MEMO

SUBJECT
Cullompton Model Updates 2016 / 2017

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DEPARTMENT
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1. Introduction

This memo summarises the updates made to the River Culm and tributaries hydraulic model. The hydraulic model has been used to inform the Flood Risk Assessment for the Cullompton Eastern Relief Road and Proposed New Southern Bridge/Proposed Junction 28A (M5) (the Scheme).

This memo focusses on the key updates made to the model following the Environment Agency's (EA) detailed review issued in July 2016. It does not provide full details of the model build, this has been covered in the supporting model documents in Appendix B of the FRA[1]. Information on the model history is also included in the FRA[1] of which this memo forms part of Appendix B.

2. Model Data

2.1 Supplied Models

The model is based on an ISIS (1D) model developed by Haskoning, 2002. This model was linked to TUFLOW by Arcadis (formerly Hyder Consulting) in 2014 and further enhancements in 2016 / 2017, which are discussed in this memo. Details of the linking of the ISIS TUFLOW model (Arcadis, 2014) is detailed in Appendix B of the FRA.

2.2 Elevation Data

The base ground elevation model is based on LiDAR supplied in June 2013. This model has been supplemented using the data sources listed in Table 2-1.

[1] Arcadis Consulting (UK) Limited (December 2017) Cullompton Eastern Relief Road and Proposed New Southern Bridge / Proposed Junction 28A Flood Risk Assessment (Report number 0005-UA005763-UU41R-04)

Survey Source	Survey Date	Location	Application of Data
Sumo Surveys	October 2013	Adjacent to the M5 southbound carriageway north of the A373 (Venn Farm) Raleigh Drive Tesco Site	Elevation points from the topographic survey was merged with the LiDAR, to create a combined DTM which was read into the TUFLOW model. Topographic survey provided current details in areas where the LiDAR was not representative.
Arcadis (formerly Hyder Consulting)	December 2015	Spot levels were obtained along Millennium Way and at the sluice controlling flows into the adjacent flood storage area.	These were used to define the road and embankment crests using 2d_zsh.
		Spot levels and soffit measurements of bridges at Duke Street / First Bridge.	These were subsequently superseded by the December 2016 Survey.
APLS Surveys	December 2016 / January 2017	Levels and dimensions of a number of key structures crossing the network of drains on the floodplain of the River Culm..	See Section 3.2
		Rivermead Flood Defences.	See Section 3.4.
Mid Devon District Council	January 2017	Cattle fences near First Bridge / Last Bridge	See Section 3.6

Table 2-1 Survey Data

3. Baseline Model Updates

Sections 3.1 to 3.10 demonstrate how the comments in the EA's 2016 model review have been addressed in the final baseline model which was approved by the EA in June 2017.

3.1 Culm Bypass / M5 / Venn Farm

Issue: New survey data was collected for the Culm Bypass Channel west of Venn Farm (Sumo Surveys October 2013) and used to create the base DTM 'Cullompton_Combined_DTM_v02'. However the zp points applied to the 2d_bc HX layer adjacent to the Culm Bypass Channel were based on the old channel survey rather than the newer Sumo survey data and hence water was restricted from entering the bypass channel.

Resolution: These zp points have now been removed ensuring that water can flow into the Culm Bypass Channel.

3.2 Floodplain Structures and Channels

Issue: The use of 2d_zsh and 2d_fcsh to represent channels and structures (with dimensions informed by LiDAR and online photography) on the floodplain, did not provide sufficient detail to assess their impacts on conveyance.

Resolution: Collection of new survey data was arranged by Mid Devon District Council (MDDC) in December 2016 / January 2017. The survey was used to update the structures on the floodplain as detailed in Table 3-1.

In addition to the structures update, surveyed cross sections at the upstream and downstream of the structures were used to refine the invert levels and percentage blockage values used in the 2d_fcsh representing the minor watercourses crossing the floodplains.

Survey Section ID	Photo	Notes
1.002		Railway culvert downstream of M5 west of Hayne Barton Cottages. Modelled as an I type ESTRY culvert with opening data taken from December 2016 / January 2017 survey.
1.006		M5 Culvert west of Hayne Barton Cottages Three R type ESTRY Culverts representing the main channel and the two higher level side channels spanning the banks. Data taken from December 2016 / January 2017 survey
3.003		Armco Culverts under A373 (east of M5 J28) Modelled as four I type ESTRY culverts with opening data taken from December 2016 / January 2017 survey.
5.001		Cullompton Community Association Access Track crossing minor watercourse north east of First Bridge. Modelled as a 2d_lfcsh for stability. Data taken from December 2016 / January 2017 survey.
5.006		Railway culvert downstream of M5 (5.011) Modelled as an lfcsh for stability Note that due to stability issues, some smoothing has been applied to the gradient of the channel and structures in this location. Rather than take account of all the scour, a typical bed profile has been used. Data taken from December 2016 / January 2017 survey.
5.011		M5 immediately north of Old Hill Modelled as an lfcsh for stability See comment on 5.006 regarding channel gradient. Data taken from December 2016 / January 2017 survey.

Survey Section ID	Photo	Notes
6.003		Armco culverts under Old Hill Modelled as two I type ESTRY culverts with opening data taken from December 2016 / January 2017 survey.

Table 3-1 Structures on the Floodplain

3.3 Millennium Way

Issue: The source of the data used to define the elevation of Millennium Way between the B3181 and Head Weir Road was unclear.

Resolution: The information is included in the FRA[1]; the data is based on an in-house survey carried out by Arcadis in December 2015 (Section 2.2)

3.4 Rivermead Defences

Issue: In the 2014 Arcadis model, the elevations of the Rivermead Flood Defences were taken from NFCDD data supplied by the EA. However, the 2016 EA review indicated that the NFCDD data was not reliable.

Resolution: New survey data collected in December 2016 / January 2017 was used to update the defence levels in TUFLOW. Further information was supplied by the EA in May 2017 to refine the representation of the Rivermead defences at their northern and southern extents.

3.5 Storage Reduction Factors

Issue: Clarification was required regarding the derivation of the SRF and pBlockage factors used in the 2d_fcsh and 2d_SRF layers.

Resolution: The pBlockage value is a function of the channel width (determined using the LiDAR) and the grid cell size. A 'Shape_width_or_dMax' value of 8 is used in order to apply the 2d_fcsh to two cells. This ensures that a constant line of adjoining grid cells, side to side, are lowered, allowing water to flow through each cell, and avoids cells on a diagonal being selected, which stops water flowing through the cells. Figure 3-1 shows how the 2d_fcsh lowers a width of 8m, two 4m grid cells in this case giving a cross sectional area of 4m². However, the cross sectional area of the channel in this example is 0.98m² giving a pBlockage value of 76%. The SRF factor allows the storage of the cell to be reduced in conjunction with blockage of the conveyance.

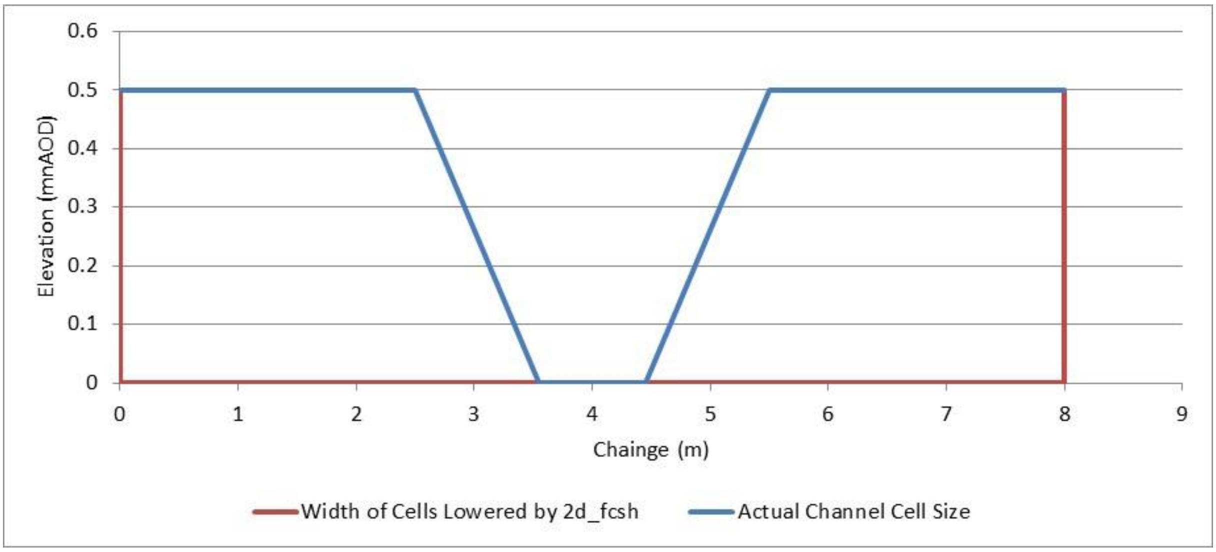

Figure 3-1 2d_fsch and SRF Factor Derivation

3.6 Cattle Fences

Issue: A sensitivity test to look at the impact of removing the cattle fences near First Bridge / Last Bridge was required.

Resolution: Following inclusion of these fences in the model as 2d_lfcsh, discussion of the results with the EA confirmed that the baseline model should include these fences. Consequently, additional survey data was obtained by MDDC (January 2017) and used to refine the 2d_lfcsh accordingly.

3.7 Reach Lengths

Issue: The EA 2016 review identified some discrepancies in modelled reach lengths compared to the actual reach lengths measured in GIS on the River Culm, Spratford Stream and Spratford Mill Stream. Note that this was a legacy issue carried through from the original Haskoning model arising from the fact that 1D structures such as bridges and weirs do not have a chainage associated with them.

Resolution: An explanation was provided to the EA as follows. The 1D units calculate the losses across the structures; inclusion of any additional chainage within the reach, to account for the chainage lost through use of a 1D structure unit (which does not have any chainage associated with it) is only required for storage estimation and not for conveyance calculation. However, in a linked 1D-2D model discrepancies can arise if chainages are increased upstream or downstream of a 1D structure to account for the chainage lost, because the length of the associated HX lines will be shorter than the distance to next in the 1D model. The EA confirmed that this explanation was acceptable when signing off the baseline hydraulic model and hence no changes were made.

3.8 Representation of Bridges/Structures

3.8.1 Long Bridge

Issue: Long Bridge was represented using Bernoulli Loss Units rather than a bridge structure unit.

Resolution: Long Bridge was updated from a Bernoulli Loss unit to an Arch Bridge unit using the new 2016 survey data.

Issue: The railway crossing downstream of Long Bridge was represented as an Orifice unit rather than a bridge unit.

Resolution: New survey data was collected, and the crossing is now represented as an Arch Bridge unit.

Furthermore, a new 2d_zsh was created to allow 2D flood flows from the north to flow along the railway line towards the Trading Estate and Community Playing Fields.

3.8.2 First Bridge

Issue: The channel cross section upstream of First Bridge (ST11us) did not match the surveyed structure cross section.

Resolution: ST11us was amended to reflect the surveyed section on the upstream face of the bridge (FirstBru).

3.8.3 Motorway and Railway Culverts Downstream of Last Bridge

Issue: The 2014 model included only the M5 crossing of the River Culm downstream of Last Bridge and not the railway crossing immediately downstream.

Resolution: The railway crossing immediately downstream of the M5 was added to the model using dimensions obtained in the December 2016 survey. Spill units were added to model any overtopping of the structures.

3.9 Panel Markers

Issue: Missing panel markers in the 1D model.

Resolution: Panel markers in the vicinity of the Scheme were reviewed and amended where necessary to ensure that conveyance curves were smooth.

3.10 Dflood

Issue: A high dflood value, 19 has been applied to the 1D model.

Resolution: The dflood has been reduced to 10.

3.11 Baseline Model Sign Off

Following further review and discussion, the EA signed off the baseline model in June 2017. The final baseline models are *Cullompton_v40_X* where 1 in X is the annual chance.

3.12 Modelling Software

The 2014 model was run using ISIS 3.6 and TUFLOW 2012-05-AC. The 2017 model was run using Flood Modeller Pro 4.2 and TUFLOW 2016-03-AD.

4. Scheme Modelling

4.1 Model Version

The 'with Scheme' model is *Cullompton_v40_Option_v19_X_B* where X is the annual chance. Full details of the Scheme components are included in the FRA[1].

4.2 Model Files

Modelling of the Scheme is outlined in the FRA[1]. Table 4-1 provides a list of the files used to model the Scheme and associated mitigation. The Scheme was added to the baseline model which had been signed off by the EA.

File Name	Description
1d_nwk_cullompton_ISIS_proposed_v14.shp	Changes to ISIS node locations to place new bridge crossings.
1d_nwk_Cullompton_proposed_v18.shp	Culverts through the road embankments (ESTRY).
proposed_DEM.asc	New road alignment and embankment elevations combined with baseline LiDAR elevations.
2d_code_Cullompton_proposed_v03.shp	Amendments to active area along the River Ken (South) to improve stability in the 'with Scheme' model.
2d_bc_Cullompton_proposed_v18_R.shp	Changes to inactive cells for the River Ken (South) channel to improve stability in the 'with Scheme' model.
2d_mat_Cullompton_proposed_embankment_v01.shp	Roughness polygons defining Scheme embankment.
2d_mat_Cullompton_proposed_road_v01.shp	Roughness polygons defining Scheme tarmaced areas.
2d_mat_Cullompton_proposed_stability_v12.shp	Additional and amended stability patches for the 'with Scheme' model.
2d_bc_Cullompton_proposed_v18_L.shp	Revised 1D-2D connections for the River Ken (South) channel to improve stability in the 'with Scheme' model (lines).
2d_bc_Cullompton_proposed_v18_P.shp	Revised 1D-2D connections for the River Ken (South) channel to improve stability in the 'with Scheme' model (bank elevation points)
2d_bc_Cullompton_proposed_v18_R.shp	Revised 1D-2D connections for the River Ken (South) channel to improve stability in the 'with Scheme' model (polygons).
2d_zsh_Cullompton_proposed_v03_P.shp	Existing railway line and M5 as they pass beneath the proposed road (points).
2d_zsh_Cullompton_proposed_v03_R.shp	Existing railway line and M5 as they pass beneath the proposed road (polygons).
2d_zsh_cullompton_lowering_v16_R.shp	Floodplain compensation areas (polygons).
2d_zsh_cullompton_lowering_v16_P.shp	Floodplain compensation areas (points).
2d_lfcsh_EmbankmentCulverts_V17_L.shp	Floodplain culverts through embankments modelled using 2d_lfcsh (lines).
2d_lfcsh_EmbankmentCulverts_V17_P.shp	Floodplain culverts through embankments modelled using 2d_lfcsh (points).

File Name	Description
Cullompton_v40_option_v19.dat	Proposed crossing of the River Culm at Culm2187 modelled using a modified channel cross section to model the effect of a clear span, high level crossing (Figure 4-1). New crossing on the River Ken (South) using bridge unit (KS0243); all sections upstream of this structure now modelled in 1D to improve model stability. Channel section KS0243 has been extended using LiDAR or improved stability and representation of the structure size. Proposed crossing of the Spratford Mill Stream at node MSpropo1c. Rectangular box culvert unit, 44m long, 5m wide, 1.5m high.

Table 4-1 Model Files Used to Model the Scheme

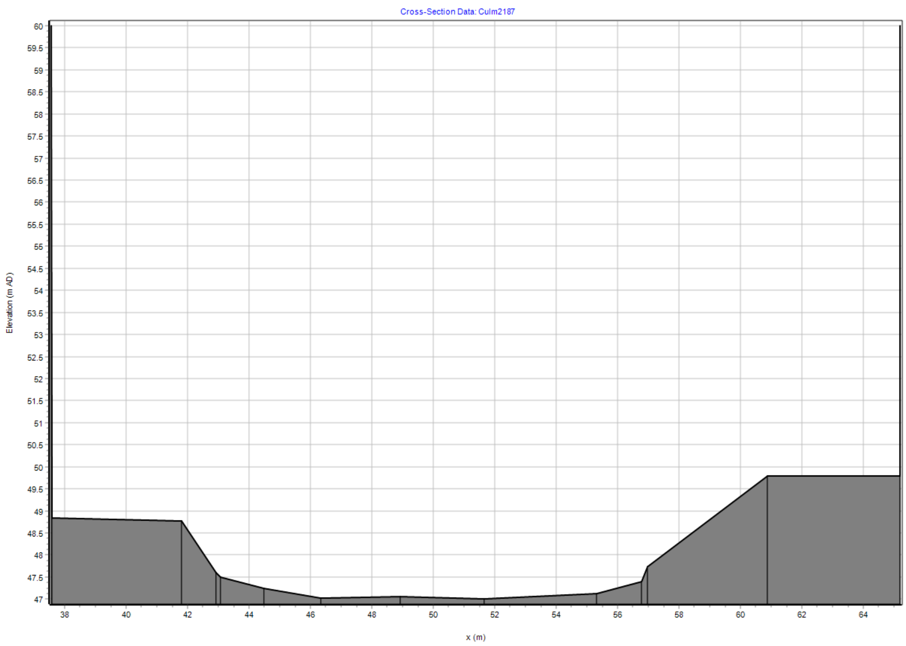

Figure 4-1 Channel Cross Section at Culm2187

4.3 Floodplain Culverts

The proposed culverts under the road embankments, which are to be used to improve floodplain conveyance are detailed in Table 4-2. The locations of these culverts are shown in Figure 4-2.

Culvert ID	Dimensions	Model Schematisation
L1	30m wide, 3m high	Layered flow constriction shape Shape_width_dmax = 30 Layer 1 pBlockage = 0
L2	30m wide, 3m high	Layered flow constriction shape Shape_width_dmax = 30 Layer 1 pBlockage = 0
L3	30m wide, 3m high	Layered flow constriction shape Shape_width_dmax = 30 Layer 1 pBlockage = 0
L4	30m wide, 3m high	Layered flow constriction shape Shape_width_dmax = 30 Layer 1 pBlockage = 0
L5	30m wide, 3m high	Layered flow constriction shape Shape_width_dmax = 30 Layer 1 pBlockage = 0
E6	8m wide, 3m high	ESTRY R Culvert
E7	4m wide, 2m high	ESTRY R Culvert
E8	1.2m diameter	ESTRY C Culvert
E9	1.2m diameter	ESTRY C Culvert

Table 4-2 Floodplain Culverts

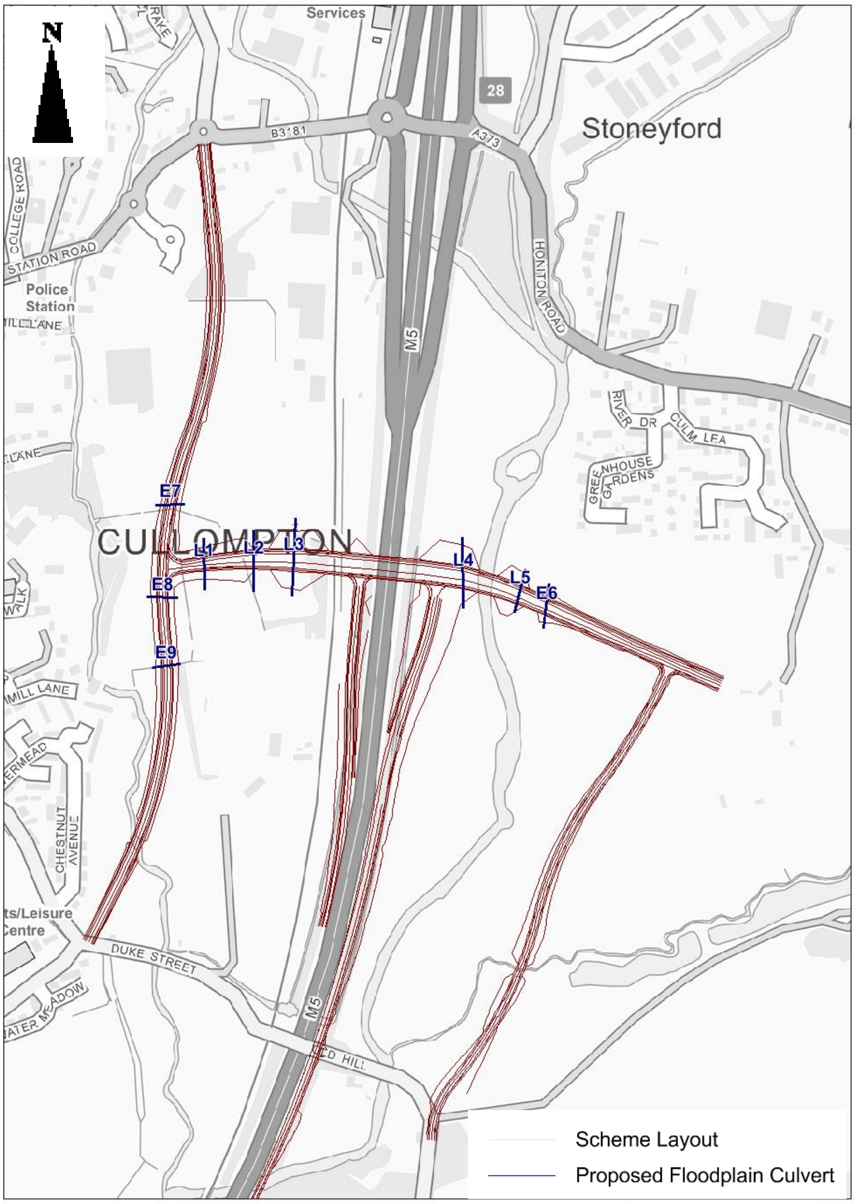

Figure 4-2 Floodplain Culverts (Contains Ordnance Survey data © Crown copyright and database right 2017)

4.3.1 Afflux across Proposed Culverts

The EA 2016 Review requested an analysis of the change in water level (afflux) across the proposed floodplain culverts (Table 4-3).

Culvert ID	50% AEP	5% AEP	2% AEP	1% AEP	1% AEP Plus 40%	0.1% AEP
L1	No Flooding	No Flooding	No Flooding	No Flooding	0.27m	0.27m
L2	No Flooding	No Flooding	No Flooding	No Flooding	0.20m	0.20m
L3	No Flooding	No Flooding	No Flooding	0.00m	0.19m	0.20m
L4	0.17m	0.32m	0.25m	0.18m	0.11m	0.12m
L5	0.00m	0.03m	0.08m	0.09m	0.08m	0.08m
E6	0.00m	0.06m	0.12m	0.12m	0.11m	0.11m
E7	No Flooding	No Flooding	No Flooding	No Flooding	0.15m	0.14m
E8	No Flooding	No Flooding	No Flooding	No Flooding	0.08m	0.06m
E9	No Flooding	No Flooding	No Flooding	No Flooding	-0.11m	-0.10m

Table 4 Afflux across proposed culverts in the floodplain

Culvert L4 shows a large afflux for the lower flood events (5% and 2% AEP), which is due to some small differences in ground levels at the entrance and exit of the culvert where the lfcsh abuts the base DTM. Ground levels are very close to the peak stage for the smaller events and hence this difference is accentuated. Further optimisation of the culverts at detailed design stage will improve this. Results from the larger events show a much smaller afflux which is to be expected given the size of the culvert.

Culverts E8 and E9 are the smallest of all the floodplain culverts and pass a maximum of 0.02m³/s and 0.54m³/s, respectively. ESTRY results indicate that these culverts do not run full which may also suggest some scope for optimising levels and dimensions as part of the detailed design.

The negative afflux observed at culvert E9 suggests that there is scope for optimisation of this culvert, to improve flow conveyance as water levels are being maintained at a higher level on the area of floodplain between the north south link road to the west of the M5 and the M5 / railway line. Ideally, the culvert should allow water levels to equalise either side of the new road.

The sizes of the remaining crossings (L1, L2, L3, L4, L5, E6 and E7) have been maximised as far as practical within the constraints of the Scheme outline design and do not exhibit excessive afflux for the modelled events reviewed. However, the design of these crossings will be refined during the detailed design stage.

5. Model Performance

5.1 FMP Convergence

The convergence plot for run 1% AEP 'with Scheme' model run (Cullompton_v40_Option_v19_100_B), is shown below in Figure 5-1. Overall the model performs quite well, there are times of poor convergence which occur either side of the peak of the flood event. Review of the .zzd indicates that one model node is reporting poor convergence, Cole649u, which is located upstream of the Exeter Road culvert, 800m upstream of the confluence of the River Cole and River Culm at Woodmill (downstream model extent). The stage and flow output at Cole649u are stable, however there are small jumps in flow either side of the peak, coinciding with the reported poor convergence. Results from the baseline model (Cullompton_v40_100) exhibit very similar results. These issues are minor and do not impact on the assessment of the Scheme.

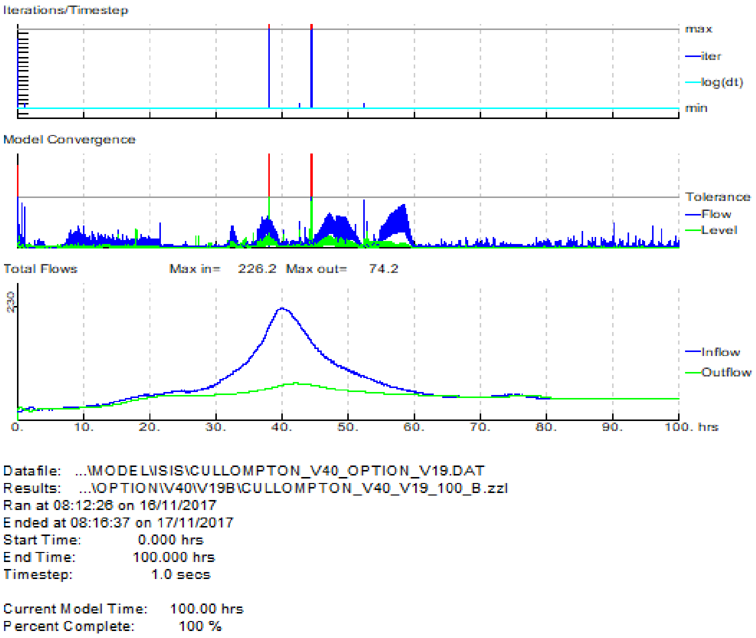

Figure 5-1 Convergence Plot 1% AEP 'with Scheme' model

5.2 TUFLOW Mass Error

The mass balance for the 1% AEP 'with Scheme' model (Cullompton_v40_Option_v19_100_B) is shown below in Figure 5-2. This represents the combined 1D 2D model results. There is a spike (up to -33%) in the percentage mass error at the very start of the simulation which settles down quickly. A review of the MB1 and MB2 outputs indicates that these higher percentage errors are associated with some of the 2d_fcsh used to model the ditches crossing the floodplain to the north of the Scheme as they become rapidly wet at the start of the simulation. Given that the mass error settles down quickly, some 35 hours before the event peak, and that the areas where higher errors are observed are located away from the Scheme, it is considered that the model is fit for purpose.

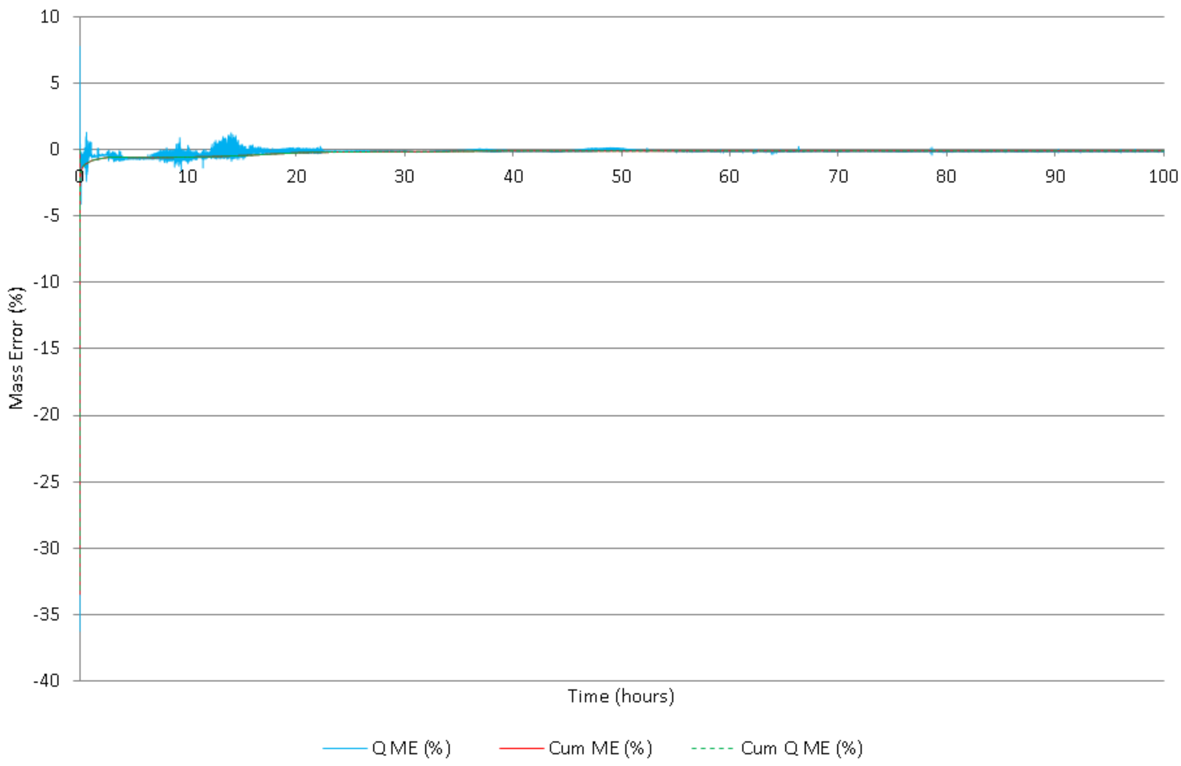

Figure 5-2 Percentage Mass Error 1% AEP 'with Scheme' model

5.3 TUFLOW Warnings and Checks

The TUFLOW warnings and checks for Cullompton_v40_Option_v19_100_B have been reviewed, and discussed below:

- The majority of checks and warnings relate to locations where the Z flag in an ESTRY SX connection has lowered the ZC Z point. This is appropriate as ESTRY culverts connect into 2D channels which have been defined in the DTM using 2d_fcsh.
- Warnings relating to repeat application of HX cells at structure interfaces (where spilling occurs in the 2D domain) do not cause any problems with the model.
- Two warnings regarding SX cells activating inactive cells are acceptable as this occurs on a 1D2D boundary.
- Negative depths are reported at the Armco culverts under the A373. However, these warnings are constrained to the boundary cells immediately adjacent to the culvert outlets.