Gladelands Flood Study

Ferndown

Dorset County Council

January 2016

Such · Salinger · Peters

CONSULTING ENGINEERS

Issue Record

Revision	Date	Details
First Issue	11/12/15	DRAFT ISSUE for client comment
Second Issue	06/01/16	DRAFT ISSUE for client comment, incorporating previous feedback
Third Issue	17/02/16	Final Issue

Copy No	Issued To
One	Gary Cleaver

First Issue	Name	Signature	Date
Originator	JHW		11/12/15
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Authoriser	NA		11/12/15

Second Issue	Name	Signature	Date
Originator	JHW		05/01/16
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Originator	*JEP*		*17/02/16*
Reviewer	*NDA*		*17/02/16*
Authoriser	*JEP*		*17/02/16*

Contents

GENERAL NOTES

1. This report is provided as an assessment only, in the context of the stated study proposals and should not be used in a different context.

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1. Introduction

1.1 Dorset County Council in conjunction with East Dorset District Council are investigating a flood event which occurred on Christmas Eve 2013. The event saw the flooding of a number of residential park homes on the Gladelands site in Ferndown, Dorset.

1.2 This report has been commissioned by Dorset County Council to try to ascertain the causes of the flooding and to identify potential measures which could be put in place to prevent or mitigate future flood events.

1.3 In preparing this report, a hydraulic model of the Uddens Water and the small tributary to the west of the study area has been built. JBA Consulting have been employed as an external consultant to provide flow data for use in the hydraulic model.

1.4 A location plan showing the site and the study area is included in the appendices.

2. Study Area Description

2.1 The study area focusses on the Gladelands site, which lies to the immediate south of the A31 dual carriageway in Ferndown, Dorset. The site is home to approximately 100 residential park homes, each set on a concrete hardstanding accessed via tarmac site roads.

2.2 The site is bounded by dual carriageway roads to the north A31 and east A348. To the south lies a large supermarket and to the west is woodland. Access is via a private tarmac driveway from the dual carriageway to the east of the site.

2.3 The Gladelands site itself lies at a low point in the local surroundings, with the A31 dual carriageway embankment effectively forming a dam between the site and the Uddens Water to the north. Ground levels rise in all directions from the site, meaning that any overland surface water flows will collect on the site and be trapped by the A31 embankment.

2.4 The major watercourse in the area is the Uddens Water (Main River), which lies to the immediate north of the A31, flowing west to east. Within the study area, the watercourse is primarily open channel within woodland. At the eastern end of the study area the watercourse passes beneath the A31 Palmersford Roundabout via a 6m wide, 2.5m high concrete box culvert.

2.5 On the north western boundary of the site there is a tributary which serves a large industrial estate. The tributary flows west to east until it reaches the study site boundary, where it turns sharply north to pass through a 2.1m wide, 1.5m high concrete box culvert beneath the A31 before joining the Uddens Water.

2.6 In addition to the tributary noted above, there are a number of small ditches draining through the woodland to the south of Gladelands and across the study site in a combination of open ditches and piped culverts, the majority of these small ditches combine before crossing under the A31. There are essentially two principle channels, each connected to a minor culvert together with one major culvert which cross under the A31 in order to discharge into the Uddens Water.

2.7 There are a number of public and highway surface water sewers in the area, primarily serving the A31 and the dual carriageway to the east of the site. Of particular note are two surface water sewers which run south-north along the A348 dual carriageway to the east, these systems both receive Highway runoff. One of these enters the Uddens Water via a piped connection inside the large concrete box culvert beneath the Palmersford Roundabout on the A31. The second enters the Uddens Water immediately downstream of the culvert A31 Palmersford Roundabout.

2.8 There are a number of public foul sewers in the study area, including a Wessex Water owned and operated Foul Sewerage Pumping Station to the south of Palmersford Roundabout.

2.9 The Wessex Water Sewer Record for the area is provided in Appendix 2.

3. Flood Event Overview and Commentary

Flood Event Overview

3.1 A flood event occurred on Christmas Eve 2013 during which a significant part of the Gladelands site was flooded. Parts of the adjacent road network were also flooded, in particular part of the Palmersford Roundabout on the A31, which lies to the immediate north east of the site. Several photographs showing the flood event are contained in the appendices.

3.2 There are a number of contemporary reports regarding the flood event which make reference to rate of floodwaters rising and falling along with the locations where floodwaters were observed entering the Gladelands site.

3.3 Having reviewed the reports and all other supporting information provided as part of this study, an indicative sequence of events has been pieced together as follows:

- Prolonged heavy rainfall occurred in the upper catchments of the Uddens Water and other local watercourses. EA data suggests that the rainfall experienced correlates with a 1 in 100 to 1 in 200 year event, this however is unconfirmed with other sources are referring to a 1 -75 year event.
- Water levels in the Uddens and adjacent watercourses / surface water sewers rise until they come out of bank / above ground
- Overland flow enters the Gladelands site from two directions:
    - Initially, floodwater flows into the site from the east, coming from the direction of Palmersford Roundabout
    - Subsequently, a second flow of floodwater enters the site from the north west, coming from the direction of the tributary at the point where it turns sharply north to enter the culvert beneath the A31
- Eventually, the two flows of floodwater join and collect in the lower areas of the Gladelands site, flooding a number of properties and prompting an emergency evacuation of residents.

3.4 The reports covering the flood event suggest that floodwaters rose relatively quickly and remained elevated for some time, which is consistent with flood events occurring in the lower catchments of rivers where the flood levels are dictated by elevated downstream water levels.

3.5 Wessex Water have been consulted regarding water levels at their Sewage Pumping Station to the south east of Palmersford Roundabout. Telemetry within the station wet well recorded elevated water levels but the station did not flood, indicating external flood water levels remained below the cover slab level on the station. The telemetry data also indicates that water levels peaked just after midnight on 24 December and remained elevated for approximately 12 hours, before gradually returning to normal levels by midday on 25 December.

Flood Event Commentary

3.6 Wessex Water have kindly provided photographs taken during the flood event showing their Sewage Pumping Station and the Uddens Water downstream of the A31 Palmersford Roundabout culvert. These photographs enable an estimate of downstream water levels to be made - a water level of 12.80-12.90mAOD is estimated for the Uddens downstream of the culvert. It is noted that this only reflects levels at the time the photographs were taken. Records show the photographs were taken during the day on 24 December, which coincides with the peak water levels recorded at the pumping station.

3.7 The Wessex Water pumping station cover slab level is 12.99mAOD and this was not breached during the flood event. It can therefore be surmised that flood levels downstream of the A31 Palmersford Roundabout culvert did not exceed 12.99mAOD.

3.8 There are a number of other photographs showing the extent of flooding on the Gladelands site and on the adjacent A31. Several of the photographs are reproduced in the appendices. Careful study of the photographs allows an estimation of the water level to be made; we estimate the water level at the time of the photographs being taken on the A31 Palmersford Roundabout to be 13.1-2mAOD, based on surveyed levels on the roundabout correlated against photographic evidence.

3.9 Based on information provided by Highways England regarding water levels in the rear gardens of two properties on Priory Road, a very broad peak flood level between 13.0mAOD and 14.0mAOD has been estimated, this range is based on Lidar data correlation over distances of only 6 – 10m (very steep) and hence the wide range. If further topographic survey work was undertaken a narrower range could be established.

3.10 It is noted that there are various contemporary reports of tree/wood and other debris building up in the Uddens Water, both at the time of the flood event and at other times. It is also noted that questions were raised regarding the condition of the surface water drainage serving the dual carriageway to the east of the site.

4. Hydraulic Modelling

Hydraulic Model Commentary

4.1 A hydraulic model has been created of the Uddens Water with a downstream limit at the large concrete culvert beneath the A31 and an upstream limit set a short distance upstream of the confluence where the tributary serving the industrial estate joins the Uddens Water. A schematic plan of the model is given in the appendices. The plan also shows the three points at which flow data has been sourced from JBA Consulting.

4.2 The model uses a number of cross sections based on site surveys undertaken in August and October 2015. Each cross section has been extended laterally to ensure the full flood plain is contained within the model.

4.3 The model incorporates two structures – a small concrete culvert on the tributary and a large concrete culvert on the Uddens Water itself. Both are modelled as culverts with no wing walls, and have been modelled as clean culverts, ie no allowance has been made for siltation.

4.4 JBA Consulting have undertaken a catchment analysis for the study site and have provided indicative flow rates for both the Uddens Water and the tributary. The flow rates cover a range of return periods from 1 in 2 to 1 in 1000 years. The hydraulic model has been run using all provided flow rates. A copy of the JBA Consulting report is provided in the appendices.

4.5 The table below shows the JBA Consulting flows at each of the three locations:

Site	Flood Peak (m^3/s) for the following return periods (in years)								
	2	5	10	20	50	75	100	100 +CC	1000
Uddens_US	13.1	16.7	19.5	22.4	26.8	29.0	30.8	40.0	52.7
Uddens_DS	13.2	16.9	19.7	22.6	27.1	29.3	31.1	40.4	53.4
Tributary_DS	0.4	0.5	0.6	0.7	0.9	1.0	1.1	1.4	2.1

4.6 The hydraulic model has been created using freely distributed HEC-RAS software. Digital copies of the model are available on request.

4.7 Based on the information available, an analysis has been undertaken of likely scenarios which could replicate the flooding experienced at Gladelands in December 2013. These scenarios have then been tested using the hydraulic model to ascertain if the modelled effects match those experienced on site. Scenarios included raised downstream water levels, blockages within the A31 culverts and various combinations thereof.

Hydraulic Model Outputs

4.8 The outcome of running the various scenarios is that one set of conditions produced the only viable correlation between the modelled results and the flood event which occurred. The scenario generating this outcome is driven by elevated water levels in the Uddens River downstream of the Palmersford Roundabout–no other scenarios that were modelled produced water levels which matched those noted during the flood event.

4.9 During the modelling process it was noted that the open channel section of the Uddens, along with the A31 Palmersford Culvert, has sufficient capacity to deal with the 1 in 100 year (including climate change) flows from their contributing catchments, provided there are no artificial downstream controls on water levels (ie. the hydraulic model was set with the downstream boundary condition as critical).

4.10 During the flood event of December 2013 downstream water levels reached at least 12.80mAOD, which would have surcharged the A31 Palmersford Road culvert and backed up the open channel section of the Uddens. This level would also have drowned out the 600mm culvert crossing the Gladelands site and the box culvert serving the upstream tributary. These restrictions on flow within the Uddens and its contributing catchments then caused upstream water levels to rise, flooding firstly the Palmersford roundabout itself and subsequently the land to the west of the Gladelands site. Floodwaters from both locations then entered the site.

5. Recommendations

5.1 The primary factor causing the flooding of the Gladelands site has been determined as elevated water levels downstream of the Palmersford Roundabout on the River Uddens. Improvements to the downstream watercourse to reduce flood levels is beyond the scope of this report, and is likely to require significant investigation and modelling by the Environment Agency as the managing authority of Main Rivers. It is understood that the Uddens Water is the subject of a modelling exercise which is due to be completed in the next 1-2 years.

5.2 Although there is currently limited scope to improve downstream water level conditions, there are several smaller contributing factors which could be improved to mitigate the impact of future flood events.

5.3 During the survey it was noted that the A31 Palmersford Road culvert contained a significant level of silt, which will impede flow to some extent during a flood event. It is recommended that the culvert be cleaned out and that a more proactive maintenance regime is put in place to ensure the culvert is inspected and cleared on a regular basis.

5.4 It is noted that questions have been raised as to the condition of the two surface water drainage systems serving the dual carriageway to the east of the site. No evidence of any investigation or cleaning out of these systems has been found, and it is recommended that both systems are inspected and jetted out to ensure they are able perform to their optimum ability.

5.5 Further to 5.4 above, it may be prudent to further investigate the two surface water drainage systems to ascertain if any upgrade works could improve their performance. In particular, it may be beneficial to look into diverting the system which outfalls into the A31 culvert so that it outfalls downstream of the culvert. This could potentially reduce the surcharge on the system and allow it to discharge more freely, reducing the likelihood of flooding the road network, however it is recognised that this should not be undertaken until the Environment Agency modelling (5.1 above) is completed as this may remove the need for any changes.

5.6 There is an existing small flood bank on the western boundary of the site, to the rear of Plot 101. It is recommended that this bank is reinforced and extended to provide additional protection; relatively minor improvements to the bank would result in significant betterment in the level of protection provided. Indicatively, by increasing the bank level to 13.50mAOD along its full length, and extending it southwards until ground levels are concurrent with the top of bank, would help provide protection against a repeat event of December 2013. The bank is already at this level at its north eastern extremity, reducing to a level of 12.90mAOD at its lowest point where a walkway has been cut.

5.7 Whilst not recorded as contributing to the flood event in question, December 2013, the ground levels around the entrance to the 600mm culvert receiving the run off from the adjacent Sainsbury's supermarket (close to Plot 38) could be raised to provide additional protection.

6. Summary

6.1 Dorset County Council in conjunction with East Dorset District Council are investigating an event which occurred on December 24 2013, causing a number of residential park homes on the Gladelands site in Ferndown, Dorset to flood.

6.2 This report has been commissioned to try to ascertain the causes of the flooding and to identify potential measures which could be put in place to prevent or mitigate future flood events.

6.3 The site is bounded by Dual Carriageway roads A31to the north and A348 to the east, by a supermarket to the south and by woodland to the west. The road to the north A31 is on a raised embankment. To the immediate north of the A31 is the Uddens Water, a designated Main River. The site lies within a natural low spot which, during storm events, will collect surface water runoff.
In addition to the Uddens Water, there are a number of smaller watercourses and surface water sewers on and around the site.

6.4 There are a number of accounts and photographs relating to the flood event on December 23 2013 which have been studied, and the following timeline of events has been pieced together from this information:

- Prolonged heavy rainfall occurred in the upper catchments of the Uddens Water and other local watercourses
- Water levels in the Uddens and adjacent watercourses / surface water sewers rose until they come out of bank / above ground
- Overland flow entered the Gladelands site from two directions:
    - Initially, floodwater flows into the site from the east A348
    - Subsequently, a second flow of floodwater enters the site from the north west
- Eventually, the two flows of floodwater joined and collected in the lower areas of the Gladelands site, flooding a number of properties and prompting an emergency evacuation of residents.

6.5 The Uddens Water and the largest of the tributary watercourses have been modelled using HEC-RAS software, and various scenarios run through the model replicating culvert blockages, raised downstream water levels and combinations thereof. The outcome of the modelling is that raised downstream water levels is the only scenario which can replicate the observations made during the flood event.

6.6 It is therefore concluded that the primary reason behind the flood event in December 2013 was elevated water levels in the Uddens Water downstream of the site.

6.7 There is currently limited scope to improve downstream water level conditions, and this area is subject to an Environment Agency modelling exercise which may yield proposals that would result in a lowering of the downstream water levels.

There are a number of other contributing factors which could be improved to mitigate the impact of future flood events.

The following works are listed as being worthy of interim action:

- The large culvert beneath the A31 Palmersford roundabout is cleared and desilted on a regular basis

- The two Wessex Water operated surface water sewers in the dual carriageway to the east of the site should be inspected and cleaned out if found necessary.

- Investigation into the feasibility of diverting the outfall of one of the surface water sewers downstream of the A31 culvert is suggested

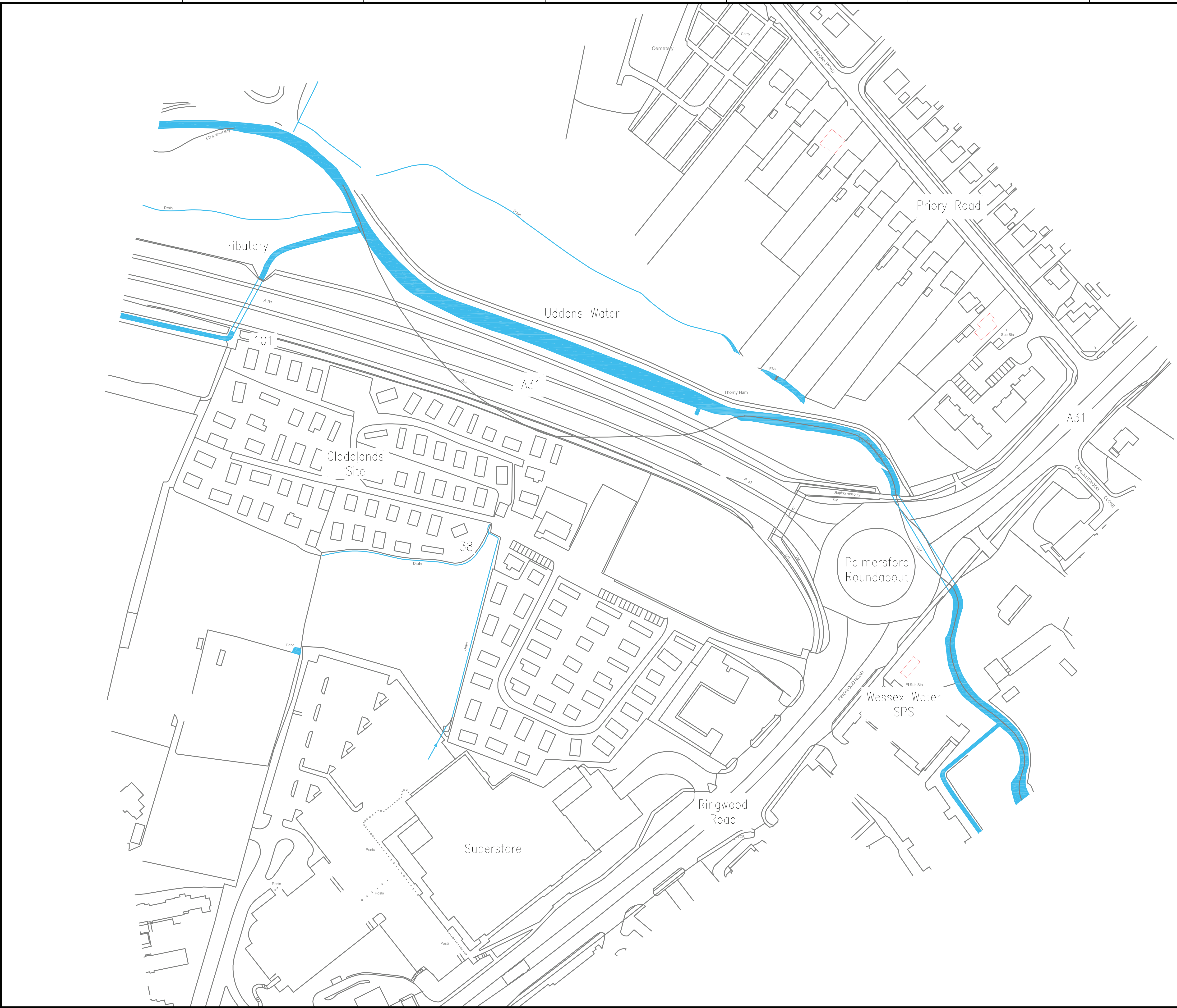
- The existing flood bank on the western boundary of the site should be reinforced and extended to provide protection from the tributary to the west.

- An additional flood mitigation feature could be considered around the entrance to the 600mm culvert which passes beneath the site, serving the supermarket

50891
SSP Bournemouth

Appendix 1

Study Area Location Plan



NOTES:

1. All dimensions in millimetres unless otherwise stated.
2. All levels in metres above Ordnance Datum.
3.

MK	REVISIONS	DRN	CHK	DATE
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–	FIRST ISSUE	JHW	JEP	11/12/15

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CLIENT
DORSET COUNTY COUNCIL

PROJECT
GLADELANDS FLOOD STUDY

DRAWING TITLE
STUDY AREA LOCATION PLAN

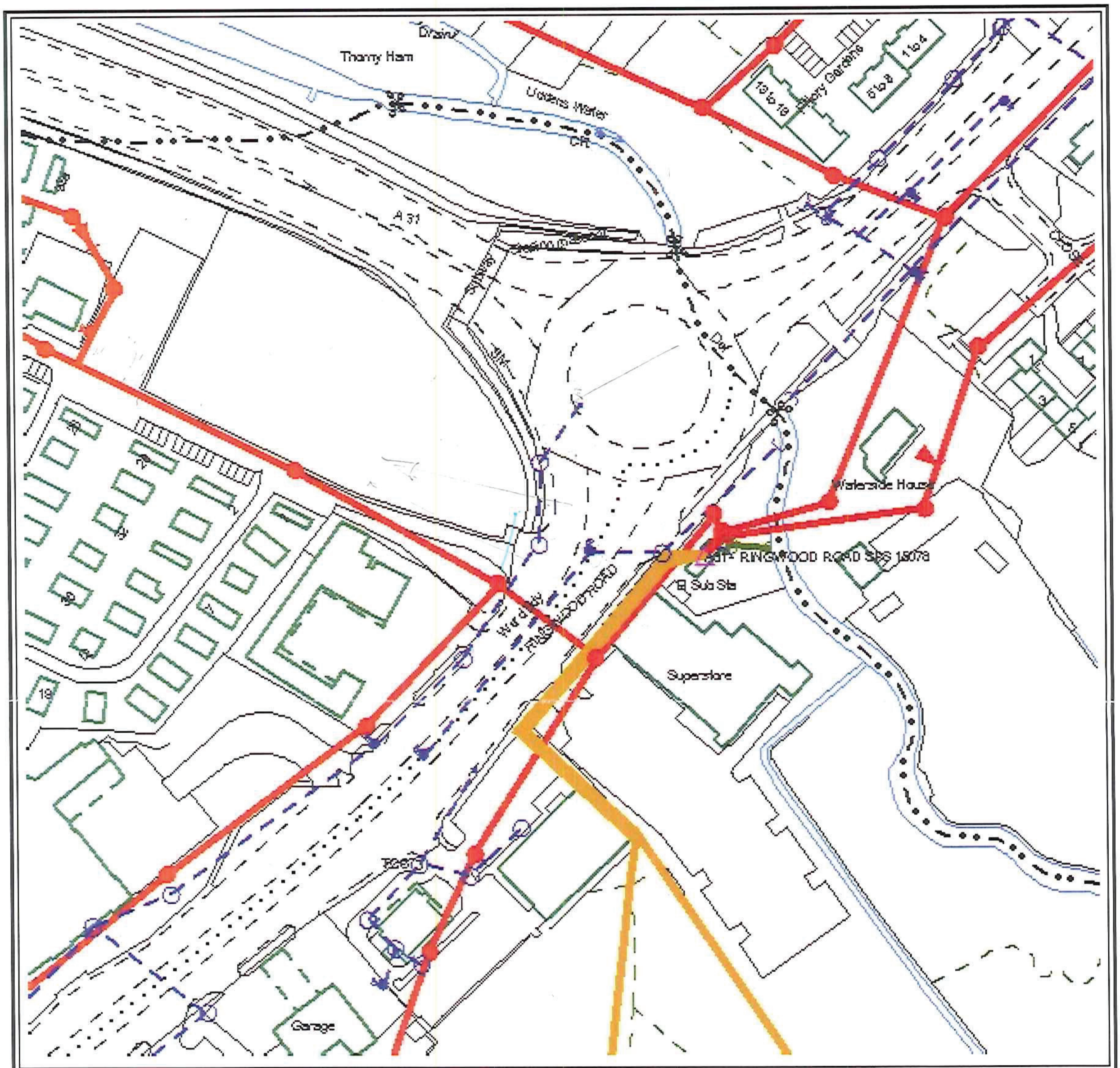
SCALE	DATE		
1 : 2000 @ A3 size	11/12/15		
	DESIGNED JHW	CHECKED JEP	
DRAWING No. 50891–02		REVISION –	

Appendix 2

Wessex Water Sewer Record

clear commitment

Waste Network



WATER MAINS

- Public
- Private
- Abandoned
- Raw Water

SEWERS	**Public**	**Private/ Section 104**
Foul		
Combined		
Surface		
Rising Main		

- Culverted Water Course
- Highway Drain
- Effluent Disposal Main

Scale 1:1998. **Centre** (409062, 101459).

23/07/2014 16:17:07

The information supplied in this plan is for guidance only, and Wessex Water does not accept responsibility for any inaccuracies. In carrying out any works, you accept liability for the cost of any repairs required to be undertaken by Wessex Water as a consequence of your actions or those of your contractors. You are advised to commence excavations using hand tools only, and not to use mechanical digging equipment until pipe-work has been precisely located.

Appendix 3

December 2013 Flood Event Photographs

Gladelands Site, viewed from the dual carriageway to the East, looking West

Palmersford Roundabout, viewed from Northern central island on A31, looking South West

Palmersford Roundabout, viewed from dual carriageway, looking North East

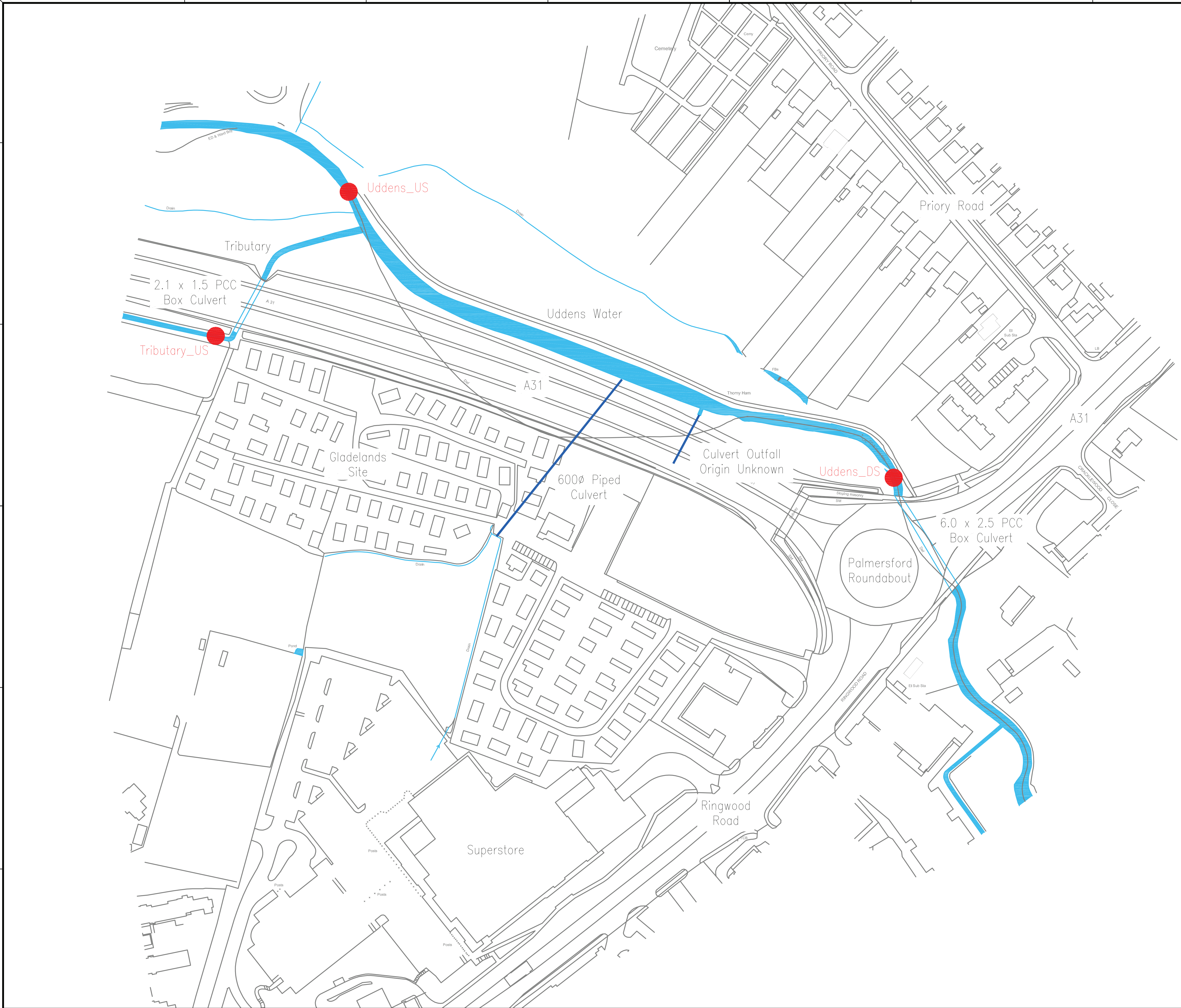
Palmersford Roundabout, viewed from dual carriageway, looking North West

Wessex Water Pumping Station (Right of picture), viewed looking South

Uddens Water, taken from Wessex Water Pumping Station, looking South

Appendix 4

Hydraulic Model Schematic Plan



NOTES:

1. All dimensions in millimetres unless otherwise stated.
2. All levels in metres above Ordnance Datum.
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CLIENT
DORSET
COUNTY COUNCIL

PROJECT
GLADELANDS
FLOOD STUDY

DRAWING TITLE
HYDRAULIC MODEL
SCHEMATIC PLAN

SCALE	DATE	
1 : 2000 @ A3 size	11/12/15	
	DESIGNED JHW	CHECKED JEP
DRAWING No. 50891–03		REVISION –

Appendix 5

JBA Consulting Flow Estimation Report

Flood estimation calculation record for single sites

Introduction

This calculation record is based on a supporting document to the Environment Agency's flood estimation guidelines (Version 4, 2012). It provides a record of the calculations and decisions made during flood estimation. It will often be complemented by more general hydrological information given in a project report. The information given here should enable the work to be reproduced in the future. This version of the record is for studies where flood estimates are needed at a single location.

Contents

Approval

	Name and qualifications
Calculations prepared by:	Kevin Haseldine BSc MSc MCIWEM
Calculations checked by:	Duncan Faulkner MSc DIC MA FCIWEM C.WEM CSci

Abbreviations

AM................................ Annual Maximum

AREA .... Catchment area (km^2)

BFI .... Base Flow Index

BFIHOST .... Base Flow Index derived using the HOST soil classification

CFMP............................. Catchment Flood Management Plan

CPRE............................. Council for the Protection of Rural England

FARL.............................. FEH index of flood attenuation due to reservoirs and lakes

FEH................................ Flood Estimation Handbook

FSR................................ Flood Studies Report

HOST .... Hydrology of Soil Types

NRFA .... National River Flow Archive

POT................................ Peaks Over a Threshold

QMED .... Median Annual Flood (with return period 2 years)

ReFH .... Revitalised Flood Hydrograph method

SAAR .... Standard Average Annual Rainfall (mm)

SPR................................ Standard percentage runoff

SPRHOST .... Standard percentage runoff derived using the HOST soil classification

Tp(0) .... Time to peak of the instantaneous unit hydrograph

URBAN .... Flood Studies Report index of fractional urban extent

URBEXT1990 .... FEH index of fractional urban extent

URBEXT2000 .... Revised index of urban extent, measured differently from URBEXT1990

WINFAP-FEH .... Windows Frequency Analysis Package – used for FEH statistical method

1 Method statement

1.1 Overview of requirements for flood estimates

Item	Comments
Give an overview which includes: • Purpose of study • Approx. no. of flood estimates required • Peak flows or hydrographs? • Range of return periods and locations	JBA Consulting was commissioned by Such Salinger Peters in December 2015 to estimate flood flows on two watercourses in Ferndown, Dorset. Flooding was recorded in the study area in December 2013 and Such Salinger Peters are investigating the cause of this inundation. The study area includes two channels; Uddens Water as it flows through Ferndown and below the A31 dual carriageway and a small tributary to Uddens Water draining land to the south of A31 road. The tributary drains the Slop Bog area and significant urban portions of Ferndown. Three flow estimation points were required, two on Uddens Water and one on the tributary. The resulting flow estimates are to be used by Such Salinger Peters as inputs to a hydraulic model, aimed at assessing the performance of culverts on each watercourse beneath the A31. Flow estimates were calculated for eight return periods: 2, 5, 10, 20, 50, 75, 100 and 1,000-year. Additionally, as requested, a climate change allowance of 30% will be made for the 100-year flow. Please note the Environment Agency guidance document for planners recommends use of a 20% to account for climate change[1]. A value of 30% is consistent with the South West change factor for the 2080s as per UKCP09[2]. Full hydrographs are required for all flow estimation points.

1.2 Overview of catchment

Item	Comments
Brief description of catchment, or reference to section in accompanying report	Uddens Water drains a predominantly rural area of some 50km^2, the only major settlement in the catchment being Ferndown at the downstream extent. The Flood Estimation Handbook (FEH) CD-ROM catchment boundaries appear to be incorrect, with the Wimborne Road East area shown to drain to the Uddens Water A31 culvert, whereas the finer resolution digital terrain model shows this draining downstream of this location. The catchments were adjusted accordingly. The catchment is not permeable (BFIHOST value of 0.49) and has no reservoir influence. The average annual rainfall is 823mm. In contrast, the tributary catchment is small (around 1.0km^2) and much of the catchment is urbanised, with housing estates making up around 50% of the total catchment area. The FEH CD-ROM provides an URBEXT2000 value of 0.36, but during this investigation this was revised to 0.30 to reflect the urban extent noted on Ordnance Survey mapping. The catchment area shown on the CD-ROM is also incorrect, with much of the eastern catchment missing, but with too extensive an area around Wimborne Road East included. This was re-estimated using digital terrain data. The catchment is also more permeable than Uddens Water with a BFIHOST value of 0.61. Otherwise, the catchment is similar in nature to Uddens Water, with no reservoir influence and an average annual rainfall of 807mm. The catchment areas are illustrated in Figure 1 (below); this map records both the FEH CD-ROM derived tributary catchment and the revised catchment area used in this analysis.

[1] Environment Agency (2013) Climate change allowances for planners. Guidance to support the National Planning Policy Framework.
[2] Environment Agency (2011). Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities.

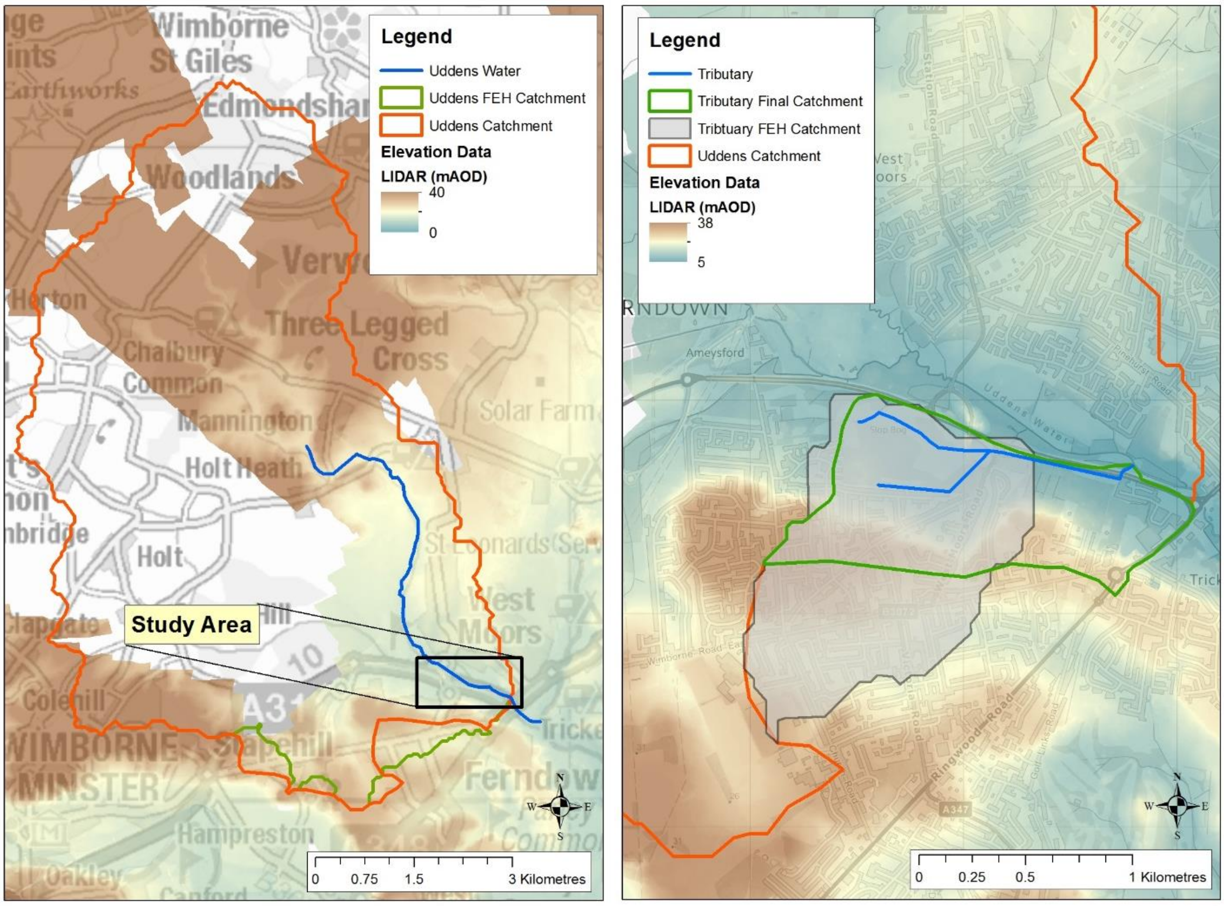

Figure 1-1: Ferndown study catchments

1.3 Source of flood peak data

Was the HiFlows UK dataset used? If so, which version? If not, why not? Record any changes made	Yes – v.3.3.4.

1.4 Gauging stations (flow or level)

Three gauging stations are located close to the study reach. Details of each are outlined below.

Water-course	Station name	Gauging authority number	NRFA number	Catchment area (km²)	Type (rated / ultrasonic / level…)	Start of flow record and end if station closed
Moors River	Hurn Court	43022	43022	143.3	Rated	1992 - present
River Allen	Loverley Farm	43010	43010	94.0	Rated	1970 - present
River Allen	Walford Mill	43018	43018	170.9	Rated	1974 - present

The Hurn Court gauge is downstream of Ferndown, located on the Moors Rive into which Uddens Water discharges. However, this station is not included in the Environment Agency's HiFlows-UK database and the rating is known to be influenced by backing up of water from the downstream River Stour. For this reason it was discarded from further consideration.

Both gauging stations on the River Allen, the adjacent catchment to Uddens Water, are included within HiFlows-UK. The Loverley Farm gauge is deemed suitable for estimation of QMED, but is not recommended for inclusion in pooling groups given the large degree of extrapolation used to estimate high flows. Walford Mill is considered suitable for both QMED estimation and pooling, although the catchment area is significantly larger than that of Uddens Water at our subject site.

It was concluded that the Loverley Farm gauge was most suitable for use in this analysis, given the proximity to the subject site.

1.5 Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available ?	Source of data and licence reference if from EA	Date obtained	Details
Historic flood data – give link to historic review if carried out.	Yes	No	n/a	n/a	Although flooding occurred in December 2013 no details regarding flood extent or mechanism are available.
Results from previous studies	Yes	No	n/a	n/a	n/a
Other data or information (e.g. groundwater, tides)	n/a	n/a	n/a	n/a	n/a

1.6 Initial choice of approach

Is FEH appropriate? (it may not be for very small, heavily urbanised or complex catchments) If not, describe other methods to be used.	The catchment areas are larger than $0.5km^2$ and therefore FEH methods are applicable.
Outline the conceptual model, addressing questions such as: • Where are the main sites of interest? • What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides…) • Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir? • Is there a need to consider temporary debris dams that could collapse?	Estimation of flow is required at three sites; • Upstream of A31 culvert on tributary; • Upstream of the tributary confluence on Uddens Water; • Upstream of A31 culvert on Uddens Water. Flooding from either the tributary or Uddens Water is likely to be driven by backing up of water behind the aforementioned culverts. It was considered that the hydrological characteristics of the urbanised tributary are likely to differ significantly from Uddens Water given the differences in catchment size and land use.
Any unusual catchment features to take into account? e.g. • highly permeable – avoid ReFH if BFIHOST>0.65, consider permeable catchment adjustment for statistical method if SPRHOST<20% • highly urbanised – avoid standard ReFH if URBEXT1990>0.125; consider FEH Statistical or other alternatives; consider method that can account for differing sewer and topographic catchments • pumped watercourse – consider lowland catchment version of rainfall-runoff method	The Uddens Water catchment displayed no unusual catchment characteristics. The incoming tributary is significantly urbanised and as such this was accounted for in the hydrological analysis.

• major reservoir influence (FARL<0.90) – consider flood routing, extensive floodplain storage – consider choice of method carefully	
Initial choice of method(s) and reasons Will the catchment be split into subcatchments? If so, how?	Flow estimates on both Uddens Water and the tributary catchment were initially estimated using the FEH Statistical method. The Revitalised Flood Hydrograph (ReFH) method was also used as this includes allowances for flood volume on both watercourses (in additional to peak flow estimates), given the tendency for flood waters to back up behind the A31 road embankment. The high levels of urbanisation on the tributary were accounted for using the ReFH urban extension.
Software to be used (with version numbers)	FEH CD-ROM v3.0[3] JBA Flood Estimation Software ISIS v3.7

[3] FEH CD-ROM v3.0 © NERC (CEH). © Crown copyright. © AA. 2009. All rights reserved.

2 Locations where flood estimates required

2.1 Summary of subject sites

Site code	Type of estimate L: lumped catchment S: Sub-catchment	Watercourse	Name or description of site	Easting	Northing	AREA on FEH CD-ROM (km^2)	Revised AREA if altered
Uddens_US	L	Uddens Water	Upstream of tributary confluence on Uddens Water.	408750	101700	50.88	50.21
Uddens_DS			Upstream of Uddens Water culvert beneath A31.	409090	101550	51.31	51.23
Tributary_US		Ferndown tributary	Upstream of tributary culvert beneath A31.	408720	101630	1.27	1.01

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

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

2.2 Catchment descriptors (incorporating and changes made)

The table below records catchment descriptors for each catchment. Where urban ReFH is applied (i.e. on the tributary watercourse), further catchment sub-division are made.

Site	FARL	PROP WET	BFIHOST	DPLBAR (km)	DPSBAR (m/km)	SAAR (mm)	SPRH-OST	URBEXT		FPEXT
								1990	2000	
Uddens_US	0.99	0.35	0.49	7.6	29.4	823	33.5	0.03	0.06	0.16
Uddens_DS	0.99	0.35	0.49	7.9	29.3	823	33.5	0.03	0.06	0.16
Tributary_US	1.00	0.35	0.62	1.4	11.9	807	26.5	0.44	0.57	0.14

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (refer to maps if needed)	Catchment boundaries from the FEH CD-ROM were checked against freely available Light Detection and Ranging (LIDAR) data. It was noted that the CD-ROM derived catchments did not clear catchment delineations seen in LIDAR for the urbanised tributary and therefore new catchment boundaries were derived. The final catchment area can be seen in Figure 1-1.
Record how other catchment descriptors (especially soils) were checked and describe any changes. Include before/after table if necessary.	BFIHOST, SPRHOST and FARL were maintained from those values given on the FEH-CDROM. URBEXT 1990 and 2000 values were re-calculated for the urbanised tributary based on Ordnance Survey mapping. DPLBAR was adjusted for this tributary using the equation in volume 5 of the Flood Estimation Handbook[4].
Source of URBEXT	URBEXT1990 / URBEXT2000
Method for updating of URBEXT	CPRE formula from FEH Volume 4 / CPRE formula from 2006 CEH report on URBEXT2000

[4] Bayliss, A. (1999) Flood Estimation Handbook Volume 5: Catchment Descriptors. Institute of Hydrology, Wallingford.

3 Statistical method

3.1 Search for donor sites for QMED

Comment on potential donor sites Mention: • Number of potential donor sites available • Distances from subject site • Similarity in terms of AREA, BFIHOST, FARL and other catchment descriptors • Quality of flood peak data Include a map if necessary. Note that donor catchments should usually be rural.	Loverley Farm gauge on the adjacent River Allen catchment was used as a donor site in the estimation of QMED for Uddens Water. This catchment centroid of this gauged watercourse is close to the centroid of the subject catchment (12.5km). The catchment area is the closest match to the subject site of any nearby gauging stations. No gauging station was used as a donor site for the urbanised tributary.

3.2 Overview of estimation of QMED at each subject site

Site code	QMED from CDs (m^3/s)	Final method	Data transfer						Final estimate of QMED (m^3/s)
			NRFA numbers for donor sites used (see 3.3)	Distance between centroids d_{ij} (km)	Power term, a	Moderated QMED adjustment factor, $(A/B)^a$	If more than one donor		
							Weight	Weighted ave. adjustment	
River Gowy									
Uddens_US	11.87	DT	43010	12.5	1.00	1.18	n/a		14.06
Uddens_DS	12.12	DT	43010	12.5	1.00	1.18	n/a		14.35
Tributary_US	0.44	CD	n/a						0.44
Are the values of QMED spatially consistent?			Insufficient number of flow estimation points to conclude.						

Notes

Methods: AM – Annual maxima; POT – Peaks over threshold; DT – Data transfer (with urban adjustment); CD – Catchment descriptors alone (with urban adjustment).

When QMED is estimated from POT data, it should also be adjusted for climatic variation. Details should be added below.

The QMED adjustment factor A/B for each donor site is given in Table 3.2. This is moderated using the power term, a, which is a function of the distance between the centroids of the subject catchment and the donor catchment. The final estimate of QMED is $(A/B)^a$ times the initial estimate from catchment descriptors.

If more than one donor has been used, use multiple rows for the site and give the weights used in the averaging. Record the weighted average adjustment factor in the penultimate column.

Important note on urban adjustment

The method used to adjust QMED for urbanisation, for both subject sites and donor sites, is that published in Kjeldsen (2010)[5] in which PRUAF is calculated from BFIHOST. The result will differ from that of WINFAP-FEH v3.0.003 which does not correctly implement the urban adjustment of Kjeldsen (2010). Significant differences will occur only on urban catchments that are highly permeable.

[5] Kjeldsen, T. R. (2010). Modelling the impact of urbanization on flood frequency relationships in the UK. Hydrol. Res. **41**. 391-405.

3.3 Derivation of pooling groups

Name of group	Site code from whose descriptors group was derived	Subject site treated as gauged? (enhanced single site analysis)	Changes made to default pooling group, with reasons .
Uddens	Uddens_Water	No	No changes to default group
Tributary	Tributary_DS	No	

Notes
Pooling groups were derived using the procedures from Science Report SC050050 (2008).

3.4 Derivation of flood growth curves at subject sites

Site	Method (SS, P, ESS, J)	Distribution used	Note any urban adjustment (and state v2 or v3) or permeable adjustment	Parameters of distribution (location, scale and shape) after adjustments	Growth factor for 100-year return period
Uddens_US	P	Generalised logistic	Yes – v3	Location: 1 Scale: 0.239 Shape: -0.106	2.42
Uddens_DS					
Tributary_DS				Location: 1 Scale: 0.147 Shape: -0.341	2.64

Notes
Methods: SS – Single site; P – Pooled; ESS – Enhanced single site; J – Joint analysis
Urban adjustments can be either **v2**: FEH (1999) updated by Bayliss (2006) or **v3**: Kjeldsen (2010).
Growth curves were derived using the revised procedures from Science Report SC050050 (2008).

3.5 Flood estimates from the statistical method

Site	Flood peak (m3/s) for the following return periods (in years)								
	2	5	10	20	50	75	100	100+CC	1000
Uddens_US	14.1	19.1	22.4	25.7	30.3	32.4	34.0	44.2	48.3
Uddens_DS	14.4	19.5	22.8	26.2	30.9	33.1	34.7	45.1	49.4
Tributary_US	0.4	0.6	0.7	0.8	1.0	1.1	1.2	1.6	2.2

4 Revitalised flood hydrograph (ReFH) method

4.1 Parameters for ReFH model

The standard ReFH method (excluding the urban extension) was used to estimate flood flows on Uddens Water. The urban extension (detailed below) was used on the urbanised tributary.

Site	Method: OPT: Optimisation BR: Baseflow recession fitting CD: Catchment descriptors DT: Data transfer (give details)	Tp (hours) Time to peak	C_{max} (mm) Maximum storage capacity	BL (hours) Baseflow lag	BR Baseflow recharge
Uddens_US	CD	5.8	391	44.3	1.2
Uddens_DS	CD	5.9	391	44.5	1.2

4.2 Catchment sub-divisions for urban ReFH model

The urban ReFH method was used for estimation of design flows on the Ferndown urbanised tributary. It was assumed that all paved areas within the catchment drain towards the channel, and not away from the topographic area via sewer systems. To account for the permeable nature of some urban areas (such as verges, gardens and parks), 70% of the urban area within each catchment was added to the rural area. The urban extent is shown in Figure 4-1 below.

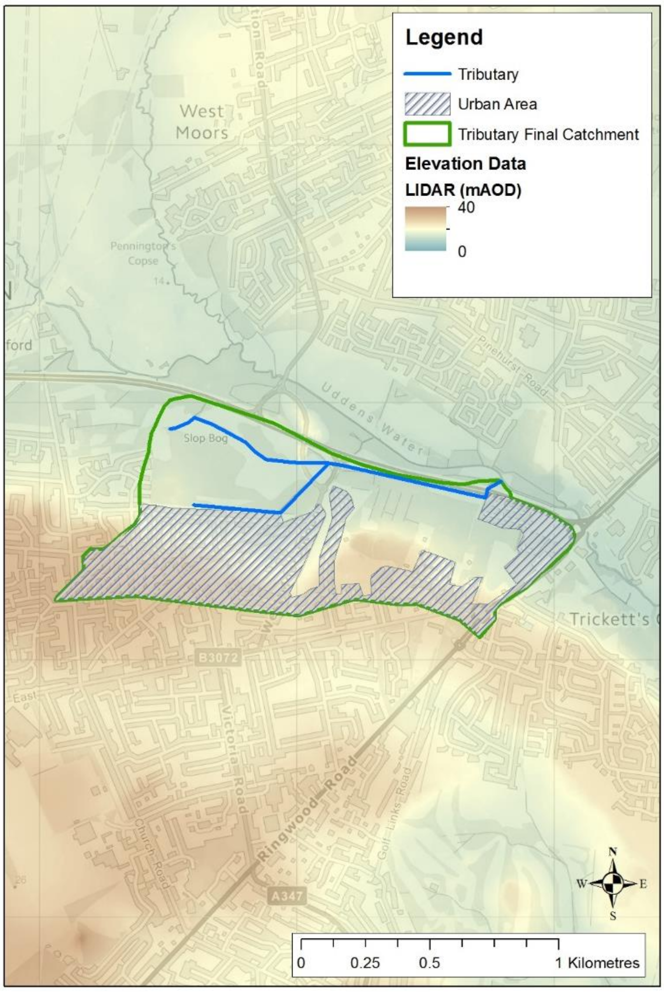

Figure 4-1: Ferndown urban tributary

Site code	Area (km²)			DPLBAR
	Total	Rural or undeveloped	Paved	
Tributary_US	1.01	0.87	0.14	1.01

4.3 Parameters for ReFH model (urban or mixed urban & rural catchments)

Percentage runoff (PR) is set to 70% for the urban catchments, the value recommended in Kjeldsen (2009)[6]. Guidance produced alongside the release of ReFH2 software[7] recommended setting an urban time-to-peak (Tp) at 0.5 times that of the rural portion of the catchment. In order to force this ratio, the URBEXT1990 values used in the urban sub-catchment are set to 0.23.

Site code	Method	Tp_{rural} (hours)	Tp_{urban} (hours)	C_{max} (mm)	PR_{imp} % runoff for impermeable surfaces	BL rural (hours)	BL urban (hours)	BR
Tributary_US	Urban ReFH	2.46	1.23	484	70	35.4	19.0	1.5

4.4 Design events for ReFH method

The design flood occurs on Uddens Water and the urbanised tributary as a result of different design storms; as expected a much shorter storm duration will lead to the greatest flows on the tributary. It is not suitable to assume the design return period is likely to occur simultaneously on both watercourses given the differences in catchment size and land use.

Site	Urban or rural	Season of design event (summer or winter)	Storm duration (hours)	Storm area for ARF (if not catchment area)
Uddens_US	Rural	Winter	17.50	n/a
Uddens_DS	Rural	Winter	17.50	
Tributary_US	Urban	Summer	7.75	

4.5 Flood estimates from the ReFH method

Site	Flood peak (m3/s) for the following return periods (in years)								
	2	5	10	20	50	75	100	100+CC	1000
Uddens_US	13.1	16.7	19.5	22.4	26.8	29.0	30.8	40.0	52.7
Uddens_DS	13.2	16.9	19.7	22.6	27.1	29.3	31.1	40.4	53.4
Tributary_US	0.4	0.5	0.6	0.7	0.9	1.0	1.1	1.4	2.1

[6] Kjeldsen, T. R. (2009). Modelling the impact of urbanisation on flood runoff volume. *Proc. Instn. Civ. Engrs. Wat. Man*. **162**, 329-336

[7] Wallingford HydroSolutions Limited and CEH (2015). The Revitalised Flood Hydrograph Model ReFH2: Technical Guidance.

5 Discussion and summary of results

5.1 Comparison of results from different methods

This table compares peak flows from ReFH with those from the FEH Statistical method at example sites for two key return periods. Blank cells indicate that results were not calculated using that method.

Site	Ratio of peak flow to FEH Statistical peak	
	Return period 2 years	Return period 100 years
	ReFH	ReFH
Uddens_DS	0.92	0.89
Tributary_US	0.00	0.92

5.2 Final choice of method

Choice of method and reasons – include reference to type of study, nature of catchment and type of data available.	It is recommended the ReFH flows are adopted for use in the HEC-RAS hydraulic model. ReFH allows explicit inclusion of the urban catchment areas associated with the urbanised tributary, producing quickly peaking hydrographs as would be expected on such impermeable areas. By using a rainfall-runoff approach the results also include an allowance for flood volume, rather than simply scaling a hydrograph to a fixed flood peak as is the case in FEH Statistical. Representation of flood volume is likely to be an important factor in the resulting flood extents given water is known to back up behind hydraulic structures in the study area. Given no gauging station is present on either watercourse to verify these flows estimates against, it is recommended the FEH Statistical estimates are used as a sensitivity test to highlight the uncertainty between each method.

5.3 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	The following assumptions have been made during this analysis: • ReFH is a suitable approach for estimating flood flows at Ferndown. Given the lack of flow gauge there is significant uncertainty using any hydrological method. • It is assumed all land within the urban catchment area drains to the subject watercourse, and nothing is transferred away from this catchment, or bought into the catchment, by sewer systems. • For the FEH Statistical method it is assumed the Loverly Park flow gauge is a suitable donor for Uddens Water.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return periods for which they were developed	The main limitation surrounding this analysis is the lack of local flow data. Any flow data, or information from historical flood events, could be used to refine the flow estimates produced here.
Give what information you can on uncertainty in the results – e.g. confidence limits for the QMED estimates using FEH 3 12.5 or the factorial standard error from Science Report SC050050 (2008).	No confidence intervals for the ReFH methodology have ever been published and therefore it is not possible to quantify uncertainty of these results. The 95% confidence intervals for ungauged FEH Statistical flows are 0.5 – 2 times the best estimate.
Comment on the suitability of the results for future studies, e.g. at	The results described have been derived for the purposes of this study only.

nearby locations or for different purposes.	
Give any other comments on the study, for example suggestions for additional work.	The flow estimates could be improved with flow records on the either watercourse. Provision of sewer maps for the urbanised areas could offer an indication of the volume of water transferred away from the subject watercourse during a given flood event.

5.4 Checks

Are the results consistent, for example at confluences?	Yes
What do the results imply regarding the return periods of floods during the period of record?	n/a
What is the 100-year growth factor? Is this realistic? (The guidance suggests a typical range of 2.1 to 4.0)	2.4 for Uddens Water 2.8 on urbanised tributary
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	1.7 for Uddens Water 1.9 on urbanised tributary
What range of specific runoffs (l/s/ha) do the results equate to? Are there any inconsistencies?	6.1 l/s/ha for Uddens Water 10.8 l/s/ha for urbanised tributary
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	n/a
Are the results compatible with the longer-term flood history?	n/a
Describe any other checks on the results	

5.5 Final results

Site	Flood peak (m3/s) for the following return periods (in years)								
	2	5	10	20	50	75	100	100+CC	1000
Uddens_US	13.1	16.7	19.5	22.4	26.8	29.0	30.8	40.0	52.7
Uddens_DS	13.2	16.9	19.7	22.6	27.1	29.3	31.1	40.4	53.4
Tributary_DS	0.4	0.5	0.6	0.7	0.9	1.0	1.1	1.4	2.1

If flood hydrographs are needed for the next stage of the study, where are they provided? (e.g. give filename of spreadsheet, name of ISIS model, or reference to table below)	Flood hydrographs are provided in the attached spreadsheets: *2015s3643 – ReFH Results Spreadsheet.xlsx* *2015s3643 – FEH Stats Results Spreadsheet.xlsx*

6 Annex – supporting information

6.1 Pooling group composition

Uddens Water

Station ID	Station Name	Start Year	End Year	Rank
33032	Heacham	30 May 1967	07 Jun 2012	1
34005	Costessey Park	11 Nov 1961	06 Mar 2012	3
33054	Castle Rising	11 Feb 1977	06 Jul 2012	4
26003	Foston Mill	10 Feb 1960	06 Jul 2012	7
43014	Upavon	11 Jun 1971	07 Jul 2012	10
205005	Ravernet	20 Jan 1973	24 Oct 2011	13
76019	Stockdalewath	03 Dec 1999	23 Jun 2012	19
37003	Crabbs Bridge	15 Mar 1964	03 May 2012	20
36003	Polstead	05 Mar 1964	03 May 2012	21
34012	Burnham Overy	26 May 1967	27 May 2012	22
39042	Priory Mill Lechlade	16 Dec 1972	14 May 2012	26
41020	Clappers Bridge	23 Jan 1970	11 Jun 2012	27

Urbanised tributary

Station ID	Station Name	Start Year	End Year	Rank
76011	Coalburn	27 Feb 1967	28 Jun 2012	1
27073	Snainton Ings	28 Mar 1981	03 May 2012	2
45816	Upton	20 Dec 1993	03 Jan 2012	3
27051	Burn Bridge	27 Sep 1973	24 Sep 2012	5
28033	Hollinsclough	29 Nov 1966	05 Jul 2012	6
91802	Intake	15 Nov 1939	11 Nov 1973	7
25003	Moor House	05 Mar 1963	22 Jun 2012	9
25019	Easby	03 Feb 1972	27 Apr 2012	11
26802	Kirby Grindalythe	20 May 1998	05 Aug 2012	13
25011	Langdon	10 Aug 1970	08 Dec 2011	14
47022	Newnham Park	27 Dec 1979	07 Jul 2012	15
54022	Plynlimon flume	05 Aug 1973	05 Oct 2008	18
206006	Recorder	24 Sep 1896	06 Jan 1943	19
27010	Bransdale Weir	14 Dec 1936	02 Oct 1976	20
203046	Rathmore Bridge	08 Dec 1982	22 Jun 2012	21
44008	Winterbourne Steepleton	24 Nov 1974	08 Jul 2012	22

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