
%RUN% -e1 100R -s1 DES Thurlow_~e1~_~s1~_016.tcf
%RUN% -e1 1000R -s1 DES Thurlow_~e1~_~s1~_016.tcf
%RUN% -e1 100R_CC08 -s1 DES Thurlow_~e1~_~s1~_016.tcf
```

ANNEX 02

Hydrological Reports

Annex 02 – Hydrological Reports

UK Design Flood Estimation

Generated on 19 January 2023 13:34:30 by gfrisby
Printed from the ReFH2 Flood Modelling software package, version 3.3.8355.27598

Summary of estimate using the Flood Estimation Handbook revitalised flood hydrograph method (ReFH2)

Site details Checksum: 614C-19F2

Site name: FEH_Catchment_Descriptors_564400_246750

Easting: 564400

Northing: 246750

Country: England, Wales or Northern Ireland

Catchment Area (km^2): 9.47

Using plot scale calculations: No

Model: 2.3

Site description: None

Model run: 100 year

Summary of results

Rainfall - FEH 2013 model (mm):	72.86	Total runoff (ML):	228.79
Total Rainfall (mm):	46.65	Total flow (ML):	442.40
Peak Rainfall (mm):	12.69	Peak flow (m^3/s):	6.55

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)	09:00:00	No
Timestep (hh:mm:ss)	01:00:00	No
SCF (Seasonal correction factor)	0.67	No
ARF (Areal reduction factor)	0.96	No
Seasonality	Winter	No

Loss model parameters

Name	Value	User-defined?
Cini (mm)	128.8	No
Cmax (mm)	294.28	No
Use alpha correction factor	No	No
Alpha correction factor	n/a	No

Routing model parameters

Name	Value	User-defined?
Tp (hr)	5.92	No
Up	0.65	No
Uk	0.8	No

Baseflow model parameters

Name	Value	User-defined?
BF0 (m^3/s)	0.36	No
BL (hr)	39.04	No
BR	0.93	No

Urbanisation parameters

Name	Value	User-defined?
Urban area (km^2)	0.07	No
Urbext 2000	0	No
Impervious runoff factor	0.7	No
Imperviousness factor	0.4	No
Tp scaling factor	0.75	No
Depression storage depth (mm)	0.5	No
Exporting drained 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 (m^3/s)	Net Rain (mm)	Runoff (m^3/s)	Baseflow (m^3/s)	Total Flow (m^3/s)
00:00:00	1.333	0.000	0.588	0.000	0.360	0.360
01:00:00	2.501	0.000	1.119	0.014	0.351	0.366
02:00:00	4.651	0.000	2.138	0.071	0.343	0.414
03:00:00	8.496	0.000	4.095	0.207	0.338	0.545
04:00:00	12.688	0.000	6.571	0.497	0.338	0.835
05:00:00	8.496	0.000	4.705	1.049	0.347	1.396
06:00:00	4.651	0.000	2.679	1.877	0.373	2.249
07:00:00	2.501	0.000	1.471	2.858	0.419	3.277
08:00:00	1.333	0.000	0.793	3.870	0.487	4.357
09:00:00	0.000	0.000	0.000	4.800	0.576	5.377
10:00:00	0.000	0.000	0.000	5.492	0.682	6.174
11:00:00	0.000	0.000	0.000	5.755	0.797	6.552
12:00:00	0.000	0.000	0.000	5.594	0.911	6.505
13:00:00	0.000	0.000	0.000	5.168	1.014	6.183
14:00:00	0.000	0.000	0.000	4.606	1.104	5.710
15:00:00	0.000	0.000	0.000	3.991	1.177	5.168
16:00:00	0.000	0.000	0.000	3.405	1.235	4.639
17:00:00	0.000	0.000	0.000	2.909	1.278	4.187
18:00:00	0.000	0.000	0.000	2.497	1.309	3.807
19:00:00	0.000	0.000	0.000	2.139	1.331	3.470
20:00:00	0.000	0.000	0.000	1.811	1.344	3.155
21:00:00	0.000	0.000	0.000	1.501	1.349	2.850
22:00:00	0.000	0.000	0.000	1.197	1.347	2.545
23:00:00	0.000	0.000	0.000	0.903	1.338	2.242
24:00:00	0.000	0.000	0.000	0.627	1.322	1.950
25:00:00	0.000	0.000	0.000	0.384	1.301	1.685
26:00:00	0.000	0.000	0.000	0.199	1.275	1.474
27:00:00	0.000	0.000	0.000	0.089	1.246	1.336
28:00:00	0.000	0.000	0.000	0.034	1.216	1.250
29:00:00	0.000	0.000	0.000	0.009	1.186	1.194
30:00:00	0.000	0.000	0.000	0.000	1.156	1.156
31:00:00	0.000	0.000	0.000	0.000	1.127	1.127
32:00:00	0.000	0.000	0.000	0.000	1.098	1.098
33:00:00	0.000	0.000	0.000	0.000	1.070	1.070
34:00:00	0.000	0.000	0.000	0.000	1.043	1.043

Time (hh:mm:ss)	Rain (mm)	Sewer Loss (m^3/s)	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	0.000	1.017	1.017
36:00:00	0.000	0.000	0.000	0.000	0.991	0.991
37:00:00	0.000	0.000	0.000	0.000	0.966	0.966
38:00:00	0.000	0.000	0.000	0.000	0.942	0.942
39:00:00	0.000	0.000	0.000	0.000	0.918	0.918
40:00:00	0.000	0.000	0.000	0.000	0.895	0.895
41:00:00	0.000	0.000	0.000	0.000	0.872	0.872
42:00:00	0.000	0.000	0.000	0.000	0.850	0.850
43:00:00	0.000	0.000	0.000	0.000	0.829	0.829
44:00:00	0.000	0.000	0.000	0.000	0.808	0.808
45:00:00	0.000	0.000	0.000	0.000	0.787	0.787
46:00:00	0.000	0.000	0.000	0.000	0.767	0.767
47:00:00	0.000	0.000	0.000	0.000	0.748	0.748
48:00:00	0.000	0.000	0.000	0.000	0.729	0.729
49:00:00	0.000	0.000	0.000	0.000	0.711	0.711
50:00:00	0.000	0.000	0.000	0.000	0.693	0.693
51:00:00	0.000	0.000	0.000	0.000	0.675	0.675
52:00:00	0.000	0.000	0.000	0.000	0.658	0.658
53:00:00	0.000	0.000	0.000	0.000	0.641	0.641
54:00:00	0.000	0.000	0.000	0.000	0.625	0.625
55:00:00	0.000	0.000	0.000	0.000	0.609	0.609
56:00:00	0.000	0.000	0.000	0.000	0.594	0.594
57:00:00	0.000	0.000	0.000	0.000	0.579	0.579
58:00:00	0.000	0.000	0.000	0.000	0.564	0.564
59:00:00	0.000	0.000	0.000	0.000	0.550	0.550
60:00:00	0.000	0.000	0.000	0.000	0.536	0.536
61:00:00	0.000	0.000	0.000	0.000	0.523	0.523
62:00:00	0.000	0.000	0.000	0.000	0.509	0.509
63:00:00	0.000	0.000	0.000	0.000	0.496	0.496
64:00:00	0.000	0.000	0.000	0.000	0.484	0.484
65:00:00	0.000	0.000	0.000	0.000	0.472	0.472
66:00:00	0.000	0.000	0.000	0.000	0.460	0.460
67:00:00	0.000	0.000	0.000	0.000	0.448	0.448
68:00:00	0.000	0.000	0.000	0.000	0.437	0.437
69:00:00	0.000	0.000	0.000	0.000	0.426	0.426
70:00:00	0.000	0.000	0.000	0.000	0.415	0.415

Time (hh:mm:ss)	Rain (mm)	Sewer Loss (m³/s)	Net Rain (mm)	Runoff (m³/s)	Baseflow (m³/s)	Total Flow (m³/s)
71:00:00	0.000	0.000	0.000	0.000	0.404	0.404
72:00:00	0.000	0.000	0.000	0.000	0.394	0.394
73:00:00	0.000	0.000	0.000	0.000	0.384	0.384
74:00:00	0.000	0.000	0.000	0.000	0.375	0.375
75:00:00	0.000	0.000	0.000	0.000	0.365	0.365

Appendix

Catchment descriptors

Name	Value	User-defined value used?
Area (km^2)	9.47	No
ALTBAR	106	No
ASPBAR	67	No
ASPVAR	0.14	No
BFIHOST	0.37	No
BFIHOST19	0.35	No
DPLBAR (km)	3.12	No
DPSBAR (mkm^{-1})	28	No
FARL	1	No
LDP	6.85	No
PROPWET	0.26	No
RMED1H	11.2	No
RMED1D	28.5	No
RMED2D	36.8	No
SAAR (mm)	596	No
SAAR4170 (mm)	645	No
SPRHOST	45.39	No
Urbext2000	0	No
Urbext1990	0	No
URBCONC	0	No
URBLOC	0	No
DDF parameter C	-0.02	No
DDF parameter D1	0.29	No
DDF parameter D2	0.31	No
DDF parameter D3	0.27	No
DDF parameter E	0.31	No
DDF parameter F	2.5	No
DDF parameter C (1km grid value)	-0.02	No
DDF parameter D1 (1km grid value)	0.29	No
DDF parameter D2 (1km grid value)	0.31	No
DDF parameter D3 (1km grid value)	0.28	No
DDF parameter E (1km grid value)	0.31	No
DDF parameter F (1km grid value)	2.5	No

UK Design Flood Estimation

Generated on 19 January 2023 13:33:47 by gfrisby
Printed from the ReFH2 Flood Modelling software package, version 3.3.8355.27598

Summary of estimate using the Flood Estimation Handbook revitalised flood hydrograph method (ReFH2)

Site details Checksum: 614C-19F2

Site name: FEH_Catchment_Descriptors_564400_246750

Easting: 564400

Northing: 246750

Country: England, Wales or Northern Ireland

Catchment Area (km^2): 9.47

Using plot scale calculations: No

Model: 2.3

Site description: None

Model run: 1000 year

Summary of results

Rainfall - FEH 2013 model (mm):	129.96	Total runoff (ML):	456.98
Total Rainfall (mm):	83.22	Total flow (ML):	788.36
Peak Rainfall (mm):	22.63	Peak flow (m^3/s):	12.57

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)	09:00:00	No
Timestep (hh:mm:ss)	01:00:00	No
SCF (Seasonal correction factor)	0.67	No
ARF (Areal reduction factor)	0.96	No
Seasonality	Winter	No

Loss model parameters

Name	Value	User-defined?
Cini (mm)	128.8	No
Cmax (mm)	294.28	No
Use alpha correction factor	No	No
Alpha correction factor	n/a	No

Routing model parameters

Name	Value	User-defined?
Tp (hr)	5.92	No
Up	0.65	No
Uk	0.8	No

Baseflow model parameters

Name	Value	User-defined?
BF0 (m^3/s)	0.36	No
BL (hr)	39.04	No
BR	0.73	No

Urbanisation parameters

Name	Value	User-defined?
Urban area (km^2)	0.07	No
Urbext 2000	0	No
Impervious runoff factor	0.7	No
Imperviousness factor	0.4	No
Tp scaling factor	0.75	No
Depression storage depth (mm)	0.5	No
Exporting drained 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 (m^3/s)	Net Rain (mm)	Runoff (m^3/s)	Baseflow (m^3/s)	Total Flow (m^3/s)
00:00:00	2.378	0.000	1.053	0.000	0.360	0.360
01:00:00	4.462	0.000	2.027	0.026	0.351	0.377
02:00:00	8.297	0.000	3.949	0.127	0.344	0.471
03:00:00	15.156	0.000	7.817	0.376	0.340	0.716
04:00:00	22.632	0.000	13.124	0.914	0.343	1.257
05:00:00	15.156	0.000	9.760	1.966	0.360	2.326
06:00:00	8.297	0.000	5.673	3.578	0.402	3.980
07:00:00	4.462	0.000	3.147	5.520	0.474	5.995
08:00:00	2.378	0.000	1.705	7.549	0.582	8.130
09:00:00	0.000	0.000	0.000	9.445	0.722	10.167
10:00:00	0.000	0.000	0.000	10.893	0.889	11.783
11:00:00	0.000	0.000	0.000	11.497	1.072	12.569
12:00:00	0.000	0.000	0.000	11.239	1.253	12.492
13:00:00	0.000	0.000	0.000	10.423	1.420	11.842
14:00:00	0.000	0.000	0.000	9.312	1.565	10.876
15:00:00	0.000	0.000	0.000	8.078	1.685	9.763
16:00:00	0.000	0.000	0.000	6.894	1.779	8.673
17:00:00	0.000	0.000	0.000	5.887	1.852	7.739
18:00:00	0.000	0.000	0.000	5.053	1.905	6.958
19:00:00	0.000	0.000	0.000	4.331	1.943	6.274
20:00:00	0.000	0.000	0.000	3.673	1.968	5.641
21:00:00	0.000	0.000	0.000	3.052	1.980	5.032
22:00:00	0.000	0.000	0.000	2.445	1.981	4.426
23:00:00	0.000	0.000	0.000	1.856	1.970	3.826
24:00:00	0.000	0.000	0.000	1.299	1.950	3.248
25:00:00	0.000	0.000	0.000	0.803	1.920	2.723
26:00:00	0.000	0.000	0.000	0.421	1.883	2.304
27:00:00	0.000	0.000	0.000	0.191	1.841	2.032
28:00:00	0.000	0.000	0.000	0.072	1.796	1.869
29:00:00	0.000	0.000	0.000	0.018	1.752	1.770
30:00:00	0.000	0.000	0.000	0.001	1.708	1.709
31:00:00	0.000	0.000	0.000	0.000	1.665	1.665
32:00:00	0.000	0.000	0.000	0.000	1.622	1.622
33:00:00	0.000	0.000	0.000	0.000	1.581	1.581
34:00:00	0.000	0.000	0.000	0.000	1.541	1.541

Time (hh:mm:ss)	Rain (mm)	Sewer Loss (m^3/s)	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	0.000	1.502	1.502
36:00:00	0.000	0.000	0.000	0.000	1.464	1.464
37:00:00	0.000	0.000	0.000	0.000	1.427	1.427
38:00:00	0.000	0.000	0.000	0.000	1.391	1.391
39:00:00	0.000	0.000	0.000	0.000	1.356	1.356
40:00:00	0.000	0.000	0.000	0.000	1.322	1.322
41:00:00	0.000	0.000	0.000	0.000	1.288	1.288
42:00:00	0.000	0.000	0.000	0.000	1.256	1.256
43:00:00	0.000	0.000	0.000	0.000	1.224	1.224
44:00:00	0.000	0.000	0.000	0.000	1.193	1.193
45:00:00	0.000	0.000	0.000	0.000	1.163	1.163
46:00:00	0.000	0.000	0.000	0.000	1.133	1.133
47:00:00	0.000	0.000	0.000	0.000	1.105	1.105
48:00:00	0.000	0.000	0.000	0.000	1.077	1.077
49:00:00	0.000	0.000	0.000	0.000	1.050	1.050
50:00:00	0.000	0.000	0.000	0.000	1.023	1.023
51:00:00	0.000	0.000	0.000	0.000	0.997	0.997
52:00:00	0.000	0.000	0.000	0.000	0.972	0.972
53:00:00	0.000	0.000	0.000	0.000	0.947	0.947
54:00:00	0.000	0.000	0.000	0.000	0.923	0.923
55:00:00	0.000	0.000	0.000	0.000	0.900	0.900
56:00:00	0.000	0.000	0.000	0.000	0.877	0.877
57:00:00	0.000	0.000	0.000	0.000	0.855	0.855
58:00:00	0.000	0.000	0.000	0.000	0.834	0.834
59:00:00	0.000	0.000	0.000	0.000	0.812	0.812
60:00:00	0.000	0.000	0.000	0.000	0.792	0.792
61:00:00	0.000	0.000	0.000	0.000	0.772	0.772
62:00:00	0.000	0.000	0.000	0.000	0.752	0.752
63:00:00	0.000	0.000	0.000	0.000	0.733	0.733
64:00:00	0.000	0.000	0.000	0.000	0.715	0.715
65:00:00	0.000	0.000	0.000	0.000	0.697	0.697
66:00:00	0.000	0.000	0.000	0.000	0.679	0.679
67:00:00	0.000	0.000	0.000	0.000	0.662	0.662
68:00:00	0.000	0.000	0.000	0.000	0.645	0.645
69:00:00	0.000	0.000	0.000	0.000	0.629	0.629
70:00:00	0.000	0.000	0.000	0.000	0.613	0.613

Time (hh:mm:ss)	Rain (mm)	Sewer Loss (m³/s)	Net Rain (mm)	Runoff (m³/s)	Baseflow (m³/s)	Total Flow (m³/s)
71:00:00	0.000	0.000	0.000	0.000	0.597	0.597
72:00:00	0.000	0.000	0.000	0.000	0.582	0.582
73:00:00	0.000	0.000	0.000	0.000	0.568	0.568
74:00:00	0.000	0.000	0.000	0.000	0.553	0.553
75:00:00	0.000	0.000	0.000	0.000	0.539	0.539
76:00:00	0.000	0.000	0.000	0.000	0.526	0.526
77:00:00	0.000	0.000	0.000	0.000	0.512	0.512
78:00:00	0.000	0.000	0.000	0.000	0.499	0.499
79:00:00	0.000	0.000	0.000	0.000	0.487	0.487
80:00:00	0.000	0.000	0.000	0.000	0.474	0.474
81:00:00	0.000	0.000	0.000	0.000	0.462	0.462
82:00:00	0.000	0.000	0.000	0.000	0.451	0.451
83:00:00	0.000	0.000	0.000	0.000	0.439	0.439
84:00:00	0.000	0.000	0.000	0.000	0.428	0.428
85:00:00	0.000	0.000	0.000	0.000	0.417	0.417
86:00:00	0.000	0.000	0.000	0.000	0.407	0.407
87:00:00	0.000	0.000	0.000	0.000	0.397	0.397
88:00:00	0.000	0.000	0.000	0.000	0.387	0.387
89:00:00	0.000	0.000	0.000	0.000	0.377	0.377
90:00:00	0.000	0.000	0.000	0.000	0.367	0.367

Appendix

Catchment descriptors

Name	Value	User-defined value used?
Area (km^2)	9.47	No
ALTBAR	106	No
ASPBAR	67	No
ASPVAR	0.14	No
BFIHOST	0.37	No
BFIHOST19	0.35	No
DPLBAR (km)	3.12	No
DPSBAR (mkm^{-1})	28	No
FARL	1	No
LDP	6.85	No
PROPWET	0.26	No
RMED1H	11.2	No
RMED1D	28.5	No
RMED2D	36.8	No
SAAR (mm)	596	No
SAAR4170 (mm)	645	No
SPRHOST	45.39	No
Urbext2000	0	No
Urbext1990	0	No
URBCONC	0	No
URBLOC	0	No
DDF parameter C	-0.02	No
DDF parameter D1	0.29	No
DDF parameter D2	0.31	No
DDF parameter D3	0.27	No
DDF parameter E	0.31	No
DDF parameter F	2.5	No
DDF parameter C (1km grid value)	-0.02	No
DDF parameter D1 (1km grid value)	0.29	No
DDF parameter D2 (1km grid value)	0.31	No
DDF parameter D3 (1km grid value)	0.28	No
DDF parameter E (1km grid value)	0.31	No
DDF parameter F (1km grid value)	2.5	No

UK Design Flood Estimation

Summary of ESS/Pooled Estimation Analysis using the Flood Estimation Handbook Statistical Method

Date of creation:	29-06-2022 22:13:09
Software:	WINFAP Version: 5.0.7947 (29986)
Peak Flow dataset:	Peak Flow Dataset 10.0.0
Supplementary data used:	No

Site details

Site number:	2676182186
Site name:	Thurlow Downstream
Site location:	TL 64400 46750
Easting:	564400
Northing:	246750
Catchment area:	9.47 km^2
SAAR:	596 mm
BFIHOST19:	0.352
FPEXT:	0.060
FARL:	1.000
URBEXT2000:	0.0044

Analysis settings

At-site data

At-site data present:	No

Urbanisation settings

User defined:	No
Urban area:	0.07 km^2
PRimp:	70.00%
Impervious Factor:	0.300
UAF:	1.00400

Growth curve settings

Distance Measure Method:	Small catchment
Pooling group URBEXT2000 Threshold:	0.030
Deurbanise Pooling Group L-moments:	Yes

QMED settings

Use at-site data:	No
Method:	Donor Station(s)

Growth curve data and results

Pooling Group

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised	Discordancy
27073 (Brompton Beck @ Snainton Ings)	0.560	40	0.816	0.214	**0.215**	0.020	**0.019**	0.621
26016 (Gypsey Race @ Kirby Grindalythe)	0.797	23	0.101	0.312	**0.312**	0.258	**0.258**	0.155
36010 (Bumpstead Brook @ Broad Green)	0.847	53	7.500	0.377	**0.379**	0.173	**0.172**	0.651
25019 (Leven @ Easby)	1.018	42	5.384	0.338	**0.339**	0.386	**0.385**	0.760
27051 (Crimple @ Burn Bridge)	1.041	48	4.544	0.219	**0.220**	0.146	**0.145**	0.632
26014 (Water Forlornes @ Driffield)	1.116	22	0.431	0.298	**0.299**	0.120	**0.119**	0.475
36004 (Chad Brook @ Long Melford)	1.322	53	4.938	0.304	**0.305**	0.167	**0.166**	0.447
39033 (Winterbourne Stream @ Bagnor)	1.347	58	0.401	0.342	**0.342**	0.383	**0.382**	1.437
33054 (Babingley @ Castle Rising)	1.354	44	1.132	0.204	**0.205**	0.069	**0.068**	0.783
7011 (Black Burn @ Pluscarden Abbey)	1.376	7	5.205	0.544	**0.544**	0.571	**0.571**	2.507
36003 (Box @ Polstead)	1.424	60	3.875	0.314	**0.317**	0.088	**0.086**	0.587
26013 (Driffield Trout Stream @ Driffield)	1.430	10	2.685	0.292	**0.293**	0.281	**0.280**	2.634
36007 (Belchamp Brook @ Bardfield Bridge)	1.447	55	4.630	0.378	**0.378**	0.112	**0.111**	1.312
Total		**515**						

Short records Discordant No Pooling No Pooling, no QMED

Pooling Group Rejected Stations

Station	Distance	Years of data	QMED AM	L-CV Observed	L-CV Deurbanised	L-SKEW Observed	L-SKEW Deurbanised

Growth curve L-moments

Rural L-CV:	0.311	Urban L-CV:	0.310
Rural L-Skewness:	0.190	Urban L-Skewness:	0.191

Rural fitted parameters

Distribution	Location	Scale	Shape	H	Bound
GL	1.000	0.324	-0.190		-0.704
GEV	0.821	0.487	-0.031		-14.800
LN3	1.000	0.578	-0.392		-0.473

Urban fitted parameters

Distribution	Location	Scale	Shape	H	Bound
GL	1.000	0.323	-0.191		-0.692
GEV	0.821	0.485	-0.032		-14.188
LN3	1.000	0.576	-0.394		-0.463

Goodness of fit

GL:	1.1025 *
GEV:	-0.9213 *
P3:	-2.0405
GP:	-5.4251
KAP3:	0.3631 *

** Distribution gives an acceptable fit (absolute Z value < 1.645)*

Heterogeneity

Standardised test value H2: 3.4012

The pooling group is heterogeneous and a review of the pooling group is desirable.

Standardised growth curves

Rural

Return period	GL	GEV	LN3
2	1.000	1.000	1.000
5	1.514	1.568	1.576
10	1.883	1.955	1.963
20	2.278	2.335	2.336
25	2.414	2.457	2.455
30	2.528	2.558	2.552
50	2.867	2.840	2.825
75	3.158	3.066	3.042
100	3.377	3.228	3.197
200	3.957	3.623	3.575
500	4.847	4.157	4.085
1000	5.630	4.571	4.480

Urban

Return period	GL	GEV	LN3
2	1.000	1.000	1.000
5	1.512	1.566	1.575
10	1.881	1.953	1.961
20	2.276	2.333	2.334
25	2.411	2.455	2.453
30	2.525	2.555	2.550
50	2.864	2.838	2.823
75	3.155	3.064	3.040
100	3.375	3.226	3.195
200	3.955	3.622	3.573
500	4.846	4.158	4.084
1000	5.630	4.574	4.480

QMED data and results

Donor selection criteria

Only sites suitable for QMED:	Yes
URBEXT2000:	<0.030
Donor adjusted FSE:	1.331
No. of donors:	6

Donor stations

Station	Distance	URBEXT	Use QMED obs deurbanised	QMED obs	QMED deurbanised	QMED CDs urban	QMED CDs rural	Centroid X	Centroid Y	Area	SA
*Thurlow Downstream @ TL 64400 46750)		0.004						563328	246082	9.470	59
36010 (Bumpstead Brook @ Broad Green)	5.48	0.007	Yes	7.500	**7.448**	3.797	3.797	565864	241223	27.582	58
33055 (Granta @ Babraham)	5.69	0.012	Yes	3.964	**3.876**	3.552	3.552	557639	246192	101.972	57
36008 (Stour @ Westmill)	6.70	0.023	Yes	16.850	**16.472**	20.720	20.720	569914	247315	222.820	58
36012 (Stour @ Kedington)	6.71	0.010	Yes	12.000	**11.886**	9.061	9.061	567273	251505	76.642	59
37016 (Pant @ Copford Hall)	10.46	0.009	Yes	7.470	**7.406**	7.394	7.394	562347	235667	63.800	58
37012 (Colne @ Poolstreet)	12.61	0.009	Yes	9.636	**9.556**	6.794	6.794	572775	237728	64.490	57

Unused Donor stations

Station	Distance	URBEXT	Use QMED obs deurbanised	QMED obs	QMED deurbanised	QMED CDs urban	QMED CDs rural	Centroid X	Centroid Y	Area	SA
36015 (Stour @ Lamarsh)	13.58	0.021	Yes	30.600	**29.914**	31.003	31.003	576876	247077	481.290	58
37017 (Blackwater @ Stisted)	14.42	0.025	Yes	14.300	**13.901**	10.623	10.623	567758	232356	140.377	57
33051 (Cam @ Chesterford)	15.36	0.025	Yes	7.860	**7.559**	6.817	6.817	551710	236033	140.018	59
36006 (Stour @ Langham)	16.26	0.019	Yes	28.200	**27.585**	31.551	31.551	579556	245068	571.362	58

QMED

Rural:	1.982 m^3/s
Urban:	1.990 m^3/s

Flood Frequency Curve

Rural Flood Frequency Curve

Return period	GL (m^3/s)	GEV (m^3/s)	LN3 (m^3/s)
2	1.982	1.982	1.982
5	3.000	3.107	3.124
10	3.732	3.874	3.889

Urban Flood Frequency Curve

Return period	GL (m^3/s)	GEV (m^3/s)	LN3 (m^3/s)
2	1.990	1.990	1.990
5	3.009	3.117	3.134
10	3.743	3.886	3.901

Rural Flood Frequency Curve

20	4.515	4.628	4.629
25	4.783	4.870	4.865
30	5.009	5.069	5.058
50	5.681	5.628	5.598
75	6.258	6.076	6.029
100	6.693	6.397	6.336
200	7.841	7.179	7.084
500	9.604	8.238	8.094
1000	11.156	9.059	8.878

Urban Flood Frequency Curve

20	4.528	4.642	4.644
25	4.798	4.885	4.881
30	5.025	5.084	5.074
50	5.699	5.646	5.616
75	6.278	6.097	6.049
100	6.715	6.419	6.357
200	7.869	7.207	7.109
500	9.642	8.273	8.125
1000	11.203	9.101	8.913

EUROPEAN OFFICES

United Kingdom

AYLESBURY
T: +44 (0)1844 337380

BELFAST
T: +44 (0)28 9073 2493

BRADFORD-ON-AVON
T: +44 (0)1225 309400

BRISTOL
T: +44 (0)117 906 4280

CAMBRIDGE
T: + 44 (0)1223 813805

CARDIFF
T: +44 (0)29 2049 1010

CHELMSFORD
T: +44 (0)1245 392170

EDINBURGH
T: +44 (0)131 335 6830

EXETER
T: + 44 (0)1392 490152

GLASGOW
T: +44 (0)141 353 5037

GUILDFORD
T: +44 (0)1483 889800

LEEDS
T: +44 (0)113 258 0650

LONDON
T: +44 (0)203 691 5810

MAIDSTONE
T: +44 (0)1622 609242

MANCHESTER
T: +44 (0)161 872 7564

NEWCASTLE UPON TYNE
T: +44 (0)191 261 1966

NOTTINGHAM
T: +44 (0)115 964 7280

SHEFFIELD
T: +44 (0)114 245 5153

SHREWSBURY
T: +44 (0)1743 23 9250

STAFFORD
T: +44 (0)1785 241755

STIRLING
T: +44 (0)1786 239900

WORCESTER
T: +44 (0)1905 751310

Ireland

DUBLIN
T: + 353 (0)1 296 4667

France

GRENOBLE
T: +33 (0)4 76 70 93 41