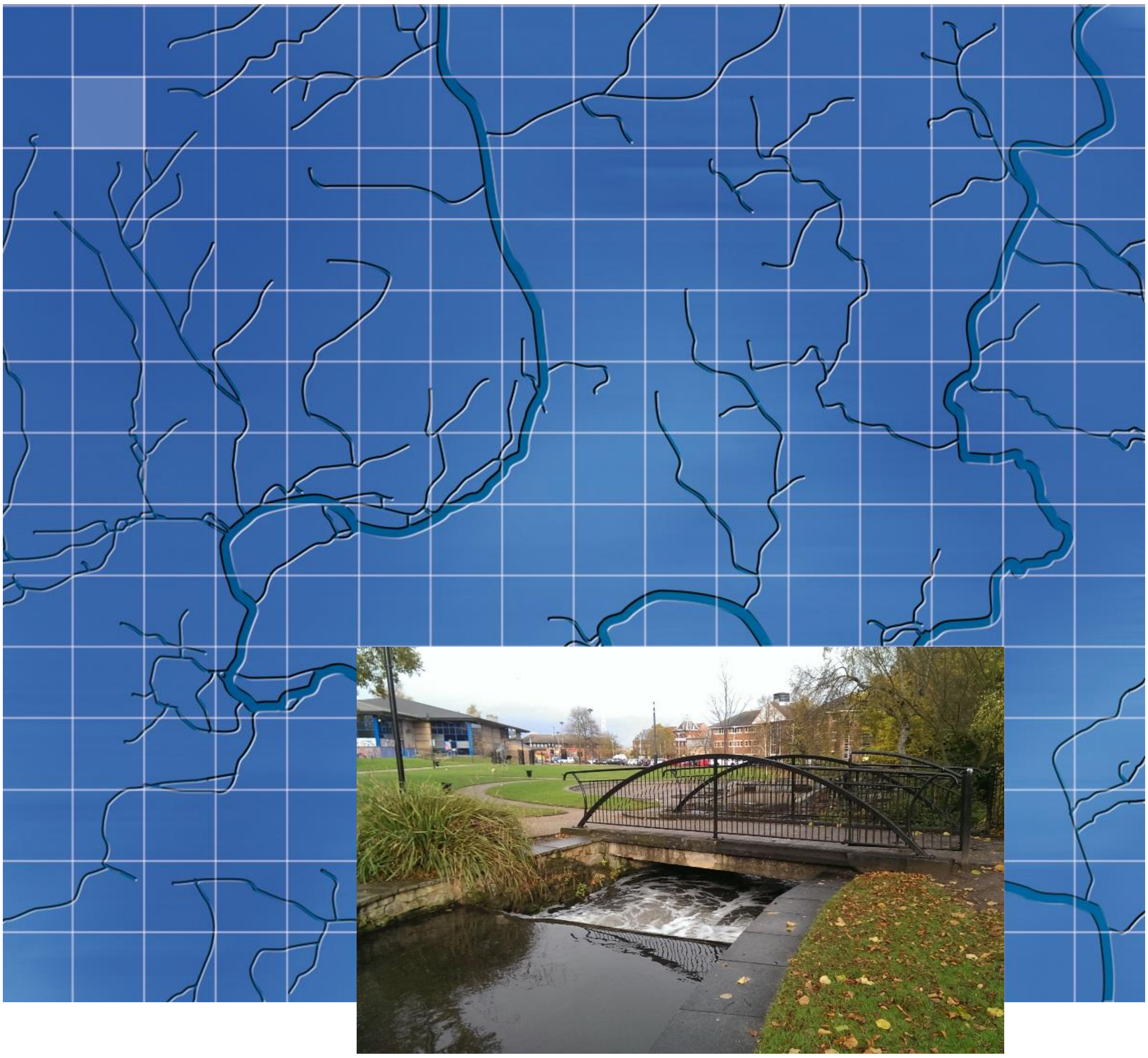
Mansfield District Council

February 2018

Mansfield Central Area Hydraulic Modelling Report



Wallingford HydroSolutions Limited
www.hydrosolutions.co.uk

Mansfield District Council

Mansfield Central Area Hydraulic Modelling Report

Document issue details

WHS1469

Version	Issue date	Issue status	Prepared By	Approved By
1	20/04/2017	Draft	Alexandros Petrakis (*Flood Risk Consultant*)	Laura Clements (*Senior Consultant*)
1.1	05/01/2018	Final	Alexandros Petrakis (Consultant)	Paul Blackman (*Technical Director*)
1.2	08/02/2018	Final	Alexandros Petrakis (Consultant)	Paul Blackman (*Technical Director)*

For and on behalf of Wallingford HydroSolutions Ltd.

WHS

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Contents

1 Introduction

1.1 Background

WHS have been commissioned by Mansfield District Council to undertake hydraulic modelling of the River Maun through the central area of Mansfield. It is noted that there is an existing 1D ISIS model for the River Maun, developed by JBA in 2007 for the River Maun Flood Risk Mapping Study, 2007. This model has been obtained from the Environment Agency (EA) to assist with the study, however, it was considered appropriate to develop a new model of the River Maun utilizing the latest available survey data.

1.2 Scope

The model and associated outputs will be used to inform the overall flood risk review of the Mansfield central area. This, in turn, will inform the emerging Mansfield District Council Local Plan. The flood risk review is to focus on the flood risk and flood risk opportunities through Mansfield in the context of 3 key development sites:

A. White Hart Street – 3.5 ha (draft plan policy MCA1(b));

B. Riverside – 3.9 ha (draft plan policy MCA1(g));

C. Former Mansfield Brewery (part) – 1.2 ha (draft plan policy MCA1(h))

Hydrodynamic modelling will be undertaken for the River Maun for the reach between Quarry Lane railway viaduct (NGR 453218, 360120) and the weir south of Sandy Lane (NGR 454645, 361597).

1.3 Data Sources

It is noted that the best available data currently referred to by the Environment Agency consists of outputs from the River Maun Flood Risk Mapping Study, July 2007, the only existing detailed hydrodynamic model for the study area. Unfortunately, this contradicts the information published in the Mansfield District Council SFRA, which was published in March 2008. These 2 studies will form the basis of the review of existing information, which will also be supplemented with reference to the following pertinent data sources:

- Mansfield District Council SFRA 2008[1]
- Mansfield District Council SFRA Addendum 2016[2]
- River Maun Flood Risk Mapping Study (2007)[3]
- EA flood map[4]
- EA surface water flood map[5]
- Mansfield District Local Plan (2013-2033)[6]
- National Planning Policy Framework[7]

[1] Mansfield District Council Strategic Flood Risk Assessment, Guide for Planners and Developers, June 2008
[2] Addendum to the Strategic Flood Risk Assessment, Mansfield District Council, March 2016
[3] River Maun Flood Risk Mapping, JBA on behalf of the Environment Agency, Final Report, March 2007
[4] Environment Agency Flood Map for Planning (Rivers and Sea), 2016
[5] Long term flood risk information, GOV.UK, 2016
[6] Mansfield District Local Plan – Consultation Draft, Mansfield District Council, January 2016
[7] National Planning Policy Framework, Department for Communities and Local Government, March 2012

- Nottinghamshire Preliminary Flood Risk Assessment[8]

In addition to the available data from previous studies and reporting, this flood risk review is also informed by a site visit and river channel survey, which was commissioned as part of the study.

[8] Nottinghamshire Preliminary Flood Risk Assessment, Nottinghamshire County Council, June 2011

2 Previous Studies

2.1.1 White Hart FRA - Mott MacDonald 2014

In 2014, Mott MacDonald completed a Flood Risk Assessment (FRA) for a mixed use development in the Bridge Street central area. The existing 1D ISIS model of the River Maun catchment was obtained and updated in order for linkage with a TuFLOW 2D domain. An informal review of the existing model was carried out, suggesting that there were issues with the way in which culvert losses were represented. Mott MacDonald updated the representation of the Rock Valley culvert using intermediate sections, resulting in a 100yr flood level being produced that was similar to the JBA HEC-RAS model. Recommendations for the further modelling included that a rebuild of the model was required, utilizing new survey data to improve the representation of the River Maun.

2.1.2 Mansfield Riverside Renaissance - WYG 2010 HECRAS model

WYG conducted a site-specific FRA for the Mansfield Riverside Renaissance area situated to the south east of the town centre. This study used a copy of the existing River Maun ISIS model and the HECRAS model which was more local to the site and Rock Valley culvert. The Mansfield SFRA and River Maun Hydraulic Modelling report were also referred to.

As a result of the modelling work and further detailed negotiations with the Environment Agency, WYG undertook site specific modelling utilising HECRAS software. Following extensive review and consultation, it was agreed and concluded that the appropriate 1 in 100 year event plus CC flood level for the existing site varied between 99.32m AOD at upstream end of the site and 98.25m AOD at the downstream end of the site. A freeboard of 600mm was proposed, giving a minimum floor level to vary between 99.92m AOD and 98.85m AOD depending on location of the buildings within the site.

3 River Channel Survey, 2016

In order to inform this updated study and in accordance with the recommendations set out by the EA, Interlock Surveys were commissioned to undertake a detailed river channel survey of the River Maun. This was undertaken in November 2016, and consisted of 39 river cross sections in total for the reach between the viaduct at Quarry Lane and the B6033/Bath Lane. A plan showing the surveyed sections is provided as Figure 1, with the identified key development sites also shown.

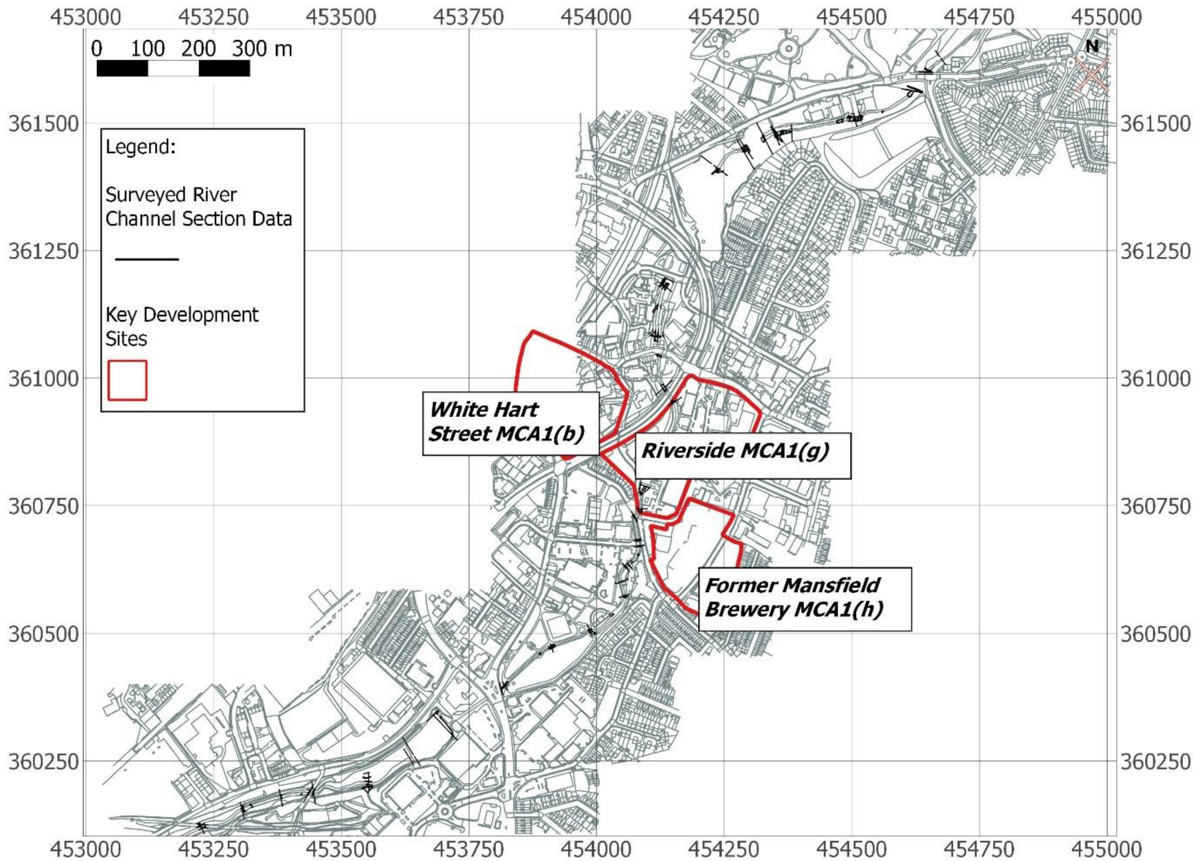


Figure 1- River Channel Survey and Key Development Sites

3.1 Identification of formal flood defences

The MDC SFRA concluded that there are no significant flood defence infrastructure through the Mansfield Central Area. The EA defence dataset was acquired for the study, also showing that thare are no formal flood defences in the study area. Other than high ground, the only informal flood defence was identified on the right bank of the river Maun, between Bath Street and Brunt Street, in the form of a wall that runs parallel to Littleworth. Due to this not being a formal flood defence and the fact that this study intends to update the existing EA flood map (which is based on undefended runs), this feature has not been modelled, resulting in all model runs being undefended.

An additional flood defence has been identified on the left bank of the river Maun parallel to Church Lane. This was not included in the EA defence dataset as anything other than high ground and has again not been modelled due to intention of updating the existing EA flood zones.

4 Hydrological Analysis

4.1 Peak Flow Estimates

The peak flows for the model were obtained using version 4.0 WINFAP software. Flow estimates were also carried out using ReFH2 software, however the WINFAP flows were used as these were the most conservative. Full details on the hydrological analysis can be found in the supplementary hydrology report provided as Appendix 1. Table 1 displays the peak flows used for each return period.

Table 1 - Peak flow values

Return Period (years)	Pooled Analysis Peak Flow estimate (m^3/s)
20	16.47
100	23.99
100yr+30%CC	31.15
1000	40.92

The inflows into the hydraulic model have shown a significant increase compared with the previous hydrological assessment. This has been considered attributable to the way in which the growth curve is adjusted to account for urbanisation and permeability.

4.2 Critical Storm Duration

The catchment was modelled using the ReFH 2.2 software. This uses standard design rainfall events and catchment descriptors to produce hydrographs for the site. The FEH13 rainfall was used to generate the hydrographs.

The recommended duration and time step of 9.0 hours and 1.0 hours respectively were used to define the design rainfall event

4.3 Climate Change Allowances

Liaison with the EA and MDC confirmed the required climate change allowances to incorporate into the model runs. In order to provide a robust assessment of flood risk throughout the centre of Mansfield, and for the three key development sites, a range of climate change allowances were modelled as follows; central allowance (20%), higher central allowance (30%) and the upper end allowance (50%). These values were obtained in line with EA and NPPF climate change guidance for the Humber river basin district.

5 Hydraulic Model Build

The 1D/2D hydraulic model has been developed using the latest Flood Modeller and TuFLOW software. The River Maun channel is modelled in the 1D using Flood Modeller software, and the floodplain is modelled using the 2d model software, TUFLOW. The river channel survey is used to inform the 1D model construction. The floodplain is defined using LiDAR data (2015), which was obtained specifically for this study.

5.1 Model Overview

The new hydraulic model for the River Maun extends from the Quarry Lane railway viaduct (NGR 453218, 360120) to the weir south of Sandy Lane (NGR 454645, 361597), as specified by Mansfield District Council. The model domain is shown in Figure 2 below.

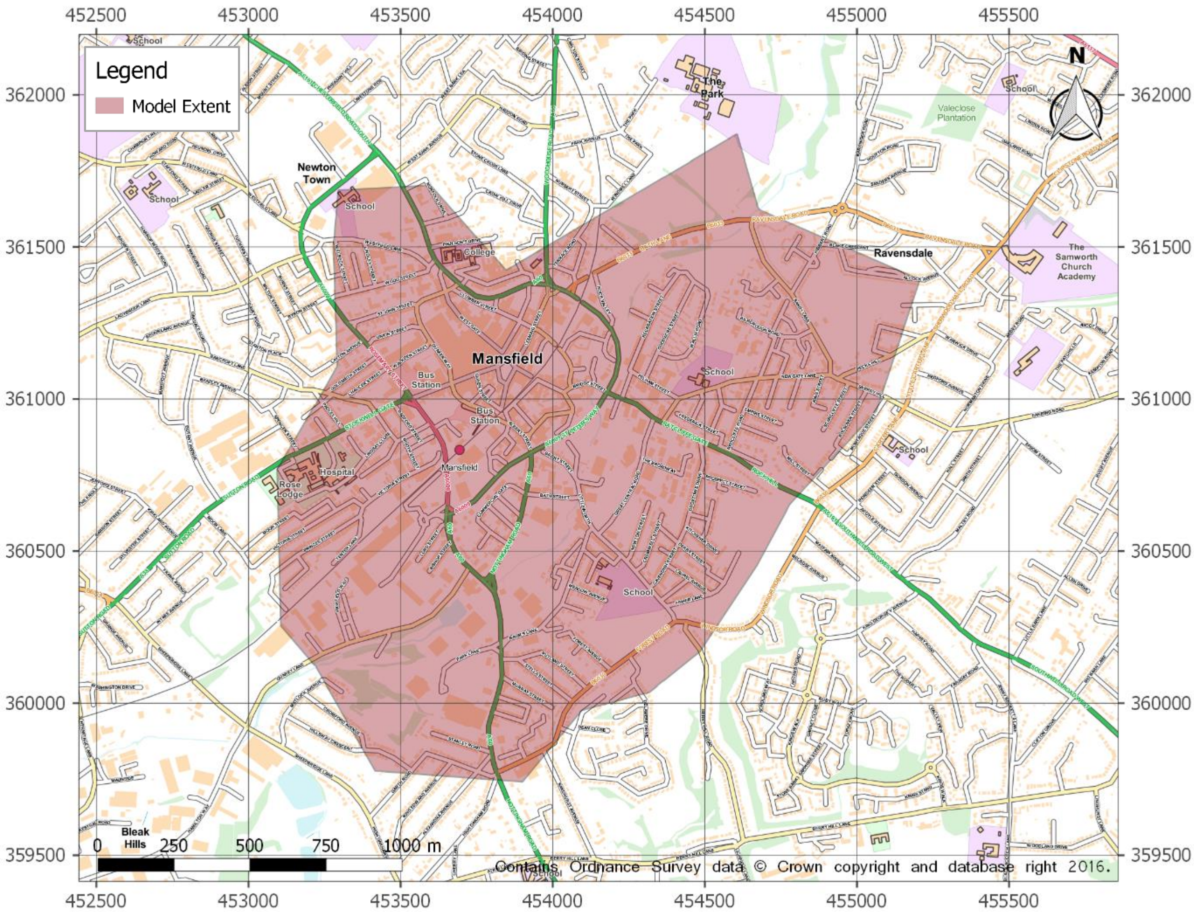


Figure 2- Model extent

5.2 1D Model Build

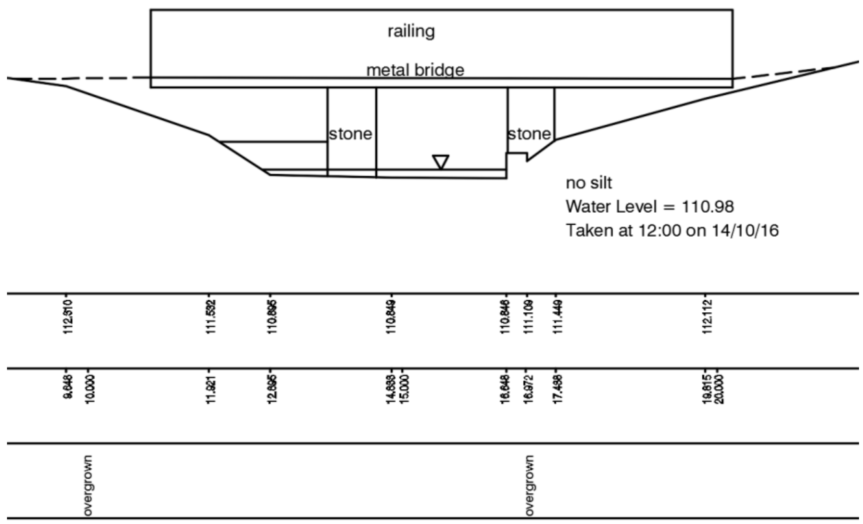
5.2.1 River Channel and Structures

Full details of the review of each structure is provided in this section within the following tables.

Structure #01		**Type**	Bridge
Source of Data	Interlock Survey Data, 2016	**Modelled**	Yes
NGR	453307, 360153	**Node**	MAUN_80bu

- Modelled as an USBPR1978 bridge with default Flood Modeller parameters.
- Cross section and opening dimensions informed from survey data.
- Manning's values as per upstream river channel.
- Spill unit added as per surveyed levels.

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)



Photograph

Structure #02		Type	SCWEIR
Source of Data	Interlock Survey Data, 2016	Modelled	Yes
NGR	453325, 360161	Node	MAUN_98.5

- Modelled as a Sharp Crested Weir with default Flood Modeller parameters.
- Cross section and invert levels informed from survey data.
- Manning's values as per upstream river channel.

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

N/A

Photograph

Structure #03		Type	SCWEIR
Source of Data	Interlock Survey Data, 2016	Modelled	Yes
NGR	453325, 360161	Node	MAUN_98.5

- Modelled as a Sharp Crested Weir with default Flood Modeller parameters.
- Cross section and invert levels informed from survey data.
- Manning's values as per upstream river channel.

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

N/A

Photograph

Structure #04		**Type**	SCWEIR
Source of Data	Interlock Survey Data, 2016	**Modelled**	Yes
NGR	453414, 360185	**Node**	MAUN_195.5

- Modelled as a Sharp Crested Weir with default Flood Modeller parameters.
- Cross section and invert levels informed from survey data.
- Manning's values as per upstream river channel.

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

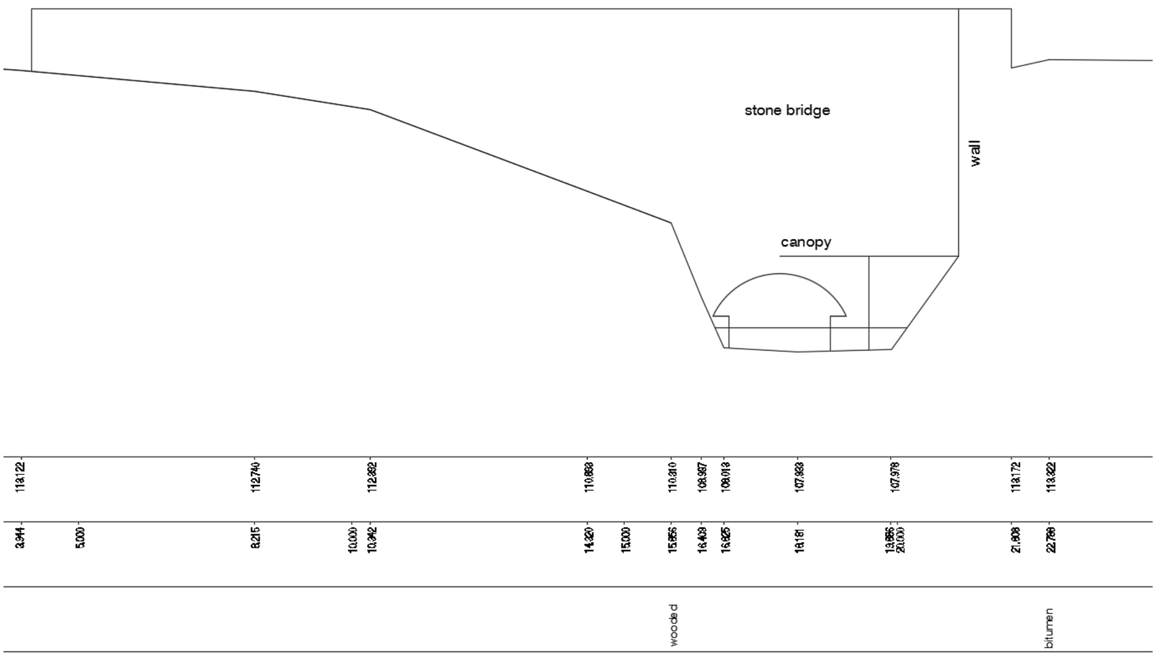
N/A

Photograph

Structure #05		**Type**	Bridge
Source of Data	Interlock Survey Data, 2016	**Modelled**	Yes
NGR	453440, 360186	**Node**	MAUN_208

- Modelled as an ARCH bridge with default Flood Modeller parameters.
- Cross section and opening dimensions informed from survey data.
- Manning's values as per upstream river channel.
- No spill unit specified

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)



Photograph

Structure #06		Type	Reservoir
Source of Data	Interlock Survey Data, 2016 River Maun Model (2007)	Modelled	Yes
NGR	453642, 360258	Node	MAUN_401

- Modelled as a RESERVOIR unit with default Flood Modeller parameters.
- Reservoir geometry informed by previous 2007 model data
- Data from existing 2007 model retained

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

N/A

Photograph

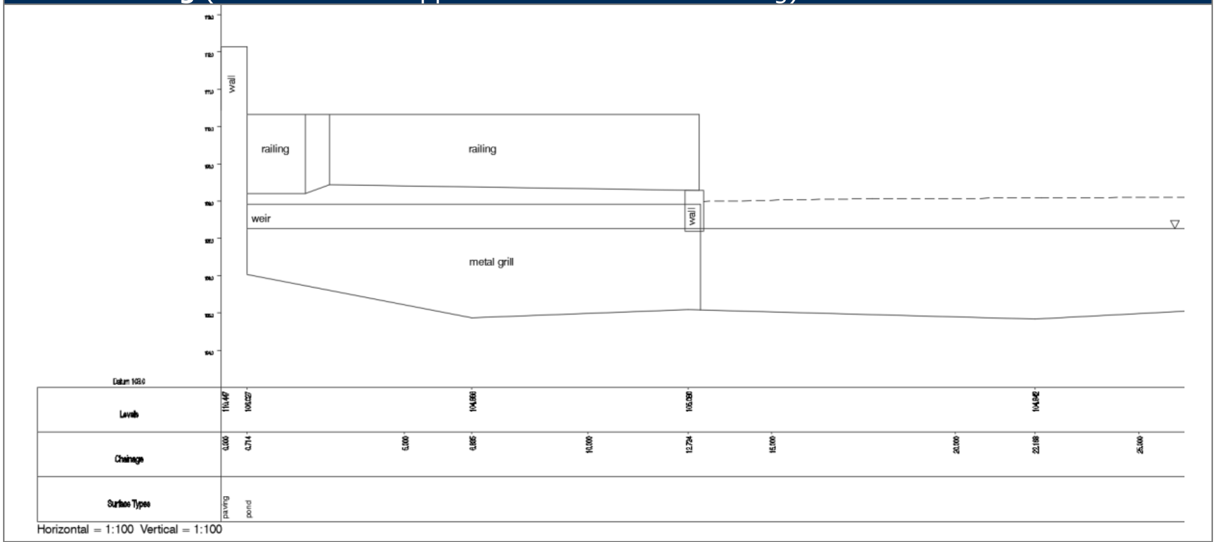
-

Structure #07		Type	Spill
Source of Data	Interlock Survey Data, 2016	Modelled	Yes
NGR	453708, 360317	Node	MAUN_487

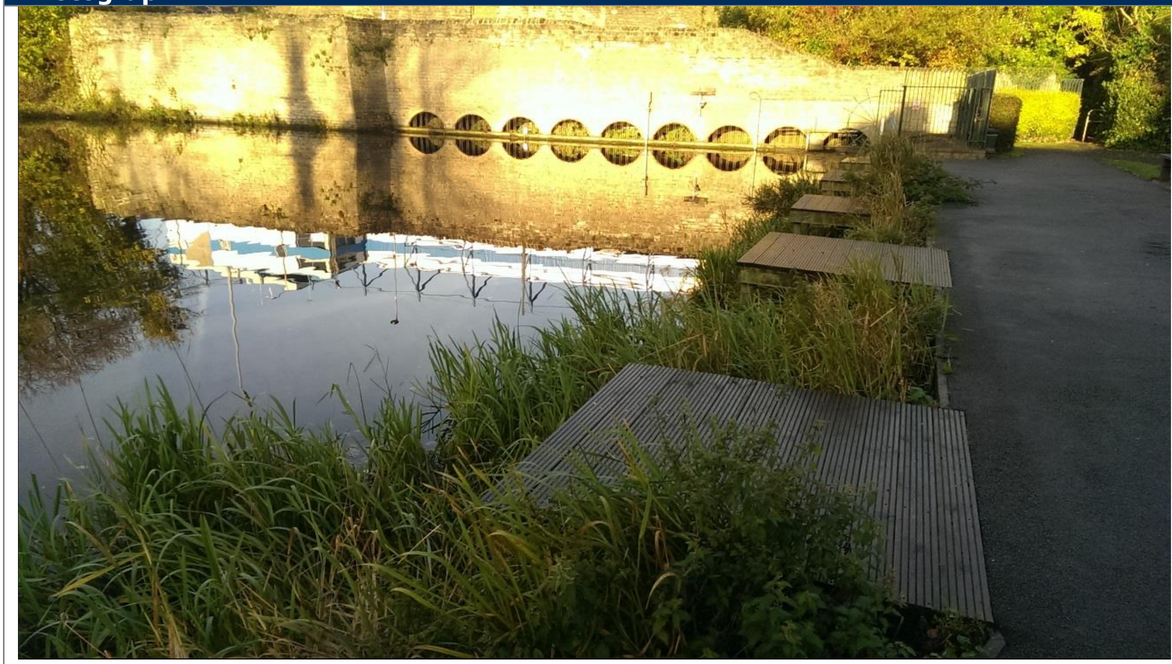
The River Maun reaches the Field Mill Pond, and water exits the pond through a complex system of culvert openings on the northern side. In addition, there is a spill weir protected by a trash screen and metal grate. These convey water underneath the A60 Nottingham Road, and the river re-emerges in Titchfield Park.

- The culvert was represented as a Rectangular Conduit unit
- The series of small overflow orifices on the left bank of the pond are represented as two weirs using spill units (to represent the lateral spillway behind the openings which feeds into the culvert)
- Entrance losses associated with culvert shape and trash screen were modelled using a Culvert Inlet unit
- Culvert Outlet unit used at the downstream face of the rectangular culvert
- Reference to the 2007 model confirmed that this feature was represented using extended 1D sections to represent the pond, followed by two spills to represent the overflow culverts at the northern edge of the pond. The spill onto the main road was represented using a broad crested weir unit.
- The downstream end of the pond discharges into a 0.5m long boxed culvert which drops into another boxed culvert 132m in length, and the river re-emerges downstream of Nottingham Road.
- The approach used in the 2007 was largely retained, with the following amendments:
  - Broad crested weir unit removed as the spill level is represented in the 2D domain.
  - Extended river sections removed, replaced by a reservoir unit.

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)



Photograph



Structure #07		**Type**	Bridge
Source of Data	Interlock Survey Data, 2016	**Modelled**	Yes
NGR	453817, 360395	**Node**	MAUN_624.4bu

- Pipe crossing modelled as a USBPR1978 unit with default Flood Modeller parameters.
- Bridge opening dimensions informed by survey data
- Spill unit inserted to model flow over pipe surface

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

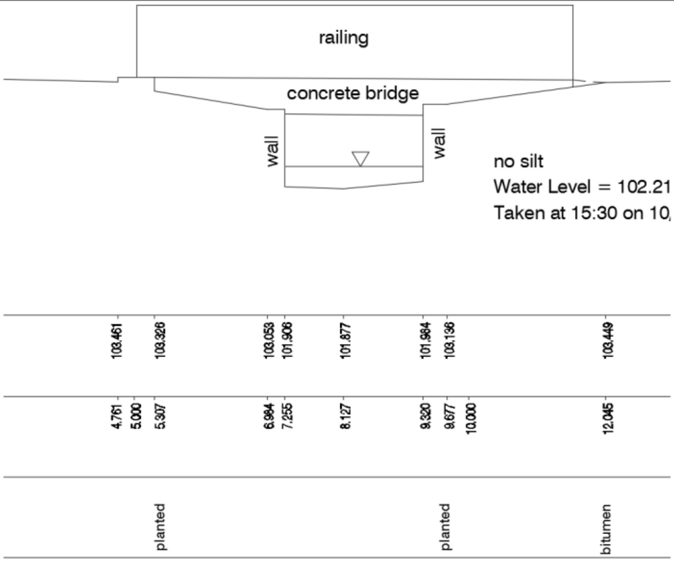
N/A

Photograph

Structure #08		**Type**	Bridge
Source of Data	Interlock Survey Data, 2016	**Modelled**	Yes
NGR	453820, 360397	**Node**	MAUN_626.5bu

- Pedestrian Bridge modelled as a USBPR1978 unit with default Flood Modeller parameters.
- Bridge opening dimensions informed by survey data
- Spill unit inserted to model flow over bridge deck

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

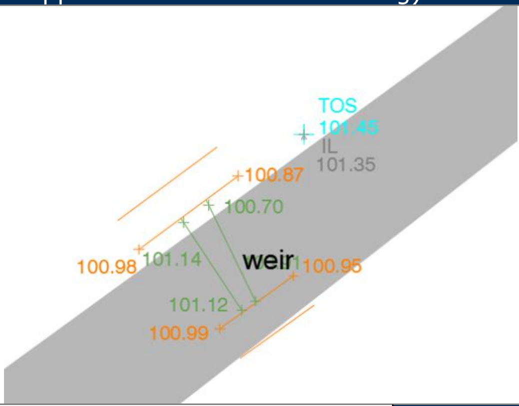


Photograph

Structure #09		Type	SCWEIR
Source of Data	Interlock Survey Data, 2016	Modelled	Yes
NGR	453889, 360458	Node	MAUN_716.5

- Modelled as a Sharp Crested Weir with default Flood Modeller parameters.
- Cross section and invert levels informed from survey data.
- Manning's values as per upstream river channel.

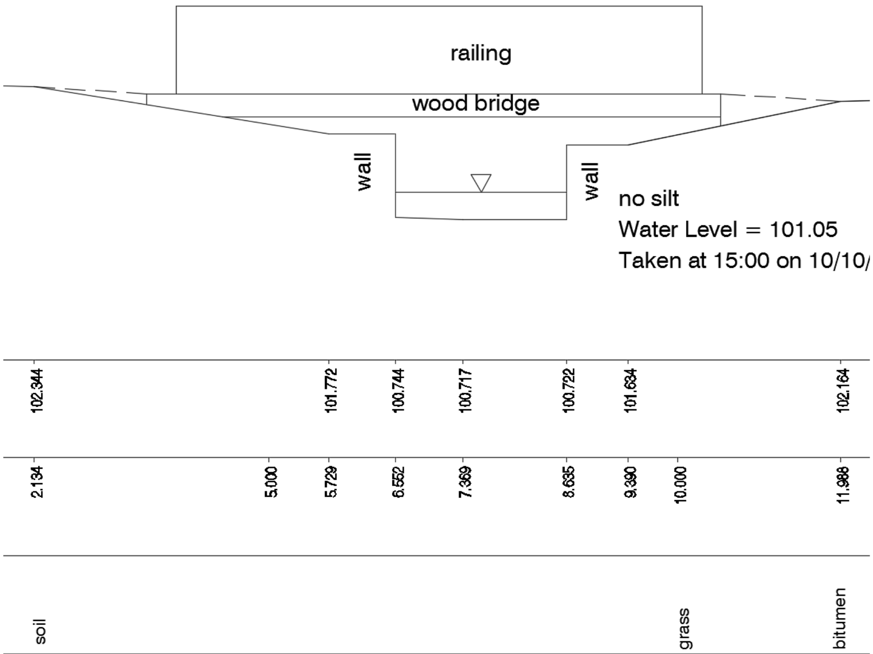
CAD Drawing (See CAD file Appendix 2 for detailed drawing)



Structure #10		**Type**	SCWEIR and Bridge
Source of Data	Interlock Survey Data, 2016	**Modelled**	Yes
NGR	453912, 360472	**Node**	MAUN_734.8 MAUN_739.5bu

- Weir upstream of bridge modelled as SCWEIR unit
- Pedestrian Bridge modelled as a USBPR1978 unit with default Flood Modeller parameters.
- Bridge opening dimensions informed by survey data
- Spill unit inserted to model flow over bridge deck

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

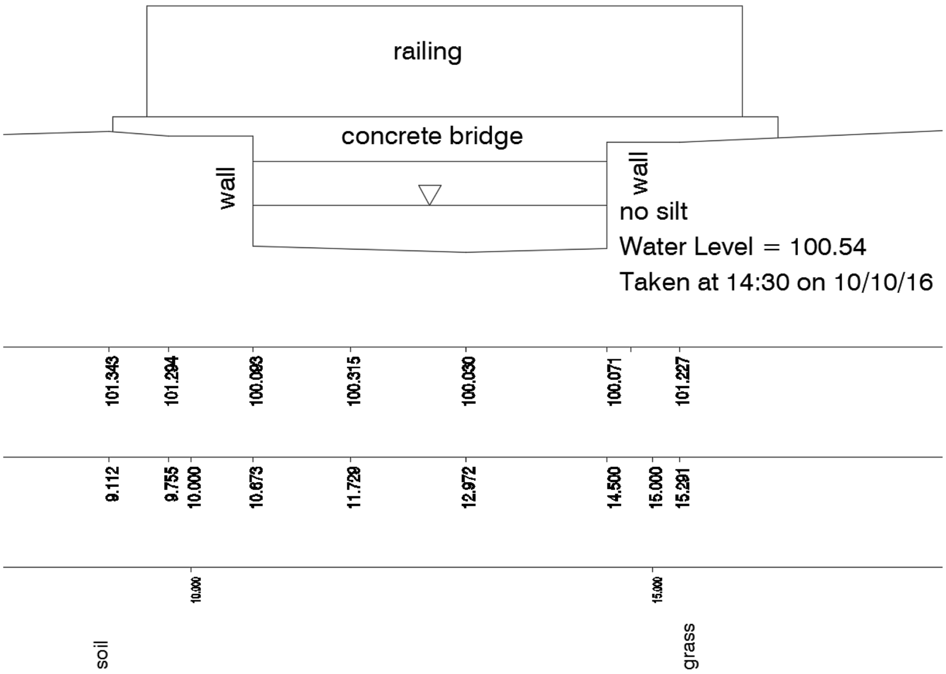


Photograph

Structure #11		**Type**	Weir and Bridge
Source of Data	Interlock Survey Data, 2016	**Modelled**	No
NGR	453989, 360505	**Node**	MAUN_813.5

- Neither bridge or weir modelled due to significant model instability at this location
-

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

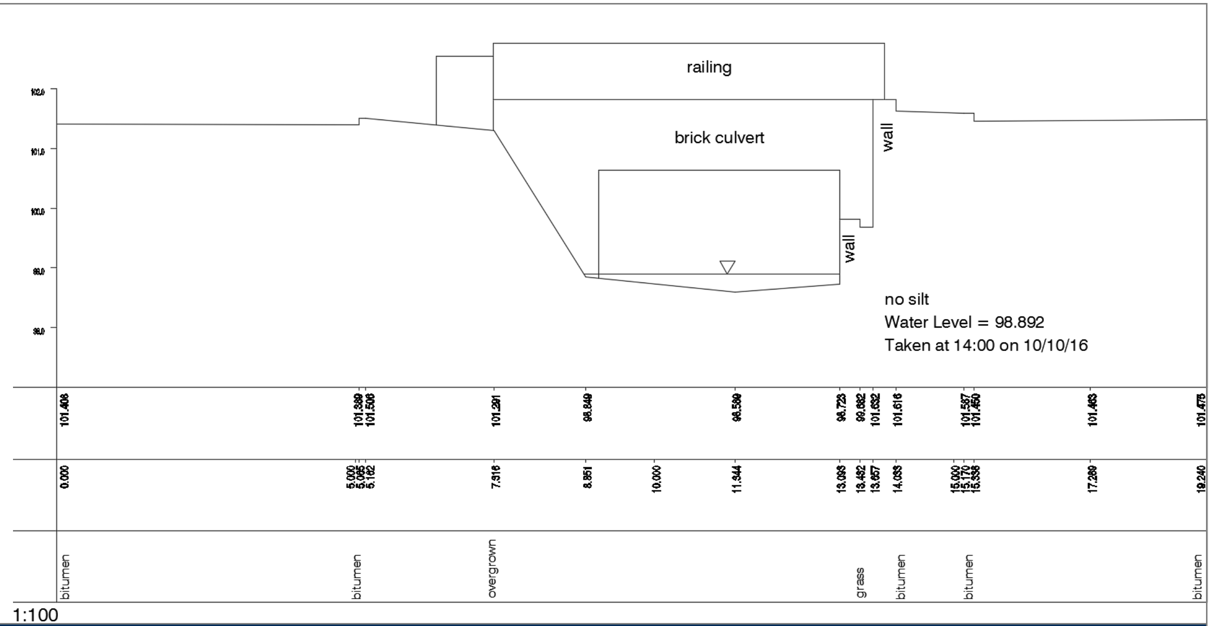


Photograph

Structure #12		Type	Bridge
Source of Data	Interlock Survey Data, 2016	Modelled	Yes
NGR	454055, 360571	Node	MAUN_906.5bu

- Weir immediately upstream not modelled due to model instability
- Modelled as a Rectangular Conduit unit with default Flood Modeller parameters.
- Culvert opening dimensions informed by survey data
- No Spill unit specified
- Culvert inlet and outlet units to specify associated losses

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

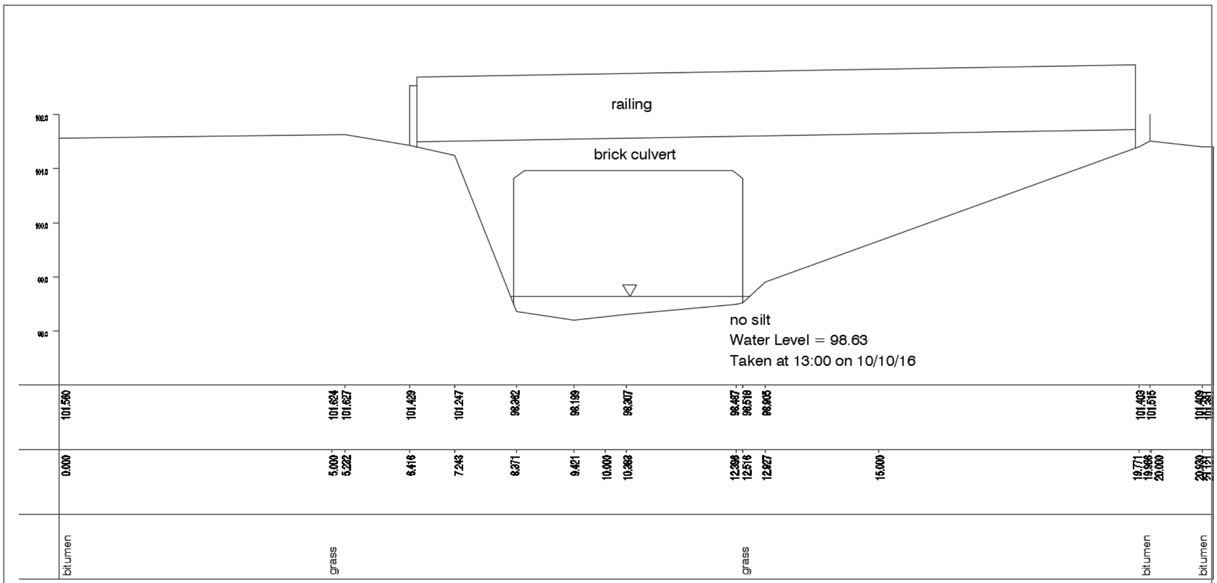


Photograph

Structure #13		**Type**	Bridge
Source of Data	Interlock Survey Data, 2016	**Modelled**	Yes
NGR	454061, 360631	**Node**	MAUN_965

- Modelled as a Rectangular Conduit unit with default Flood Modeller parameters.
- Culvert opening dimensions informed by survey data
- No Spill unit specified
- Culvert inlet and outlet units to specify associated losses

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)



1:100

Photograph

Structure #14		**Type**	Bridge
Source of Data	Interlock Survey Data, 2016	**Modelled**	No
NGR	454067, 360639	**Node**	MAUN_989.1

- Not modelled due to significant model instability
- Similar instability experienced in 2007 model build

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

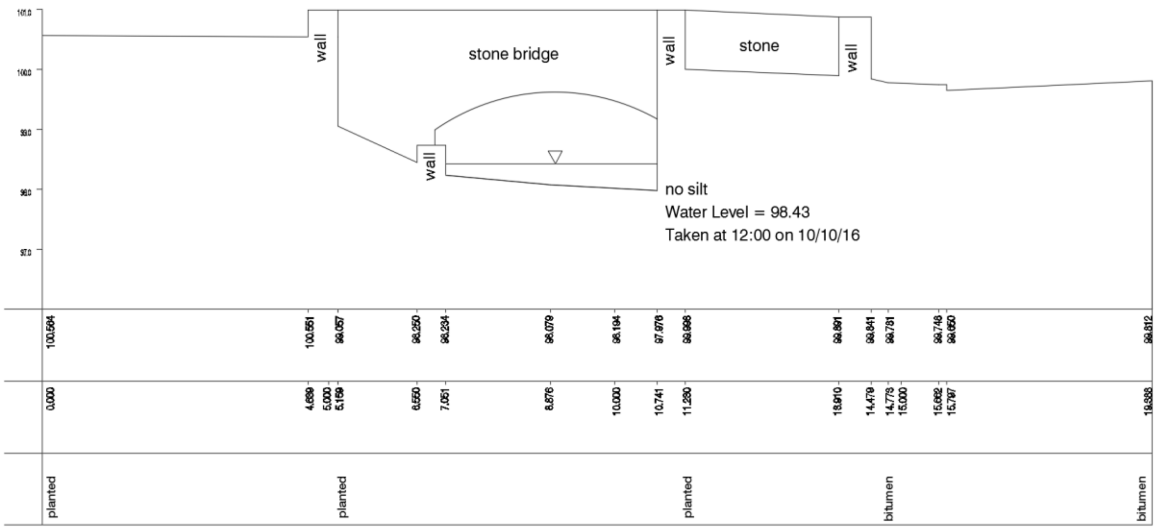
N/A

Photograph

Structure #15		Type	Bridge
Source of Data	Interlock Survey Data, 2016	**Modelled**	Yes
NGR	454081, 360675	**Node**	MAUN_1011bu

- Modelled as an ARCH Bridge unit with default Flood Modeller parameters.
- Bridge opening dimensions informed by survey data
- Spill unit specified

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)



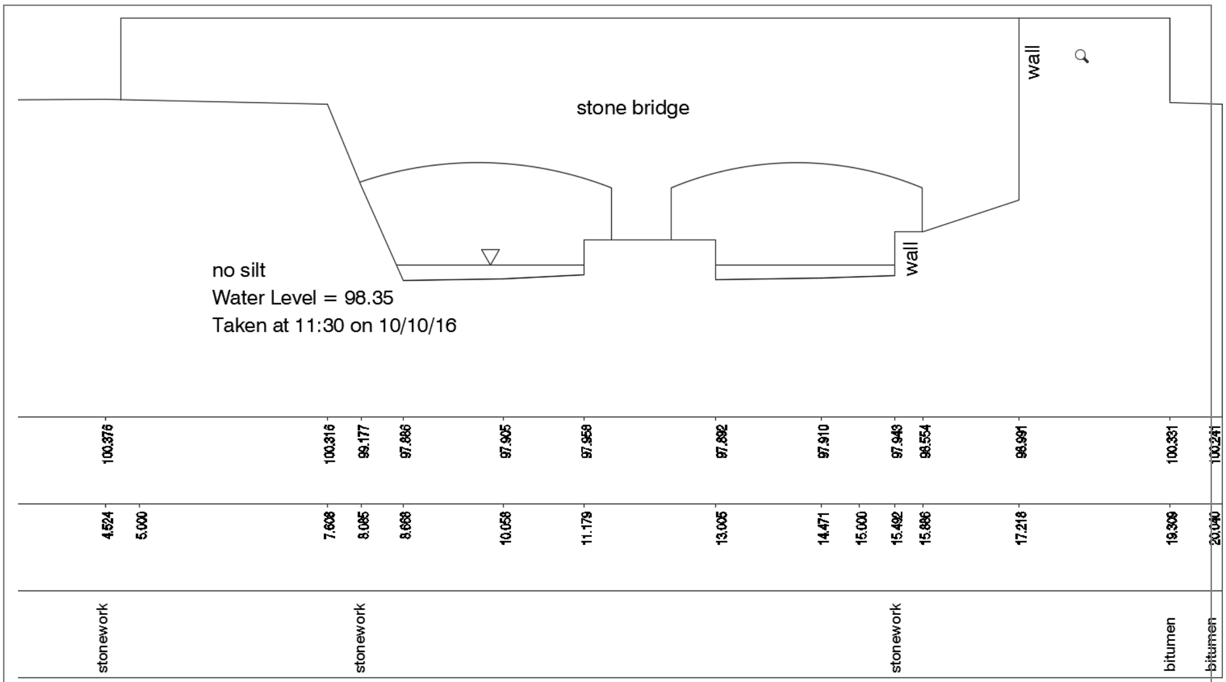
1:100

Photograph

Structure #16		Type	Bridge
Source of Data	Interlock Survey Data, 2016	Modelled	Yes
NGR	454080, 360732	Node	MAUN_1064bu

- Modelled as an ARCH Bridge unit with default Flood Modeller parameters.
- Bridge opening dimensions informed by survey data
- Spill unit specified

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)



stone bridge
wall
wall
no silt
Water Level = 98.35
Taken at 11:30 on 10/10/16
100.376
100.316
99.177
97.886
97.905
97.958
97.892
97.910
97.943
98.554
98.991
100.331
100.241
4.524
5.000
7.608
8.085
8.668
10.058
11.179
13.005
14.471
15.000
15.492
15.886
17.218
19.309
20.040
stonework
stonework
stonework
bitumen
bitumen

Photograph

Structure #17		Type	Pipe Crossing
Source of Data	Interlock Survey Data, 2016	Modelled	Yes
NGR	454087, 360775	Node	MAUN_1103.7bu

- Pipe crossing modelled as a USBPR1978 unit with default Flood Modeller parameters.
- Bridge opening dimensions informed by survey data
- Spill unit inserted to model flow over pipe surface

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

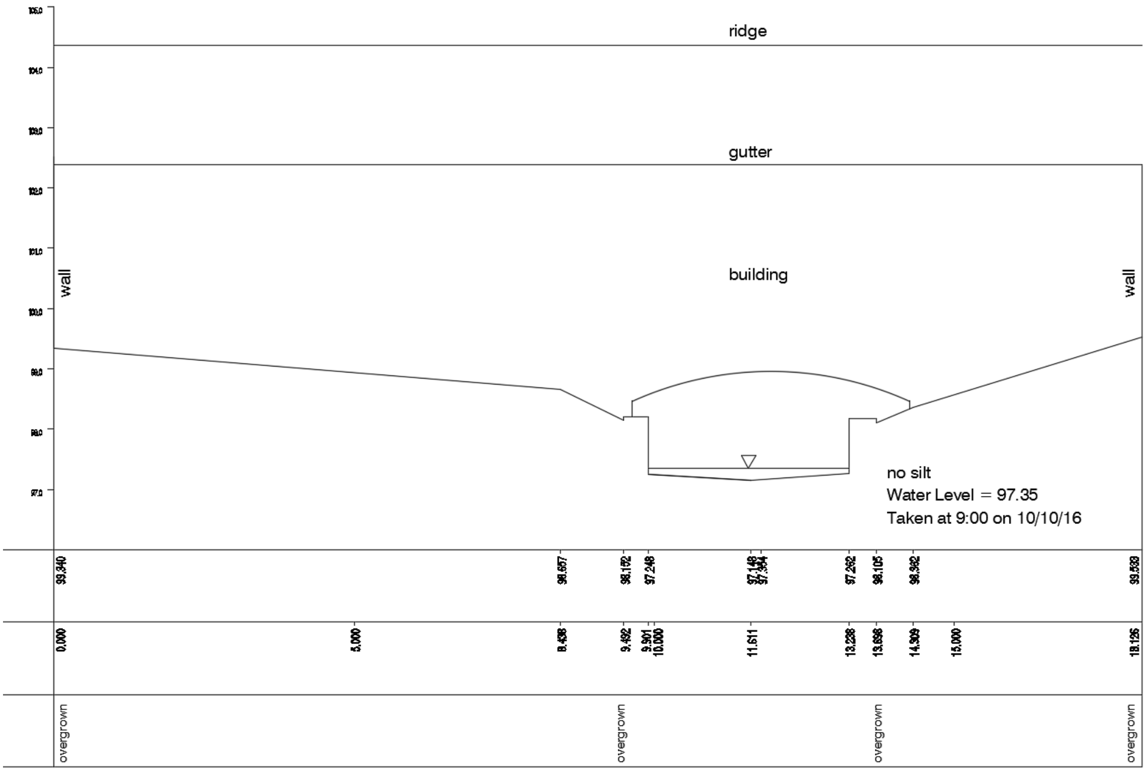
N/A

Photograph

Structure #18		Type	SPRUNG ARCH
Source of Data	Interlock Survey Data, 2016	Modelled	Yes
NGR	454097, 360788	Node	MAUN_1120.5

- Modelled as a SPRUNGARCH Bridge unit with default Flood Modeller parameters.
- Bridge opening dimensions informed by survey data
- No spill unit specified
- Bridge inlet is an arch opening, bridge outlet is a rectangular opening. Upstream face used to model inlet dimensions.

CAD Drawing (See CAD file in Appendix 2 or detailed drawing)



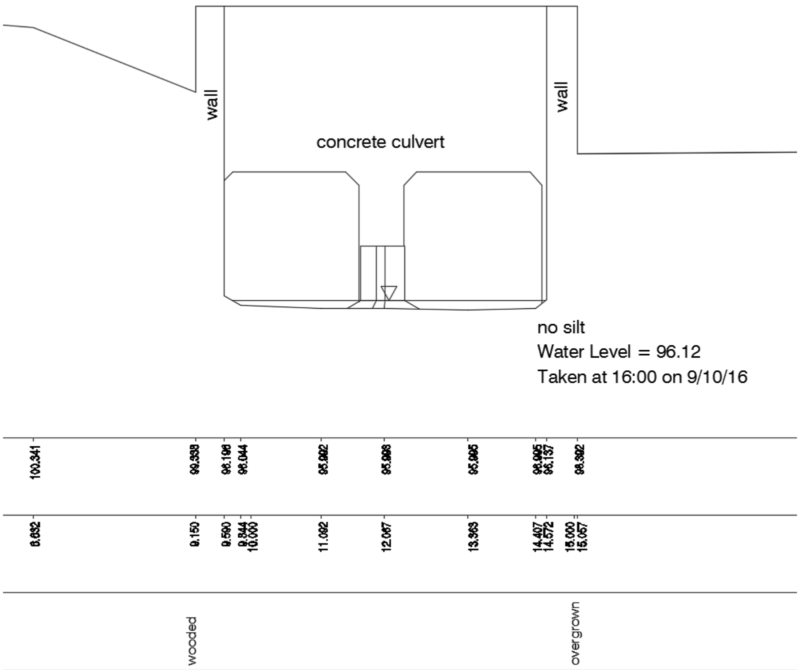
1:100

Photograph

Structure #19		Type	2 X Rectangular Culverts
Source of Data	Interlock Survey Data, 2016	Modelled	Yes
NGR	454150, 360955	Node	MAUN_1283

- Modelled as 2 X parallel Rectangular Conduit units with default Flood Modeller parameters.
- Culvert opening dimensions informed by survey data
- No Spill unit specified
- Culvert inlet and outlet units to specify associated losses

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

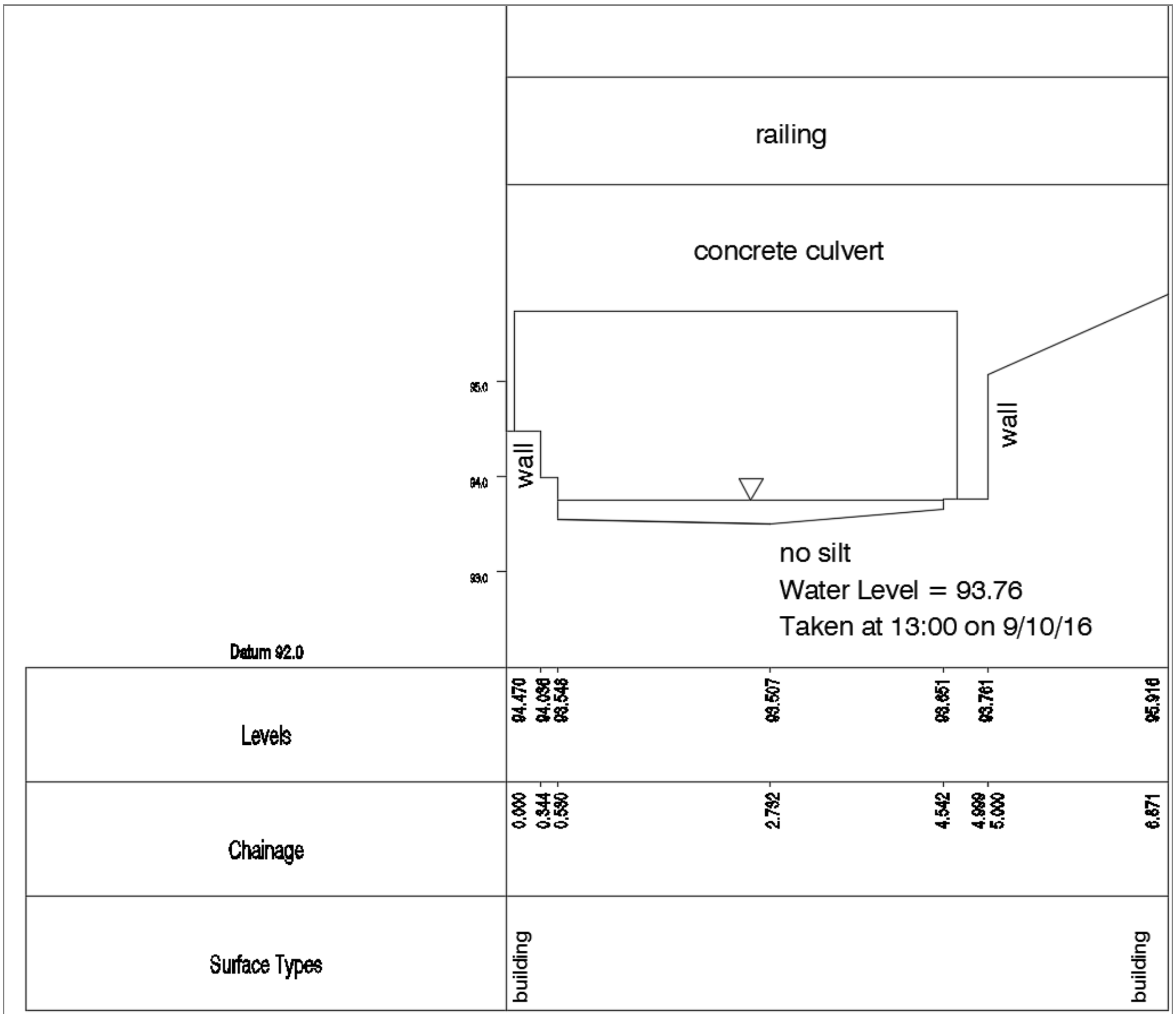


Photograph


Structure #20		**Type**	Rectangular Culvert (Bridge Street)
Source of Data	Interlock Survey Data, 2016	**Modelled**	Yes
NGR	454121, 361044	**Node**	MAUN_1357.3

- Modelled as Rectangular Conduit unit with default Flood Modeller parameters.
- Culvert opening dimensions informed by survey data
- No Spill unit specified
- Culvert inlet and outlet units to specify associated losses
- Upstream inlet different opening dimensions to downstream outlet. Upstream dimensions used to specify culvert.

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)



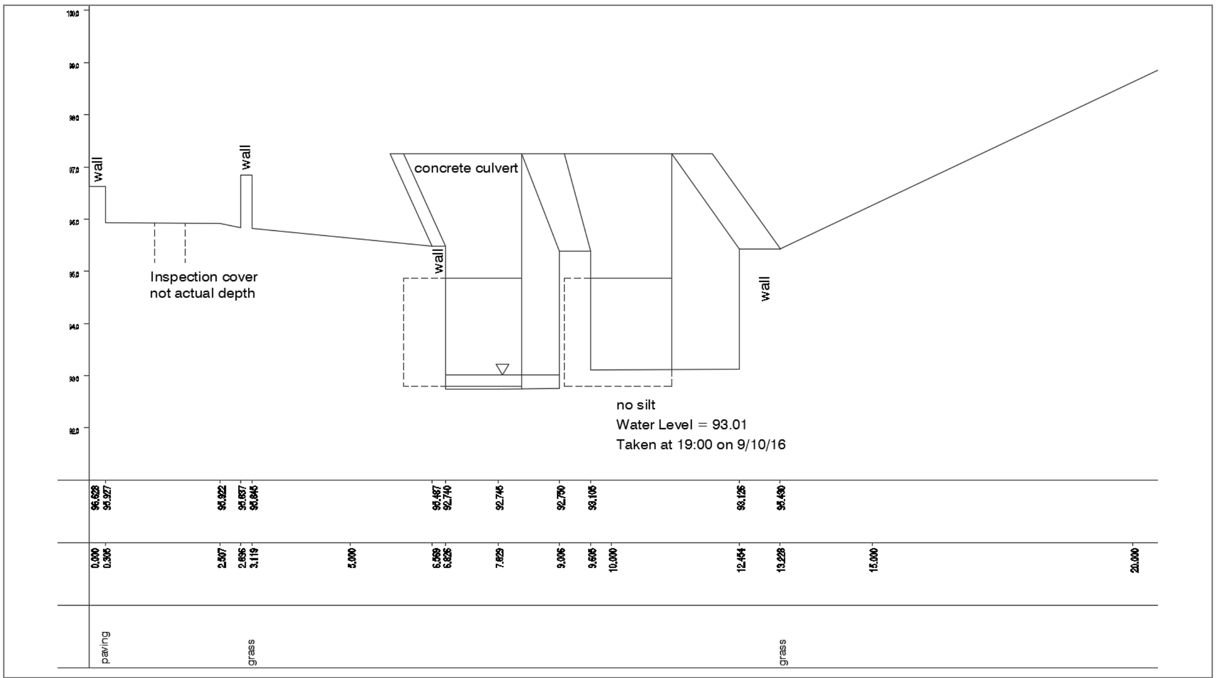
Horizontal = 1:100 Vertical = 1:100

Photograph

Structure #21		Type	2 X Rectangular Culverts (Rock Valley Culvert)
Source of Data	Interlock Survey Data, 2016	Modelled	Yes
NGR	454139, 361186	Node	MAUN_1479

- Survey indicates 2 X Box Culverts at structure inlet. Inlet structure face surveyed and differs from downstream face which has not been surveyed.
- Reference to previous studies and the Cleaning and Attendance Works Survey report at Rock Valley (produced by WS Atkins in August 1996) confirms that the Rock Valley Culvert changes shape and dimensions ten times throughout its length.
- Similarly to the 2007 modelling exercise, considerable model instability was experienced at this location; therefore the approach models the culvert as a single culvert with dimensions retained from the existing 2007 model.
- The 2007 flood mapping model report confirms that culvert dimensions of 2.15m X 2.15m were used within the 2007 modelling as this was considered representative of the most constrictive section along the culverts barrel.
- Modelled as 1 X parallel Rectangular Conduit unit, with default Flood Modeller parameters.
- Culvert inlet and outlet units to specify associated losses; adjusted to account for losses associated with contraction at opening and change of shape from 2 box culverts to a single culvert.
- No Spill unit specified

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

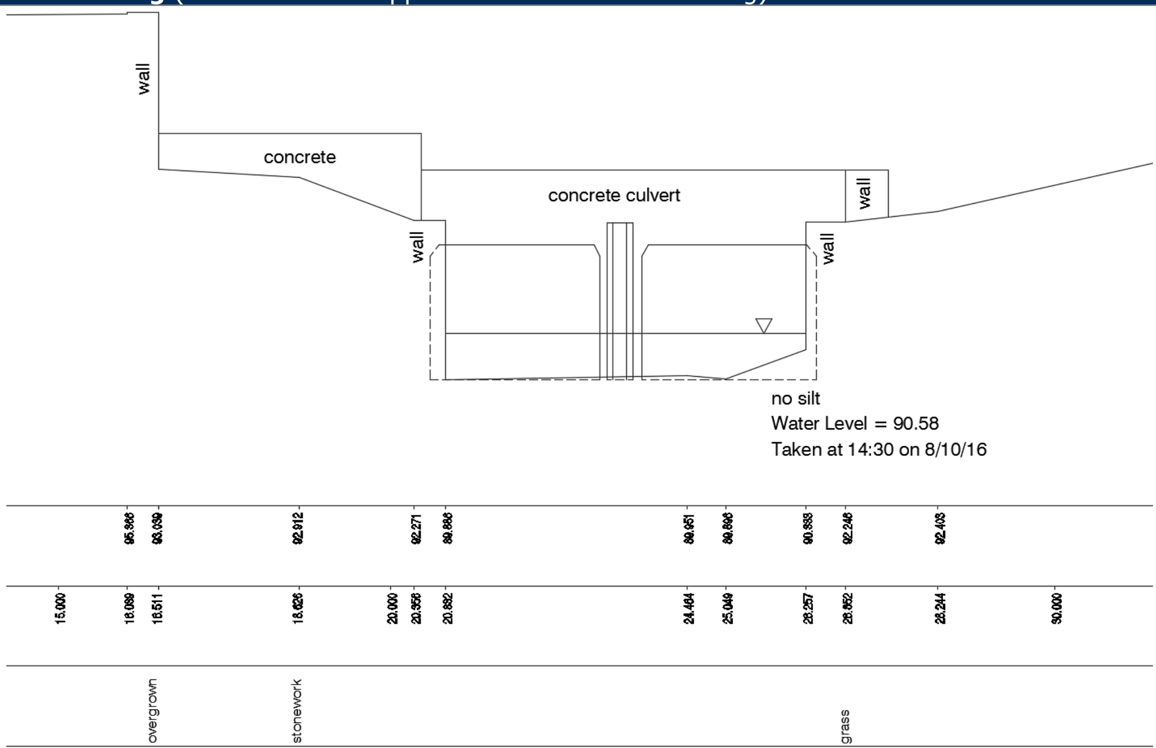

wall
wall
concrete culvert
wall
Inspection cover
not actual depth
wall
no silt
Water Level = 93.01
Taken at 19:00 on 9/10/16
0.000
0.305
2.507
3.119
5.000
6.569
6.826
7.829
9.006
9.606
10.000
12.454
13.228
15.000
20.000
paving
grass
grass

Photograph

Structure #22		Type	2 no. Rectangular Culverts
Source of Data	Interlock Survey Data, 2016	Modelled	Yes
NGR	454291, 361450	Node	MAUN_1788

- Modelled as 2 no. parallel Rectangular Conduit units with default Flood Modeller parameters.
- Culvert opening dimensions informed by survey data
- No Spill units specified
- Weir immediately upstream not modelled due to model instability
- Culvert inlet and outlet units to specify associated losses

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)



Photograph

Structure #23		**Type**	Bridge
Source of Data	Interlock Survey Data, 2016	**Modelled**	Yes
NGR	454350, 361478	**Node**	MAUN_1848du

- Modelled as a USBPR1978 BRIDGE unit with default Flood Modeller parameters.
- Culvert opening dimensions informed by survey data
- Spill unit specified

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

Photograph

Structure #24		Type	SCWEIR
Source of Data	Interlock Survey Data, 2016	Modelled	Yes
NGR	454470, 361501	Node	MAUN_1969

- Modelled as a Sharp Crested Weir with default Flood Modeller parameters.
- Cross section and invert levels informed from survey data.
- Manning's values as per upstream river channel.

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

N/A

Photograph

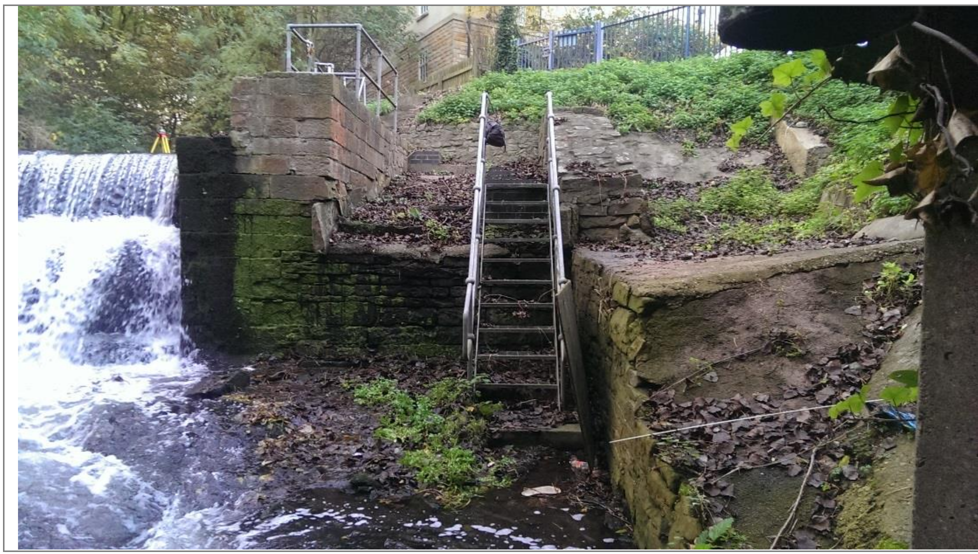
Structure #25		Type	SCWEIR
Source of Data	Interlock Survey Data, 2016	Modelled	Yes
NGR	454495, 361505	Node	MAUN_1986.6

- Modelled as a Sharp Crested Weir with default Flood Modeller parameters.
- Cross section and invert levels informed from survey data.
- Manning's values as per upstream river channel.

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

N/A

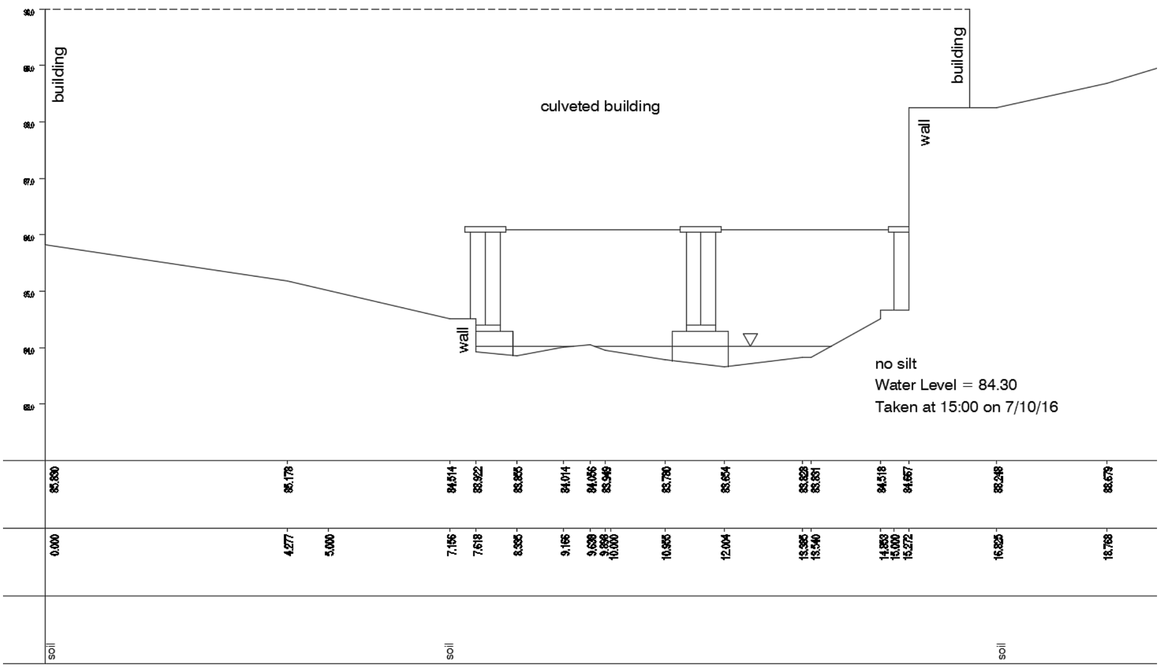
Photograph



Structure #26		**Type**	Bridge
Source of Data	Interlock Survey Data, 2016	**Modelled**	Yes
NGR		**Node**	MAUN_1997bu

- Modelled as a USBPR1978 BRIDGE unit with default Flood Modeller parameters.
- Bridge opening dimensions informed by survey data
- Spill unit specified
- Piers specified in bridge dimension data

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)



Photograph

Structure #27		Type	SCWEIR
Source of Data	Interlock Survey Data, 2016	Modelled	Yes
NGR	454606, 361551	Node	MAUN_2104.9

- Modelled as a Sharp Crested Weir with default Flood Modeller parameters.
- Cross section and invert levels informed from survey data.
- Manning's values as per upstream river channel.

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)

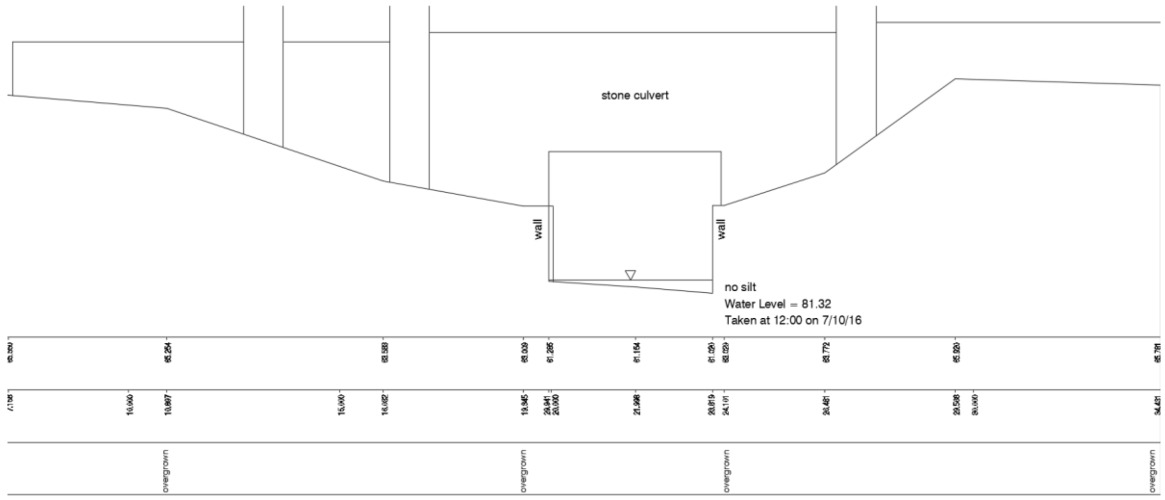
N/A

Photograph

Structure #28		Type	Rectangular Culvert
Source of Data	Interlock Survey Data, 2016	Modelled	Yes
NGR	454619, 361562	Node	MAUN_2117.5

- Modelled as a Rectangular Conduit unit with default Flood Modeller parameters.
- Culvert opening dimensions informed by survey data
- No Spill units specified
- Culvert inlet and outlet units to specify associated losses

CAD Drawing (See CAD file in Appendix 2 for detailed drawing)



Photograph

5.2.2 Resistance to flow

The River Maun is a medium-sized watercourse, which is heavily urbanised as it flows through the Central Mansfield Area. The river channel survey and associated site walkover confirms that the river bed comprises of largely silt, intermixed with gravel. Where there are reaches with in-channel vegetation, such as at the downstream extent of the model, seasonal growth will affect the amount of vegetation present. In accordance with the EA specification for flood mapping, which indicates that flood levels should be modelled assuming 'typical' conditions, average conditions in the watercourse have been assumed.

The resistance to flow in the model is represented using the Manning's *n* roughness coefficient. Roughness coefficients were assigned using a combination of aerial photography, site photographs and survey field notes. Variable Manning's n values have been used to account for varying roughness across each cross-section.

In most places, a Manning's n value of 0.04 has been assigned to the channel to represent a light amount of in-channel vegetation. All manning's *n* values are based on literature guidance (Chow, 1959). Sensitivity analysis is also carried out on the roughness coefficients to ensure confidence in the model outputs. Table 2 displays a summary of Manning's *n* values used in the model.

Table 2 - Summary of roughness coefficients

Material	Manning's *n* Value
River channel	0.04
Concrete culvert	0.013
Buildings	0.08
Roads	0.02
General Manmade surface	0.04
General Natural Surface	0.05
Trees	0.1
Stability	0.5

5.2.3 1D model boundaries

In accordance with the Statement of Requirement, which specified that the model outputs merge with the existing EA Flood Zone outlines, the model boundaries are located where the River Maun flood extents are shown to remain in-channel.

It is considered that the location of the downstream boundary, downstream of the Bath Lane bridge structure, will ensure that any backwater effects of the boundary are negligible.

A normal depth boundary is specified at the downstream extent of the 1D model, with a slope calculation based on the bed slope.

5.2.4 Initial Conditions

Initial conditions have been generated for the 1D model to ensure that the river channel is 'full' at time 0 hours. In order to ensure model stability, a minimum, flow of 3.5 cumecs is also specified, as the model crashed when lower flows were run through.

5.3 2D Model Build

5.3.1 2D Domain

The 2D domain was represented using LiDAR data (2015) at a grid size of 4m by 4m. The 2D code layer was set as 1 which defines the floodplain domain as 'active'. The river channel, bridges and weirs are largely modelled in the 1D domain. Therefore, an additional code polygon was used to remove the 1D model area from the floodplain so that conveyance was not double-counted. A 2D_code polygon was digitised and specified a value of 0 in the relevant attribute.

5.3.2 Grid Size and Orientation

Following a review of the model extents and LiDAR data (2015), it was concluded that a model grid size of 4m was appropriate for representing the key floodplain features and topography for the study area, whilst retaining a practical model simulation time. The orientation of the computational area was aligned as perpendicular to flow, which is considered best practice.

5.3.3 Boundary Conditions

There were two boundary conditions used in the model; a hydrological inflow at the upstream extent and a downstream normal depth boundary at the downstream model extent.

In accordance with the Statement of Requirement, which specified that the model outputs merge with the existing EA Flood Zone outlines, the model boundaries are located where the River Maun flood extents are shown to remain in-channel.

It is considered that the location of the downstream boundary, downstream of the Bath Lane bridge structure, will ensure that any backwater effects of the boundary are negligible.

A normal depth boundary is specified at the downstream extent of the 1D model, with a slope value based on bed levels specified. A 2D downstream boundary in the floodplain was not considered necessary due to all flows at the downstream extent of the model remaining in bank (the 1D domain).

5.3.4 1D2D Linkage

HX lines were digitised along the top of the River Maun channel using a combination of LiDAR (2015) and survey data. These allow flows from the 1D model to be transferred to the 2D model domain and simulate overland flows.

5.4 Model Simulations

5.4.1 Baseline Scenario

The model has been run for 3 main design flood events:

- 1 in 20-year baseline
- 1 in 100-year baseline
- 1 in 1000-year baseline

All scenarios assume a design inflow hydrograph, which is derived using the recommended storm duration. Further details are provided in the associated hydrology report. In addition to the baseline scenarios, 3 additional runs have been carried out to account for the impacts of climate change:

- 1 in 100-year plus 20% climate change baseline.

- 1 in 100-year plus 30% climate change baseline.
- 1 in 100-year plus 50% climate change baseline.

5.4.2 Blockage Scenario

In addition to the baseline scenario, which assumes all structures as free-flowing, two blockage scenarios were also considered as part of this study. The locations for the blockages were confirmed following a review of the previous studies, the conclusions of the SFRA, and in agreement with both MDC and the EA.

A 50% blockage was applied to the A6009 Road Bridge, and a 75% blockage was applied to the Littleworth Road Bridge. The blockages were initially applied by inserting a blockage unit in the 1D model domain; however, this caused significant instability in the model. Therefore, an alternative approach was used which simply reduced the flow area of the two structures by physically reducing the opening area within the bridge units.

A6009 Road Bridge

The River Maun is conveyed beneath the A6009 via two box culverts. Therefore, to represent a 50% blockage scenario, one of these box culverts was deleted from the model, effectively reducing conveyance by 50%.

Littleworth Road Bridge

The River Maun is conveyed beneath the Littleworth Road via a double arch stone bridge. In order to represent a 75% blockage scenario, one of the arches was deleted and the opening area of the remaining arch was reduced by half. Overall, this equates to a 75% reduction in total flow area analogous to a blockage scenario.

6 Model Outputs

The outputs from the updated model have been compared to the current Flood Zone 3 and Flood Zone 2 in order to highlight the key differences. As the EA flood map is based on undefended data, all model runs in the following figures are undefended, in order to draw direct comparisons.

6.1 Model Extents

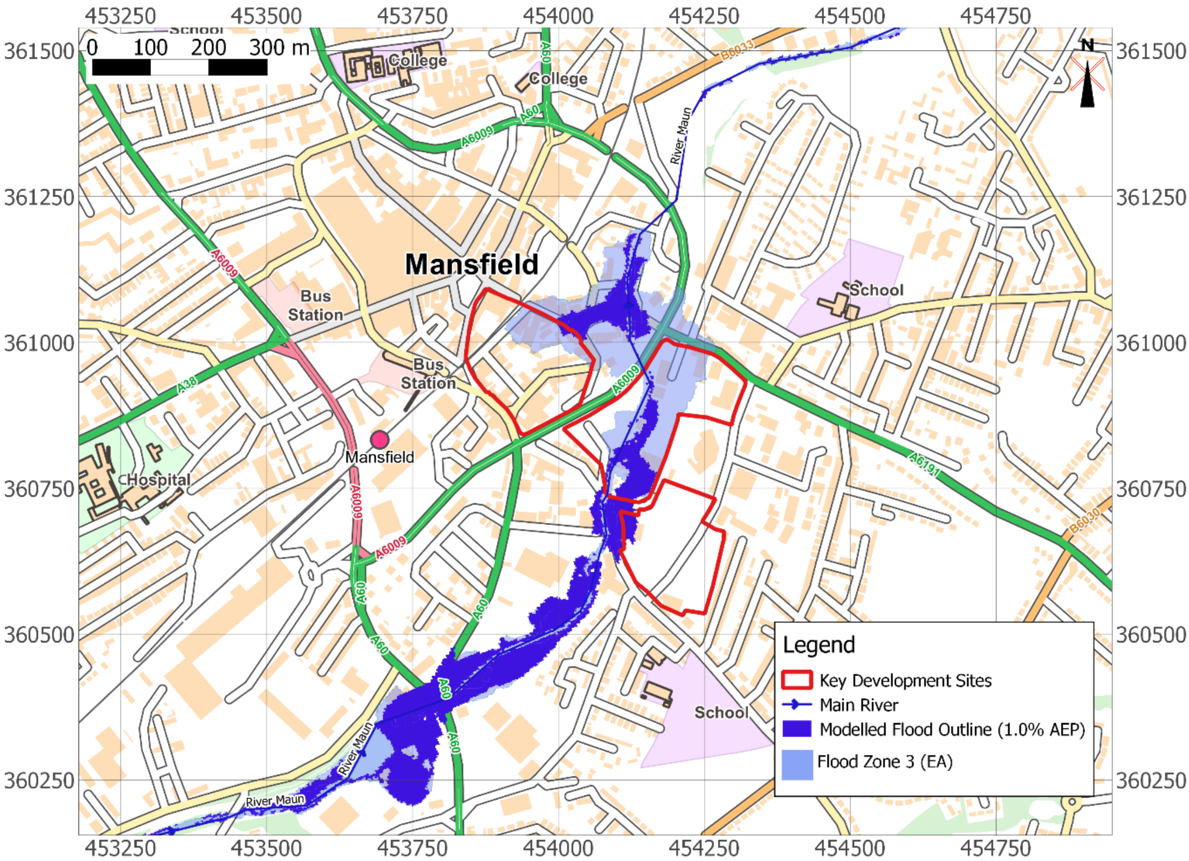


Figure 3: Modelled flood extent (undefended) vs existing EA flood extent, 1 in 100 year Annual Probability Event

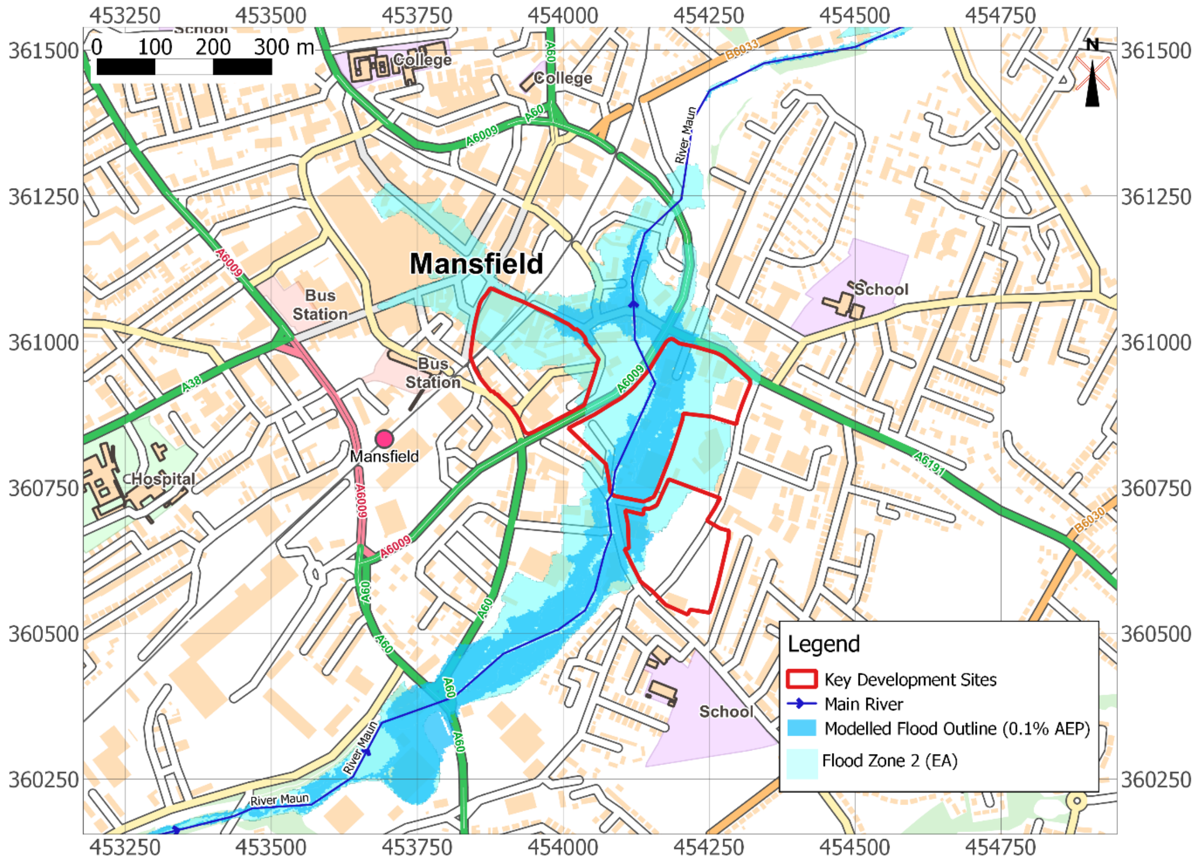


Figure 4: Modelled flood extent (undefended) vs existing EA flood extent, 1 in 1000 year Annual Probability Event

It can be seen in Figures 3 and 4 that the updated model outputs produce a less extensive Flood Zone 2 and Flood Zone 3. Notably, the modelled 1 in 1000 year outline does not extend as far west as the existing Flood Zone 2 outline, with significantly less fluvial flooding predicted for the White Hart Site during the extreme event.

In addition, the Riverside Site is shown to be affected by less flooding as a result of the updated model outputs when compared to the existing Flood Zone 3 outline.

The changes in flood extent when compared to the existing 2007 1D model extent are considered primarily due to the fact that the floodplain is more accurately represented using a 2D regular grid (modelled using TuFLOW software). This is the preferred method of modelling out of bank flows, rather than the extended sections used in 2007 in the ISIS 1D model, which is more likely to provide a conservative assessment of flood extent. The 2D domain for this study is also based on updated LiDAR data (2015).

6.2 Rock Valley Culvert

Previous studies report that there are issues with the way in which culvert losses are represented in the existing 2007 River Maun model. JBA sought to quantify this uncertainty by undertaking some additional modelling of this structure using a HEC-RAS model, which incorporated more detailed data relating to the various culvert dimensions along the Rock Valley Culvert length. A HEC RAS model, in steady state model was used to model all shape changes throughout the culvert.

The 100 year peak flow from the upstream face of the culvert was extracted from the 2007 ISIS model and used as the inflow to the HEC-RAS model. Based on the flow, the HEC-RAS model gave a peak water level of 96.83m AOD at the upstream face of the culvert. This was significantly lower than the 100.00m AOD given by the ISIS model. It was concluded that the ISIS model may have been overestimating afflux due to the culvert.

As part of their work for a site-specific FRA, Mott MacDonald obtained the River Maun model and updated the representation of the Rock Valley culvert using intermediate sections. This resulted in a 100yr flood level being produced that was similar to the JBA HEC-RAS model.

It was subsequently recommended that modelling be undertaken to refine the understanding of flood risk associated with the Rock Valley Culvert structure.

It was also concluded that there is significant afflux at the Rock Valley Structure as confirmed by both models. However, testing using the HEC-RAS software also demonstrated that whilst the Rock Valley culvert is the main control on water levels in the area around Bridge Street, the steep weir section upstream of Bridge Street bridge also acts as a significant control.

Figure 5 illustrates the model output for the 1 in 100-year probability event from the 2007 HEC-RAS model. It can be seen that there is significant afflux at the upstream face of the Rock Valley Culvert.

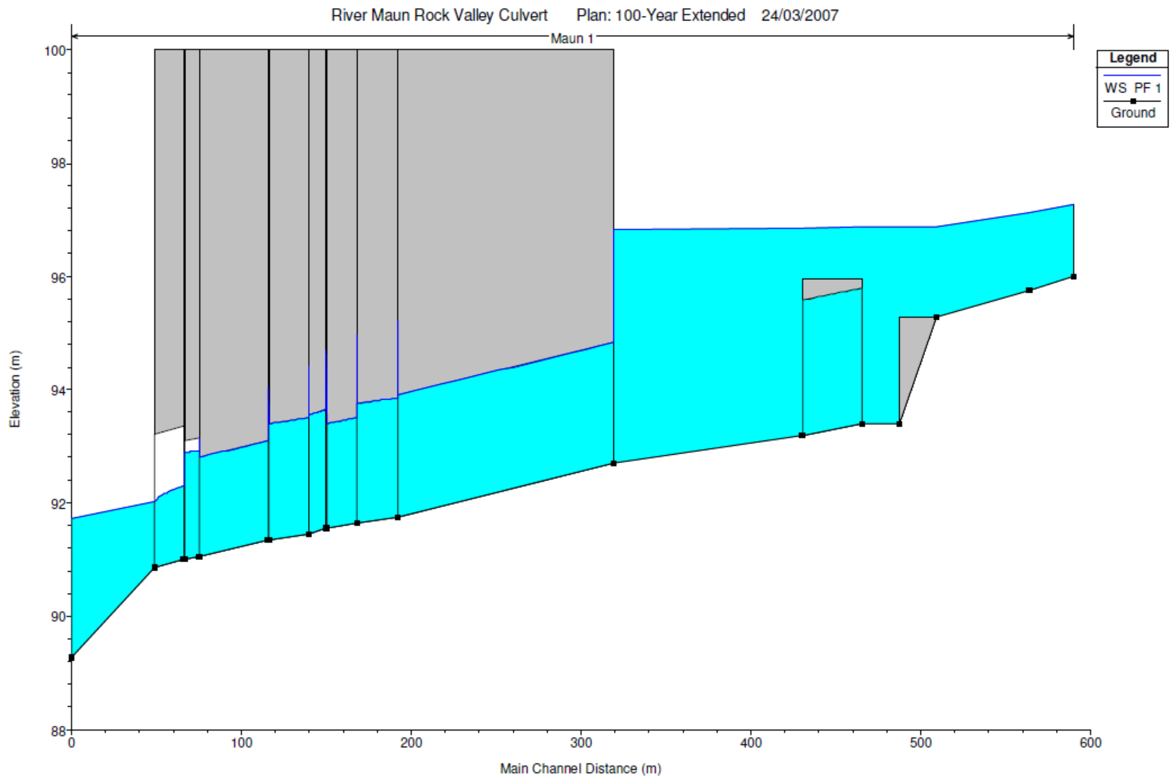


Figure 5: Predicted Flood Levels (mAOD) from the 2007 HEC-RAS model, for the 1 in 100 year annual event probability

The model outputs for the 1 in 100 year event from the updated River Maun model are provided in Figure 4 below. It can be seen that water levels are influenced by the Rock Valley Culvert, and this influence extends as far as the Bridge Street bridge and the steep section of channel between the A6009 and Bridge Street.

The updated modelling shows a flood level of 97.13m AOD upstream of the Rock Valley culvert for the 1 in 100 year event, which is comparable to the 2007 1D model result of 96.83m AOD.

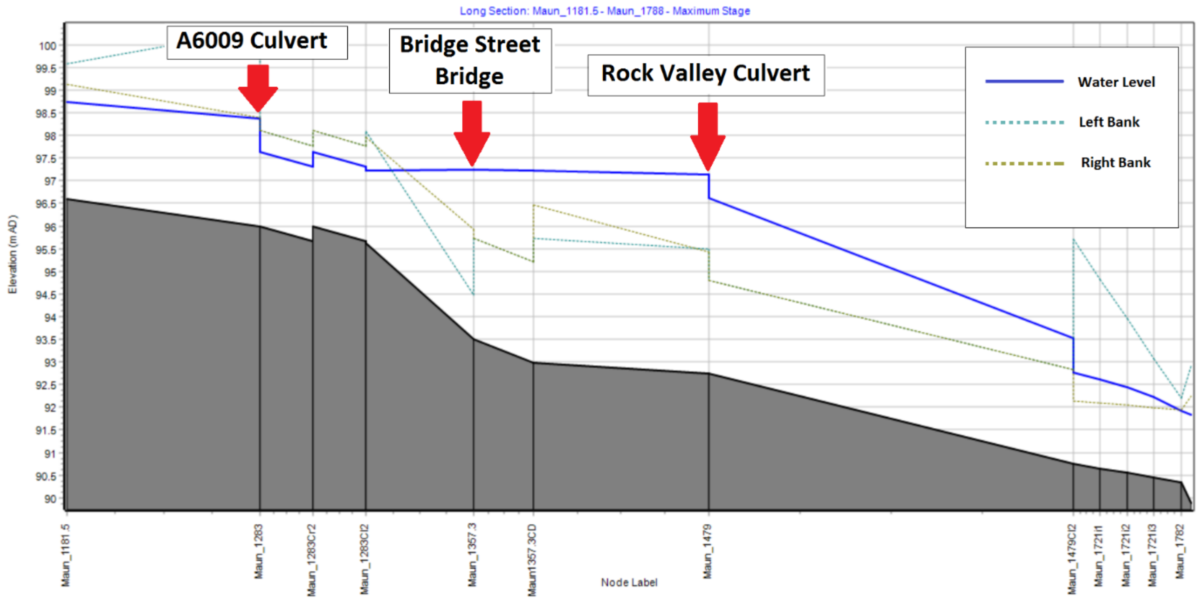


Figure 6: Modelled peak water surface elevation for the 1 in 1000 year event

As part of a site-specific FRA for the Riverside Site, WYG carried out additional hydraulic modelling using the HEC-RAS model, which retained the 2007 peak flow estimates. The results from this study are compared to the update model outputs in Table 3 below.

It is clear that the updated model outputs differ from that of the WYG FRA work. However, the corresponding peak flows within the WYG modelling study are unknown. It can be seen that the modelled levels at Maun_1315.5, _1357.3, _1389.3, and _1479 are fairly similar, giving confidence in the updated model outputs as providing realistic flood levels.

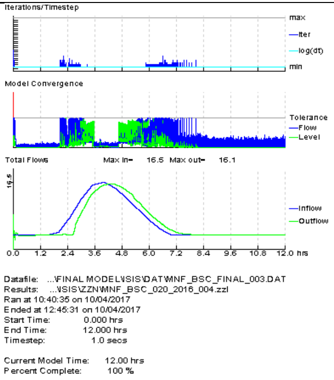
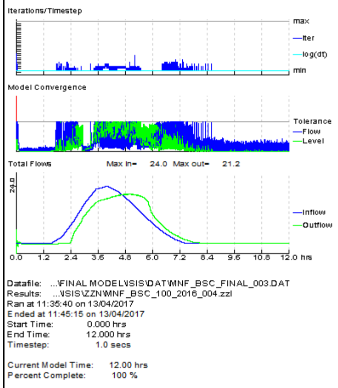
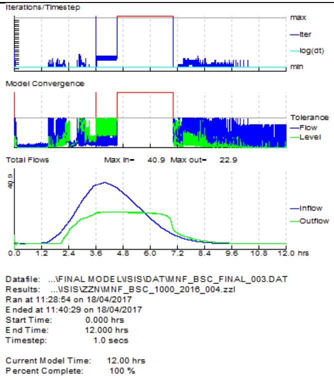
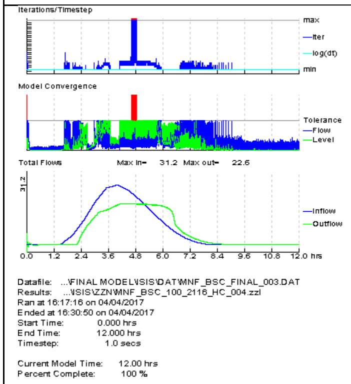
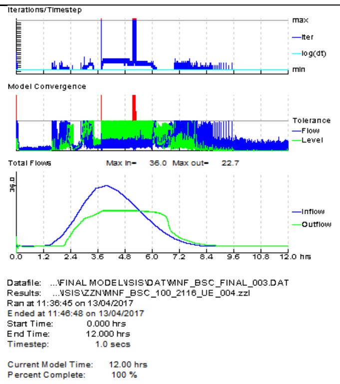
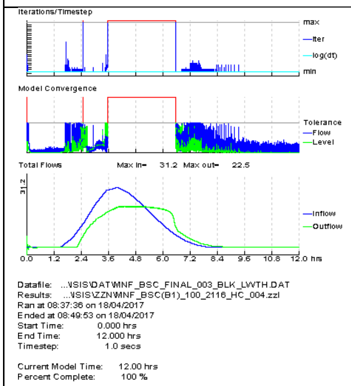
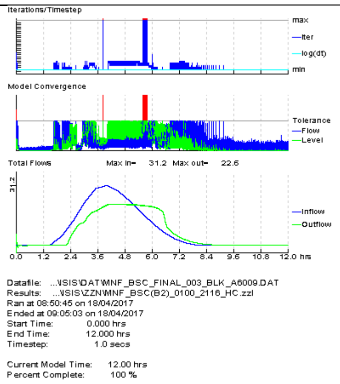
Table 3 – Flood level comparison with WYG study (2010)

Model Node WYG/WHS	WYG Peak level (mAOD) 100yr + CC (20%)	WHS Peak level (mAOD) 100yr + CC	
		Central Estimate	Higher Central Estimate
30358/Maun_1181.5	98.46	99.11	99.23
30266/Maun_1283	98.25	98.70	98.81
30212/Maun_1315.5	98.08	97.75	97.75
30167/Maun_1357.3	98.09	97.90	~98.00
30131/Maun_1389.3	97.93	~97.80	~98.00
30022/Maun_1479	97.92	~97.80	~97.80

7 Model Health

Throughout the modelling study, there were significant model instabilities associated with a number of structures and in-channel features along the River Maun study reach. For this reason, two structures were omitted, as detailed in Section 5.2.1. A summary of overall model health is provided for each simulation below.

7.1 1D Model Stability

20 Year	100 Year	1000 Year
		
100 Year + Climate Change (HC)	100 Year + Climate Change (UE)	
		
100 Year +CC (HC); Blockage 1	100 Year +CC (HC); Blockage 2	
		

In order to aid model stability, the following changes to the ISIS Event Files were made:

- Dflood increased to 5m for the 1000yr event.
- Maxitr increased to 25.
- Psdeep manually updated to 3.

A review of the outputs confirms that the main model instability is traced back to 1d channel nodes Maun1357.3CD, Maun_1389.3 and Maun_1479. Instabilities are also reported at channel node Maun_195.5. A review of stage-discharge outputs at these nodes indicates that there are conveyance instabilities, as shown in Figure 7.

A review of the extreme flood event outline is provided in Figure 8. It can be seen that the main locations of model instability are located downstream of the key development sites. It has also been shown in Figure 6 that the backwater effect of the Rock Valley culvert extends as far as the Bridge Street Bridge structure only.

The flow-discharge plots have also been reviewed for the 1d nodes for the reach between the A6009 and the inlet to the Rock Valley Culvert. The 1d nodes upstream and downstream of the A6009 appear sensible. However, there are clearly instabilities around the peak of the hydrograph for the Bridge Street bridge and Rock Valley Culvert inlet. The instability occurs when levels of 97m AOD are attained at nodes Maun_1357.3 and Maun_1389.3. It is noted that the flow-discharge relationship at node Maun_1357.3 for the Q100 event demonstrates a sensible curve which correlates closely with the initial relationship of the Q1000 event. Furthermore, there is only a brief period where the tolerance is exceeded during the Q100+CC event (Upper End) simulation. The peak flows for the Q100CC+CC (UE) and Q1000 events are very similar, with the Q1000 event design flows being approximately 5 cumecs higher. A review of the outputs for all model simulations concludes that the model instabilities have a minor impact on the modelled flood extent for the Riverside and Former Brewery Sites, which form the main focus area of this study.

The water level animations were also viewed at both the Rock Valley and Bridge Street culverts. For events above the 1 in 100 year scenario, oscillations in water level occur between 4.3-6.3 hours into the model run in both culverts. The Rock Valley culvert is prone to instabilities due to the fact that the geometry of the culvert changes 10 times throughout its length. The modelling approach to the culvert also resulted in an underestimation of conveyance as the culvert inlet is double barrel, however has been modelled as single barrel based on the outlet for a conservative approach. The oscillations in the Bridge Street Culvert are attributable to the back-water effects of the Rock Valley Culvert following a review of the flood modeller long section.

The oscillations in water level are approximately 200mm according to the stage animations in flood modeller. These are reflected in the 2D domain locally around the rock valley inlet, where the water level ranges from approximately 98mAOD-98.24mAOD. The floodplain in this area however is significantly constrained, therefore the oscillations are considered to have negligible impact on the key development sites.

It can be seen that the very edge of the extreme flood extent affects the north-eastern boundary of the White Hart Site. Due to the similarities between the Q100+CC (UE) (more stable model) and Q1000 events, it is considered that the modelled extent is appropriate at this location.

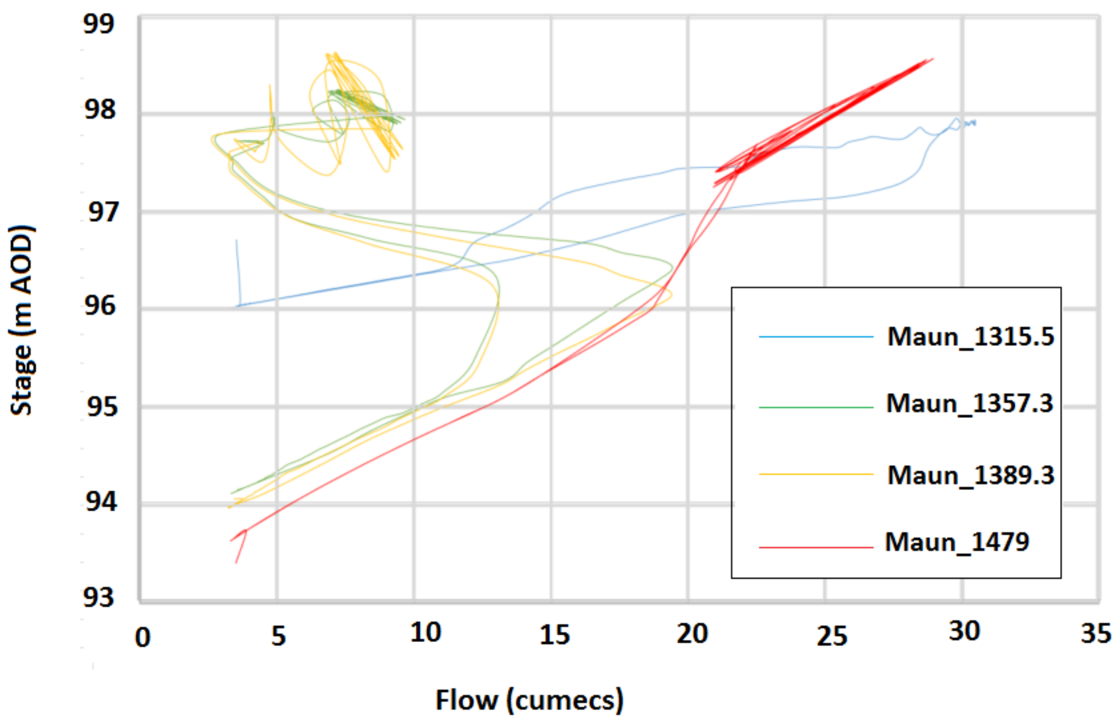


Figure 7: Flow-Discharge relationships at 1D nodes for the 1 in 1000-year event

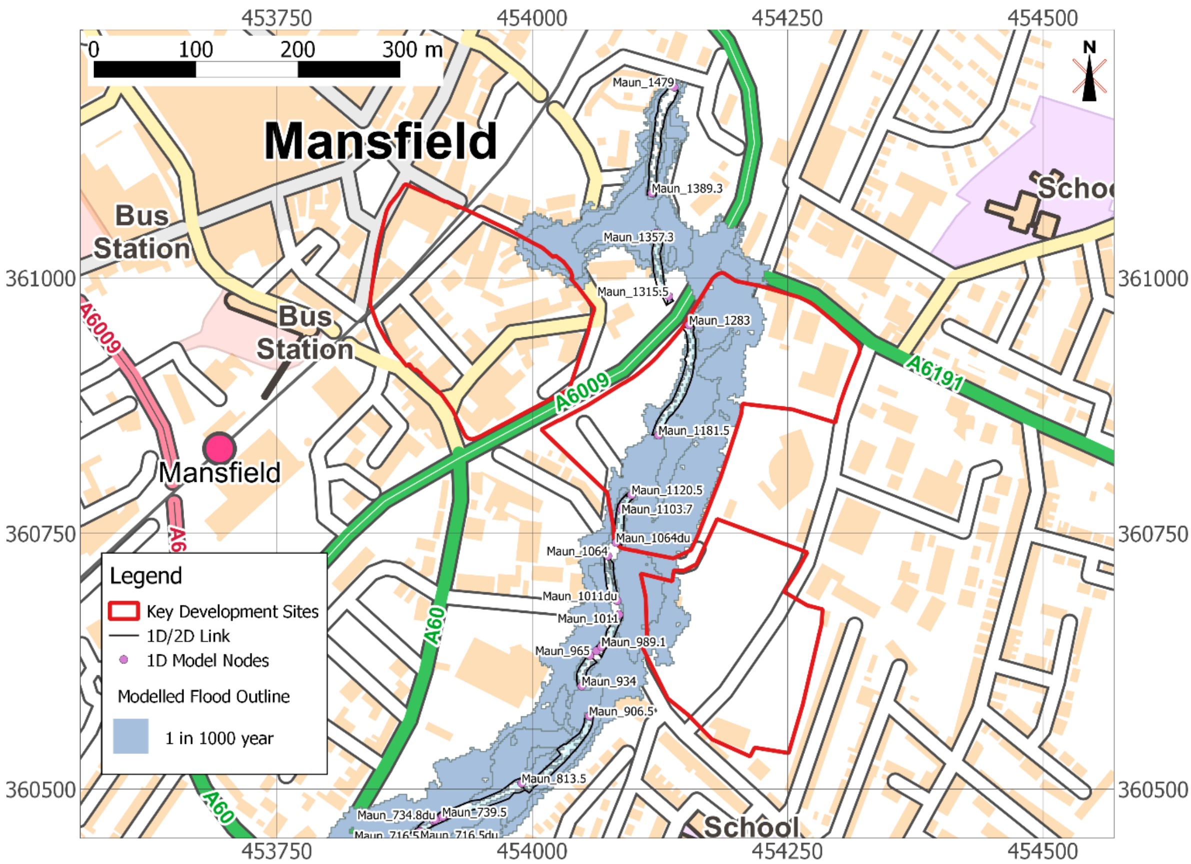


Figure 8: Modelled flood extent and location of 1D nodes

7.2 2D Model Stability

The model 2D domain is shown to remain stable, with the peak mass error remaining within the recommended +/- 1% tolerance. Flow vectors have been reviewed and all flow paths look sensible.

7.3 Model Sensitivity

In order to determine the sensitivity of the model to key assumptions, additional model sensitivity testing was undertaken. Sensitivity testing was undertaken for the 1 in 100-year flood event, as this event is used to define Flood Zone 3 and is critical when undertaking planning decisions. The key parameters selected for testing included Manning's n; and the downstream boundary condition. Testing on the design flows was not undertaken due to the range of flows modelled for the design scenarios. The outputs from the Q100 and Q100+CC simulations confirmed that the model extent does not vastly differ between these events and that the modelled extent is therefore not particularly sensitive to the selected flows. The outputs from the sensitivity runs are summarised below.

7.3.1 Manning's N

The model was re-run with the Manning's N value adjusted to quantify the effect of this parameter on the flood extent. Due to model instability, the initial global change of +/- 20% to the Manning's N value resulted in the model simulations crashing. Therefore, Manning's N sensitivity testing was undertaken by increasing the 1D model values by 10% and the 2D model domain by 20%. The outputs for this simulation against the baseline scenario is shown in Figure 9 below.

It can be seen that the modelled extent does not significantly change as a result of higher roughness values. However, peak flood depths within the model outline are slightly increased by circa 100mm.

Due to the negligible difference in flood extents, and following a review of the Manning's N values used in the baseline model, it was concluded that the baseline values are appropriate for this study.

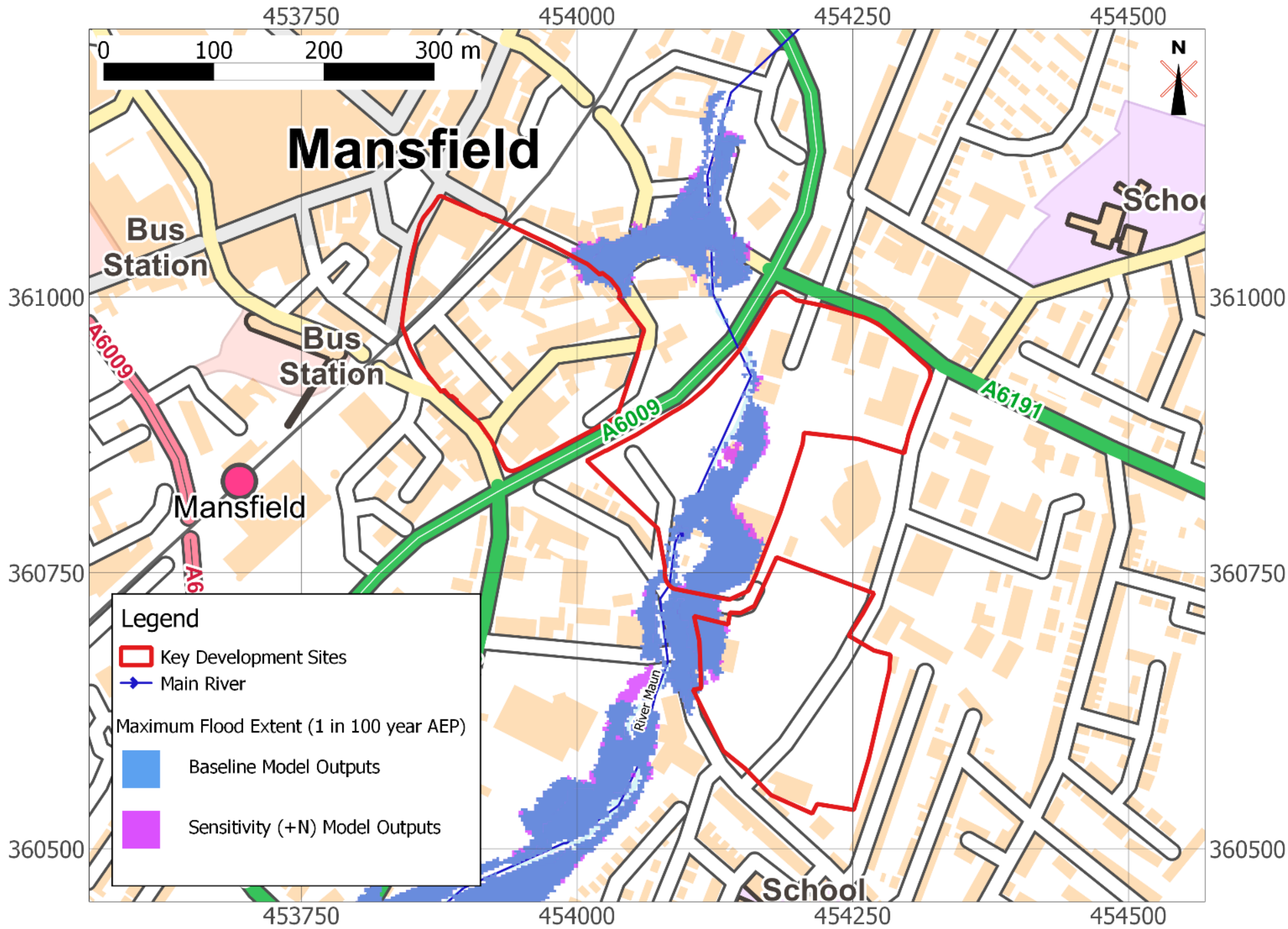


Figure 9: Difference in modelled flood extent for the baseline and the Manning's N sensitivity scenario

7.3.2 Building Roughness

Further sensitivity analysis was carried out on the hydraulic roughness values selected for buildings in the 2D domain. This was carried out across the 100-year and 1000-year return periods. A more conservative Manning's *n* coefficient of 0.3 was selected to represent buildings for the purpose of the sensitivity analysis. To assess the model sensitivity, changes in flood extent were reviewed, as the flood extent is a key aspect of updating the existing EA flood map. The changes in extent are displayed in the following figures.

100 Year

The changes in flood extent are shown below. It is evident that the extents are almost identical between the two roughness values, with the largest extent change being by approximately 8m locally within the riverside site, labelled below. This is largely due to the floodplain being relatively constrained throughout Mansfield, with only a small number of buildings lying in the flood extent.

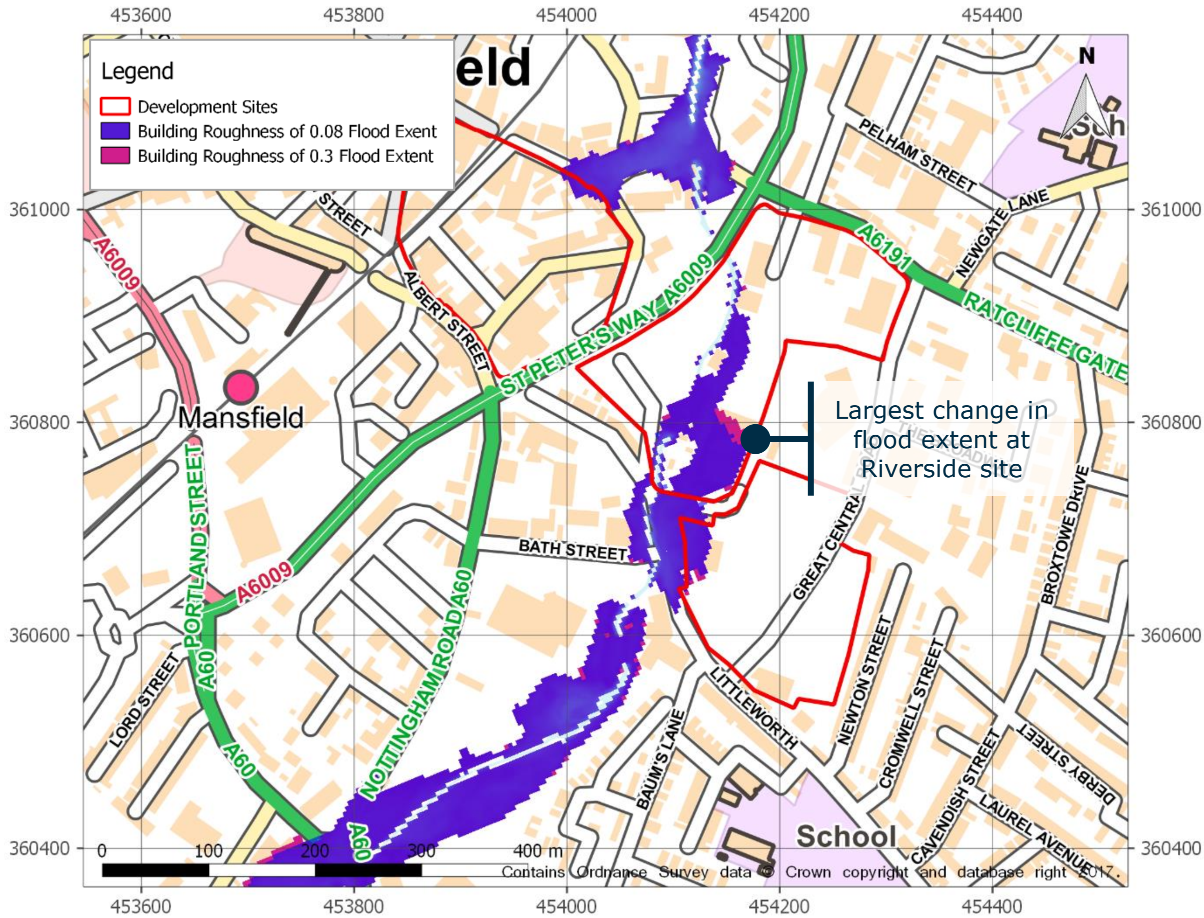


Figure 10 - 100 year event: Building sensitivity analysis comparison

1000 Year

The patterns observed for the 100 year event are largely reflected during the 1000 year event, with a building roughness value of 0.3 showing little difference in flood extent in Mansfield. The largest difference in extent is located in the Former Brewery Site by approximately 10m locally. This is again due to the constrained nature of the floodplain that results in only a small number of buildings lying in the flood extent. The comparison plot is displayed in Figure 11. Due to the flood extents for both the 100-year and 1000-year showing limited sensitivity to changes in building roughness, the baseline model is considered appropriate to update the existing flood map.

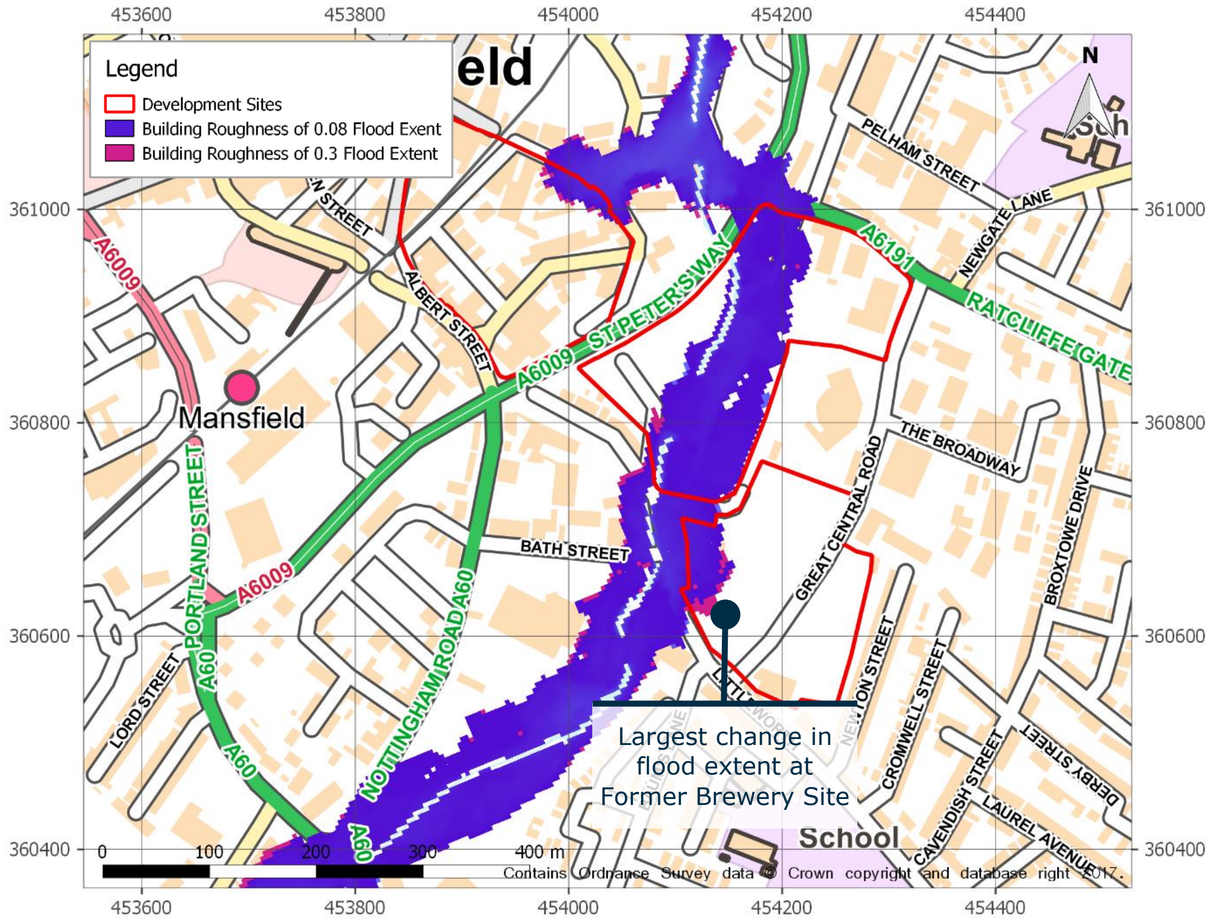


Figure 11 - 1000 year event: Building sensitivity analysis comparison

7.3.3 Downstream Boundary

In order to test the sensitivity of the model to the selected downstream boundary condition, the gradient was adjusted to a user defined value of 0.001, which simulates a very flat gradient compared to the baseline scenario, which is calculated using the channel bed slope. The peak water levels are illustrated in Figure 10. It can be seen that the flatter gradient produces higher water levels at the downstream extent of the model; however, the effect of this is reduced upstream, with all backwater effects being diminished by Maun_2008. Therefore, it is considered that the model outputs are not significantly affected by the downstream boundary, and the gradient used in the baseline scenario is retained.

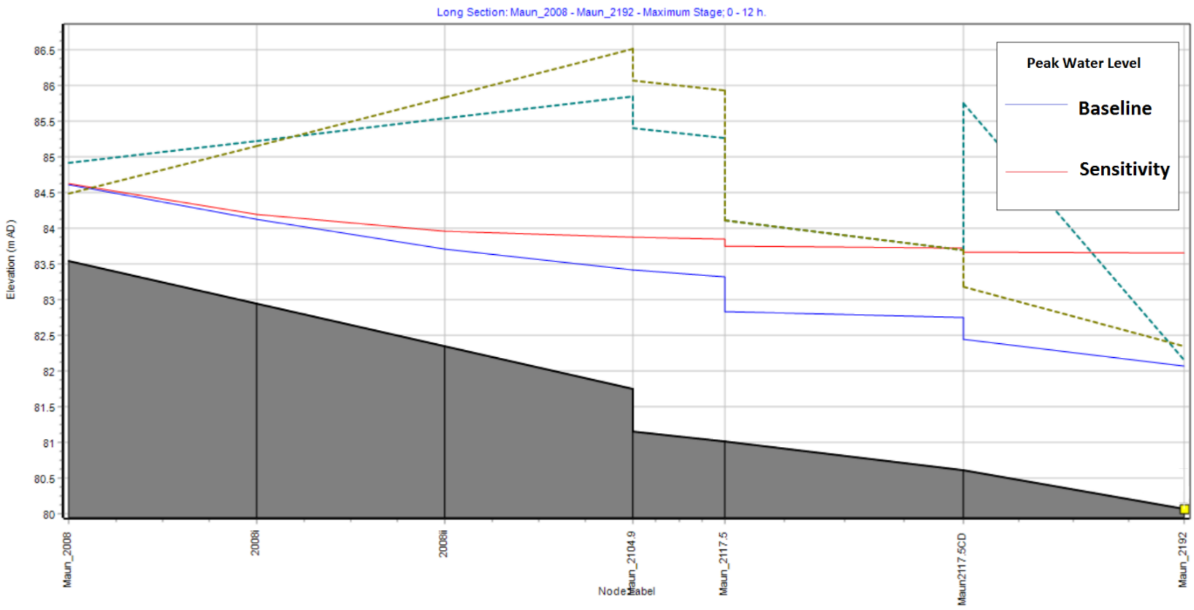


Figure 12: Difference in modelled flood level for the baseline and the downstream boundary sensitivity scenario

8 Model Run Files

The following table identifies the key model files used to run the River Maun model and provides additional details on the individual shapefiles used to represent the topography;

Model Control Files			
Event	**.ief**	**.dat**	**.tcf**
1 in 20 year	MNF_BSC_020_2016_004	MNF_BSC_FINAL_003	MNF_~s1~_~e1~_001
1 in 100 year	MNF_BSC_0100_2016_004	MNF_BSC_FINAL_003	MNF_~s1~_~e1~_001
1 in 1000 year	MNF_BSC_1000_2016_004	MNF_BSC_FINAL_003	MNF_~s1~_~e1~_001
1 in 100 year +CC (C)	MNF_BSC_0100_2016_C_004	MNF_BSC_FINAL_003	MNF_~s1~_~e1~_001
1 in 100 year +CC (HC)	MNF_BSC_0100_2016_HC_004	MNF_BSC_FINAL_003	MNF_~s1~_~e1~_001
1 in 100 year +CC (UE)	MNF_BSC_0100_2016_UE_004	MNF_BSC_FINAL_003	MNF_~s1~_~e1~_001
1 in 100 year + 50% Blockage at A6009 Road Bridge	MNF_BSC(b1)_0100_2116_HC	MNF_BSC_FINAL_003_BLK_A6009	MNF_~s1~_~e1~_001
1 in 100 year + 75% Blockage at Littleworth Road Bridge	MNF_BSC(b2)_0100_2116_HC	MNF_BSC_FINAL_003_BLK_LWTH	MNF_~s1~_~e1~_001

.tgc	
Shape File	**Description**
2d_loc_MNF_L_001.shp	Defines orientation of 2d grid
2d_bc_code_MNF_ActiveArea_R_001.shp	Defines active area for 2D domain
2d_bc_code_deactivate_1DChannel_R_003.shp	Deactivates 1D channel
DTM\sk5259_DTM_1M.asc DTM\sk5260_DTM_1M.asc DTM\sk5261_DTM_1M.asc DTM\sk5359_DTM_1M.asc DTM\sk5360_DTM_1M.asc DTM\sk5361_DTM_1M.asc DTM\sk5362_DTM_1M.asc DTM\sk5459_DTM_1M.asc DTM\sk5460_DTM_1M.asc DTM\sk5461_DTM_1M.asc	Reads in LiDAR tiles to define 2D topography

DTM\sk5462_DTM_1M.asc DTM\sk5560_DTM_1M.asc DTM\sk5561_DTM_1M.asc DTM\sk5562_DTM_1M.asc	
2d_zsh_Maun_BridgeDecks_R_001.shp	Modifies DTM where the LiDAR filtering process has removed bridge decks from the topography
GIS\2d_zsh_FieldMillPond_Verge_L_001.shp | GIS\2d_zsh_FieldMillPond_Verge_P_001.shp	Amends DTM as per survey data
2d_mat_buildings_R_001.shp 2d_mat_rail_R_001.shp 2d_mat_roads_R_001.shp 2d_mat_woodland_R_001.shp 2d_mat_stab_R_002.shp	Assigns materials values to 2D domain according to landuse

.tbc	
Shape File	**Description**
2d_bc_hxLink_Maun_L_103b.shp	1D/2D link

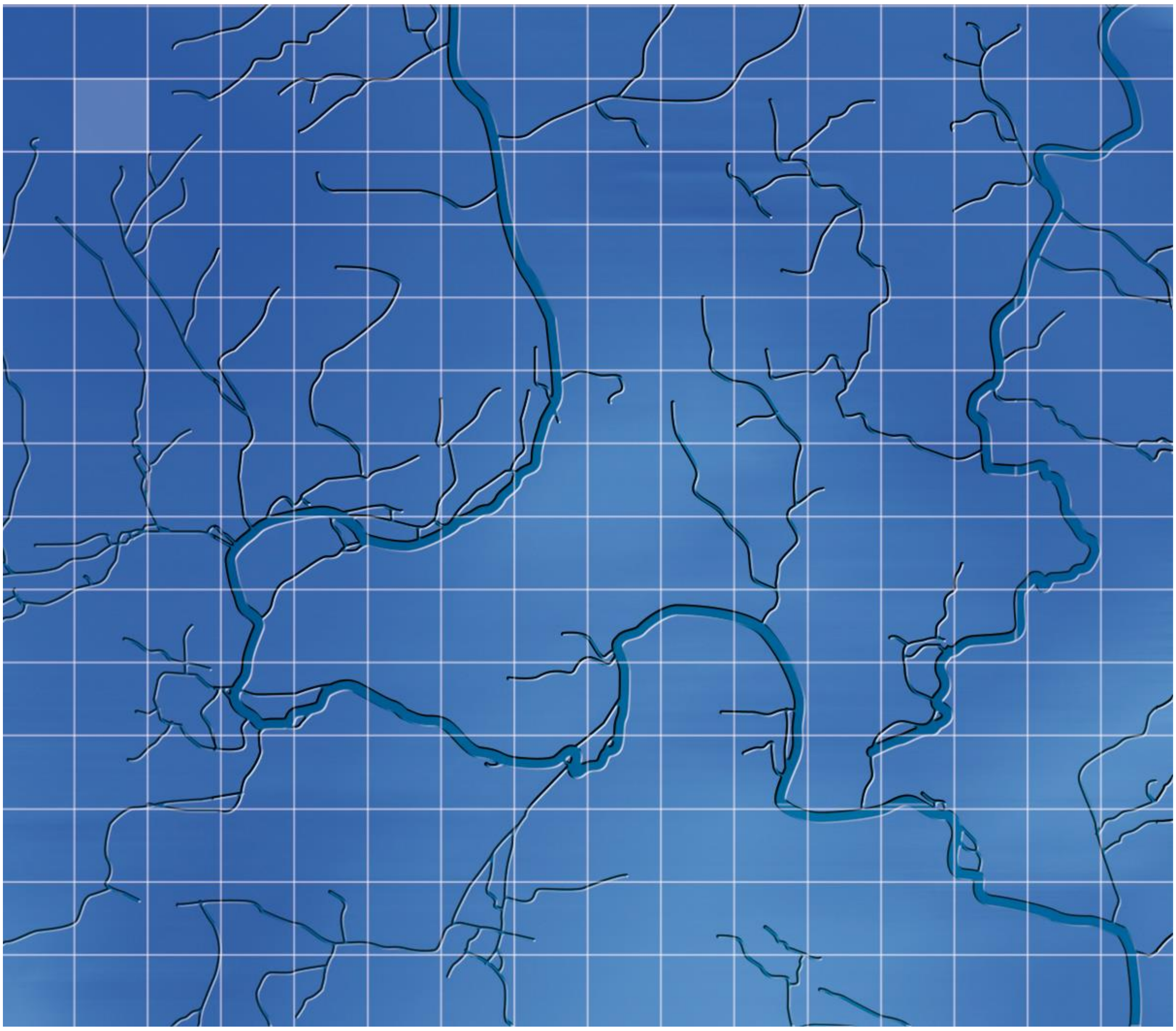
Appendix 1 – Peak Flow Report

Mansfield District Council

January 2018

Mansfield Flood Risk Modelling

Hydrology Assessment



Wallingford HydroSolutions Limited

Mansfield District Council

Mansfield Flood Risk Modelling

Hydrology Assessment

Document issue details

Version number	Issue date	Issue status	Issuing Office
1.0	19/12/2016	Final	Cardiff
1.1	05/01/2018	Amended	Cardiff

For and on behalf of Wallingford HydroSolutions Ltd.

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Approved by Tracey Haxton
Position Senior Consultant

Date 17/08/16

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Contents

1 Background and Requirements

The purpose of this hydrological assessment is to update the peak flow estimates used in an Environment Agency (EA) approved hydraulic model of the River Maun developed by JBA Consulting in 2007. The assessment will provide peak flows for an updated version of the hydraulic model, and assess flood risk in the central area of Mansfield.

A full hydrological assessment using the statistical method was undertaken by JBA in 2007 to provide inflows to the model. Flow statistics were estimated at ten flow estimation points throughout the Maun catchment. In this study, peak flow estimates are required at only one of these flow estimation points, specifically at Mansfield Old gauging station, located slightly upstream of the area of interest.

Updates are required to utilise the latest flood estimation methods. This includes an update to the NRFA Peak Flows data (this replaced the HiFlows dataset in 2014) to version 4.1. The statistical methodology was also updated by Kjeldsen[1] in 2008 and these and other methods to improve the use of local data within the methodology are included within the WINFAPv4 software[2].

A comparative set of peak flow estimates from rainfall runoff methods, not utilised in the previous study, were also developed. These used Rainfall-runoff methods first developed by Kjeldsen[3] and subsequently updated and released within the ReFH2.2 software[4]. This includes improvements that allow the use of the methodology within permeable catchments and the explicit inclusion of urban areas within the catchment[5]. The software includes the use of the FEH99 DDF rainfall model and the use of the FEH13 rainfall runoff model developed by Stewart[6] as input hyetographs.

The differences that these updates have on the peak flows used within the hydraulic model hence any impact on the predicted flood extents and levels within the localised area will be identified.

2 The Catchment

The updated hydraulic model required one inflow boundary to represent flows in the River Maun as it runs through Mansfield. For consistency the closest downstream flow estimation point derived in the previous study was selected.

The location is at Mansfield Old gauging station or the Maun at Mansfield Sewage Treatment works (Stw), NRFA number 28059, in the NFRA Peak Flows dataset. The catchment boundary for this flow estimation point is presented in Figure 1.

The FEH Web Service[7] was used to derive the catchment descriptors; the catchment has a total area of 27.52km^2. It is considered a relatively complex catchment, with an URBEXT2000 value of 0.39,

[1] Kjeldsen, T.R., Jones, D.A., and Bayliss, A.C., 2008. *Improving the FEH statistical procedures for flood frequency estimation.* Environment Agency, Bristol, pp137.

[2] http://www.hydrosolutions.co.uk/products.asp?categoryID=10838
[3] Kjeldsen, T. R. 2007. The revitalised FSR/FEJ rainfall-runoff method. Supplementary Report No.1. CEH.
[4] http://www.hydrosolutions.co.uk/products.asp?categoryID=4671
[5] http://files.hydrosolutions.co.uk/refh2/ReFH2_Technical_Report.pdf
[6] Stewart, E. J., Jones, D. A., Svensson, C., Morris, D. G., Dempsey, P., Dent, J. E., Collier, C. G. & Anderson, C. W. (2010) Reservoir Safety – Long return period rainfall. R&D Technical Report WS 194/2/39/TR (two volumes), Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme
[7] http://www.hydrosolutions.co.uk/products.asp?categoryID=4670

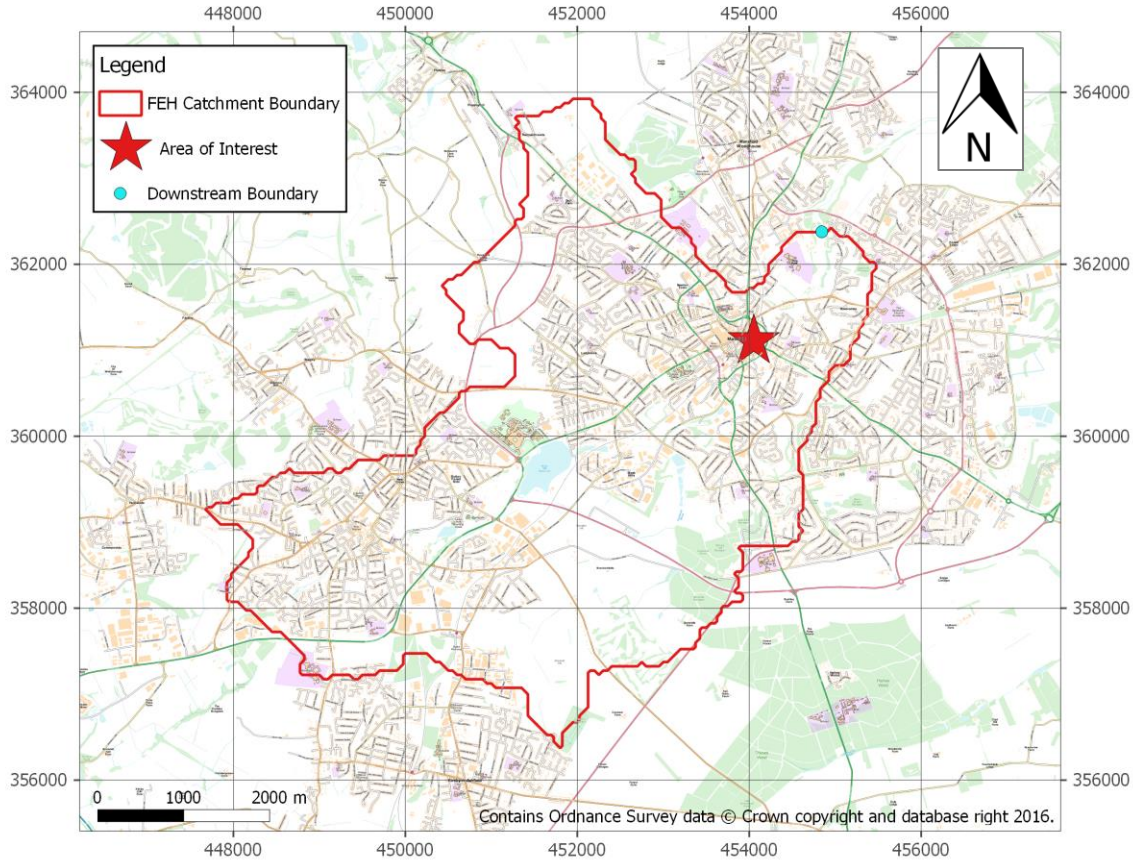
classing it as 'very heavily urbanised' based on FEH guidance[8]. The catchment is also considered to be highly permeable with a BFIHOST VALUE of 0.84 and SPRHOST of 15.02. The FARL value is 0.91, this suggests that there is some impact from upstream storage within the catchment, since a value of 1 represents no impact.

Figure 1 – Catchment boundary and Area of Interest

A comparison of the catchment boundary against OS data indicated that the FEH catchment boundary reflected the mapped data. In addition, a number of spot checks at catchment boundary locations were carried out to ensure that the catchment derived from the FEH web service was consistent with the LiDAR data. This review indicated that the boundary was similar for the two datasets at the locations assessed. Therefore, the catchment derived from the FEH web service was considered appropriate for use.

Table 1 summarises the relevant catchment descriptors obtained from the FEH web service.

Given the downstream location of the gauging station in relation to the area of interest, the peak flow estimates derived are considered to be a conservative estimate of flows in the central area of Mansfield.



[8] Bayliss, A.C., Black, K.B., Fava-Verde,. Kjelsden, T. R. 2006. URBEXT2000 – A new FEH catchment descriptor. Calculation, dissemination and application. Defra R&D Technical Report No. FD1919/TR.

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Table 1 - Catchment Descriptors for Study catchment

Catchment Descriptor	
Area (km^2)	27.52
BFIHOST	0.84
FARL	0.91
SAAR	717
URBEXT2000	0.39
SPRHOST	15.02

3 Previous Hydrological Study

A previous study was undertaken by JBA Consulting in 2007, it involved hydraulic modelling along the entire length of the River Maun, and included the area to be assessed in this study. The work was undertaken on behalf of the Environment Agency to develop flood risk mapping in Mansfield and the surrounding area, in order to help support future development planning and control.

The study considered the statistical method to be the most suitable method for estimating design flows, particularly as the catchment is permeable, and relatively well gauged. QMED at each of the flow estimation points was estimated by means of donor transfer.

Gauging stations in the catchment were selected, based on a review of the quality of flow data and ratings, this revealed that only two stations in the catchment, Mansfield Old and Church Warsop could be used as donor sites. These two sites were used extensively in the hydrological analysis, along with four analogue stations selected to provide a more robust estimate of peak flow at a number of the flow estimation points. At each flow estimation point a combination of donor and analogue stations were used, it was necessary to apply a multi-site adjustment procedure to provide a weighted average of the individually transferred estimates.

Pooled growth curves were also identified using WINFAP. It was not necessary to create pooling groups for every flow estimation point as many of the sites were hydrologically similar, therefore growth curves were often transferred. This led to a total of four pooling groups across the catchments. As the study catchment is permeable, most of the stations selected for pooling were also permeable, and a permeable adjustment was applied to each of the pooling growth curves. This was followed by an urban adjustment to the estimated permeable adjusted growth curve.

The hydrology followed the FEH best practice methodology at the time however, as outlined within Section 2, the methods and software used to estimate peak flows have subsequently been updated.

4 Outline of Methodology

The flood estimates have been developed using the latest Flood Estimation Handbook statistical and rainfall runoff methods as outlined in Section 1.

The WINFAPv4 software is used to apply the statistical methodology using the NRFA Peak Flow Dataset v4.1[9]. This method requires the estimation of a normalised flood frequency curve, termed the flood growth curve and the estimation of the normalising variable; the median annual flood, QMED. The ReFH2.2 software is used to apply the rainfall runoff model using the FEH13 rainfall model.

Both methods supersede older methods as the national design standard for estimating flood frequency. The methods are therefore suitable for the study catchment.

5 Peak Flow Estimation using the Statistical Method

5.1 Derivation of the Median Annual Flood (Qmed)

The downstream boundary of the study catchment is located at a gauging station at Mansfield Sewage Treatment Works (28059), and is therefore classified as a gauged catchment. Because the record length is greater than 13 years, the FEH recommends that the median of the ranked Annual Maximum (AM) Flood series be used over the peaks over threshold method[10].

The catchment is not considered suitable for QMED estimation or pooling. The gauging station although not closed for technical reasons, is noted as potentially experiencing problems due to the sewage treatment works, therefore the data is treated with caution. The QMED is significantly underestimated when using the catchment descriptors method, compared with the observed data at 28059 using either that implemented within WINFAPv2, or the updated model from 2008. This may be due to the high urbanisation and high permeability and the difficulties in modelling these types of catchment or may be a result of the difficulties in measurement at the station which are noted above.

In the previous study it was concluded that the station could be used provided a multi-site adjustment was applied such that undue weight was not provided to the observed data. This involves using a combination of donor stations and obtaining the final QMED estimate as a weighted average of the individually transferred estimates. Whilst the updated donor adjustment procedure as applied within WINFAP4 could be used, in application this is only possible if the data from the station itself is ignored, i.e. there is an automatic weighting of 1 if the observed data is used. In line with the previous study and due to the uncertainty in the gauging record at the sewage treatment works, but a desire to include the observed data to some extent, the same approach has been applied herein.

Two further stations were used to supplement the existing gauging data for the site, these were the Dover Beck at Lowdham and the Ryton at Worksop, which was used by JBA in the previous study. These stations were chosen based on their proximity to the study site (less than 50km), they were

[9] http://www.ceh.ac.uk/data/nrfa/data/peakflow_retrieval.html
[10] FEH WINFAP-FEH 3-User Guide www.e-secure.biz/documents/KLGJU9XGH9/WINFAP-FEH3-UserGuide.pdf

also of a similar size and had comparable BFIHOST values and SAAR values. The Ryton at Worksop also had a significant degree of urbanisation.

The previous study used three donor sites instead of two, this was not considered necessary, as other potential sites were considered too far from the target catchment, with dissimilar BFIHOST values. The NFRA peak flow dataset has also changed significantly since the previous report.

The choice of weight, W, reflects the similarity of the gauged sites to the subject site. A higher weighting was given to the donor station at the study site, the same as that adopted in the previous study. Due to the influence of the sewage treatment work, there was thought to be no benefit in applying a higher weighting to the additional donor stations. Appendix 1 provides the calculation record for the multi-site adjustment procedure.

The impact of urbanisation on flood peaks is accounted for by the Urban Adjustment Factor (UAF) implemented within WINFAP. The UAF for the target catchment is 2.50, in line with the high URBEXT value derived for the catchment. Table 2 shows the QMED value compared with the value estimated in the previous study.

Table 2 - Estimated QMED Values (m^3s^{-1}) for Tributary Catchments

	Qmed (m^3s^{-1})
QMED Catchment Descriptor (Rural)	0.85
QMED Catchment descriptor (Urban)	2.13
QMED (AMAX data 28059)	11.02
$Qmed_{old}$	8.00
$Qmed_{new}$	**8.54**

5.2 Derivation of the Growth Curve using pooled analysis

Within the FEH methodology flood growth curves can be formed by pooling annual maxima data from similar catchments which are flagged as being suitable for pooling. A threshold of 500 station-years is required (a sum of record lengths). In line with the previous study the gauging station at the sewage treatment works was not used as part of the pooling analysis.

The pooling group consisted of 16 stations. The Henmore Brook at Ashbourne (NRFA 28058) was removed as this has a bounded distribution reflected by a negative skew value; its record length was only 12 years. The site may be valid, with the skew value the result of sampling error, however it may also indicate issues with the quality of the data. In this case it was removed as a precautionary approach which may result in a conservative (high) estimate of the growth factors within the target catchment.

Table , shows the full list of pooling group members for the reach of the River Maun considered in this assessment. The distance shown is the distance from each candidate station to the sites in a similarity distance space (the FEH distance measure). Stations removed from the pooling group are noted.

The FEH recommended distribution for use within UK flood data to model the growth curves is generally the GL distribution hence for this reason and for consistency the GL distribution was used for all catchments within this study.

Table 3 – River Maun Pooling group and reasons for retaining or removing stations

Station	Distance SDM	AREA (km^2)	SAAR	FARL	URBEXT 2000	Accept	Reasoning
36010 (Bumpstead Brook @ Broad Green)	0.715	27.58	588	0.999	0.007	Accept	
26803 (Water Forlornes @ Driffield)	0.79	32.43	721	1	0.007	Accept	Permeable Adjustment
41020 (Bevern Stream @ Clappers Bridge)	0.795	35.42	886	0.993	0.013	Accept	
39033 (Winterbourne Stream @ Bagnor)	0.959	45.34	717	1	0.001	Accept	
203046 (Rathmore Burn @ Rathmore Bridge)	0.986	22.51	1043	1	0	Accept	
53017 (Boyd @ Bitton)	0.994	47.71	806	0.998	0.016	Accept	
41022 (Lod @ Halfway Bridge)	1.006	52.44	857	0.951	0.009	Accept	
44013 (Piddle @ Little Puddle)	1.013	31.27	1004	1	0.004	Accept	Permeable Adjustment
20002 (West Peffer Burn @ Luffness)	1.014	26.31	616	0.996	0.002	Accept	
26802 (Gypsey Race @ Kirby Grindalythe)	1.025	15.85	757	1	0	Accept	Permeable Adjustment
24007 (Browney @ Lanchester)	1.04	44.59	797	1	0.001	Accept	
73015 (Keer @ High Keer Weir)	1.042	30.06	1158	0.976	0.003	Accept	
33054 (Babingley @ Castle Rising)	1.072	48.51	686	0.944	0.005	Accept	Permeable Adjustment
72014 (Conder @ Galgate)	1.089	28.99	1183	0.975	0.006	Accept	
44008 (South Winterbourne @ Winterbourne Steepleton)	1.097	20.17	1012	1	0.004	Accept	
28058 (Henmore Brook @ Ashbourne)	0.834	38.48	895	0.977	0.021	Reject	Negative Skew Value

Table 4 presents the flood growth curve indexed by return period. As a large number of the stations in the pooling group were also permeable, a permeable adjustment was therefore required for a number of the gauging stations. Furthermore given the high URBEXT value for the Maun at Mansfield Stw, the growth curve was also adjusted for urbanisation.

Table 4 - Growth curve using pooled analysis with permeable adjustment and urban adjustment.

Return Period (years)	Growth Curve for Site
2	1
25	2.03
50	2.39
100	2.81
200	3.30
500	4.08
1000	4.79

5.3 Statistical Peak River Flows

The peak flows estimated from the statistical method are is presented in Table . These represent the QMED value rescaled by the growth curves derived using a pooled analysis.

Table 5 – Statistical Peak Flow Estimates

Return Period (years)	Pooled Analysis Peak Flow estimate (m^3/s)
2	8.54
25	17.36
50	20.42
100	23.99
500	34.83
1000	40.92

6 Peak Flows Estimation using the Rainfall- Runoff methodology

The catchment was modelled using the ReFH 2.2 software. This uses standard design rainfall events and catchment descriptors to produce hydrographs for the site. The FEH13[11] rainfall was used to generate the hydrographs.

The recommended duration and time step of 9.0 hours and 1.0 hours respectively were used to define the design rainfall event. Default parameters for urbanisation were used, as the catchment was urbanised the final peak flows are sensitive to these. Table shows the peak flows for the tributary and inflow basins for a range of return periods. The lower flows from ReFH are due to the estimated QMED being lower than the QMED from the statistical method. The growth curves from the two methods are similar. The sensitivity of the results to the urbanisation parameters is far smaller than the differences between the peak flows from the two methods.

Table 6 – ReFH2 Peak Flow Estimates

Return Period (years)	Peak Flow estimate FEH13 (m^3/s)
2	3.96
25	7.81
50	9.20
100	10.93
500	16.17
1000	18.76

[11] Stewart, E. J., Jones, D. A., Svensson, C., Morris, D. G., Dempsey, P., Dent, J. E., Collier, C. G. & Anderson, C. W. (2010) Reservoir Safety – Long return period rainfall. R&D Technical Report WS 194/2/39/TR (two volumes), Joint Defra/EA Flood and Coastal Erosion Risk Management R&D Programme

7 Final Hydrology

7.1 Final Peak Flows

The flood peaks for the catchment in this study has been assessed using both the statistical method and the rainfall run-off method.

The peak flows estimated using the statistical method are significantly higher than those produced using the rainfall runoff methodology. The use of the statistical method is therefore recommended for the hydraulic model, to provide a more conservative estimate of peak flow.

As the statistical method takes into account the available gauging data at the Mansfield Old station, and the FARL value it is also likely to provide the more accurate estimate of peak flows in the catchment. The pooled analysis also reduces the uncertainty in relying too heavily on the gauging record at Mansfield Stw.

The ReFH2 hydrographs are rescaled to the peak flows derived from the statistical analysis, these hydrographs will be used within the hydraulic model. The final flood peaks are presented in Table .

Table 7- Final Peak Flows

Return Period (years)	Pooled Analysis Peak Flow estimate (m^3/s)
2	8.54
25	17.36
50	20.42
100	23.99
500	34.83
1000	40.92

7.2 Comparison of Peak Flows to the Previous Hydrology Assessment

A comparison has been made between the final peak flows derived in this assessment and the hydrology assessment made in 2007. It can be seen that this revised assessment has led to a significant increase in peak flows.

The marked increase in the peak flows can be mostly attributed to changes in the way in which the growth curve is adjusted to account for urbanisation and permeability. For heavily urbanised and permeable catchments, the older methods significantly reduce the slope of the growth curve, and thereby the flow magnitude for high return period events. The statistical method has since been updated and the influence of urban and permeable adjustment on the growth curve is less pronounced.

The allowance for climate change has also increased from +20% in 2014 to +30% in 2016. The current climate change allowance of +30% is based on the Higher Central allowance category for the Humber River Basin District and the total potential change to 2115, i.e. 100 years of climate change[12]. Table 9 provides a comparison between both assessments.

Table 8 - Comparison of 2007 and 2016 Assessment of Peak Flows (m^3s^{-1})

	TOTAL FLOW	
	2007	2016
QMED	8.00	8.54
100	11.7	23.99
100+CC	14.04	31.18
1000	13.60	40.87

[12] NPPF (2016), *Flood risk assessments: climate change allowances.* https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances. Accessed: 17th August 2016.

Appendix 1 Multi-Site Adjustment Procedure

WHS

FEH Multi-site Adjustment Procedure Calculation Sheet

Site Name	Maun at Mansfield Stw
Site Location	Mansfield, Nottinghamshire
X (Eastings)	454850
Y (Nothings)	362350
Engineer	Daniel Hamilton
Checked by	Tracey Haxton
Reference	WHS 1469
Revision	1
Date	16-Dec-16

QMEDcds rural = 0.851

Selected Gauged Stations

Station Name	Distance	Area	URBEXT	BFIHOST
28059 (Maun @ Mansfield Stw)	0	27.51	0.39	0.835
28060 (Dover Beck @ Lowdham)	12.28	62.75	0.067	0.748
28049 (Ryton @ Worksop)	21.95	75.50	0.038	0.751

QMED obs/QMED CDs

Station Name	QMED obs	QMED Deurbanised	QMED CD Urban	QMED CD Rural	Ratio QMEDObs deurbanised/QMED CD Rural
28059 (Maun @ Mansfield Stw)	11.02	4.41	2.13	0.85	5.18
28060 (Dover Beck @ Lowdham)	2.61	2.41	2.93	2.85	0.85
28049 (Ryton @ Worksop)	5.46	4.77	3.27	2.70	1.76

Adjusted QMED Gauged Stations

$$QMED_{s,adj} = QMED_{s,cds}\left(\frac{QMED_{g,obs}}{QMED_{g,cds}}\right)$$

Station Name	QMED obs
28059 (Maun @ Mansfield Stw)	4.41
28060 (Dover Beck @ Lowdham)	0.72
28049 (Ryton @ Worksop)	1.50

Weighted QMEDs,adj

Station Name	Weighting	QMED obs
28059 (Maun @ Mansfield Stw)	0.7	3.08
28060 (Dover Beck @ Lowdham)	0.15	0.11
28049 (Ryton @ Worksop)	0.15	0.23

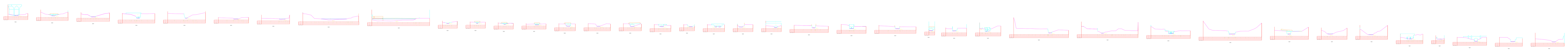
Adjusted QMED

Rural QMED = 3.42

Urban Adjustment Factor = 2.5

Urban QMED = 8.54

Appendix 2 - Survey



Symbol & Abbreviation Key.

	BARBED WIRE FENCE
	POST & RAIL FENCE
	CLOSE BOARD FENCE
	RAILINGS
	CHAIN LINK FENCE
	OTHER FENCE
	KERB
	DROPPED KERB
	GULLY CHANNEL
	TOP / BOTTOM OF BANK
	FOLIAGE
	DITCH
	VERGE
o·h	OVERHEAD CABLES
	GATE
	HEDGE
	TREE - BROAD LEAVED
	TREE - CONIFEROUS
	BUSH
	BUILDING
	BOREHOLE
	SURVEY STATION
	ORDNANCE SURVEY BENCH MARK

A/C	AIR CONDITIONING UNIT	KO	KERB OFFLET
AV	AIR VALVE	LC	LIGHTING COLUMN
BOL	BOLLARD	LP	LAMP POST
BH	BOREHOLE	NP	NAME PLATE
BL	BED LEVEL	NB	NOTICE BOARD
BM	BENCH MARK	PR	PIPE RISER
BT	BRITISH TELECOM	RP	RODDING POINT
CTV	CABLE TV	RS	ROAD SIGN
CL	COVER LEVEL	SP	SIGN POST
CR	CABLE RISER	SV	STOP VALVE
DP	DOWN PIPE	TL	TRAFFIC LIGHT
ER	EARTH ROD	TP	TELEGRAPH POLE
EP	ELECTRICITY POLE	TOF	TOP OF FENCE
EM	ELECTRICITY MARKER	TOH	TOP OF HEDGE
FB	FUSE BOX	TOR	TOP OF RAILINGS
FH	FIRE HYDRANT	TOS	SERVICE LEVEL
FP	FENCE POST	TOW	TOP OF WALL
FL	FLOOR LEVEL	UTL	UNABLE TO LIFT
GV	GAS VALVE	VM	VALVE MARKER
GM	GAS MARKER	VP	VENT PIPE
GU	GULLY	WL	WATER LEVEL
HM	HYDRANT MARKER	WM	WATER MARKER
IL	INVERT LEVEL	WO	WASH OUT

General.

This survey has been prepared with a scaling accuracy for a plot at a scale of 1:20

All tree heights and spreads are approximate. We have tried to identify tree types, however if tree species are critical specialist advice should be gained.

Drainage pipe sizes have been measured from the surface. Chamber access has not been gained for safety reasons, therefore sizes should be regarded as approximate.

Some detail may have been omitted due to parked vehicles.

Notes.

Coordinates related to OS National Grid by GPS (No scale factor added).
Levels related to GPS.

N
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ONLY

Rev	Details of Revision	Drawn	Date

Surveyed	Drawn	Date	Checked	Date	Approved	Date
AS	AS	18/11/16	GM	21/11/16	GM	21/11/16

INTERLOCK SURVEYS

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Title.

RIVER MAUN

RIVER SECTIONS

Dwg No. **160605** Sheet **2 of 2**

Scale NTS A0 Sheet Rev. -