it is concluded that the proposed FAS is robust against variation in the catchment characteristics as part of further investigation requested by NRW.

7.4 Boverton Brook Inflows

Following correspondence with NRW (09/01/19), it was agreed that a sensitivity simulation including all flows on Boverton Brook between the Llanmaes Brook confluence and the Boverton Brook railway bridge would be simulated to robustly demonstrate the proposed scheme provides no detriment downstream in Boverton. To achieve this, the Llanmaes FAS Baseline and Proposed Option models outlined in this report were incorporated into the received NAR model (with all the NAR mitigation measures). The rainfall catchment was extended to include all of the Boverton Brook catchment to immediately downstream of the B4265 culvert (Figure 7-7). The Baseline and Proposed Option was then simulated for the 1% AEP + 30% climate change event. It is noted that the grid cell size is reduced to 2m compared to the 4m grid cell size used in the received NAR model.

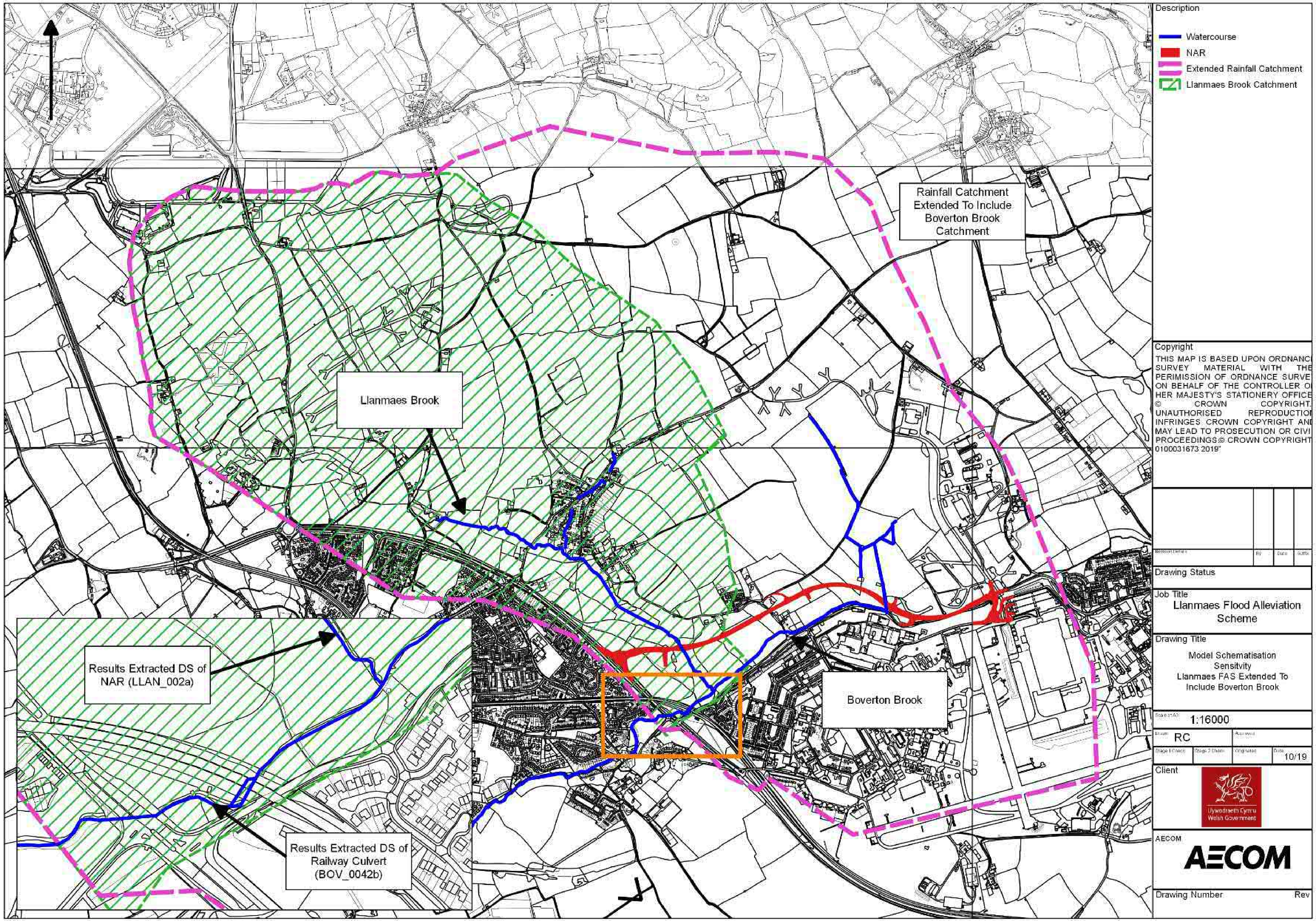


Figure 7-7: Model Schematisation For 1D Inflow Sensitivity

The baseline sensitivity results were compared to the received St Athan NAR FCA Proposed Option pluvial results on Boverton Brook downstream of the railway bridge culvert (Figure 7-8) to ensure the flows on Boverton Brook are consistent with the received model. It has been demonstrated that the two hydrographs are comparable at the peak (11.0m^3/s vs 11.1m^3/s respectively) however there is an increase in flows earlier on in the baseline sensitivity results. These variations in hydrological phasing can be accounted for by the differences in grid cell size (4m and 2m for the St Athan FCA and Llanmaes FAS models respectively) and improved representation of flow routing in the Llanmaes Brook catchment.

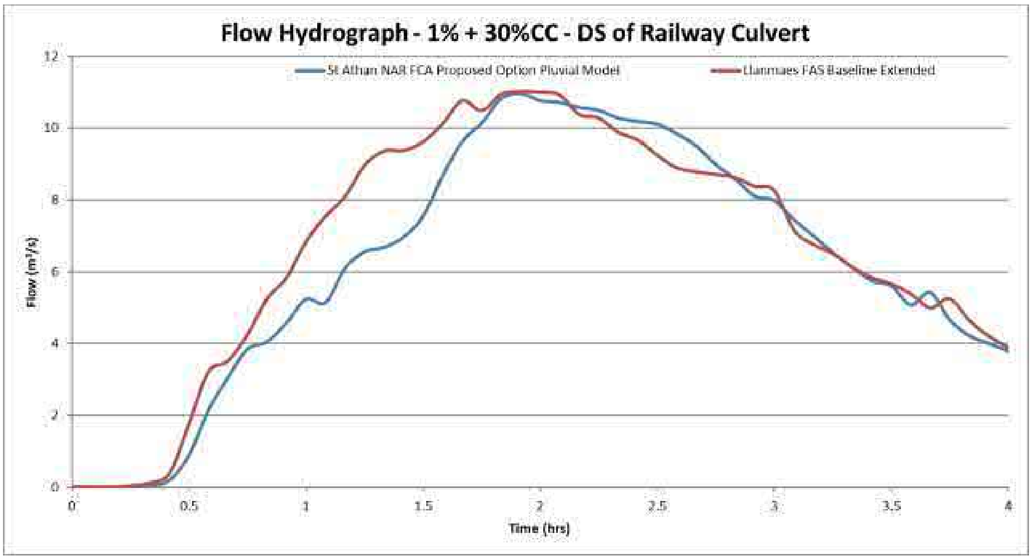


Figure 7-8: : Flow Comparison Downstream of Boverton Brook Railway Culvert 1% AEP + 30%CC (Node Bov_042b)

Flow hydrographs were then extracted for the Baseline and Proposed Option sensitivity scenarios at a location on Llanmaes Brook downstream of the NAR and on Boverton Brook downstream of the railway bridge culvert (Figure 7-9) and compared to the 1% AEP + 30% climate change results in this study (i.e. Llanmaes Brook catchment only). Figure 7-9 shows that there is no impact on the flows on Llanmaes Brook as a result of the sensitivity analysis and therefore all results on Llanmaes Brook presented in this study are considered acceptable. Figure 7-10 demonstrates as expected there is an increase in the volume of water downstream of the railway culvert as a result of extending the rainfall catchment to include the Boverton Brook catchment. Importantly, Figure 7-10 shows that there is a reduction in the flow hydrograph as a result of the Proposed Option downstream of the railway culvert when compared to the Baseline scenario. This builds confidence the Proposed Option has no detrimental impact to Boverton downstream of the scheme.

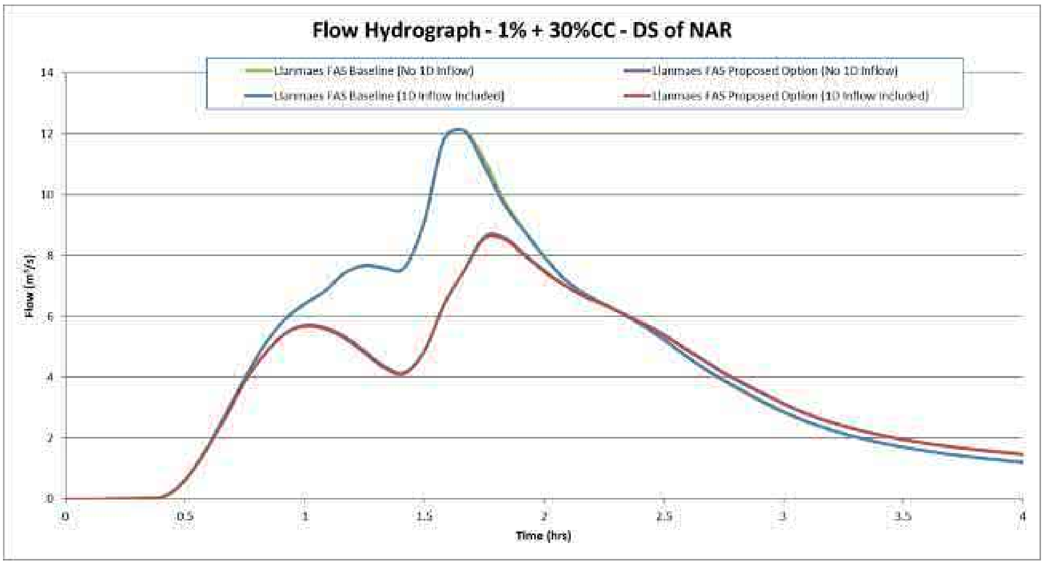


Figure 7-9: Flow Comparison Downstream of NAR 1% AEP + 30%CC (Node LLAN_002a)

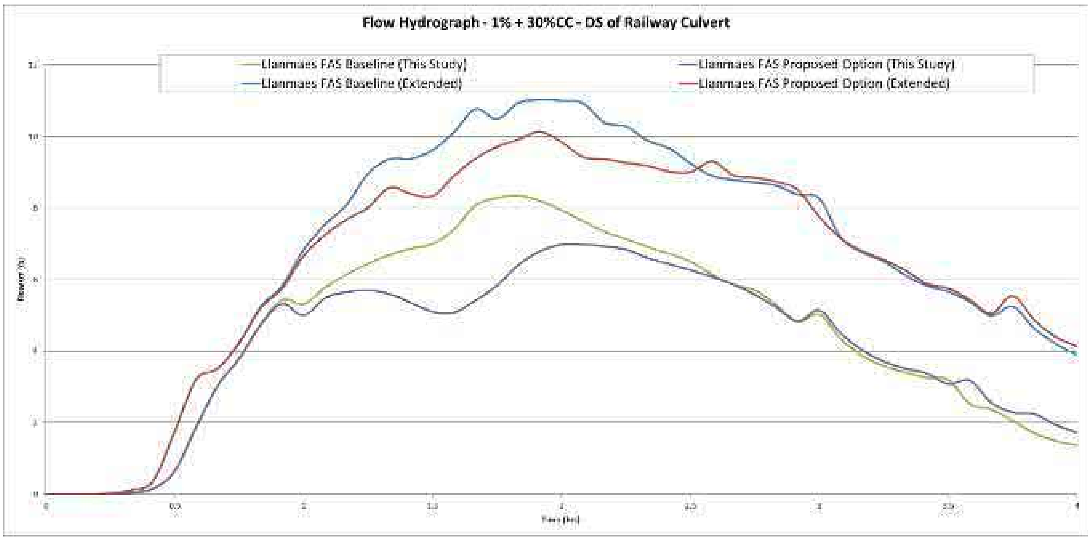


Figure 7-10: Sensitivity Flow Comparison Downstream of Boverton Brook Railway Culvert 1% AEP + 30%CC (Node Bov_042b)

The reduction in the flow hydrograph shown on Boverton Brook is supported by the maximum depth difference plot shown in Figure 7-11. It can be seen there is an overall reduction to flood depths between the confluence of Llanmaes Brook and Boverton Brook and the railway culvert when the Boverton Brook catchment is included in the model.

The results of this sensitivity analysis have demonstrated that the concluded benefits provided by the Llanmaes FAS described in this study are consistent when flows on Boverton Brook are included within the hydraulic model.

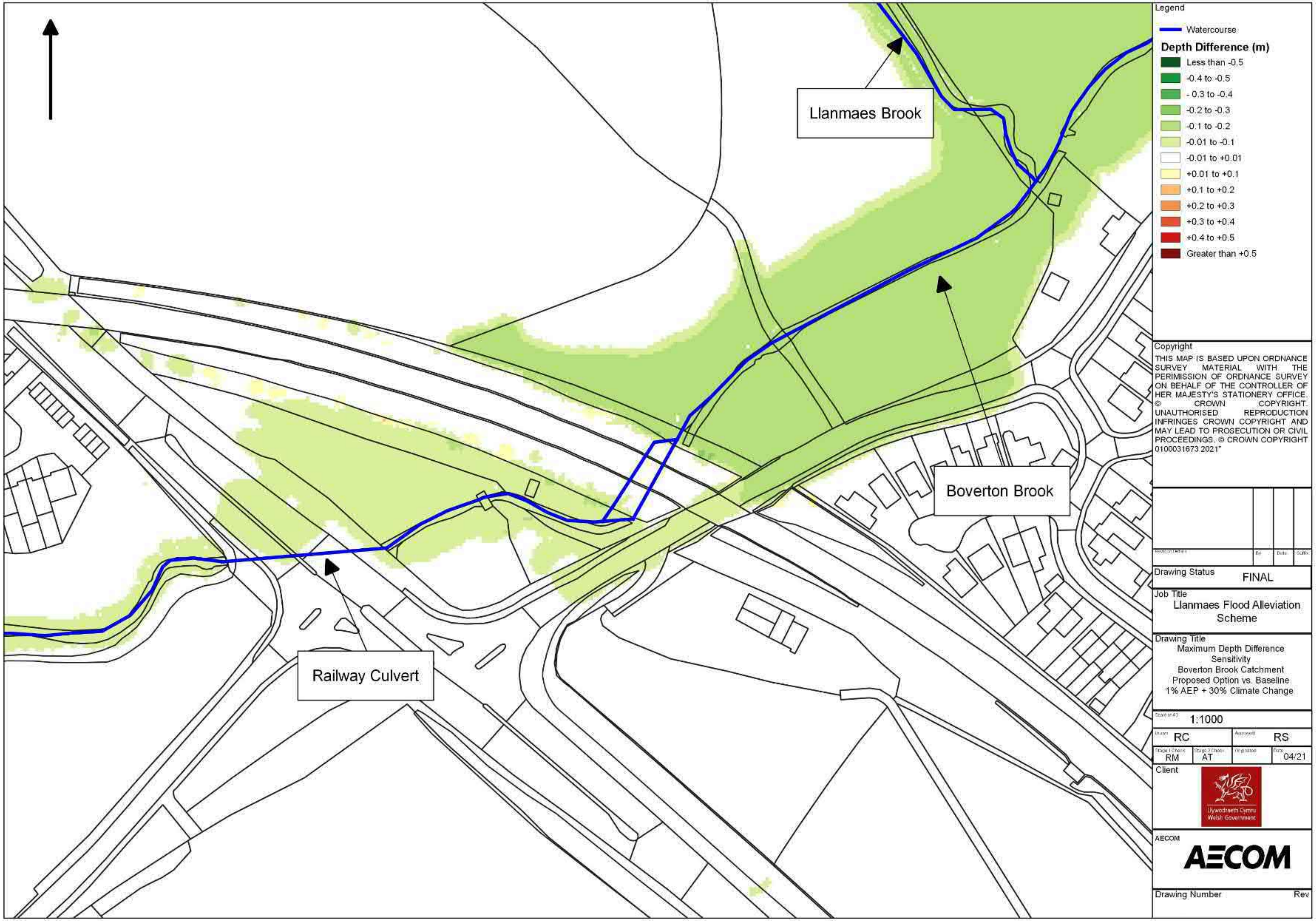


Figure 7-11: Maximum Depth Difference – Boverton Brook Inflow Sensitivity, 1% AEP + 30%CC

7.5 Model Health Indicators

Basic mass balance plots for the Baseline and Proposed Option model simulations were undertaken to assess the overall health of the hydraulic model and are shown for the 0.1% AEP scenario in Figures 7-12 and compared in Table 7-4.

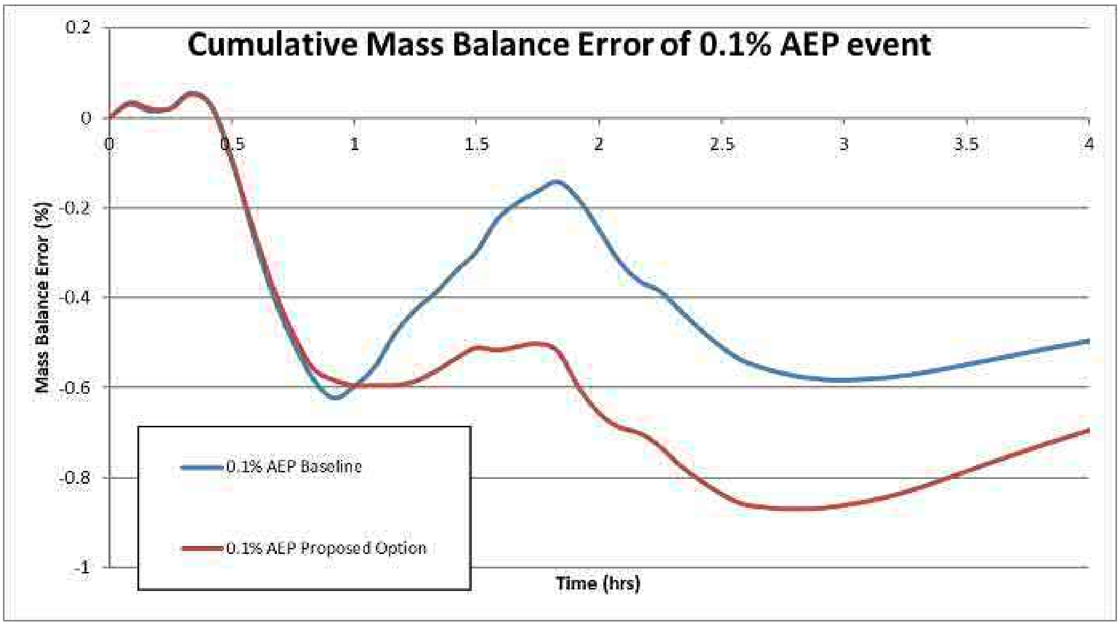


Figure 7-12: Comparison Cumulative Mass Balance Plot (0.1% AEP event)

Table 7-4: Comparison of Baseline and Proposed Option Peak Cumulative Mass Balance Error

Annual Exceedance Probability	Baseline Peak Cumulative Mass Balance Error (%)	Proposed Option Peak Cumulative Mass Balance Error (%)
20% AEP	0.59	0.23
10% AEP	0.31	0.19
5% AEP	0.41	0.41
2% AEP	0.27	0.27
1% AEP + 30%CC	-0.49	-0.46
0.1% AEP	-0.62	-0.87

Figure 7-12 shows that during the 0.1% AEP event, the observed Mass Balance Error for both the Baseline and Proposed Option is within the bounds of the recommended +/- 1% specified within the TUFLOW manual. The peak of the mass balance error is approximately 2.5hrs into the model simulation which, as demonstrated in Figures 6-16 and 6-17, is past the peak of the event on Llanmaes Brook. Table 7-4 demonstrates that for all other AEP's for the Baseline and Proposed Option model the peak cumulative mass balance is within acceptable tolerances.

7.6 Check/Warning Messages

Table 7-5 shows the additional check\warning messages for the 0.1% AEP event for the Proposed Option model. Further details are provided within the supplied Model Log. The checks/warnings which exist are considered minor and unlikely to affect model results and conclusions drawn.

Table 7-5: Check/Warning Messages (Proposed Option Model)

Message Code	Message	Comments/ Likely Impact Upon Results
CHECK 1037	Channel "xx" interpolated from ….	Within the Existing NAR Model and does not impact the results
CHECK 1152	For channel xx, using centre cross-section and ignoring end cross-section(s).	Message occurs at bridge units. All those within Llanmaes study area are suitable and correctly applied
CHECK 1284	Connecting a 1D H boundary to 2D HX link.	Within the Existing NAR Model and does not impact the results
CHECK 2078	End of 3D line is dangling.	Within the Existing NAR Model and does not impact the results
CHECK 2099	Ignored repeat application of boundary to 2D cell.	Occurrences associated with unnamed watercourse through Llanmaes. Reviewed and is correct therefore does not affect the results
CHECK 2118	Lowered SX ZC Zpt by xxm to 1D node bed level.	This is correct for the outfall of the upstream storage areas. Other checks are within the Existing NAR model
CHECK 2231	No ZP points snapped to HX line. HX line not used to modify Zpts.	Within the Existing NAR Model and does not impact the results
CHECK 2370	Ignoring coincident point found in xx layer.	Majority are within the Existing NAR Model and does not impact the results. Reviewed occurrences within Llanmaes and topographic changes have been correctly applied.
WARNING 1100	Structure xx crest/invert (xx) is below bed (xx) of primary downstream channel xx.	Within the Existing NAR Model and does not impact the results
WARNING 1253	Unused 1d_ta line with attributes	Within the Existing NAR Model and does not impact the results
WARNING 1317	WLL does not cross (2 point WLL only) or snap to 1D channel	Within the Existing NAR Model and does not impact the results
WARNING 1991	0:19:05: Negative depth at Node xx.1: y xx Bed = xx dh xx	See Section 7.5.1
WARNING 2073	NONE object ignored. Only Regions, Lines, Polylines & Multiple Polylines used.	Within the Existing NAR Model and does not impact the results
WARNING 2117	Inactive 2D cell made active by 2D SX link.	Within the Existing NAR Model and does not impact the results
WARNING 2118	Lowered SX ZC Zpt by xxmto 1D node bed level.	Mainly within the Existing NAR Model. Single occurrence at Storage Area 3 has been correctly applied
WARNING 2468	Active cell has no active faces	All cells are within the Existing NAR Model on Boverton Brook and do not impact the results. Area becomes active in the sensitivity described in Section 7.4.
WARNING 2991	Negative V depth at xx]. Time = 0:36:36; Depth = xx; 2D Domain = Domain_001	Within the Existing NAR Model and does not impact the results

7.6.1 Negative Depths

During the Baseline and Proposed Option model build 1D negative depths were identified at the upstream extent of the Low Road culvert leading to instabilities highlighted in Section 3.3 and also identified downstream of the B4265 culvert outside of the main study area. Recurring negative depths indicate the model is having difficulty in convergence at that location and may lead to instability and inaccurate results. Table 7-6 shows the total number of negative depths encountered within the model results for the Baseline and Proposed Option scenarios. Further details can be found within the supplied Model Log.

Table 7-6: Number of 1D Negative Depths Warnings Encountered During Model Simulation

		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP+30%CC	0.1% AEP
Baseline	1D Negative Depths Outside of Study Area	28	38	36	32	34	26
	1D Negative Depths In Llanmaes Only	21	13	12	4	11	11
Proposed Option	1D Negative Depths Outside of Study Area	28	38	36	32	34	26
	1D Negative Depths In Llanmaes Only	0	0	11	15	12	10

It can be seen that the majority of the 1D negative depths identified in the model are found outside of the study area and are not considered to impact upon the results presented in this report. The greatest number of 1D negative depth warnings encountered during the Proposed Option scenario within Llanmaes are found during the 2% AEP event where there are 15 occurrences identified around cross section L_FAS_038. A review of the results shows that all the negative depths occur prior to the peak of the event (approximately 0.65hrs) for a period of no longer than 4 seconds. There are no associated spikes or oscillations within the nearby cross sections as a result of the negative depths and therefore given the short period of time that the negative depths occur, the minimal impact on the flow hydrographs in the surrounding cross sections and the timing of the negative depths, it is concluded that they have negligible impact upon the outcome of this report.

8. Conclusions

The existing NAR model has been updated to include the unnamed watercourse through Llanmaes. The updated Baseline model has been created, in agreement with NRW, under the assumption that the NAR has been constructed. A series of flood mitigation measures have been developed within the updated Baseline model to create a Proposed Option for the Llanmaes FAS.

The Baseline model showed that a series of overland flow paths contribute to flooding within Llanmaes where the watercourse and culvert network is not capable of conveying such high flows. Flooding is prevalent around the Village Green and Low Road in all simulated events. This is consistent with recent historical flood event information between 2012 and 2020. The model results also show that flooding of properties at the downstream limits of Llanmaes is exacerbated by the confluence between the unnamed watercourse and Llanmaes Brook.

A series of flood mitigation measures have been tested within the hydraulic model and a site visit was undertaken in November 2017 to undertake a constructability exercise with VoGC. Further site visits have been undertaken by the design team in 2018 and 2019 during the detailed design stage. The Proposed Option is a combination of upstream storage, cut off ditches and highway improvements. The Proposed Option hydraulic model results show that there is a significant decrease in maximum flood depths within Llanmaes across all simulated events. Due to the volume of water entering Llanmaes from many discreet locations, in conjunction with the limited capacity of the existing watercourse, it was not possible to completely eliminate flooding within the village to the design event standard. During the 1% AEP +30% climate change event, the Proposed Option produces a reduction of properties affected by flooding from 61 to 26. Those properties which could not be completely removed from the flood extents have been identified as those which may be managed through the implementation of targeted Property Level Resilience measures.

The Proposed Option has been demonstrated to provide a reduction in the overall flow hydrograph on Llanmaes Brook, downstream of Llanmaes. This allows for the more effective use of the flood storage area at the NAR and also, as a consequence, provides a reduction in flood volumes further downstream in urbanised region of Boverton.

Sensitivity analysis has been undertaken to further explore parameter reliance and uncertainties in the model outputs to ensure that the conclusions drawn from the hydraulic model results are robust. Four sensitivity scenarios have been tested in this study which includes an increase/decrease in Manning’s Roughness Coefficients, structural blockage of attenuation storage areas, catchment surface percentage runoff and adjustments to flows on Boverton Brook. The results show that the efficiency of the Proposed Option is reduced when catchment runoff is increased however for all sensitivity simulations the Proposed Option still provides an overall benefit to Llanmaes and Boverton.

A key risk to the successful implementation of the Llanmaes FAS is in acquiring land permission to create the upstream storage locations and formalise the outfalls of the two proposed ditches. Without introduction of upstream storage measures, the scheme will not be nearly as effective. It is recommended that discussions are undertaken between VoGC and the land owners at the earliest opportunity to discuss the potential for land permission.

Appendix A – Llanmaes Flooding Events

Legend

Watercourse

Flood Depth (m)

- 0.00 - 0.05
- 0.05 - 0.10
- 0.10 - 0.2
- 0.20 - 0.30
- 0.30 - 0.40
- 0.40 - 0.50
- 0.50 - 1.00
- > 1.00

Revision Details	By	Date	Suffix

Drawing Status

Job Title

Llanmaes Flood Alleviation Scheme

Drawing Title

Flooding Photos and Location with Maximum Flood Depths Baseline 20% AEP

Scale at A3	1:200		
Drawn	RC	Approved	MD
Stage 1 Check	Stage 2 Check	Originated	Date 10/19

Client

Llywodraeth Cymru Welsh Government

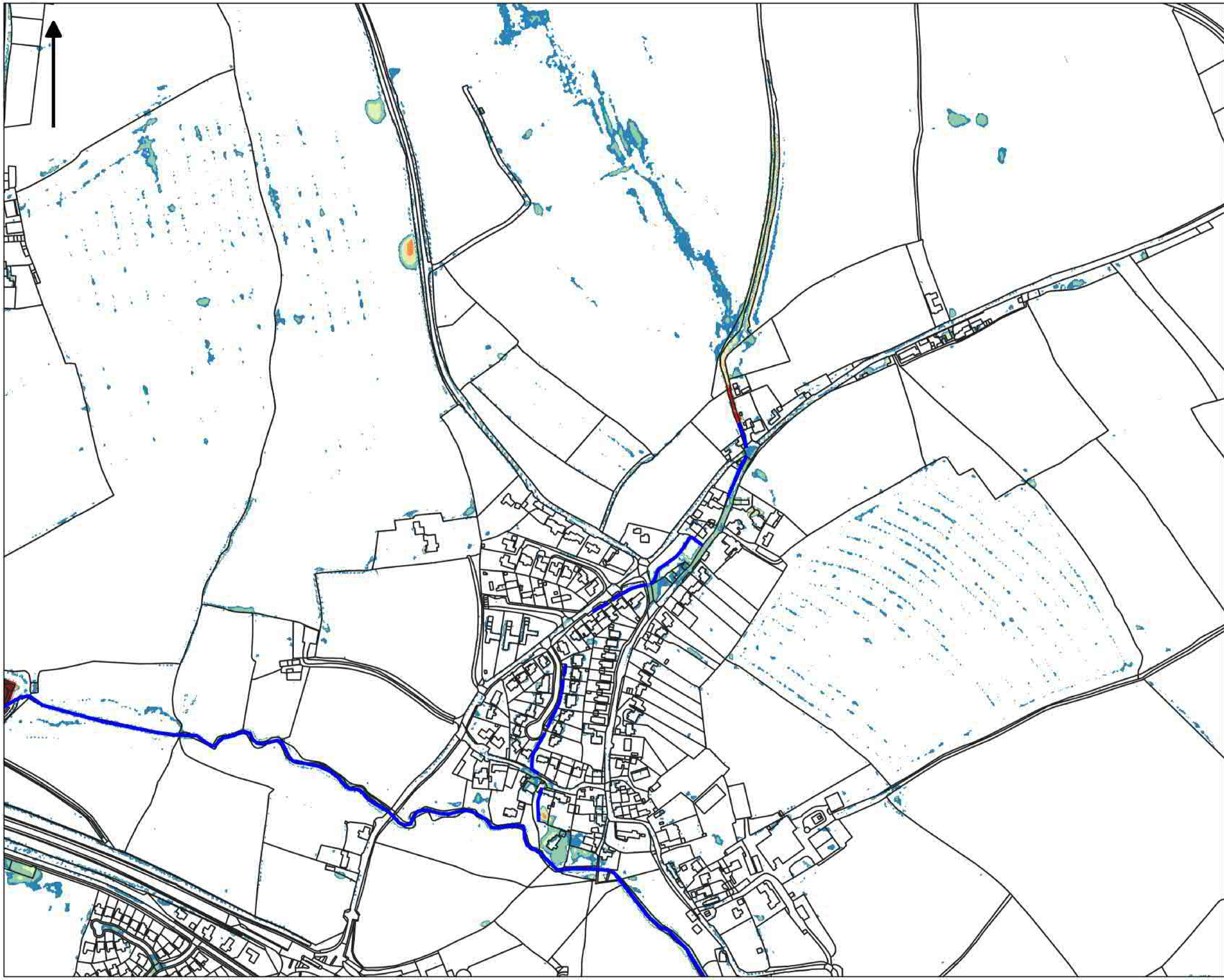
AECOM

AECOM

Drawing Number: A1

Rev

Appendix B – Baseline Modelling Results



Legend

Watercourse

Maximum Flood Depths (m)

- 0 - 0.05
- 0.02 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 1.0
- > 1.0

Revision Details	By	Date	Suffix

Drawing Status: FINAL

Job Title: Llanmaes Flood Alleviation Scheme

Drawing Title: Maximum Flood Depth Baseline 20% AEP

Scale at A3: 1:4000

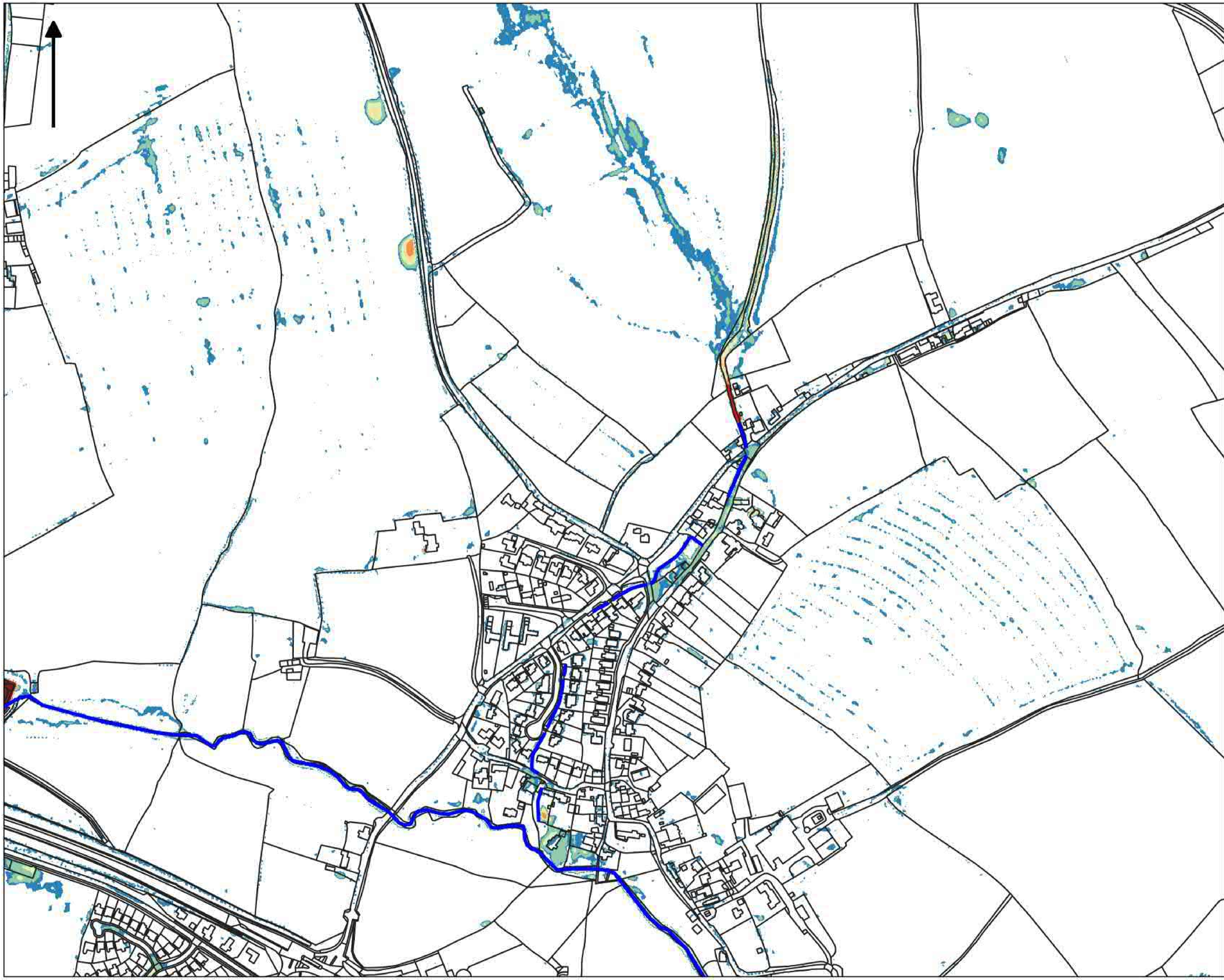
Drawn	RC	Approved	RS
Stage 1 Check: RM	Stage 2 Check: AT	Originated	Date: 04/21

Client: Llywodraeth Cymru Welsh Government

AECOM

Drawing Number: B1

Rev



Legend

Watercourse

Maximum Flood Depths (m)

- 0 - 0.05
- 0.02 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 1.0
- > 1.0

Revision Details	By	Date	Suffix

Drawing Status: FINAL

Job Title: Llanmaes Flood Alleviation Scheme

Drawing Title: Maximum Flood Depth Baseline 10% AEP

Scale at A3: 1:4000

Drawn	Approved
RC	RS

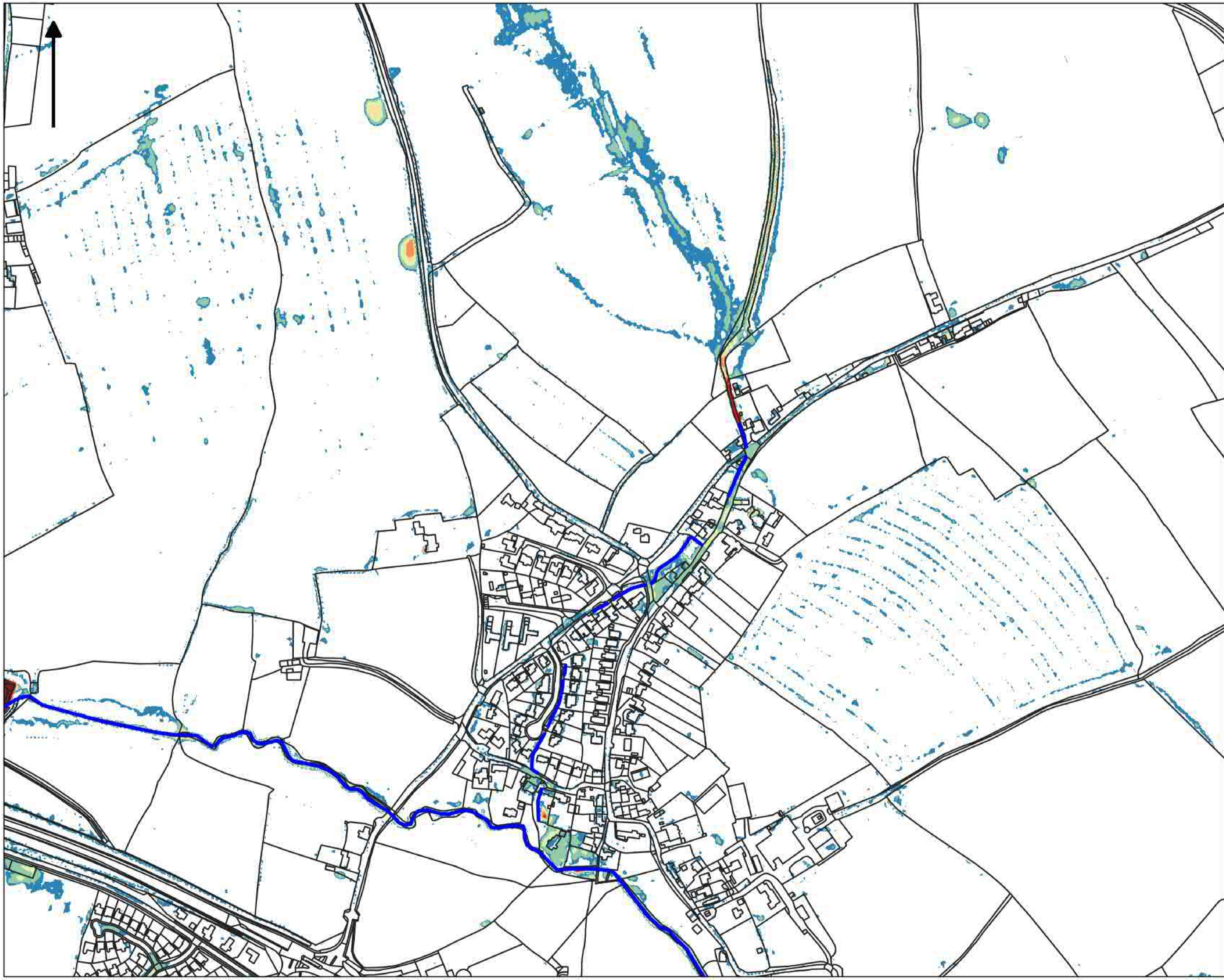
Stage 1 Check	Stage 2 Check	Originated	Date
RM	AT		04/21

Client: Llywodraeth Cymru Welsh Government

AECOM

Drawing Number: B2

Rev



Legend

Watercourse

Maximum Flood Depths (m)

- 0 - 0.05
- 0.02 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 1.0
- > 1.0

Revision Details	By	Date	Suffix

Drawing Status: FINAL

Job Title: Llanmaes Flood Alleviation Scheme

Drawing Title: Maximum Flood Depth Baseline 5% AEP

Scale at A3: 1:4000

Drawn	Approved
RC	RS

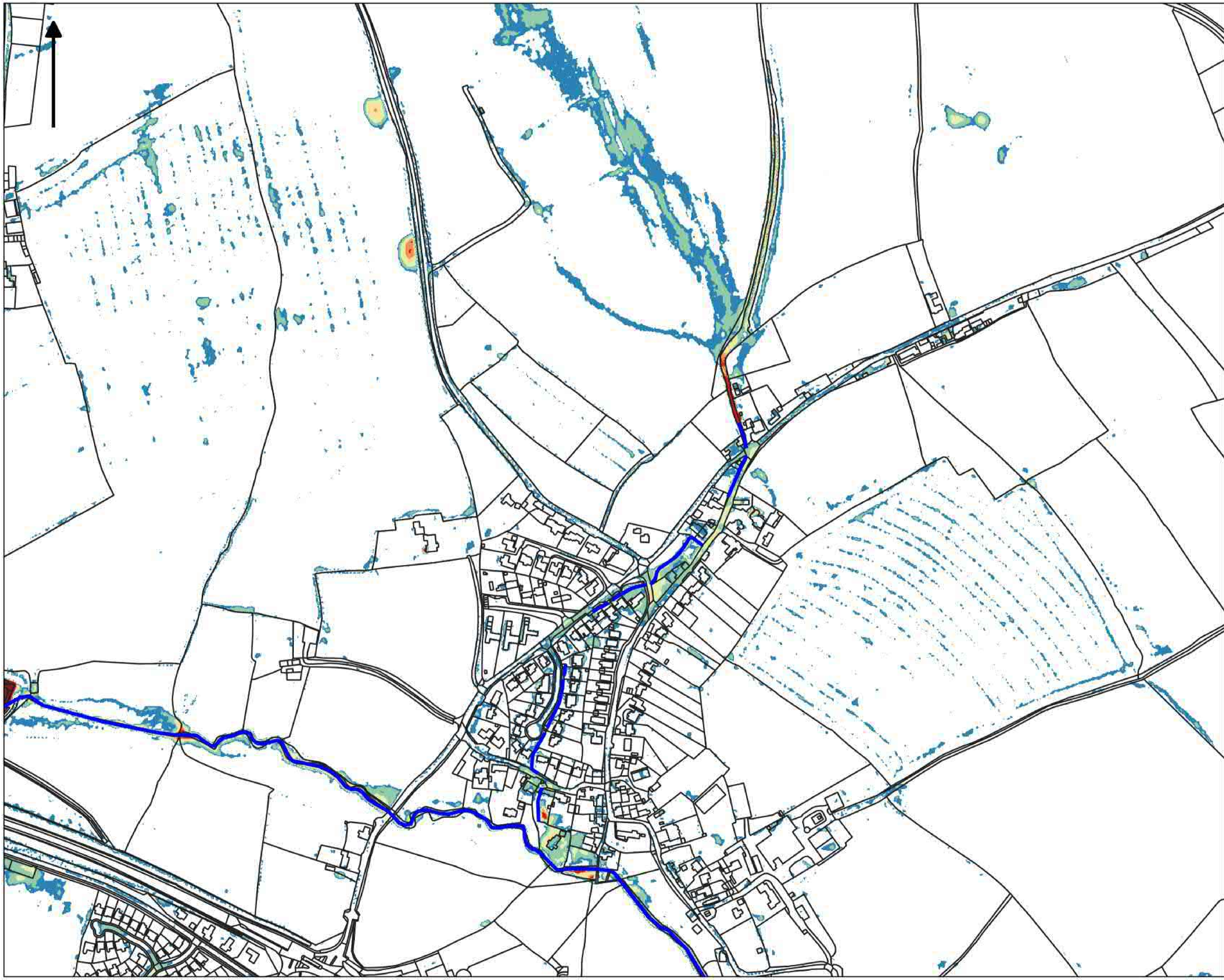
Stage 1 Check	Stage 2 Check	Originated	Date
RM	AT		04/21

Client: Llywodraeth Cymru Welsh Government

AECOM

Drawing Number: B3

Rev



Legend

Watercourse

Maximum Flood Depths (m)

- 0 - 0.05
- 0.02 - 0.1
- 0.1 - 0.2
- 0.2 - 0.3
- 0.3 - 0.4
- 0.4 - 0.5
- 0.5 - 1.0
- > 1.0

Revision Details	By	Date	Suffix

Drawing Status: FINAL

Job Title: Llanmaes Flood Alleviation Scheme

Drawing Title: Maximum Flood Depth Baseline 2% AEP

Scale at A3: 1:4000

Drawn	Approved
RC	RS

Stage 1 Check	Stage 2 Check	Originated	Date
RM	AT		04/21

Client

Llywodraeth Cymru Welsh Government

AECOM

AECOM

Drawing Number: B4

Rev