Cullompton Eastern Distributor

A review of the Environment Agency's existing ISIS model

Technical note

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Technical note

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Front cover. Upstream view of the Spratford Millstream

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1 Introduction

Devon County Council plans to build a distributor road around Cullompton, Mid Devon, to ease traffic congestion and improve air quality in this historic market town. Since the route options cross the floodplain of the River Culm, the Council has commissioned Hyder Consulting (UK) Ltd. to prepare a Flood Risk Assessment (FRA) in support of the proposed road. The FRA will include detailed hydraulic modelling to assess flood risk impacts, inform selection of the preferred route option and identify flood mitigation measures.

This technical note presents the findings of a review of the Environment Agency’s existing River Culm ISIS model. As set out in Hyder’s project proposal, the existing model has been assumed to provide a suitable basis for the FRA model build. To confirm whether this is the case, Hyder has a carried out a number of checks on the model, including structure representation, run parameter values and convergence performance; further details are given in section 2.

Hyder has also revised the inflows to the ISIS model, based on peak flow frequency estimates provided by the Environment Agency. Details of the approach taken and the findings from this hydrology update are documented in section 3.

Overall, the existing ISIS model provides a detailed representation of the River Culm and tributaries, and, after some adjustments, runs with the updated hydrology. However, a number of improvements are needed to ensure that the model complies with latest best practice modelling standards and provides a robust basis for the FRA. These improvements are outlined in section 4.

2 ISIS model review

2.1 Background

The existing River Culm model was built by PDMM Posford Haskoning in 2002, under the Environment Agency's former Section 105 Flood Risk Mapping Framework Agreement. The model covers ten watercourses near Cullompton: the River Culm, Spratford Stream, River Ken (North), River Ken (South), Heron's Bank, St Andrew's Well Stream, Crow Green Stream, Cole Brook, Lower Cole Brook Stream, and Spratford Millstream. Figure 1 shows the watercourses modelled.

The model was constructed using a number of different channel surveys dating from the late 1990s and early 2000s:

- 1999 – Halcrow Group Ltd.
- November 1999 – Merrett Survey Partnership
- November 2000 – Merrett Survey Partnership
- July 2001 – Land and Sea Survey Company
- September 2001 – Halcrow Group Ltd.

2.2 Model comparison

A different model (.dat) file has been created for each calibration and design event, this is not the ideal way to handle differing storms but it is acceptable. Best practice would be to have one single model and then reference different event (.ied) files in the scenario (.ief) file. This allows greater ease of adjusting the hydrology and prevents duplication of model data thus offering space savings where the model is stored.

Where different dat files are used for each calibration and design event, each of the models should be identical apart from the hydrological boundary data. To examine this, the existing ISIS models were compared using the compare tool in ISIS 3.6. This tool allows models to be compared easily side-by-side and highlights clearly any differences. No significant differences were found between the models.

2.3 Model build checks

2.3.1 Cross sections

Comparison of cross sections to survey

A sample of modelled cross sections and structures has been compared to the surveyed sections to ensure that the cross section data has been input correctly.

Generally, the data in the in-channel cross sections looks to be correctly represented. There are a few sections which have slots in them, this has been done for stability purposes. However, with the stability upgrades in later versions of ISIS these slots should be removed if possible.

There are differences between survey and cross section data on the floodplain where a slot has been added to the floodplain sections to allow the model to run during low flow conditions. This is discussed further later on in the report.

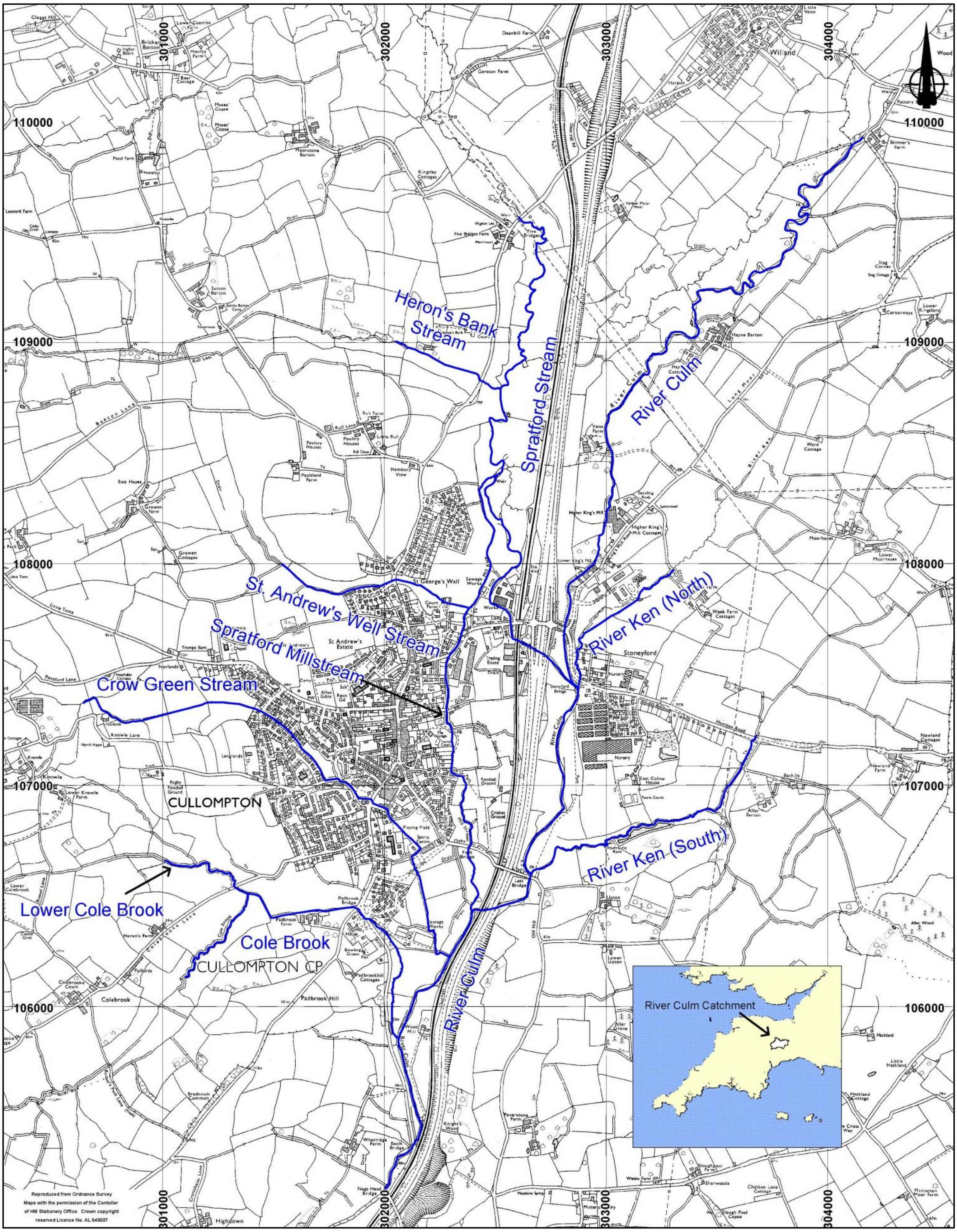

Figure 1. Modelled watercourses (taken from PDMM, 2002)

Chainage checks

Model chainage has been checked against the surveyed chainage. Another rough check of the chainage has been performed by comparing the chainage between two known structures in the model and then measuring the distance between the two structures on OS Opensource Streetview map tiles. Through the sampled nodes and reach lengths, the chainage of the model matched the survey and the measurements on the OS tiles well.

Node spacing checks

The distance between model nodes relative to the slope of the channel has been checked. There are some very long distances, relative to the slope of the channel, between modelled nodes at locations throughout the model. These long distances can result in numerical instabilities occurring as ISIS attempts to calculate flow volume and velocities over the reaches between nodes. It would be best to add more interpolates to the model based on the slopes of the channels to reduce the possibility of these instabilities occurring.

The distance between nodes has also been checked in order to find areas that may be overpopulated with nodes. There are no regions of the model which are excessively overpopulated with nodes.

Roughness checks

The Manning's 'n' values used have been checked against guideline values from the Roughness Advisor tool in ISIS, standard hydraulics texts and modelling experience/judgement.

PDMM's (2002) report states that Manning's 'n' roughness values have been chosen based on recommendations from 'Open Channel Hydraulics' (VT Chow 1959). Based on a random sample of cross sections the Manning's 'n' values appear to be appropriate for most sections, however at the top end of the Crow Green Stream the in-channel roughness values are very high, and based on the surveyed drawings this does not seem to be appropriate (although there are no photographs available to confirm this). There are also sections which have zero roughness values for the floodplain areas. This is assumed to represent buildings, but given the distance between sections it would be more realistic to use a high roughness value to represent water having to flow around buildings rather than a zero value which results in standing water.

A detailed review of the roughness values should be undertaken, against images of the watercourses in the vicinity of sections, to ensure that all roughness values used are appropriate.

2.3.2 Model boundaries

The hydrological boundaries in the model have been checked to ensure that they are inputted correctly, consistently and at realistic locations.

There are 12 existing hydrological boundaries in the model. These boundaries are QT units representing the catchments upstream of the model and lateral catchments throughout the model. The lateral catchments have been entered into the model as discreet point inflows. This may be the best method for these catchments. However, it is worth determining if they could be better represented using a lateral unit to distribute the flows over a reach rather than lump them at a single inflow location.

There are also two dummy inflows onto the floodplain, these inflows have not been extracted from the model at the downstream end of the floodplain reaches. Since the dummy flows are quite high relative to the flows that can be expected in the floodplain channels, they could lead to overestimation of flood levels.

The downstream boundary of the model is represented by a stage-discharge relationship downstream of Baulk Bridge. It is not clear from PDMM's (2002) report or the model how this relationship has been derived, and this boundary should be examined in detail to determine if it is appropriate.

2.3.3 Structure checks

The structures represented in the model have been checked to ensure that the most appropriate ISIS units have been used and that there are valid reasons for any omitted structures.

The model was built in ISIS version 1.5, and there have since been numerous improvements and changes to how structures are represented by the software including the addition of new structure units. Therefore, the units used by PDMM (2002) may no longer be the most appropriate units for the structures modelled.

Key findings of the structure checks are as follows:

- The geometry of the structures matches that surveyed.
- At a large number of structures the surveyed sections either side are much smaller than the channel sections upstream and downstream, this can lead to inaccurate calculations of water level and flow due to ISIS interpolating between the wide and narrow sections.
- For several structures the 'p' levels in the model, representing distance of invert above upstream and downstream bed level, are inconsistent with the channel beds, this can lead to inaccurate calculations of flow and head loss through/ over the structures as well as inaccurate calculation of the switch between free and drowned flow.
- The sluices in the model need weir lengths in the units as this field has been added to the unit since the model was built.
- The invert levels of Bernoulli loss units should be checked as they do not match the surveyed levels in the sections upstream and downstream.
- Several structures do not have bypass spills. In PDMM's (2002) report, it is stated that this is because the 1 per cent annual exceedance probability (AEP) water level will not overtop the structure. However, this should be checked against updated hydrology and against larger events, and spills should be inserted into the model where necessary.
- Several culverts have no inlet or outlet unit. This should be rectified to appropriately model the entry and exit losses of the culverts.
- Irregular culverts have been used to model regular shapes. These should be modelled as the correct culvert shapes since the calculations used are specific for each shape.
- Orifice units have been used to model nearly all of the bridges. These should be examined and replaced with the appropriate bridge unit if necessary.

2.3.4 Floodplain representation

The methods used to represent the floodplain have been checked to ensure that they are appropriate for the local area.

The floodplain has been represented by three different methods: the methods used are extended sections, parallel channels and reservoir units.

Most of the extended sections are surveyed for their entire widths; however there are a few sections which have been extended using data from different surveys or using 1:25,000 map contours. The sections which have been extended using 1:25,000 map contours will need to be trimmed down to their surveyed widths and re-extended using LiDAR data.

Several of the extended sections have been smoothed, these smooth sections should be removed and the survey data reinstated in these areas as floodplain storage may be over/ underestimated, leading to inaccurate results. Figure 2 shows an example of smoothed floodplain at SA0935.

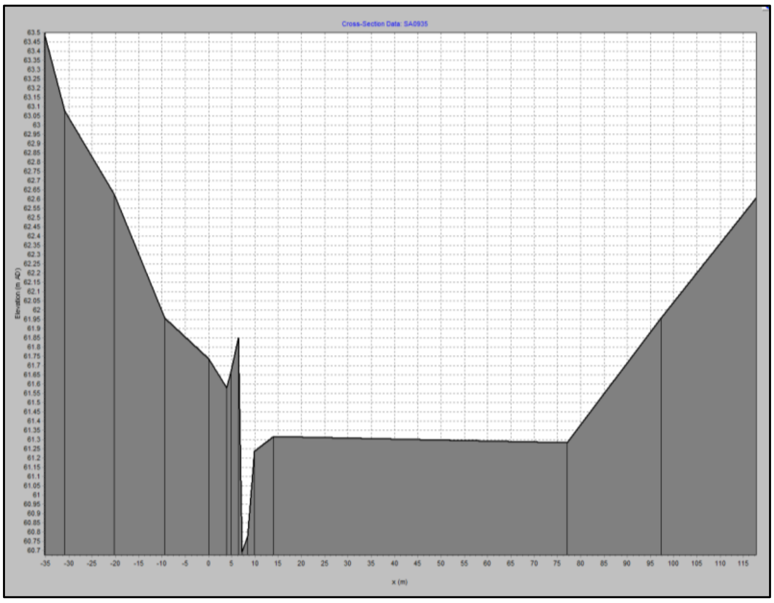

Figure 2. Example of smoothed floodplain

Several extended sections have additional channels represented in the floodplain, this can lead to inaccurate modelling of water levels in the main channel as ISIS models one water level across the entire section. The floodplain channels provide additional storage at lower levels which results in the conveyance of the section being increased and the water level in the main channel being underestimated. Sections with these additional channels should be split at appropriate locations on the floodplain and modelled as parallel channels. Figure 3 shows an example of additional channels at Culm5388.

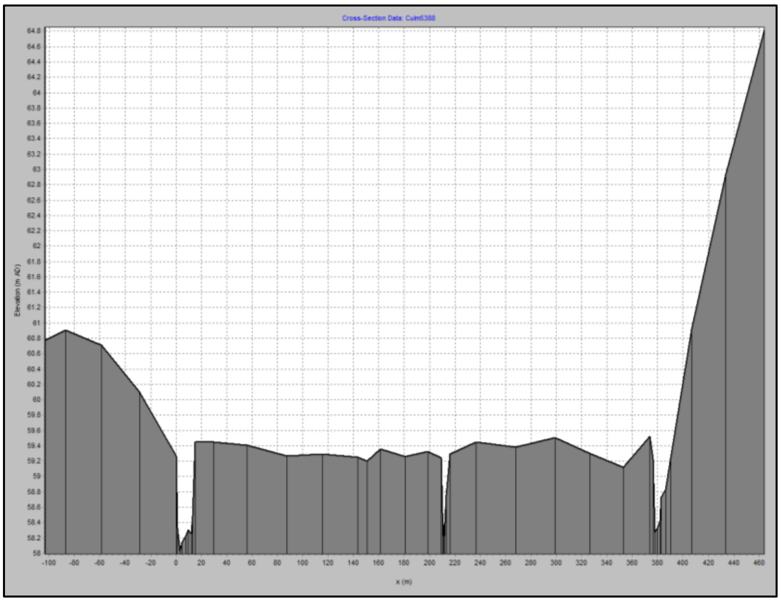

Figure 3. Example of additional channels

Sections of the floodplain have been modelled as parallel channels which is an appropriate method for this area, as the floodplain slopes in such a fashion that it will convey water downstream without attenuation areas interrupting it. Most of the parallel channels have slots in them and a dummy flow at the upstream end to keep the model stable, this is a valid method however the slots are very large and should be reduced in size. A knock on effect of this is that the dummy flow cannot fill the slot and, therefore, when overtopping from the main channel occurs it first goes into the slot to fill this up rather than going onto the floodplain resulting in a reduced flood level on the floodplain. The slots in the parallel channels should be resized to adequately take the dummy flow without resulting in overestimating storage. The dummy flows are not abstracted from the model at the downstream end of the parallel channels resulting in additional flow being passed forward in the system. The dummy flows in the floodplain should also be reduced to a minimum value so that they have a negligible impact on floodplain flow regimes.

The connectivity between the parallel channels and the main channels is very poor with very few connections between the channels. This should be corrected so that the parallel channels and the main channels are connected along their entire lengths.

Reservoirs have been used to represent sections of the floodplain. Three of these have been schematised using manhole data, spot level survey and cross section data.

Seven reservoirs (Spill1ds, Spill2ds, Spill3ds, RES1A, CGSpill2ds, Sp0900, ReliefRs) have a very large area, and depth has been used to represent infinite storage. From the LiDAR there are no areas which can be found that are supposed to be represented by these reservoirs. These reservoirs should be removed and the model re-schematised appropriately.

There are numerous sections within the model which glass wall and are not connected to any other form of floodplain representation. These sections should be extended or connected to another form of floodplain representation to avoid underestimating the amount of storage available and overestimating the water levels.

The lengths of a large number of lateral spills do not match the channel lengths in the river sections that they are attached to; this can lead to inaccurate calculation of flow over these spills as the model uses smaller or longer lengths of spill, relative to the channel length, than appropriate to transfer flow. Several lateral spills (MS1364LB to MS2167LB) have very low spill coefficients, these values should be re-examined and re-schematised as appropriate.

At the bypass channel between Venn Farm on the River Culm and the Spratford Stream there is a very complex flood flow interaction as there are floodplain flows coming from the north which would overtop the bypass channel and then carry on to the south. This has been modelled with the floodplain channel unbroken by the bypass channel and very limited connectivity between the two channels. This simplification should be tested to see if it adequately models flood levels and flows in the area, as it is possible that more of the floodplain flow will enter the bypass channel, and modified if it does not.

2.3.5 Geo-referencing information

The presence and consistency of any geo-referencing information in the model has been checked. None of the sections have geo-referencing information in them. Geo-referencing information is essential to accurately connect the 1D model to a 2D representation of the floodplain. Hyder has, therefore, added geo-referencing information to each cross-section.

2.3.6 General checks

Initial conditions

The initial conditions embedded within the model network (.dat) files themselves and steady state results files (.zzs) have been provided for each model, these files can be used as initial conditions for unsteady runs.

It is normally best practice for the base initial conditions to be imported into the model to allow easier troubleshooting of the initial conditions and to reduce both the number of files necessary to run the model and the risk of losing or incorrectly referencing files.

Flat spills

There are twenty six flat spills in the model, these occur when two adjacent data points in a spill have exactly the same elevation value. Having flat spills can result in numerical instability during the times when the spills are activating and de-activating. This instability manifests itself in oscillations over the spill. This is purely a numerical instability and generally has very little effect on the results, but it can sometimes cause inaccurate results to be produced. Adjusting one of the data points by 1 mm can remove this problem and stop the spill generating “noise”.

Visualiser

An IXY visualiser file exists for each model, the IXY appears to be identical for each model. An IXY is a good way to visualise complex watercourses with multiple channels and allows easy navigation of the model.

A GXY visualise file of the model does not exist. Hyder has, therefore, created a GXY, allowing the model nodes to be set against geo-referenced mapping data and, in turn, a greater appreciation of the model node locations and how the model represents the watercourses in reality.

2.4 Run parameters

The model run parameters should be checked to ensure that they are within best practice guidelines and that they have not been altered beyond normal parameters to allow the model to run. The .ief files are not available so it is not possible to check the model run parameters that were used at the time of the original study. For the purposes of this assessment, it was attempted to re-run the model in the latest version of ISIS using standard default parameters, this run crashed 6.5 hours into the model run.

2.5 Model convergence

The model convergence and stability has been checked to ensure that the model is producing realistic outputs and that it is running realistically.

When attempting to re-run the model using standard default parameters the model became very unstable and crashed; further attempts were made to re-run the model by adjusting the model run parameters. However, the model still crashed, the reasons for the stability problem will need to be rectified. This problem is addressed further in section 3.3.

From examining the existing diagnostics (.zzd) files supplied, it can be seen that there is non-convergence in the model results. It is not known how much the non-convergence affects the results, however a large number of the areas mentioned in the .zzd file can easily be fixed by correcting some of the problems highlighted earlier in this model evaluation.

3 Hydrology update

3.1 Approach

As mentioned in section 1, Hyder has revised the inflows to the ISIS model, based on peak flow frequency estimates provided by the Environment Agency. In particular, the following steps have been taken:

- Sub-catchment boundaries have been extracted from the FEH CD-ROM, digitised, and checked against OS 10k mapping and Land-Form PANORAMA data. The FEH catchment boundaries for the River Ken North and South are incorrect, with the CD-ROM showing the upper reaches of the River Ken North to drain into the River Ken South catchment. The catchment descriptors for these watercourses have, therefore, been adjusted manually.
- The catchment descriptor values adopted for each of the model inflows are given in Appendix 1. The URBEXT1990 value, which is based on urban and suburban mapping from the year 1990, has been updated using an urban expansion factor to reflect the urbanisation that has taken place during the last 23 years.
- Given the short length of the tributaries included in the ISIS model, hydrographs have been generated for their whole catchments but entered into the upstream ends of the model.
- The hydrology report from the 2002 study is not available, and it is not known how runoff from the areas between the defined catchments was represented. For the purpose of the current study, separate boundary units have been established for these intervening areas (Appendix 1, Figure A1). Catchment descriptors have been derived using the area-weighting method, based on upstream and downstream lumped catchments.
- A boundary unit has also been established for St. Georges Well Stream, a right bank tributary of the Spratford Stream, located between Heron's Bank and St Andrew's Well Stream. This watercourse was not modelled by PDMM (2002).
- The catchment descriptors for each sub-catchment have been imported into an ISIS Revitalised Flood Hydrograph boundary (ReFHBDY) unit.
- A consistent design storm, based on the catchment of the River Culm at the downstream model limit (NGR ST 01682 04945), has been imposed upon all of the ReFHBDY units. The critical storm duration of the Culm catchment at the downstream model limit is 14 hours. The tributaries of the Culm respond to rainfall faster than this, with critical storm durations of between 2 and 10 hours (Table 1). Both a 5 hour and 14 hour storm duration have, therefore, been tested herein to assess the influence of storm duration on modelling results.
- The hydrographs for each sub-catchment have been scaled to fit the peak flow frequency estimates provided by the Environment Agency.
- The Environment Agency does not have peak flows estimates available for three of the sub-catchments: Crow Green Stream, St. Andrew's Well Stream and St. Georges Well Stream. For the time being, the peak flows from the 2002 study have been adopted for the Crow Green Stream and St. Andrew's Well Stream, while the ReFH model has been used to generate peaks for the previously un-modelled St. Georges Well Stream. It is important to note that only 1 per cent AEP year flows were derived as part of the 2002 study, and an alternative method of setting peak flows for the Crow Green Stream and St. Andrew's Well Stream will, therefore, have to be adopted for the other return periods of interest. Given the permeability of these catchments (SPRHOST < 20), application of the FEH statistical method is recommended over the ReFH model.

Table 1. Critical storm duration

Watercourse	Critical duration (hours)	Watercourse	Critical duration (hours)
River Culm	13.7	Heron's Bank Stream	5.4
River Ken North	5.6	St. Andrew's Well Stream	3.0
River Ken South	5.8	Crow Green Stream	2.5
Spratford Stream	9.6	Cole Brook	4.2

3.2 Comparison of hydrograph shape

The 2002 and revised inflow hydrographs, based on a 1 per cent AEP event, are presented in Appendix 2. Comparison of these plots reveals that the revised hydrographs generally have a steeper rising limb and higher peak than those from the 2002 study. A notable exception to this is Cole1750, a tributary of the Cole Brook; the revised 1 per cent AEP peak flow estimate for this sub-catchment is 20 per cent lower than that adopted in the 2002 study. However, the combined hydrographs for Cole1750 and SCole744 display the general pattern described above.

The revised hydrology also gives greater total runoff volumes than the 2002 study, with the exception of SA0935, Crow2496 and Cole1750. It is important to remember that the revised hydrographs for SA0935 and Crow2496 have been scaled to fit the peaks from the 2002 study, obscuring the impact of the hydrology update.

Table 2. Comparison between the old and new hydrology

Watercourse	Model inflow	Peak flow ($m^3 s^{-1}$)			Total volume of runoff (m^3)		
		2002	Updated	Difference (%)	2002	Updated	Difference (%)
		a	*b*	*(b-a)/a*	*c*	*d*	*(d-c)/c*
River Culm	Culm6173	141.3	153.0	8	6,978,672	9,621,589	38
River Ken North	NK0889	17.6	19.3	10	640,456	771,265	20
River Ken South	KS1417	12.7	14.4	13	463,968	578,311	25
Spratford Stream	Sp3922	70.2	77.2	10	3,168,306	4,227,342	33
Heron's Bank Stream	Heron0540	13.4	14.4	8	481,473	572,546	19
St. Andrew's Well Stream	SA0935[a]	2.5	2.5	0	78,552	76,020	-3
Crow Green Stream	Crow2496[a]	4.6	4.6	0	138,661	130,998	-6
	URBAN_lat[a, b]	0.5	0.5	0	11,106	12,499	13
Cole Brook tributary	Cole1750	4.0	3.2	-20	129,672	97,286	-25
Cole Brook	SCole744	6.6	7.7	16	211,563	252,001	19
	Cole combined	10.6	10.9	3	341,235	349,287	2

[a] As mentioned in section 3.1, the updated hydrographs for St. Andrew's Well Stream and the Crow Green Stream have been scaled to fit the peak flows from the 2002 study. Hence, there is no difference between the 2002 and updated peak flows.

[b] URBAN_lat has been derived by summing URBAN2, URBAN3 and URBAN4 from the 2002 study

3.3 Re-running of the existing ISIS model

The Environment Agency's existing ISIS model has been re-run with the updated 1 per cent AEP inflows, for a 5 hour and 14 hour storm duration. At first, the model crashed after about an hour into the storm events. In attempt to overcome this stability problem, the following changes to the model set-up have been made:

- Replicate open channel sections have been replaced with river sections
- Interpolates have been added
- The model has been split into individual channel reaches, with each reach run separately to generate new stable initial conditions
- The individual channel reaches have then been recombined one-by-one, with initial conditions regenerated to avoid causing further instabilities
- Weir lengths have been added to sluices
- Minimum flows have been specified for Cole1750 (0.1 $m^3\ s^{-1}$), SA0395 (0.1 $m^3\ s^{-1}$) and Crow2496 (0.13 $m^3\ s^{-1}$)
- Different run parameters have been tested in an attempt to isolate the instabilities
- Irregular culvert ST29us has been replaced with a regular culvert.

With these changes in place, the model completes a full simulation of both the 5 and 14 hour storm events, and displays reasonable convergence (Figure 4). It is worth noting that there is very little difference in peak water levels between the 5 and 14 hour storm duration (median and maximum absolute differences of 17 and 103 mm, respectively; Appendix 3). This is due to the revised hydrographs having been scaled to fit a peak. Since the peaks remain the same irrespective of storm duration, the influence that storm duration can have on modelled peak water levels is somewhat limited. For this reason, it is recommended that the FRA model is run for the 14 hour storm duration only, rather than the seven different storm durations (5, 7, 9, 11, 13, 15 and 17 hour) tested as part of the 2002 study.

Despite the updated hydrology, modelled peak water levels are also reasonably similar overall to the maximum values from the 2002 study (median absolute difference of 34 mm). There are some larger differences locally, due to the model set-up changes listed above (Appendix 3).

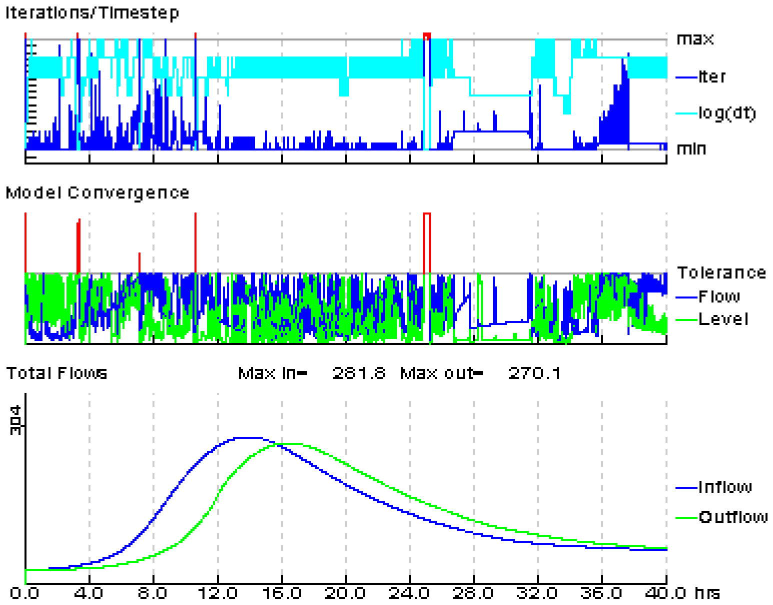

Figure 4. Convergence information for the 1 per cent AEP event

4 Further work

In order to comply with latest best practice modelling standards and ensure that the model provides a robust basis for the FRA, it is recommended that a number of improvements are made. A total of 33 improvements have been identified in sections 2 and 3 (and listed in Appendix 4 for ease of reference). However, not all of these are considered necessary for the satisfactory completion of the FRA. Moreover, some of the improvements will be addressed by the linkage of the ISIS model to a 2D representation of the floodplain and, hence, are covered by our original scope of works, while we have already addressed other improvements during the preparation of this technical note.

The improvements that we do recommend are undertaken to ensure satisfactory completion of the FRA are set out in Table 3 below. These improvements would represent additional work outside of the original scope. Our fee offer for carrying out these improvements is **£2,980 plus VAT**.

In addition to the modelling improvements, some new topographic data may need to be collected in locations where there have been topographic changes since the existing survey data were collected (e.g. desilting of the M5 flood relief channel, construction of the Tesco Superstore and the development of Millenium Way). We are liaising currently with the Highways Agency and Tesco Stores Ltd. in an attempt to obtain any existing information. Depending on the information provided by these parties, we may need to instruct a survey company to undertake additional topographic survey. We will, of course, seek Devon County Council's agreement to the survey costs, if any, prior to instructing a survey company.

Table 3. Recommended improvements for the satisfactory completion of the FRA (Ref. relates to the full list in Appendix 4)

Ref.	Description
1	The modelled sections should be extended where they suddenly reduce in width at structures
3	The invert levels of Bernoulli loss units should be checked as they do not match the surveyed levels in the sections upstream and downstream
4	Overtopping levels of structures should be examined and bypass spills added where necessary
5	Sections which have been extended using 1:25,000 map contours will need to be trimmed down to their surveyed widths and re-extended using LiDAR data
6	Extended sections which have been smoothed should have their surveyed data reinstated
7	Where necessary extended sections need to be trimmed to high points and the area beyond the high points needs to be represented as parallel channels
10	Seven reservoirs (Spill1ds, Spill2ds, Spill3ds, RES1A, CGSpill2ds, Sp0900, ReliefRs) need to be re-schematised
17	The FEH statistical method should be used to derive peak flow frequency estimates for the Crow Green Stream, St. Andrew's Well Stream and St. Georges Well Stream
18	Slots in River Sections in the main channels should be removed if possible
20	Manning's 'n' values should be examined, with additional information, for appropriateness and adjusted if necessary
21	The stage discharge relationship at the downstream end of the model should be examined to ensure it is appropriate
22	The 'p' levels at structures in the model should be examined and corrected where necessary
23	The choice of unit for culverts, bridges and orifices should be examined and altered if necessary
24	Dummy flows need to be abstracted from the model and reduced to a minimum value
25	Flat spills should be adjusted by 1 mm to reduce model non-convergence and "noise"

Appendix 1

Adopted catchment descriptor values

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Table A1-1. Adopted catchment descriptor values

Model inflow	AREA	URBEXT1990[a]	SAAR[b]	PROPWET	BFIHOST	DPLBAR	DPSBAR
KS1417	7.42	0.000	970	0.40	0.480	3.00[c]	32.70
Culm6173	128.15	0.002	970	0.40	0.530	14.29[c]	74.11
NK0889	12.13	0.001	970	0.40	0.629	3.93[c]	72.09
Sp3922	55.57	0.004	970	0.40	0.633	9.04[c]	61.78
Heron0540	8.47	0.000	970	0.44	0.764	4.51	79.20
SA0935	1.63	0.016	970	0.40	0.832	1.51	72.30
Crow2496	2.22	0.000	970	0.44	0.891	1.46	114.00
URBAN_lat	1.06	0.203	970	0.38	0.811	1.03[c]	43.40
Cole1750	2.00	0.000	970	0.42	0.862	1.69	102.00
SCole744	4.46	0.004	970	0.42	0.748	2.27[c]	114.30
Inter01	1.16	0.002	970	0.40	0.635	1.09[c]	5.96[d]
Inter02	0.53	0.015	970	0.40	0.672	0.71[c]	16.03[d]
Inter03	0.62	0.134	970	0.40	0.720	0.77[c]	35.33[d]
Inter04	1.94	0.027	970	0.40	0.608	1.44[c]	114.00[d]
RullLeat	0.77	0.010	970	0.40	0.814	1.77	86.10

[a] updated to 2013

[b] the same SAAR value has been adopted for all model inflows, reflecting a catchment-wide design storm; the SAAR value is based on the catchment draining to the downstream model limit

[c] calculated according to equation 7.1 of the FEH vol. 5

[d] estimated using LiDAR data

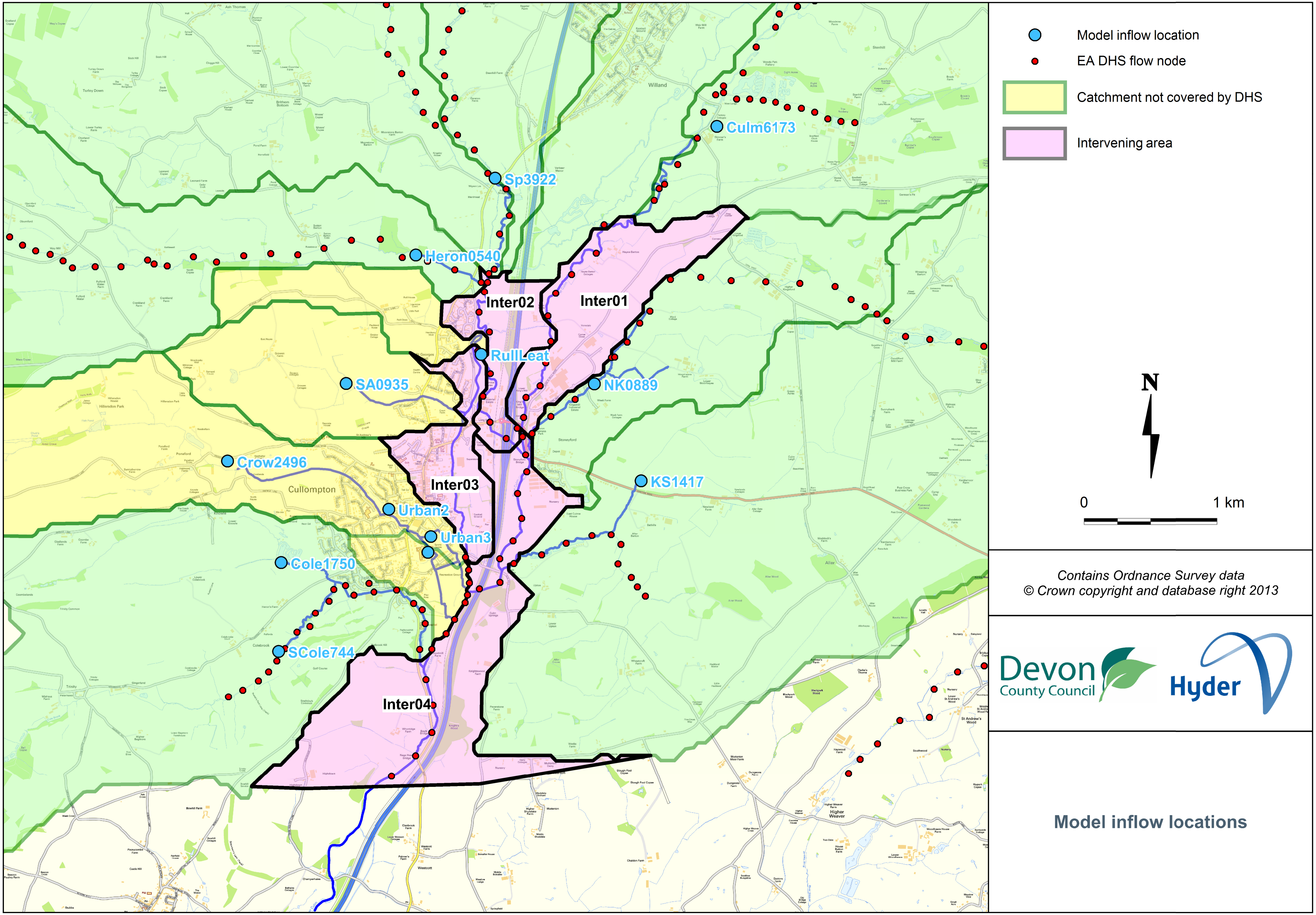
Table A1-2. Design storm parameters (based on the FEH catchment at 301650, 104900)

Parameter		Value	
Storm duration (hours)		5.25	14.25
Time step (hours)		0.25	0.75
Areal reduction factor		0.871	0.913
Storm area (km^2)		230.01	
DDF model parameters	c	-0.02417	
	d1	0.37607	
	d2	0.33309	
	d3	0.33525	
	e	0.28549	
	f	2.52322	
SAAR (mm)		970	

Table A1-3. Notes on the derivation of the inflow hydrographs

Model inflow	Comments
KS1417	FEH catchment at 302700, 106650 minus FEH catchment at 305550, 108550 Also removed a small area (1.46 km^2) draining out of the catchment - not considered necessary to adjust the other catchment descriptors to reflect this change Hydrographs scaled to fit the peaks from the Environment Agency's Devon Hydrology Strategy (DHS) node ref. 2146
Culm6173	FEH catchment at 302700, 108900 plus FEH catchment at 303700, 109300 Hydrographs scaled to fit peaks from the Environment Agency's DHS node ref. 858
NK0889	FEH catchment at 302900, 107400 plus FEH catchment at 305550, 108550 Hydrographs scaled to fit peaks from the Environment Agency's DHS node ref. 2240
Sp3922	FEH catchment at 302600, 108900 plus FEH catchment at 302650, 108950 Hydrographs scaled to fit peaks from the Environment Agency's DHS node ref. 2167
Heron0540	FEH catchment at 302500, 108800 Hydrographs scaled to fit peaks from the Environment Agency's DHS node ref. 2963
SA0935	FEH catchment at 302350, 107750 The Environment Agency's DHS does not cover this watercourse – hydrographs have, therefore, been scaled to fit peaks from the 2002 study
Crow2496	FEH catchment at 300600, 107350 The Environment Agency's DHS does not cover this watercourse – hydrographs have, therefore, been scaled to fit peaks from the 2002 study
URBAN_lat	FEH catchment at 302350, 106700 minus Crow2496 The Environment Agency's DHS does not cover this watercourse – hydrographs have, therefore, been scaled to fit peaks from the 2002 study (Urban2 + Urban3 + Urban4)
Cole1750	FEH catchment at 301400, 106500 Hydrographs scaled to fit peaks from the Environment Agency's DHS node ref. 2131 minus ref. 2132
SCole744	FEH catchment at 302050, 105950 minus FEH catchment at Cole1750 Hydrographs scaled to fit peaks from the Environment Agency's DHS node ref. 2123 minus (refs. 2131 – 2132)
Inter01	FEH catchment at 302850, 107650 minus FEH catchment at 303700, 109300 Hydrographs scaled to fit peaks from the Environment Agency's DHS

	node ref. 857 minus ref. 848
Inter02	FEH catchment at node 302750, 107600 minus the following FEH catchments: RullLeat Sp3922 Heron0540 302700, 108900 Hydrographs scaled to fit peaks from the Environment Agency's DHS node ref. 2156 minus ref. 2163
Inter03	FEH catchment at 302400, 106700 minus SA0935 Peaks derived using the ReFH model
Inter04	FEH catchment at node 301650, 104900 minus the following FEH catchments: 302850, 107350 302050, 105950 302350, 106700 302400, 106700 302700, 106650 Also removed a small area (0.36 km^2) draining to the Crow Green Stream; adjusted AREA, DPLBAR and DPSBAR accordingly but not the other catchment descriptors – this is not considered to have a significant effect on results Peaks derived using the ReFH model
RullLeat (St. Georges Well Stream)	FEH catchment at 302500, 108250 The Environment Agency's DHS does not cover this watercourse – peaks, therefore, derived using the ReFH model



Model inflow locations

Appendix 2

Old and new model inflows

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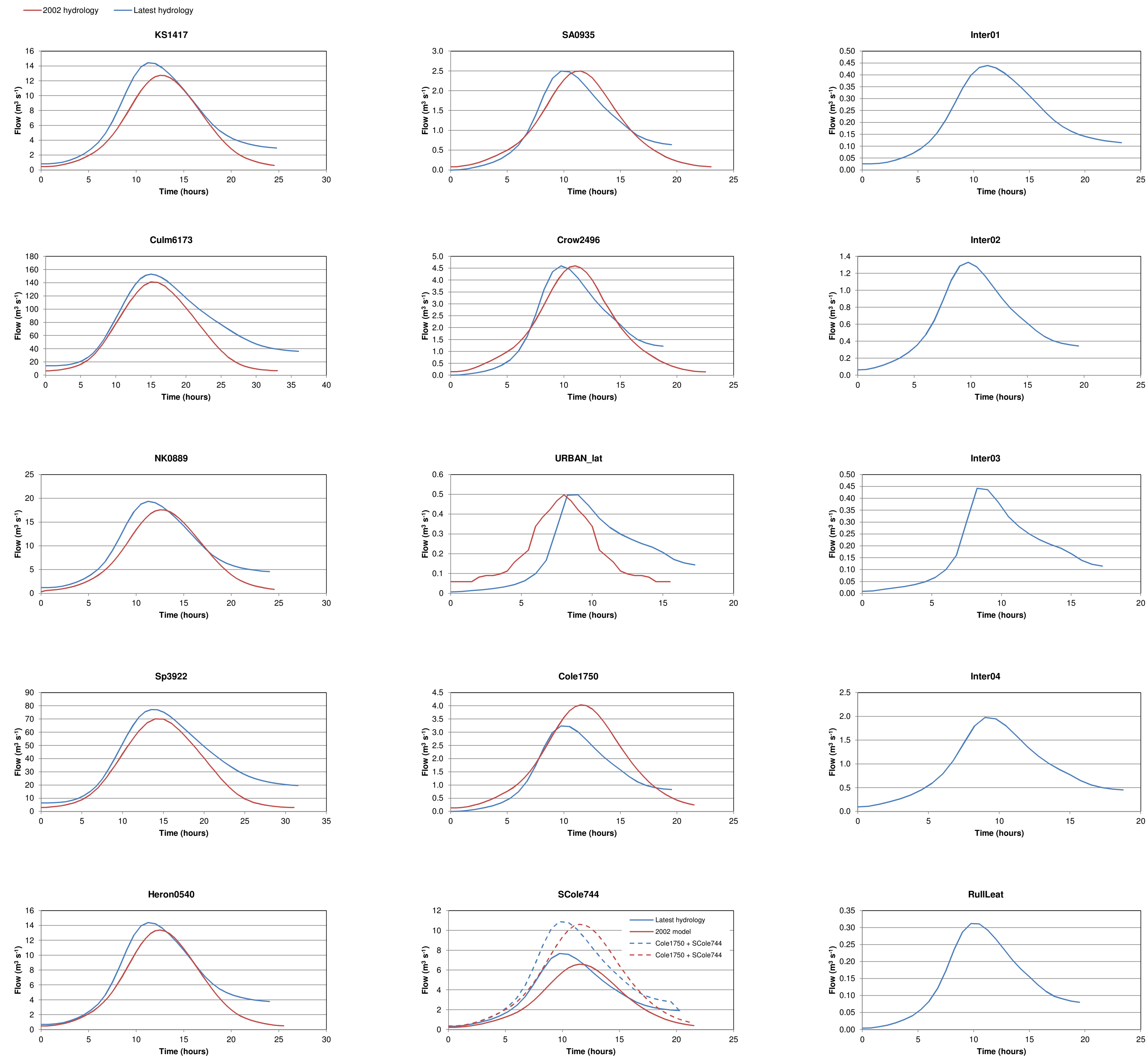

Note: the latest hydrology is based on a 14 hour storm duration, while the 2002 hydrology is based on a 15 hour storm duration

Appendix 3

Modelled peak water levels

Peak modelled water levels (m AOD)

Watercourse	Node	2002 maximum level	Latest hydrology		Difference		Watercourse	Node	2002 maximum level	Latest hydrology		Difference	
			5 hour	14 hour	5 hour	14 hour				5 hour	14 hour	5 hour	14 hour
		(a)	*(b)*	*(c)*	*(b) - (a)*	*(c) - (a)*			*(a)*	*(b)*	*(c)*	*(b) - (a)*	*(c) - (a)*
RiverCulm	Culm6173	61.92	61.95	61.95	0.03	0.03	RiverCulm	dsA373_2	50.78	50.76	50.78	-0.02	0.00
RiverCulm	Culm5982	61.46	61.39	61.39	-0.07	-0.07	RiverCulm	Culm2616	50.78	50.76	50.78	-0.02	0.00
RiverCulm	Culm5388	59.70	59.73	59.73	0.02	0.02	RiverCulm	Culm2616_1	50.77	50.75	50.77	-0.02	0.00
RiverCulm	Culm5110u	58.69	58.63	58.63	-0.06	-0.06	RiverCulm	Culm2535u	50.77	50.75	50.77	-0.02	0.00
RiverCulm	Culm5110d	58.69	58.63	58.63	-0.06	-0.06	RiverCulm	Culm2535d	50.77	50.75	50.77	-0.02	0.00
RiverCulm	Culm4628	57.44	57.30	57.30	-0.14	-0.14	RiverCulm	Culm2490	50.70	50.66	50.70	-0.03	0.00
RiverCulm	Culm4261	57.03	56.63	56.63	-0.40	-0.40	RiverCulm	Culm2490d	50.70	50.66	50.70	-0.03	0.00
RiverCulm	Culm3950	56.00	56.12	56.12	0.12	0.12	RiverCulm	CG2B	50.68	50.65	50.68	-0.03	0.00
RiverCulm	Culm3764	55.52	55.50	55.50	-0.02	-0.02	RiverCulm	Culm2490_1	50.60	50.57	50.60	-0.03	0.00
RiverCulm	Culm3626u	55.19	55.18	55.19	-0.01	-0.01	RiverCulm	Culm2490_2	50.49	50.45	50.50	-0.04	0.01
RiverCulm	Culmbp_slu	55.19	55.18	55.19	-0.01	-0.01	RiverCulm	Culm2490_3	50.39	50.35	50.41	-0.04	0.01
RiverCulm	Culmbp_500	54.85	54.83	54.83	-0.02	-0.02	RiverCulm	Culm2213	50.31	50.27	50.33	-0.04	0.02
RiverCulm	Culm3626d	55.19	55.18	55.19	-0.01	-0.01	RiverCulm	Culm2064	50.19	50.15	50.22	-0.04	0.03
RiverCulm	Culm3546	55.09	55.08	55.09	-0.01	0.00	RiverCulm	Culm1917	50.13	50.10	50.17	-0.04	0.04
RiverCulm	Kingsmillus	54.82	54.80	54.80	-0.02	-0.02	RiverCulm	Culm1791	50.10	50.06	50.14	-0.04	0.04
RiverCulm	KM_lslu	54.82	54.80	54.80	-0.02	-0.02	RiverCulm	Culm1791_1	50.06	50.02	50.10	-0.04	0.04
RiverCulm	KM_lsld	54.69	54.67	54.68	-0.02	-0.01	RiverCulm	Culm1791_2	50.01	49.97	50.05	-0.04	0.05
RiverCulm	KM_rslu	54.82	54.80	54.80	-0.02	-0.02	RiverCulm	uslast	49.93	49.89	49.98	-0.04	0.05
RiverCulm	KM_rsld	54.69	54.67	54.68	-0.02	-0.01	RiverCulm	lastspu	49.93	49.89	49.98	-0.04	0.05
RiverCulm	KM_spu	54.82	54.80	54.80	-0.02	-0.02	RiverCulm	lastspd	49.35	49.32	49.38	-0.03	0.04
RiverCulm	KM_spd	54.69	54.67	54.68	-0.02	-0.01	RiverCulm	M5LinkCulu	49.27	49.34	49.41	0.07	0.14
RiverCulm	KM_sld	54.69	54.67	54.68	-0.02	-0.01	RiverCulm	M5LinkCuld	49.93	49.89	49.98	-0.04	0.05
RiverCulm	KM_weiru	54.68	54.66	54.67	-0.02	-0.01	RiverCulm	lastculu	49.93	49.89	49.98	-0.04	0.05
RiverCulm	Kingsmillds	53.86	53.75	53.75	-0.11	-0.10	RiverCulm	lastculd	49.35	49.32	49.38	-0.03	0.04
RiverCulm	Culm3283	53.64	53.46	53.46	-0.18	-0.17	RiverCulm	lastbru	49.93	49.89	49.98	-0.04	0.05
RiverCulm	Culm3060	53.00	52.98	52.99	-0.02	-0.01	RiverCulm	lastbrd	49.35	49.32	49.38	-0.03	0.04
RiverCulm	Culm3026	50.95	50.92	50.94	-0.02	-0.01	RiverCulm	dslast	49.35	49.32	49.38	-0.03	0.04
RiverCulm	usfarm	50.93	50.90	50.92	-0.02	-0.01	RiverCulm	Culm1364	49.21	49.18	49.26	-0.03	0.05
RiverCulm	farm_bru	50.93	50.90	50.92	-0.02	-0.01	RiverCulm	usM5	49.02	48.99	49.07	-0.03	0.05
RiverCulm	farm_brd	50.84	50.82	50.83	-0.02	0.00	RiverCulm	dsM5	48.21	48.19	48.24	-0.02	0.03
RiverCulm	farm_spu	50.93	50.90	50.92	-0.02	-0.01	RiverCulm	Culm1142	48.21	48.19	48.24	-0.02	0.03
RiverCulm	farm_spd	50.84	50.82	50.83	-0.02	0.00	RiverCulm	Culm0996	48.03	48.01	48.07	-0.03	0.04
RiverCulm	dsfarm	50.84	50.82	50.83	-0.02	0.00	RiverCulm	copy0954u	48.03	48.01	48.07	-0.03	0.04
RiverCulm	Culm2881	50.82	50.80	50.82	-0.02	0.00	RiverCulm	copy0954d	48.03	48.01	48.07	-0.03	0.04
RiverCulm	usA373	50.79	50.78	50.79	-0.02	0.00	RiverCulm	Culm0725	47.92	47.90	47.96	-0.02	0.04
RiverCulm	dsA373	50.79	50.77	50.79	-0.02	0.00	RiverCulm	Culm0506u	47.82	47.79	47.85	-0.03	0.03
RiverCulm	dsA373_1	50.78	50.76	50.78	-0.02	0.00	RiverCulm	Culm0506d	47.82	47.79	47.85	-0.03	0.03

Watercourse	Node	2002 maximum level	Latest hydrology		Difference		Watercourse	Node	2002 maximum level	Latest hydrology		Difference	
			5 hour	14 hour	5 hour	14 hour				5 hour	14 hour	5 hour	14 hour
		(a)	*(b)*	*(c)*	*(b) - (a)*	*(c) - (a)*			*(a)*	*(b)*	*(c)*	*(b) - (a)*	*(c) - (a)*
RiverCulm	dsWood	47.78	47.74	47.80	-0.03	0.02	RiverCulmFloodplain	2743FP_2	51.59	51.555	51.565	-0.04	-0.03
RiverCulm	Culm0302	47.71	47.67	47.72	-0.04	0.02	RiverCulmFloodplain	2743FP_3	51.53	51.486	51.497	-0.04	-0.03
RiverCulm	Culm0259	47.67	47.62	47.68	-0.04	0.01	RiverCulmFloodplain	2743FP_4	51.46	51.421	51.432	-0.04	-0.03
RiverCulm	Baulku	47.62	47.61	47.68	-0.01	0.06	RiverCulmFloodplain	2743FP_5	51.43	51.39	51.401	-0.04	-0.03
RiverCulm	Baulkd	46.58	46.59	46.64	0.01	0.05	RiverCulmFloodplain	2618FP	51.40	51.36	51.371	-0.04	-0.03
RiverCulm	BBspilld	46.58	46.59	46.64	0.01	0.05	RiverCulmFloodplain	Sp000spd	50.77	50.75	50.768	-0.02	0.00
RiverCulm	Baulkds	46.58	46.59	46.64	0.01	0.05	RiverCulmFloodplain	Culmbp_370	54.59	54.544	54.558	-0.05	-0.03
RiverCulm	Sect1	46.49	46.50	46.55	0.00	0.05	RiverCulmFloodplain	Culmbp_273	54.54	54.481	54.5	-0.06	-0.04
RiverCulm	Sect2	46.43	46.43	46.48	0.00	0.05	RiverCulmFloodplain	Culmbp_M5u	54.58	54.502	54.528	-0.08	-0.05
RiverCulm	Sect3	46.01	46.02	46.07	0.01	0.06	RiverCulmFloodplain	Culmbp_M5d	54.59	54.502	54.529	-0.08	-0.06
RiverCulmFloodplain	5110FP	58.69	58.629	58.629	-0.06	-0.06	RiverCulmFloodplain	Culmbp_Railu	54.59	54.503	54.531	-0.09	-0.06
RiverCulmFloodplain	4628FP	57.26	57.312	57.312	0.05	0.05	RiverCulmFloodplain	Culmbp_Raild	54.59	54.503	54.531	-0.09	-0.06
RiverCulmFloodplain	4261FPr	56.48	56.578	56.578	0.10	0.10	RiverCulmFloodplain	Culmbp_180	54.59	54.503	54.531	-0.09	-0.06
RiverCulmFloodplain	4261FPr_1	56.39	56.51	56.51	0.12	0.12	RiverCulmFloodplain	2H	54.59	54.503	54.531	-0.09	-0.06
RiverCulmFloodplain	4261FPr_2	56.28	56.424	56.424	0.14	0.14	RiverCulmFloodplain	Culmbp_0	54.59	54.503	54.531	-0.09	-0.06
RiverCulmFloodplain	ST09u	56.17	56.268	56.269	0.10	0.10	SpratfordStream	Sp3922	56.21	56.166	56.166	-0.05	-0.05
RiverCulmFloodplain	ST09d	55.99	56.017	56.017	0.02	0.02	SpratfordStream	Sp3552	55.51	55.546	55.548	0.03	0.04
RiverCulmFloodplain	3A	55.23	55.339	55.342	0.11	0.12	SpratfordStream	Sp3309	55.25	55.275	55.283	0.03	0.04
RiverCulmFloodplain	3A_20	55.11	55.187	55.194	0.08	0.09	SpratfordStream	Sp2952u	55.00	55.03	55.045	0.03	0.04
RiverCulmFloodplain	Sp2952l	55.00	55.03	55.045	0.03	0.04	SpratfordStream	Sp2952d	55.00	55.03	55.045	0.03	0.04
RiverCulmFloodplain	4261FP	56.32	56.414	56.414	0.09	0.09	SpratfordStream	Heronus	54.82	54.801	54.825	-0.01	0.01
RiverCulmFloodplain	4261FP_1	55.99	55.964	55.964	-0.02	-0.02	SpratfordStream	Heronds	54.82	54.801	54.825	-0.01	0.01
RiverCulmFloodplain	4261FP_2	55.53	55.517	55.517	-0.02	-0.02	SpratfordStream	Sp2675	54.73	54.686	54.712	-0.04	-0.01
RiverCulmFloodplain	3950FP	55.22	55.212	55.212	-0.01	-0.01	SpratfordStream	Sp2395	54.62	54.542	54.57	-0.08	-0.05
RiverCulmFloodplain	3857FP	54.88	54.854	54.857	-0.03	-0.03	SpratfordStream	Sp_2250u	54.59	54.503	54.531	-0.09	-0.06
RiverCulmFloodplain	3764FP	54.64	54.586	54.593	-0.05	-0.04	SpratfordStream	Sp_2250d	54.59	54.503	54.531	-0.09	-0.06
RiverCulmFloodplain	3691FP	54.56	54.493	54.504	-0.06	-0.05	SpratfordStream	us_split	54.59	54.497	54.525	-0.09	-0.06
RiverCulmFloodplain	3618FP	54.49	54.414	54.428	-0.07	-0.06	SpratfordStream	weirus	54.59	54.497	54.525	-0.09	-0.06
RiverCulmFloodplain	3546FP	54.34	54.253	54.266	-0.09	-0.07	SpratfordStream	weirds	53.52	53.614	53.636	0.09	0.12
RiverCulmFloodplain	3380FP	53.89	53.809	53.82	-0.08	-0.07	SpratfordStream	Sp1056	53.42	53.5	53.523	0.08	0.11
RiverCulmFloodplain	3214FP	53.26	53.248	53.253	-0.01	0.00	SpratfordStream	Sp0684	53.28	53.345	53.366	0.07	0.09
RiverCulmFloodplain	3047FP	52.66	52.628	52.637	-0.03	-0.02	SpratfordStream	Sp0557	53.19	53.266	53.287	0.08	0.10
RiverCulmFloodplain	2881FP	52.17	52.129	52.139	-0.04	-0.03	SpratfordStream	Sp0484	52.94	53.027	53.047	0.08	0.10
RiverCulmFloodplain	2791FP	51.89	51.846	51.856	-0.04	-0.03	SpratfordStream	usLong	52.75	52.826	52.847	0.08	0.10
RiverCulmFloodplain	A373D1	51.89	51.846	51.856	-0.04	-0.03	SpratfordStream	dsLong	52.40	52.45	52.465	0.05	0.06
RiverCulmFloodplain	A373D1_1	51.86	51.82	51.83	-0.04	-0.03	SpratfordStream	dbr_weir	52.30	52.341	52.354	0.04	0.06
RiverCulmFloodplain	A373D2	51.83	51.793	51.803	-0.04	-0.03	SpratfordStream	Sp0331	52.34	52.396	52.412	0.05	0.07
RiverCulmFloodplain	2743FP	51.83	51.793	51.803	-0.04	-0.03	SpratfordStream	usRail	52.03	52.077	52.094	0.05	0.07
RiverCulmFloodplain	2743FP_1	51.66	51.626	51.636	-0.04	-0.03	SpratfordStream	dsRail	51.26	51.271	51.281	0.01	0.02

Watercourse	Node	2002 maximum level	Latest hydrology		Difference		Watercourse	Node	2002 maximum level	Latest hydrology		Difference	
			5 hour	14 hour	5 hour	14 hour				5 hour	14 hour	5 hour	14 hour
		(a)	(b)	(c)	(b) - (a)	(c) - (a)			(a)	(b)	(c)	(b) - (a)	(c) - (a)
SpratfordStream	usMway	51.03	51.034	51.046	0.00	0.01	SpratfordMillstream	ST11us	49.27	49.342	49.412	0.07	0.14
SpratfordStream	Sp0112	50.98	50.983	50.996	0.00	0.01	SpratfordMillstream	FirstBru	49.27	49.342	49.412	0.07	0.14
SpratfordStream	Sp0062	50.86	50.852	50.867	-0.01	0.01	SpratfordMillstream	FirstBrd	48.69	48.714	48.749	0.02	0.06
SpratfordStream	Sp000	50.77	50.75	50.768	-0.02	0.00	SpratfordMillstream	Firstspu	49.27	49.342	49.412	0.07	0.14
SpratfordStream	dbrlb_res	52.32	52.368	52.38	0.05	0.06	SpratfordMillstream	Firstspd	48.69	48.714	48.749	0.02	0.06
SpratfordStream	0331lb_res	52.32	52.368	52.38	0.05	0.06	SpratfordMillstream	ST11ds	48.69	48.714	48.749	0.02	0.06
SpratfordStream	0557RBres	52.74	52.828	52.852	0.09	0.12	SpratfordMillstream	ST11ds_1	48.37	48.369	48.417	0.00	0.05
SpratfordStream	0484RBres	52.74	52.828	52.852	0.09	0.12	SpratfordMillstream	ST11ds_2	48.24	48.226	48.281	-0.02	0.04
SpratfordStream	Alex10	53.20	53.316	53.337	0.12	0.14	SpratfordMillstream	MS023	48.21	48.191	48.248	-0.02	0.03
SpratfordStream	Alex09	53.20	53.316	53.337	0.12	0.14	SpratfordMillstream	MS023d	48.21	48.191	48.248	-0.02	0.03
SpratfordStream	Alex08	53.20	53.316	53.337	0.12	0.14	SpratfordMillstream	MS00	48.21	48.186	48.244	-0.02	0.03
SpratfordMillstream	MS2167	54.59	54.497	54.525	-0.09	-0.06	SpratfordMillstream	RES1596	52.74	52.828	52.852	0.09	0.12
SpratfordMillstream	MS1965	53.72	53.72	53.744	0.00	0.02	SpratfordMillstream	RES1531	52.74	52.828	52.852	0.09	0.12
SpratfordMillstream	MS1719	53.30	53.388	53.41	0.09	0.11	SpratfordMillstream	RES1505	52.74	52.828	52.852	0.09	0.12
SpratfordMillstream	ST17us	53.24	53.393	53.417	0.15	0.18	SpratfordMillstream	RES1454	52.74	52.828	52.852	0.09	0.12
SpratfordMillstream	ST17ds	52.92	52.942	52.966	0.02	0.05	SpratfordMillstream	RES1364	52.74	52.828	52.852	0.09	0.12
SpratfordMillstream	MS1531	52.91	52.928	52.953	0.02	0.04	ColeBrook	SCole744	63.44	63.444	63.444	0.00	0.00
SpratfordMillstream	StAndus	52.91	52.925	52.949	0.02	0.04	ColeBrook	SCole744_1	62.51	62.523	62.523	0.01	0.01
SpratfordMillstream	StAndds	52.91	52.925	52.949	0.02	0.04	ColeBrook	SCole744_2	61.57	61.567	61.566	0.00	0.00
SpratfordMillstream	MS1454	52.90	52.918	52.943	0.02	0.04	ColeBrook	SCole744_3	60.59	60.615	60.615	0.03	0.03
SpratfordMillstream	MS1364	52.86	52.877	52.899	0.02	0.04	ColeBrook	SCole368	59.67	59.683	59.683	0.01	0.01
SpratfordMillstream	ST16us	52.83	52.851	52.873	0.02	0.04	ColeBrook	SCole368_1	58.83	58.858	58.857	0.03	0.03
SpratfordMillstream	ST16ds	52.66	52.672	52.685	0.01	0.02	ColeBrook	SCole368_2	58.04	58.032	58.032	-0.01	-0.01
SpratfordMillstream	ST15us	52.53	52.538	52.55	0.01	0.02	ColeBrook	SCole368_3	57.15	57.205	57.204	0.05	0.05
SpratfordMillstream	ST15ds	50.69	50.745	50.739	0.05	0.04	ColeBrook	SCole000	56.57	56.575	56.574	0.01	0.00
SpratfordMillstream	MS1020	50.53	50.631	50.625	0.10	0.09	ColeBrook	Cole1750	63.51	63.417	63.417	-0.09	-0.09
SpratfordMillstream	MS0930	49.95	50.008	50.025	0.06	0.07	ColeBrook	Cole1750_1	62.39	62.306	62.306	-0.09	-0.09
SpratfordMillstream	MS0904	49.93	49.986	50.004	0.06	0.08	ColeBrook	Cole1750_2	61.29	61.238	61.239	-0.05	-0.05
SpratfordMillstream	MS0732us	49.77	49.868	49.887	0.09	0.11	ColeBrook	Cole1568	60.24	60.192	60.192	-0.05	-0.05
SpratfordMillstream	MS0732ds	49.38	49.457	49.517	0.07	0.13	ColeBrook	Cole1568_1	59.16	59.071	59.072	-0.09	-0.09
SpratfordMillstream	MSFP1	51.66	51.684	51.705	0.03	0.05	ColeBrook	Cole1568_2	58.11	58.015	58.015	-0.09	-0.09
SpratfordMillstream	MSFP2	51.07	51.168	51.183	0.09	0.11	ColeBrook	Cole1568_3	57.60	57.489	57.49	-0.11	-0.11
SpratfordMillstream	MSFP3	50.04	50.048	50.065	0.01	0.02	ColeBrook	Cole1347	57.42	57.286	57.286	-0.13	-0.13
SpratfordMillstream	MSFP4	49.81	49.818	49.84	0.01	0.03	ColeBrook	Spill1us	57.42	57.286	57.286	-0.13	-0.13
SpratfordMillstream	MSFP5	49.38	49.457	49.517	0.07	0.13	ColeBrook	Spill1ds	56.56	56.557	56.559	-0.01	0.00
SpratfordMillstream	StatRdus	52.74	52.828	52.852	0.09	0.12	ColeBrook	Laneus	57.42	57.286	57.286	-0.13	-0.13
SpratfordMillstream	0732ds	49.38	49.457	49.517	0.07	0.13	ColeBrook	Laneds	56.83	56.759	56.759	-0.07	-0.07
SpratfordMillstream	MS0610	49.31	49.385	49.454	0.07	0.14	ColeBrook	ST31ds	56.83	56.759	56.759	-0.07	-0.07
SpratfordMillstream	MS0323	49.28	49.345	49.415	0.07	0.14	ColeBrook	SColeus	56.57	56.575	56.574	0.01	0.00

Watercourse	Node	2002 maximum level	Latest hydrology		Difference		Watercourse	Node	2002 maximum level	Latest hydrology		Difference	
			5 hour	14 hour	5 hour	14 hour				5 hour	14 hour	5 hour	14 hour
		(a)	(b)	(c)	(b) - (a)	(c) - (a)			(a)	(b)	(c)	(b) - (a)	(c) - (a)
ColeBrook	SColeds	56.57	56.575	56.574	0.01	0.00	HeronsBankStream	culvertds	54.82	54.807	54.833	-0.02	0.01
ColeBrook	Cole1219	56.30	56.228	56.228	-0.07	-0.07	HeronsBankStream	spill1us	55.52	57.286	57.286	1.77	1.77
ColeBrook	Weirus	55.70	54.497	54.525	-1.21	-1.18	HeronsBankStream	spill1ds	54.82	56.557	56.559	1.73	1.74
ColeBrook	Weirds	54.94	53.614	53.636	-1.33	-1.31	HeronsBankStream	Heron0110ds	54.82	54.807	54.833	-0.02	0.01
ColeBrook	Cole0980	53.91	53.95	53.952	0.04	0.04	HeronsBankStream	Heron0110_1	54.82	54.803	54.827	-0.02	0.01
ColeBrook	Cole0825	51.70	51.721	51.722	0.02	0.02	HeronsBankStream	Heron0110_2	54.82	54.802	54.825	-0.01	0.01
ColeBrook	Cole729u	51.19	51.195	51.196	0.00	0.00	HeronsBankStream	Heron0110_3	54.82	54.801	54.825	-0.02	0.01
ColeBrook	ST30Cus	51.19	51.195	51.196	0.00	0.00	HeronsBankStream	Heron000	54.82	54.801	54.825	-0.01	0.01
ColeBrook	ST30Cds	50.72	50.719	50.72	0.00	0.00	SouthKen	KS1417	54.72	54.731	54.731	0.01	0.01
ColeBrook	Spill2us	51.19	51.195	51.196	0.00	0.00	SouthKen	KS1417_1	54.18	54.191	54.191	0.01	0.01
ColeBrook	Spill2ds	50.47	50.466	50.467	0.00	0.00	SouthKen	KS1351	53.71	53.729	53.729	0.02	0.02
ColeBrook	Cole729d	50.72	50.719	50.72	0.00	0.00	SouthKen	KS1351_1	53.35	53.375	53.375	0.02	0.02
ColeBrook	Cole676u	50.66	50.665	50.665	0.00	0.00	SouthKen	KS1261us	53.24	53.271	53.271	0.03	0.03
ColeBrook	ST30Bus	50.66	50.665	50.665	0.00	0.00	SouthKen	Culvrtus	53.24	53.271	53.271	0.03	0.03
ColeBrook	ST30Bds	50.46	50.462	50.463	0.00	0.00	SouthKen	Culvrtds	52.69	52.75	52.75	0.06	0.06
ColeBrook	Spill3us	50.66	50.665	50.665	0.00	0.00	SouthKen	Spillus	53.24	53.271	53.271	0.03	0.03
ColeBrook	Spill3ds	50.14	50.137	50.139	0.00	0.00	SouthKen	Spillds	52.69	52.75	52.75	0.06	0.06
ColeBrook	Cole676d	50.46	50.462	50.463	0.00	0.00	SouthKen	KS1261ds	52.69	52.75	52.75	0.06	0.06
ColeBrook	Cole649u	50.44	50.44	50.44	0.00	0.00	SouthKen	KS1172	51.78	51.813	51.813	0.04	0.04
ColeBrook	Cole649d	49.74	49.738	49.738	-0.01	-0.01	SouthKen	KS1172_1	51.06	50.886	50.886	-0.17	-0.17
ColeBrook	Cole649d_1	49.45	49.432	49.432	-0.02	-0.02	SouthKen	KS0835	50.91	50.282	50.282	-0.62	-0.62
ColeBrook	Cole649d_2	49.05	49.067	49.081	0.02	0.03	SouthKen	KS0785	50.90	50.234	50.233	-0.67	-0.67
ColeBrook	Cole649d_3	48.83	48.833	48.834	0.01	0.01	SouthKen	KS0720	50.90	50.187	50.185	-0.71	-0.71
ColeBrook	Cole0474	48.42	48.413	48.413	0.00	0.00	SouthKen	KS0491	49.97	49.901	49.998	-0.07	0.03
ColeBrook	Cole0474_1	48.10	48.088	48.139	-0.01	0.04	SouthKen	KS0491_1	49.93	49.893	49.984	-0.04	0.05
ColeBrook	Cole420u	48.05	48.016	48.072	-0.03	0.02	SouthKen	KS0491_2	49.93	49.892	49.982	-0.04	0.05
ColeBrook	Cole420d	47.88	47.824	47.904	-0.05	0.03	SouthKen	KS0243	49.93	49.892	49.982	-0.04	0.05
ColeBrook	Cole420d_1	47.82	47.788	47.849	-0.03	0.03	SouthKen	KS0243_1	49.93	49.892	49.982	-0.04	0.05
ColeBrook	Cole420d_2	47.82	47.787	47.847	-0.03	0.03	SouthKen	KS0243_2	49.93	49.892	49.982	-0.04	0.05
ColeBrook	Cole420d_3	47.82	47.787	47.847	-0.03	0.03	SouthKen	KS000	49.93	49.892	49.982	-0.04	0.05
ColeBrook	Cole260	47.82	47.787	47.847	-0.03	0.03	StAndrewsStream	SA0935	61.36	61.348	61.34	-0.01	-0.01
ColeBrook	Cole260_1	47.82	47.787	47.847	-0.03	0.03	StAndrewsStream	SA0935_1	61.01	60.997	60.988	-0.01	-0.02
ColeBrook	Cole260_2	47.82	47.787	47.847	-0.03	0.03	StAndrewsStream	SA0935_2	60.67	60.66	60.645	-0.01	-0.03
ColeBrook	Cole260_3	47.82	47.787	47.847	-0.03	0.03	StAndrewsStream	SA0935_3	60.34	60.332	60.317	-0.01	-0.03
ColeBrook	Cole0000	47.82	47.787	47.847	-0.03	0.03	StAndrewsStream	SA0935_4	60.07	60.065	60.044	-0.01	-0.03
HeronsBankStream	Heron0540	56.53	56.552	56.552	0.02	0.02	StAndrewsStream	SA0935_5	59.94	59.932	59.9	-0.01	-0.04
HeronsBankStream	Heron0272	55.56	55.877	55.878	0.32	0.32	StAndrewsStream	SA0777	59.89	59.881	59.843	-0.01	-0.04
HeronsBankStream	Heron0110us	55.52	55.869	55.871	0.35	0.35	StAndrewsStream	SA0777_1	59.82	59.81	59.76	-0.01	-0.06
HeronsBankStream	culvertus	55.52	55.869	55.871	0.35	0.35	StAndrewsStream	SA0777_2	59.71	59.701	59.643	-0.01	-0.06

Watercourse	Node	2002 maximum level	Latest hydrology		Difference		Watercourse	Node	2002 maximum level	Latest hydrology		Difference	
			5 hour	14 hour	5 hour	14 hour				5 hour	14 hour	5 hour	14 hour
		(a)	*(b)*	*(c)*	*(b) - (a)*	*(c) - (a)*			*(a)*	*(b)*	*(c)*	*(b) - (a)*	*(c) - (a)*
StAndrewsStream	SA0664	59.45	59.426	59.384	-0.03	-0.07	StAndrewsStream	SA125us_2	53.06	53.063	53.079	0.01	0.02
StAndrewsStream	INT0610	58.98	58.914	58.893	-0.06	-0.08	StAndrewsStream	SA125ds	52.92	52.93	52.954	0.01	0.04
StAndrewsStream	INT0555	58.56	58.524	58.503	-0.04	-0.06	StAndrewsStream	Sp125us	53.36	53.357	53.358	-0.01	-0.01
StAndrewsStream	INT0500	58.27	58.14	58.126	-0.13	-0.14	StAndrewsStream	Sp125ds	52.92	52.93	52.954	0.01	0.04
StAndrewsStream	SA0445	57.62	57.605	57.588	-0.02	-0.03	StAndrewsStream	SA0052	52.92	52.93	52.954	0.01	0.04
StAndrewsStream	SA0415	57.07	57.051	57.037	-0.02	-0.03	StAndrewsStream	SA0025	52.91	52.925	52.95	0.02	0.04
StAndrewsStream	SA0415_1	56.84	56.833	56.823	-0.01	-0.02	StAndrewsStream	SA0000	52.91	52.925	52.949	0.02	0.04
StAndrewsStream	SA0380	56.78	56.771	56.763	-0.01	-0.02	StAndrewsStream	RES1A	0.00	0.001	0.001	0.00	0.00
StAndrewsStream	SA0380_1	56.80	56.792	56.782	-0.01	-0.02	StAndrewsStream	RES1B	0.00	0.001	0.001	0.00	0.00
StAndrewsStream	SA0373us	56.79	56.781	56.771	-0.01	-0.02	StAndrewsStream	RES1C	0.00	0.001	0.001	0.00	0.00
StAndrewsStream	SA0373ds	56.67	56.663	56.659	0.00	-0.01	StAndrewsStream	RES1D	0.00	0.001	0.001	0.00	0.00
StAndrewsStream	SA0360	56.64	56.64	56.638	0.00	-0.01	StAndrewsStream	RES1E	0.00	0.001	0.001	0.00	0.00
StAndrewsStream	SA0360us	56.64	56.64	56.638	0.00	-0.01	StAndrewsStream	RES1F	0.00	0.001	0.001	0.00	0.00
StAndrewsStream	SA0360us_1	56.36	56.349	56.344	-0.01	-0.02	StAndrewsStream	RES1G	0.00	0.001	0.001	0.00	0.00
StAndrewsStream	SA0360us_2	56.07	56.057	56.051	-0.02	-0.02	CrowGreenStream	Crow2496	70.77	70.708	70.658	-0.06	-0.11
StAndrewsStream	SA0360ds	55.79	55.765	55.757	-0.02	-0.03	CrowGreenStream	Crow1945	63.21	63.187	63.168	-0.02	-0.04
StAndrewsStream	Sp360us	56.64	56.64	56.638	0.00	-0.01	CrowGreenStream	Crow1667	60.26	60.269	60.203	0.01	-0.06
StAndrewsStream	Sp360ds	55.79	55.765	55.757	-0.02	-0.03	CrowGreenStream	Cr1652us	60.06	60.112	60.057	0.05	0.00
StAndrewsStream	SA0300	55.79	55.765	55.757	-0.02	-0.03	CrowGreenStream	CGSpill1us	60.06	60.112	60.057	0.05	0.00
StAndrewsStream	INT261	55.24	55.215	55.21	-0.03	-0.03	CrowGreenStream	CGSpill2ds	57.91	57.906	57.906	0.00	0.00
StAndrewsStream	SA0222us	54.82	54.819	54.815	0.00	-0.01	CrowGreenStream	CGWeirus	60.06	60.112	60.057	0.05	0.00
StAndrewsStream	222us	54.82	54.819	54.815	0.00	-0.01	CrowGreenStream	Crow1651	60.03	60.102	60.047	0.07	0.01
StAndrewsStream	222ds	54.72	54.72	54.716	0.00	-0.01	CrowGreenStream	ST29us	60.03	60.102	60.047	0.07	0.01
StAndrewsStream	Sp222us	54.82	54.819	54.815	0.00	-0.01	CrowGreenStream	ST28ds	57.22	56.918	56.914	-0.30	-0.30
StAndrewsStream	Sp222ds	54.72	54.72	54.716	0.00	-0.01	CrowGreenStream	Crow1394	56.82	56.653	56.65	-0.16	-0.17
StAndrewsStream	SA0222ds	54.72	54.72	54.716	0.00	-0.01	CrowGreenStream	Crow1384	56.61	56.526	56.523	-0.08	-0.09
StAndrewsStream	SA0196	54.30	54.291	54.287	-0.01	-0.01	CrowGreenStream	Crow1354	56.38	56.146	56.143	-0.23	-0.23
StAndrewsStream	INT176	54.03	54.024	54.019	-0.01	-0.01	CrowGreenStream	Crow1289	55.72	55.682	55.679	-0.04	-0.04
StAndrewsStream	INT156	53.86	53.852	53.847	0.00	-0.01	CrowGreenStream	Crow1201	54.83	54.732	54.729	-0.09	-0.10
StAndrewsStream	SA0136us	53.81	53.804	53.8	0.00	-0.01	CrowGreenStream	1126us	54.48	54.327	54.296	-0.15	-0.18
StAndrewsStream	136us	53.81	53.804	53.8	0.00	-0.01	CrowGreenStream	ST27us	54.48	54.327	54.296	-0.15	-0.18
StAndrewsStream	136ds	53.49	53.487	53.484	0.00	-0.01	CrowGreenStream	ST27ds	54.40	54.267	54.243	-0.13	-0.16
StAndrewsStream	Sp136us	53.81	53.804	53.8	0.00	-0.01	CrowGreenStream	Sp27us	54.48	54.327	54.296	-0.15	-0.18
StAndrewsStream	Sp136ds	53.49	53.487	53.484	0.00	-0.01	CrowGreenStream	Sp27ds	54.40	54.267	54.243	-0.13	-0.16
StAndrewsStream	SA0136ds	53.49	53.487	53.484	0.00	-0.01	CrowGreenStream	1126ds	54.40	54.267	54.243	-0.13	-0.16
StAndrewsStream	INT131	53.41	53.409	53.407	-0.01	-0.01	CrowGreenStream	Crow1118	54.31	54.195	54.171	-0.12	-0.14
StAndrewsStream	SA0125	53.36	53.357	53.358	-0.01	-0.01	CrowGreenStream	Crow0971	52.98	52.784	52.753	-0.19	-0.23
StAndrewsStream	SA125us	53.36	53.357	53.358	-0.01	-0.01	CrowGreenStream	0971ds	52.56	52.28	52.244	-0.28	-0.31
StAndrewsStream	SA125us_1	53.20	53.204	53.214	0.00	0.01	CrowGreenStream	Crow0960	52.49	52.193	52.154	-0.30	-0.34

Watercourse	Node	2002 maximum level	Latest hydrology		Difference	
			5 hour	14 hour	5 hour	14 hour
		(a)	*(b)*	*(c)*	*(b) - (a)*	*(c) - (a)*
CrowGreenStream	0960ds	52.36	52.106	52.071	-0.26	-0.29
CrowGreenStream	Crow0940	52.30	52.006	51.962	-0.30	-0.34
CrowGreenStream	C-in	52.30	52.006	51.962	-0.30	-0.34
CrowGreenStream	ST26Aus	52.27	51.979	51.939	-0.29	-0.33
CrowGreenStream	ST26Ads	52.17	51.91	51.878	-0.26	-0.29
CrowGreenStream	ST26Bus	52.13	51.884	51.854	-0.24	-0.27
CrowGreenStream	ST26Bds	52.03	51.815	51.793	-0.22	-0.24
CrowGreenStream	Crow0900	52.00	51.8	51.782	-0.20	-0.21
CrowGreenStream	Crow0865	51.96	51.623	51.602	-0.34	-0.36
CrowGreenStream	Cr0794us	51.08	51.024	51.008	-0.05	-0.07
CrowGreenStream	CGweirus	51.08	60.112	60.057	9.04	8.98
CrowGreenStream	Cr0794ds	50.76	50.657	50.634	-0.10	-0.12
CrowGreenStream	Crow0775	50.65	50.533	50.51	-0.12	-0.14
CrowGreenStream	Cr0664us	49.79	49.734	49.696	-0.05	-0.09
CrowGreenStream	Crow0664	49.79	49.734	49.696	-0.05	-0.09
CrowGreenStream	Cr0490us	48.93	48.939	48.885	0.01	-0.05
CrowGreenStream	0490us	48.93	48.939	48.885	0.01	-0.05
CrowGreenStream	0490ds	48.70	48.719	48.666	0.02	-0.04
CrowGreenStream	Sp490us	48.93	48.939	48.885	0.01	-0.05
CrowGreenStream	Sp490ds	48.70	48.719	48.666	0.02	-0.04
CrowGreenStream	Cr0490ds	48.70	48.719	48.666	0.02	-0.04
CrowGreenStream	Crow0350	48.06	48.014	48.078	-0.05	0.02
CrowGreenStream	Crow0350_1	48.03	48.007	48.068	-0.03	0.03
CrowGreenStream	Crow0350_2	48.03	48.007	48.068	-0.02	0.04
CrowGreenStream	Crow0120	48.03	48.006	48.067	-0.03	0.04
CrowGreenStream	Crow0120_1	48.03	48.006	48.067	-0.03	0.04
CrowGreenStream	Crow0120_2	48.03	48.006	48.067	-0.03	0.04
CrowGreenStream	Crow0000	48.03	48.006	48.067	-0.03	0.04
CrowGreenStream	Relief1	51.08	51.024	51.008	-0.05	-0.07
CrowGreenStream	Reliefus	50.73	50.525	50.459	-0.20	-0.27
CrowGreenStream	Reliefds	50.73	50.525	50.459	-0.20	-0.27
CrowGreenStream	Relief2	49.27	49.245	49.172	-0.03	-0.10
CrowGreenStream	Relief3	48.21	48.191	48.248	-0.02	0.03
CrowGreenStream	Sp0940	52.30	52.006	51.962	-0.30	-0.34
CrowGreenStream	Sp0900	51.62	51.621	51.621	0.00	0.00
CrowGreenStream	ReliefRs	48.86	48.858	48.859	0.00	0.00
NorthKen	NK0889	53.83	53.839	53.839	0.01	0.01
NorthKen	NK0889_1	53.55	53.561	53.561	0.01	0.01
NorthKen	ST22us	53.46	53.468	53.468	0.01	0.01

Watercourse	Node	2002 maximum level	Latest hydrology		Difference	
			5 hour	14 hour	5 hour	14 hour
		(a)	*(b)*	*(c)*	*(b) - (a)*	*(c) - (a)*
NorthKen	Culvrt22us	53.46	53.468	53.468	0.01	0.01
NorthKen	Culvrt22ds	53.20	53.21	53.21	0.01	0.01
NorthKen	Spill22us	53.46	53.468	53.468	0.01	0.01
NorthKen	Spill22ds	53.20	53.21	53.21	0.01	0.01
NorthKen	ST22ds	53.20	53.21	53.21	0.01	0.01
NorthKen	NK0763	53.03	53.044	53.044	0.01	0.01
NorthKen	NK0763_1	52.61	52.54	52.54	-0.07	-0.07
NorthKen	NK0454	51.94	51.987	51.986	0.05	0.05
NorthKen	NK0260	51.24	51.117	51.147	-0.12	-0.09
NorthKen	ST04us	50.88	50.754	50.857	-0.12	-0.02
NorthKen	ST04ds	50.70	50.667	50.703	-0.04	0.00
NorthKen	NK000	50.70	50.663	50.696	-0.03	0.00
CrowGreenStream	Urban2	54.48	54.732	54.729	0.26	0.25
CrowGreenStream	Urban3	50.73	50.525	50.459	-0.20	-0.27
CrowGreenStream	Urban4	49.79	49.734	49.696	-0.05	-0.09

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Appendix 4

Recommended improvements to the existing ISIS model

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Table A4-1. Recommended improvements

Note: improvements highlighted in grey have already been completed at no extra cost, whilst those highlighted in green will be addressed through the linkage of the ISIS model to a 2D representation of the floodplain and, hence, are covered by our original scope of works

Ref.	Recommended improvement
Essential changes – Improvements 1 to 17 are considered essential to correct serious errors in the existing hydraulic model and ensure that appropriate ISIS units are used to represent key structures and flood mechanisms. These improvements should be seen as 'bare minimum' or 'must do' items.	
1	The modelled sections should be extended where they suddenly reduce in width at structures
2	The sluices in the model need weir lengths in the units as this field has been added to the unit since the model was built
3	The invert levels of Bernoulli loss units should be checked as they do not match the surveyed levels in the sections upstream and downstream
4	Overtopping levels of structures should be examined and bypass spills added where necessary
5	Sections which have been extended using 1:25,000 map contours will need to be trimmed down to their surveyed widths and re-extended using LiDAR data
6	Extended sections which have been smoothed should have their surveyed data reinstated.
7	Where necessary extended sections need to be trimmed to high points and the area beyond the high points needs to be represented as parallel channels
8	The slots in parallel channels need to be resized appropriately for the dummy flows used
9	Connectivity needs to be added between the parallel channels
10	Seven reservoirs (Spill1ds, Spill2ds, Spill3ds, RES1A, CGSpill2ds, Sp0900, ReliefRs) need to be re-schematised.
11	Glass walling sections need appropriate floodplain representation
12	Lateral spills need to be re-schematised
13	Spill coefficients of several lateral spills (MS1364LB to MS2167LB) need to be examined and altered if necessary
14	Complex interaction between bypass channel and floodplain should be examined and corrected if necessary
15	Model run parameters need to be defined
16	Model convergence issues and instabilities need to be examined and corrected wherever possible
17	The FEH statistical method should be used to derive peak flow frequency estimates for the Crow Green Stream, St. Andrew's Well Stream and St. Georges Well Stream
Preferable changes – Improvements 18 to 25 are seen as advisable or preferable. Whilst they may not always have a significant impact on model results, they are recommended to ensure that best practice modelling techniques are used, structures and reaches are represented according to channel survey and non-convergence issues are reduced. It is recommended that these improvements are considered for inclusion in any further hydraulic modelling work using this model.	
18	Slots in River Sections in the main channels should be removed if possible
19	Additional interpolates should be added to reduce the distance between nodes so that it is more appropriate for the channel slopes
20	Manning's 'n' values should be examined, with additional information, for appropriateness and adjusted if necessary
21	The stage discharge relationship at the downstream end of the model should be examined to ensure it is appropriate
22	The 'p' levels at structures in the model should be examined and corrected where necessary
23	The choice of unit for culverts, bridges and orifices should be examined and altered if necessary
24	Dummy flows need to be abstracted from the model
25	Flat spills should be adjusted by 1mm to reduce model non-convergence and "noise"

Suggested improvements - Improvements 26 to 33 are also suggested but are not considered essential for the satisfactory completion of the FRA.	
26	The hydrology should be imported into .ied files and just one model .dat file used to reduce the amount of files and storage space
27	The intermediate hydrological boundaries should be assessed to see if they would better represent the catchment hydrology by being distributed over the length of a reach
28	Orifice units representing bridges should be replaced with bridge units where it is more appropriate to use orifice units
29	Culverts should have entry and exit loss units
30	Irregular culverts modelling regular shapes should be converted to the appropriate shape
31	Reduce dummy flows to minimise impacts on floodplain
32	Geo-referencing information should be created for every section
33	A GXY visualiser should be created to allow better visualisation of the model