5. Proposed Option Development

5.1 Flood Mitigation Options Development

Following the creation of the updated Baseline model (Section 4), a series of flood mitigation options were tested in the hydraulic model to identify a suitable flood alleviation scheme. A number of options had been previously explored within the PAR (2009) and OAR (2014) studies, however little hydraulic modelling evidence had been presented to demonstrate the effectiveness of the schemes proposed – this also includes whether the schemes would result in an increase in flood risk.

5.1.1 2014 OAR Preferred Solution

AECOM incorporated the Preferred Solution specified in the OAR (Option 11a) within the updated Baseline model. The flood mitigation measures to be tested were first confirmed with VoGC prior to the model build and included:

1. $1m^2$ metre flood relief box culvert along West Road, from the Pump area to Llanmaes Brook (with a non-restricted discharge);

2. Improved drainage connections to flood relief box culvert;

3. Improved drainage around the Old Post Office area;

4. Online storage downstream of Llanmaes village on Llanmaes Brook (estimated previously as holding $6500m^3$ during a design event);

5. Re-profiling of Llanmaes Brook from culvert outfall to include removal of restriction downstream of Tara House; and,

6. Bunds to the rear of properties at the South East corner of the village behind Llanmaes House.

The OAR scheme is a hard engineered option designed to pass flow from the north end of Llanmaes through a flood relief box culvert, outfalling to Llanmaes Brook through a new outlet structure. Flood storage downstream of the confluence of the unnamed watercourse and Llanmaes Brook was proposed to mitigate any increase in flows as a result of the new culvert arrangement. Highways drainage improvements feed into the flood relief culvert and improved conveyance on Llanmaes Brook is designed to reduce water levels around Tara House.

The 1% AEP + 30% climate change OAR Preferred Solution results show that there is a general reduction in flooding within Llanmaes of approximately up to 0.1m. There is an associated increase in flood depths at the flood storage area to the south east of Llanmaes and within the field to the east of the village. Flooding still occurs to properties and highways within Llanmaes along Gadlys Lane, West Road, Tyle House Close, Low Road and Tara House (Figure 5-1). This is primarily due to the volume of water entering the north of the Llanmaes through multiple flow paths highlighted in Figure 4-1. This water cannot be conveyed fast enough into the flood relief culvert and the system becomes overwhelmed.

The effectiveness of the OAR scheme is heavily reliant on the provision of downstream storage to control the pass on flow from the north of Llanmaes. Through discussion with VoGC, it is understood that this downstream storage has now been superseded by the NAR scheme and is no longer an option. Due to the limited flood risk benefits, overall potential high cost of the OAR scheme, anticipated disruption caused to local residents during construction and untenable storage area, it was agreed with VoGC to investigate other options for the Llanmaes FAS. Given the appraisal of solutions to date, the remainder of this report discusses in detail, the process of determining an appropriate solution for the Llanmaes FAS.

5.1.2 Proposed Option Development

A series of flood mitigation options were tested in an attempt to realise the flood risk benefits available to Llanmaes. Table 5-1 describes the development of the AECOM Proposed Option for the Llanmaes FAS. The model log supplied with the hydraulic model also documents the key iterations per evolution of the model tests.

Following the completion of Stage 5 of the model development, the hydraulic model and modelling report (Revision 4) were submitted to NRW for review and comment (Dec 2018). AECOM worked with NRW to ensure that the hydraulic model provides a robust representation of flood risk to the Boverton Brook catchment.

NRW concluded that the presented Proposed Option does not increase flood risk to Boverton as a result of the Llanmaes proposals[13]. Following NRW's comments AECOM have since developed the scheme to detailed design (Stage 6) for planning through consultation with VoGC. Section 5.3 outlines the detailed design option for planning and Section 6 provides an assessment of the hydraulic model results.

[13] Email 08/01/2019 – RE: Llanmaes FAS - Model Review Response NRW to Ralph Collard

L

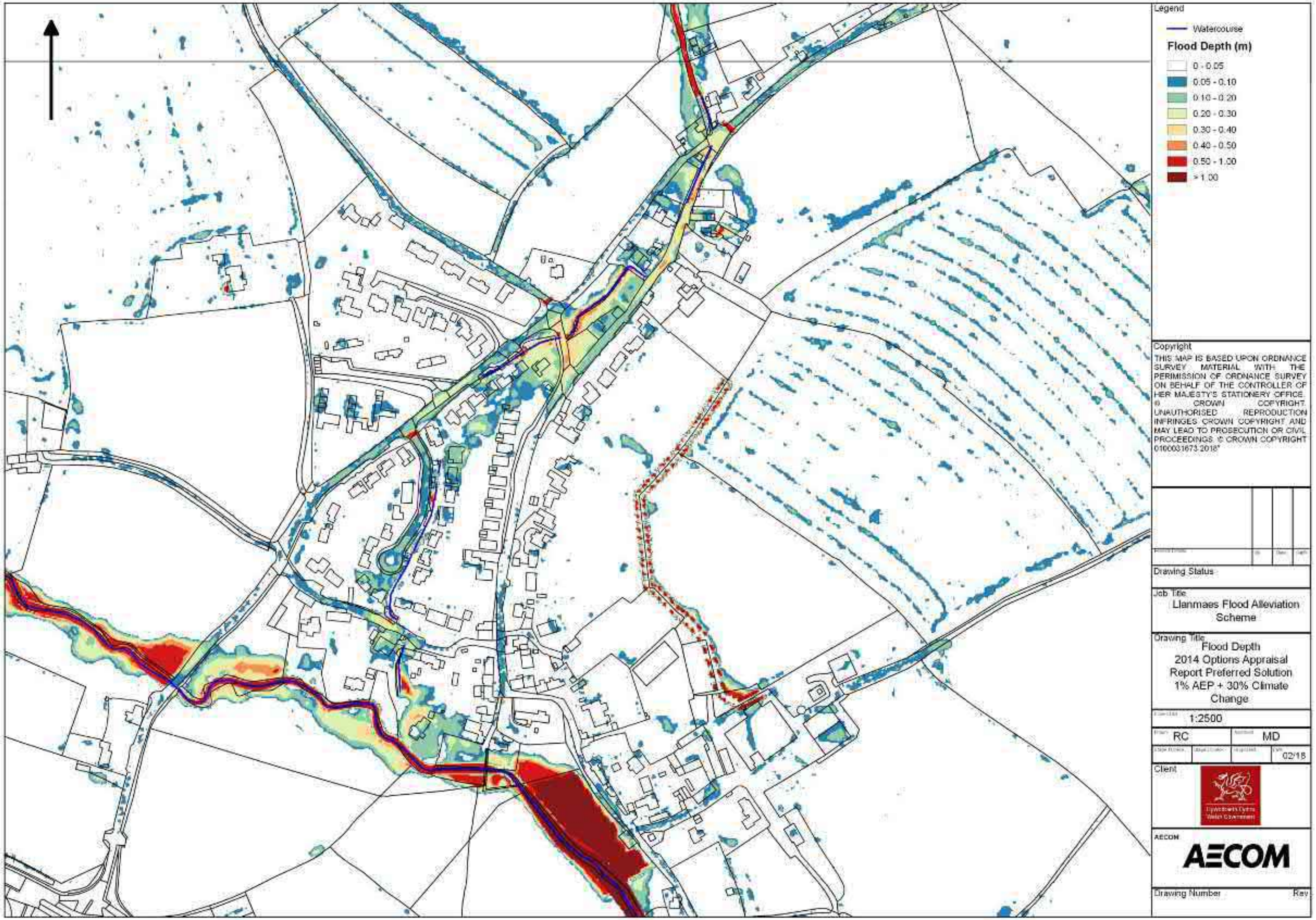

Figure 5-1: Maximum Flood Depths 2014 OAR Preferred Solution 1% AEP + 30%CC event

Table 5-1: AECOM Llanmaes FAS Proposed Option Model Development

Option #	Mitigation Option	Description	Comment
1.	OAR (2014) Solution.	Large 900mm diameter flood relief culvert beneath and along West Road from The Pump to Llanmaes Brook, downstream attenuation storage, improved highways drainage and flood bund in field to the east of Llanmaes.	Does not provide satisfactory flood risk reduction within Llanmaes, exceptionally high construction cost, large degree of disruption to community of Llanmaes and has unviable downstream storage area.
2.	Upstream Storage (interception).	Flood storage intercepting primary overland flow paths upstream of Llanmaes. It was determined that only storage areas which collected greater than 1000m^3 would be taken forward for consideration. The total number of storage areas to be taken forward is 4.	Provides a significant reduction in flood risk to Llanmaes. However, this would not solve flooding in isolation but would prove to be effective as part of a combination with other mitigation measures.
3.	Refinement of Option #2 and Highway Reprofiling.	Option #2 in conjunction with reprofiling of West Road, making more effective use of existing conveyance routes through the village.	Further reduces flood risk throughout Llanmaes. Increased residual risk recorded at properties at Low Road and Tara House, which need to be protected against.
4.	Combination of Option 3 and flood walls at Low Road and Tara House.	As per Option #3 with the inclusion of 0.7m and 1.6m flood walls on Low Road and Llanmaes Brook near Tara House respectively.	Provides significant reduction in flood risk throughout Llanmaes with no residual impact of flooding compared to the baseline design event. Not all properties could be mitigated against for the design event.
5.	Refinement of flood walls, attenuation storage areas (Option #4), and road profiling.	Utilises flood storage areas within agricultural fields to the north and up-catchment of Llanmaes in conjunction with a series of minimally disruptive highways improvements within the village and additional conveyance measures on Llanmaes Brook.	Provides significant reduction in flood risk throughout Llanmaes with no residual impact of flooding compared to the baseline design event. Hydraulic model reviewed by NRW (08/01/19).
6.	Refinement of attenuation storage areas (Option #5), refinement of West Road re-profiling, addition of interception ditches north of Llanmaes, Village Green swale improvements and removal of flood walls.	Similar to Option #5 with the inclusion of an interception ditch and storage to the north of the Village. Improved conveyance into Village Green from the surrounding roads, ditch outfall into Llanmaes Brook from West Road.	Provides significant reduction in flood risk throughout Llanmaes with no residual impact of flooding compared to the baseline design event. Submitted to VoGC for detailed design review December 2019.

5.2 Model Verification Site Visit November 2017

AECOM and VoGC carried out a site visit in November 2017, prior to Stage 6 (Table 5-1), to ground truth the proposed flood mitigation measures and the hydraulic modelling results. It was found that the construction of flood walls on Low Road and along the left bank of Llanmaes Brook, improving the conveyance of the outfall culvert and building a new culvert from the north of Pond Villa to Llanmaes Brook would not be possible due to major disruption to private land owners and potentially high construction costs. The hydraulic model was refined to produce the Proposed Option described in Stage 5 (Table 5-1).

Further site visits have been carried out in 2019, 2020 and 2021 by the design team to determine the constructability of the Proposed Option presented in this report and help make further suitable refinements to the hydraulic model. The Proposed Option is described in Section 5.3.

5.3 AECOM Proposed Option

The AECOM Proposed Option identifies four key areas in Llanmaes where flood mitigation measures are recommended. Through the modelling process it became apparent that the most effective way to reduce flooding within Llanmaes was to intercept overland flow as close to the source as possible, upstream of the village, rather than trying to control it once it has entered the village where there is little space to introduce effective measures. For this reason, the Proposed Option utilises flood storage areas within agricultural fields to the north and up-catchment of Llanmaes in conjunction with a series of minimally disruptive highways improvements within the village and additional conveyance measures to the north of Llanmaes. Figure 5-2 shows the location of the proposed flood mitigation measures, a description of the key element of the scheme are summarised in Table 5-2 and fully outlined within Appendix C:

Table 5-2: Description of Proposed Option

Area (Ref: Figure 5-2)	Flood Mitigation Measures	Reason
1	Four upstream flood storage areas with 300mm outlet pipes. The specification of outlet design can be found in the supporting planning application. Bund 1 outfalls into Ditch 2 cut off ditch. Each FSA has a 300mm flood relief pipe 1.3m above the primary outlet invert in case of blockage.	Reduce overall volume of water reaching Llanmaes during a flood event
2	(A) Road re-profiling along West Road to the Village Green (B) Associated low level kerb raising along southern roadside on West Road (C) Road re-profiling/road hump across Gadlys Lane and West Road junction (D) Re-profiling of the Village Green and re-profiling of Gadlys Lane, north of The Croft. Two swales connecting West Road and Gadlys Lane to the Village Green watercourse.	(A, B & C) Maintain overland flow from Gadlys Lane and any out of bank flow within West Road (D) Improve capacity of the channel at the Village Green and direct any overland flow from Gadlys Lane and West Road towards the unnamed tributary
3	(A) Road re-profiling along West Road from Tyle House Close to Franklin Court (B) Associated low level kerb raising and footway re-profiling along southern roadside on West Road (C) Road re-profiling/road hump at the entrance to Tyle House Close (D) Road re-profiling/road hump at Franklin Court road junction.	(A and B) Maintain overland flow within West Road and conveyed to Llanmaes Brook to the south west (C) Restrict overland flow passing down through Tyle House Close (D) Restrict overland flow passing from West Road into Low Road
4	(A) Cut off ditch along field boundary from Bund 1 outfall to Llanmaes Brook including check dams for storage. Maintains a series of agricultural crossings for access to fields (B) Low level bunding along southern edge of Ditch 1 and Ditch 2 (C) Ditch 3 taking highway drainage to the north of West Road and outfalling into Llanmaes Brook (D) Filter drain collects water from Sigingstone Lane and diverts into Ditch 1	(A) Reduce volume of water entering Llanmaes onto West Road (B) Prevent out of bank flow from cut-off ditch passing to the south (C) Ensure the FAS scheme outfalls into the fields to the north of West Road (D) Reduce the volume of water entering Llanmaes from Sigingstone Lane. It is noted that this is simplified within the hydraulic model (Appendix C)

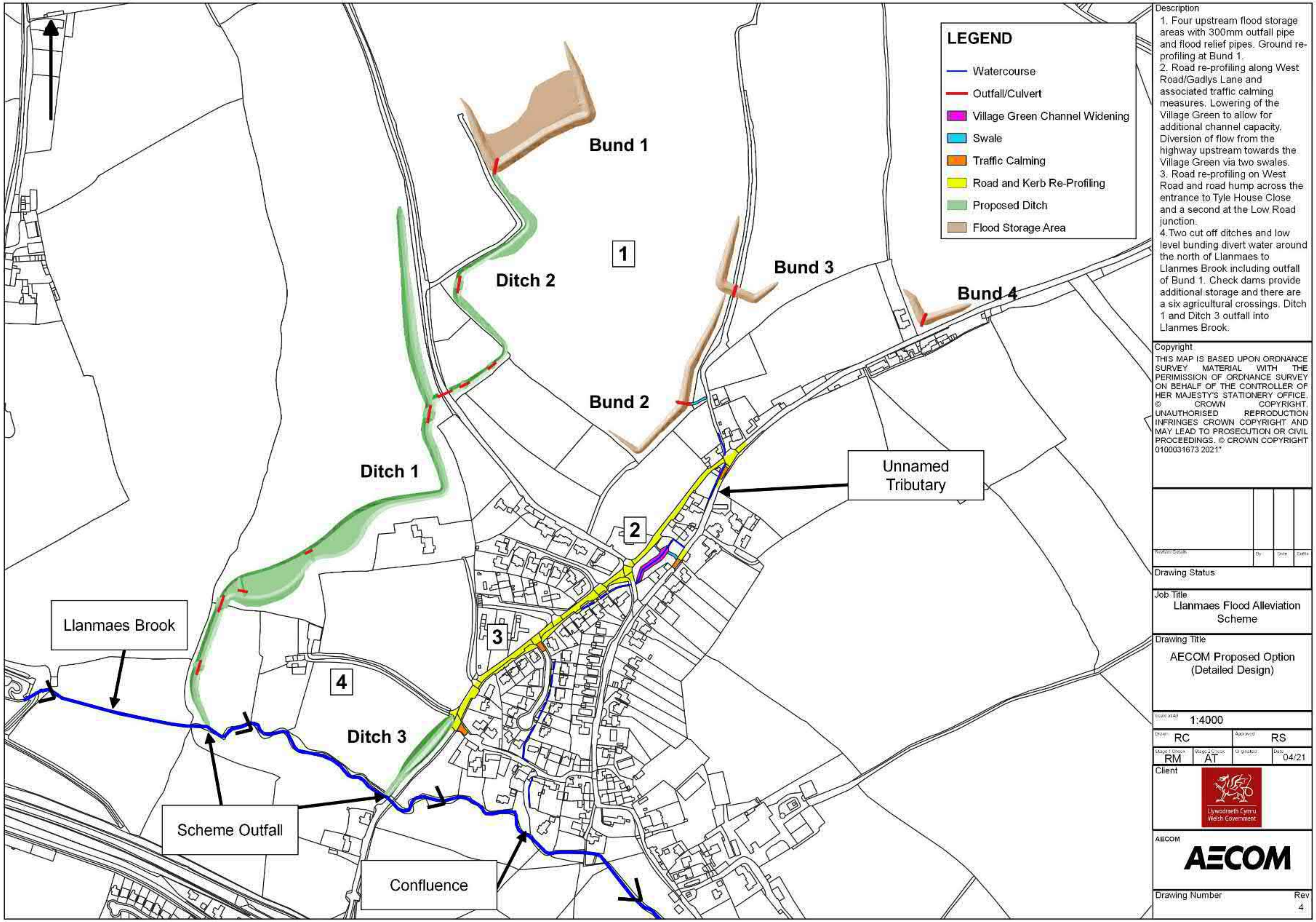

Figure 5-2: Proposed Option Layout

6. Proposed Option Results

Once the flood mitigation measures specified in Section 5.3 were included within the hydraulic model, the Proposed Option was simulated using the 60 minute storm duration for the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP + 30% climate change and 0.1% AEP events. The full suite of Proposed Option modelling results can be found in Appendix D.

6.1 Flood Depths

6.1.1 Proposed Option vs. Baseline Flood Depths

To understand the flood risk benefits, inclusive of any detrimental impact, caused by the construction of the Proposed Option, the modelled flood depths results have been compared with the Baseline model results. Figures 6-1 and 6-2 demonstrate the depth difference plots between the Proposed Option and the Baseline model for the 20% AEP and 1% AEP + 30% climate change respectively.

For the 20% AEP event the model results show there is a general reduction in the flood depths throughout Llanmaes of up to 0.1m (Figure 6-1). The largest benefit is located in the vicinity of Tara House where there is a reduction in flood depths of between 0.2-0.3m. It can be seen that there is an associated increase in flood depths at the upstream storage areas, Village Green, cut off ditches and West Road where ground profiles have been lowered and an increase in flood depth is intended. All increases in flood depths in these areas are expected based on the design within the highway re-profiling areas, cut off ditches and designated overland flow storage areas.

During the 1% AEP + 30% climate change scenario, the flood depths are reduced along the main overland flow route through Llanmaes by approximately 0.1-0.2m (Figure 6-2). The largest benefits can be seen around Tyle House Close, Low Road and Tara House where flood depths are reduced by approximately 0.2-0.3m. This demonstrates that through reducing the volume of water reaching Llanmaes, using upstream storage and cut off ditches, there is a significant benefit available to the village during flood events.

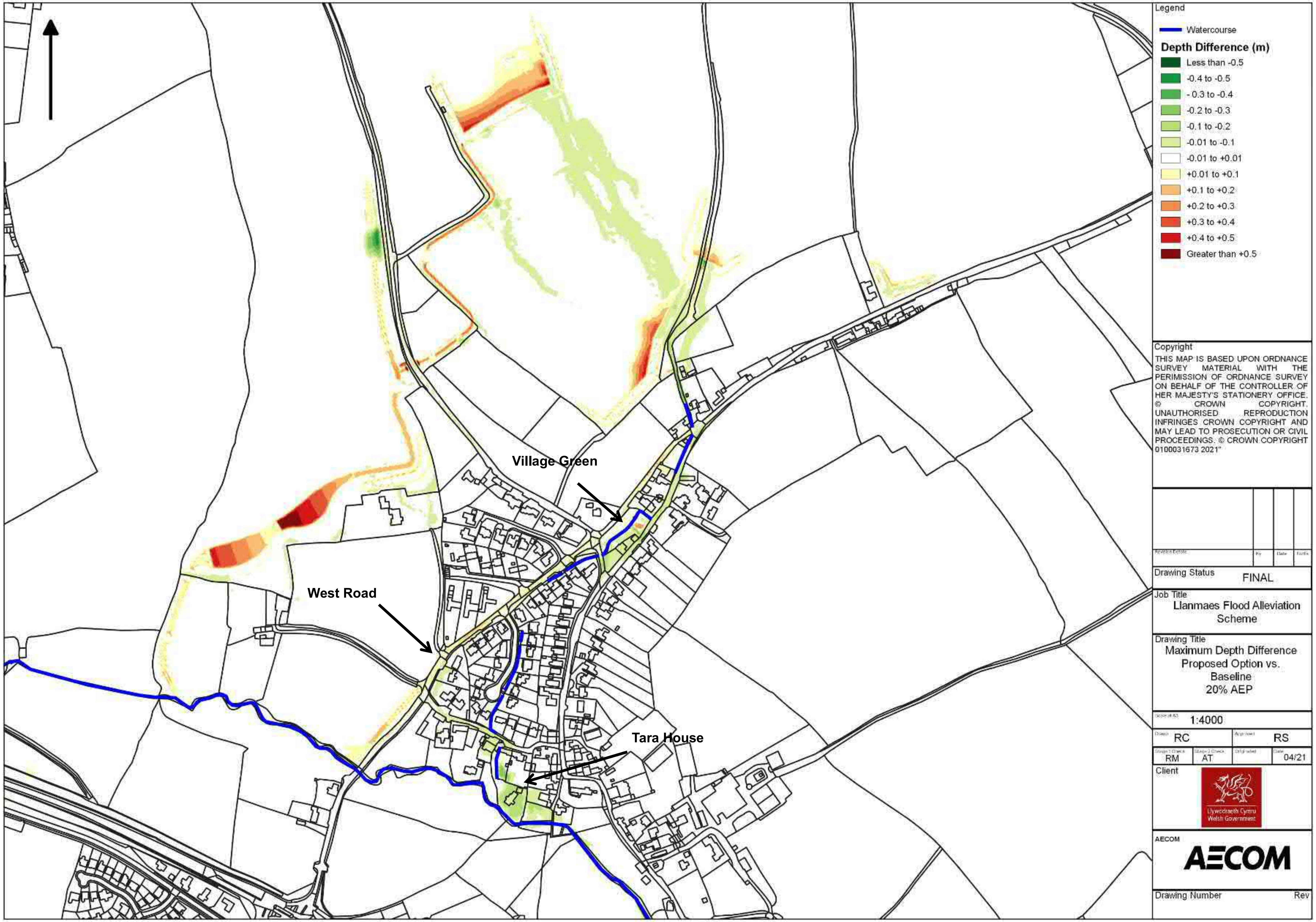

Figure 6-1: Maximum Depth Difference Map - Proposed Option vs. Baseline 20% AEP event

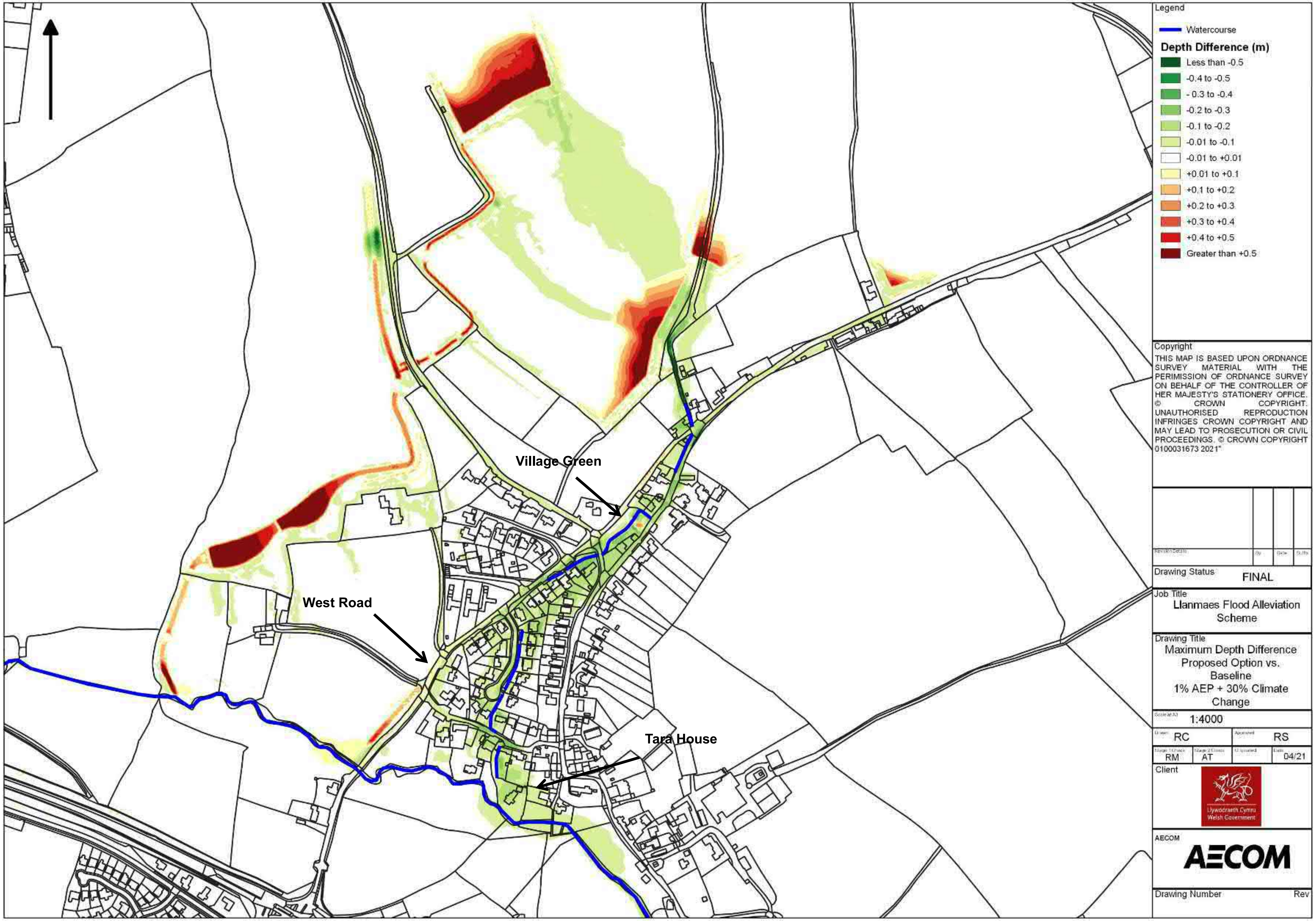

Figure 6-2: Maximum Depth Difference Map Proposed Option vs. Baseline 1% AEP + 30%CC event

The model results show an overall reduction in flood depths throughout Llanmaes. However, it can be seen from Figure 6-1 and Figure 6-2 that during the 20% AEP and 1% AEP + 30% climate change events there are three areas where there are increased flood depths outside of the intended flood mitigation measures.

The first area is within the Llanmaes Brook channel and Llanmaes Brook floodplain from the Ditch 1 outfall through to Tara House where there is a general increase in maximum flood depths of +0.01m to +0.03m. Model results indicate that this increase occurs predominately at the upstream face of West Road Bridge for all events larger than the 20% AEP and is observed at the Ditch 1 outfall for events larger than 5% AEP. All increases in flood depths are confined to the Llanmaes Brook channel or agricultural fields upstream of Tara House and there is no increase in the overall flood extent as these areas already flood within the Baseline scenario. This is demonstrated in Figure 6-3 and Table 6-1 which shows the extraction location of maximum flood depths compared to the Baseline scenario. Figure 6-3 also shows the 0.1% AEP flood extent with a maximum flood depth greater than 0.05m alongside the depth difference plot of the Proposed Option compared to the Baseline scenario demonstrating all detrimental effects are within the floodplain. Table 6-1 shows that for all flood events, the magnitude of increase is small compared to the existing baseline conditions along the Llanmaes Brook floodplain (Locations 1 to 4). It is recognised that all areas of increased flood depths are on private land and therefore we recommend that VoGC should consult with the landowners to ensure that this is acceptable.

The second and third areas are within the garden of two private properties on West Road shown in Figure 6-3 as Location 6 and Location 7. At both locations model results shown in Table 6-1 indicate there is an increase in the maximum flood depths of +0.02m in areas that already display inundation of over 0.02m during events up to the 2% AEP event.

At Location 6 the natural fall of the ground is from the property, at approximately 52.80m AOD, towards West Road where elevations drop to approximately 52.70m AOD. In the Proposed Option this flow path is impeded because the design kerbs and pavement have been included within the model and leads to the observed increase in flood depths across all design events. A low level wall located at the front of the property, which has not been modelled due to the limitations stated in Section 3.10, would act as a similar impediment to this small flow. Therefore it is concluded that the observed increase at Location 7 is not a true reflection of the proposed scheme design rather a limitation of the hydraulic modelling. The scheme design should ensure that any existing flow paths from front gardens to West Road are maintained or alternative drainage provided.

At Location 5 model results show the increase in maximum flood depths when compared to the Baseline scenario to occur for all events below the 1% AEP event. This is due to an increase in volume of an overland flow path from West Road towards Gadlys Lane. However, it is noted that at this location low level walls may impact overland flow routes and maintain water within West Road. There is uncertainty in the quality of these walls and it was highlighted in Section 3.10 that no walls have been modelled unless designated as flood walls.

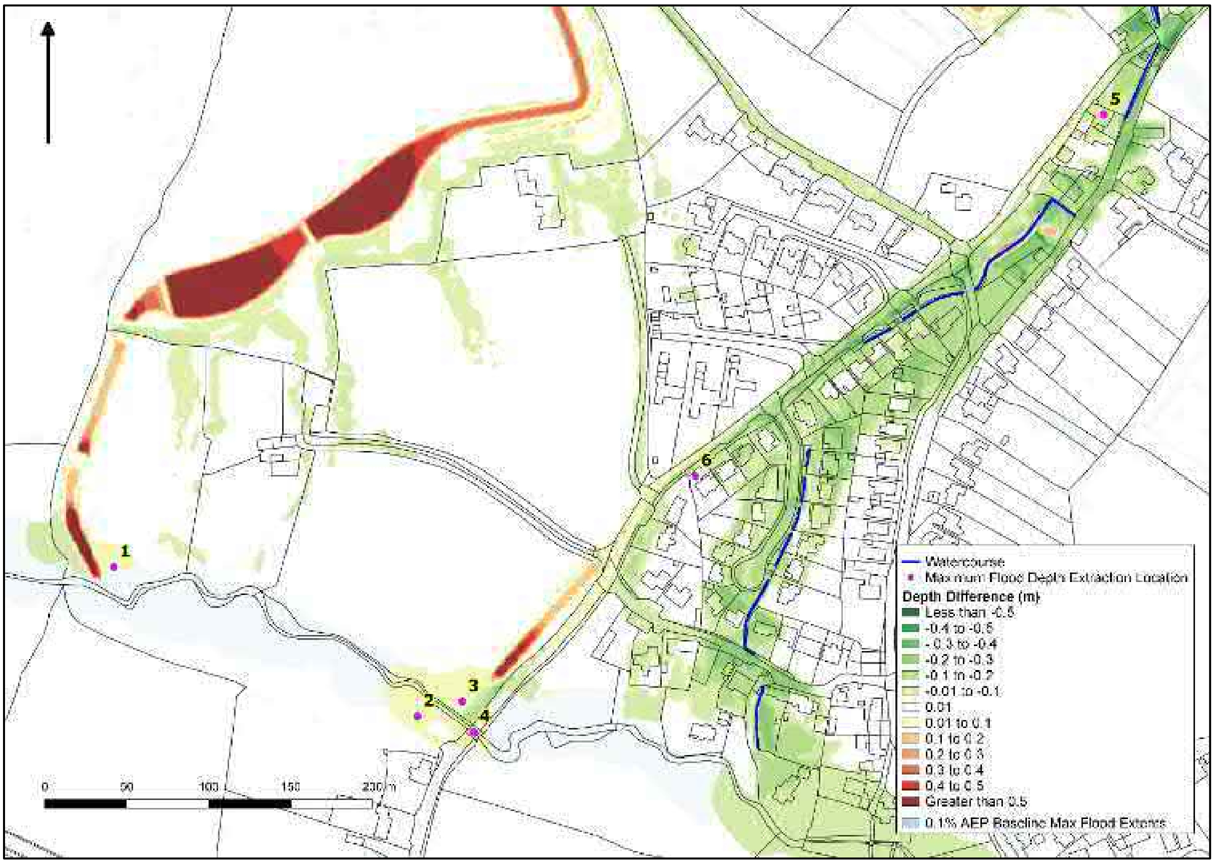

Figure 6-3: Location of Detriment on Llanmaes Brook Compared to Baseline Scenario (0.1% AEP-) With Location of Maximum Flood Depth Extraction Points

Table 6-1: Maximum Flood Depth Comparison Proposed Option vs Baseline

	Flood Data Extraction Point					
Scenario	1	2	3	4	5	6
20% AEP Baseline	0.01	0.01	0.00	0.02	0.02	0.02
20% AEP Detailed Design	0.01	0.01	0.02	0.02	0.05	0.04
Depth Difference	0.00	0.00	+0.02	0.00	+0.03	+0.02
1%+30%CC AEP Baseline	0.10	0.22	0.63	0.10	0.11	0.11
1%+30%CC Detailed Design	0.11	0.25	0.65	0.11	0.08	0.13
Depth Difference	+0.02	+0.02	+0.03	+0.02	-0.03	+0.02
0.1% AEP Baseline	0.25	0.39	0.78	0.23	0.17	0.15
0.1% AEP Detailed Design	0.26	0.41	0.80	0.25	0.09	0.15
Depth Difference	+0.01	+0.02	+0.02	+0.02	-0.08	0.00

In summary, the depth difference plots between the Proposed Option and Baseline demonstrate that the scheme has the potential to increase the resilience of flooding afforded to Llanmaes across all AEP's (Appendix D1-D8). There are areas of increased flood risk within agricultural fields within the functioning Llanmaes Brook floodplain during events greater than 20% AEP. Whilst this increase is not desirable, all increases occur in locations that currently become inundated and that there are no significant flood risk receptors at increased flood risk. Within Llanmaes there are two locations where there is an increase of +0.02m to +0.03m within front gardens of properties. It is likely that the increases are impacted by limitations of the modelling outlined in Section 3.10 due to not representing low level walls. At Location 6 further sensitivity has been undertaken to assess the impact of including low level walls in the hydraulic model and is described in Section 7.

6.1.2 Proposed Option vs Baseline Flow Paths

To understand the magnitude of the main overland flow paths throughout Llanmaes, a number of 2d_PO (Plot Output) data abstraction areas were included within the hydraulic model at key locations. Figure 6-4 shows the four locations within Llanmaes where the modelled flows were abstracted for every timestep of the model simulation. Figures 6-5 to Figure 6-8, show a comparison of overland flow between the Baseline and Proposed Option at a location upstream of Llanmaes (Location A), Tyle House Close (Location B), West Road (Location C) and West Road at Llanmaes Brook (Location D) respectively for the 1% AEP + 30% climate change event.

Results have shown that there is a significant reduction in flow volumes whereby the peak flow is significantly reduced from 4.6m^3/s to 0.6m^3/s at the north end of the village (Figure 6-5, Location A). Through reducing large volumes of water entering the village during the design event, this has the potential to result in a notable impact on the reduction of flooding within Llanmaes.

Through reducing the volumes of water entering Llanmaes and maintaining flow within West Road, model results indicate that there is a large reduction in the magnitude of the primary flow path down Tyle House Close (Location B) seen in the Baseline (Figure 4-1). Figure 6-6 shows that there is an estimated reduction in peak flow from 2.3m^3/s to 0.1m^3/s on Tyle House Close which markedly provides benefit along one of the primary overland flow paths through the village.

On West Road, downhill of Tyle House Close (Location C) the flows are reduced by approximately half in the Proposed Option scenario from 0.26m^3/s to 0.10m^3/s with the peak arriving faster than in the Baseline scenario (Figure 6-7). This demonstrates that the scheme is effective at both reducing the volume of water entering Llanmaes and routing overland flow through Llanmaes towards Llanmaes Brook along the designated highway.

Downhill of the Low Road junction (Location D), at the West Road ditch, there is an overall increase in the peak flow of the hydrograph from 0.15m^3/s in the Baseline to 0.53m^3/s in the Proposed Option scenario (Figure 6-8). This demonstrates that the road re-profiling is effective at maintaining surface water in the highway as intended and diverting flow away from flood risk receptors on Low Road. Whilst there is an increase in the size of the flow hydrograph at Location D the overall reduction in volume of water passing through Llanmaes (Figure 6-5) means that there is a reduction in the volume of water downstream of the scheme (Section 6.4).

Through the optioneering process, careful consideration has been given to the formalisation of the overland flow route on West Road in order to reduce the residual flood risk associated with the scheme. A combination of maintaining the fall of the highway away from properties where required and targeted kerbing to ensure water does not flow towards properties means that West Road effectively convey water through the village. Residual risk posed by maintaining flow within the highway is discussed in Section 6.2.

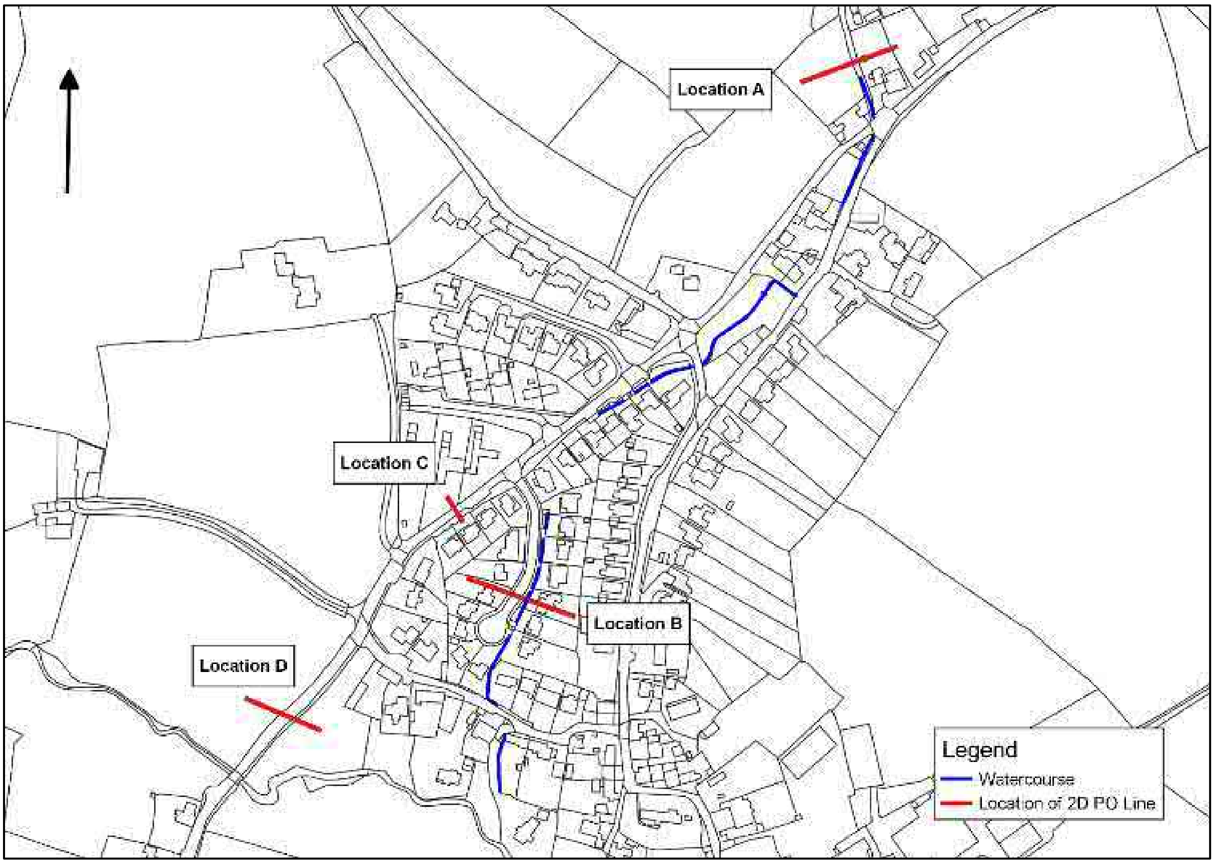

Figure 6-4: Location of 2d_PO Line Flow Estimation Locations

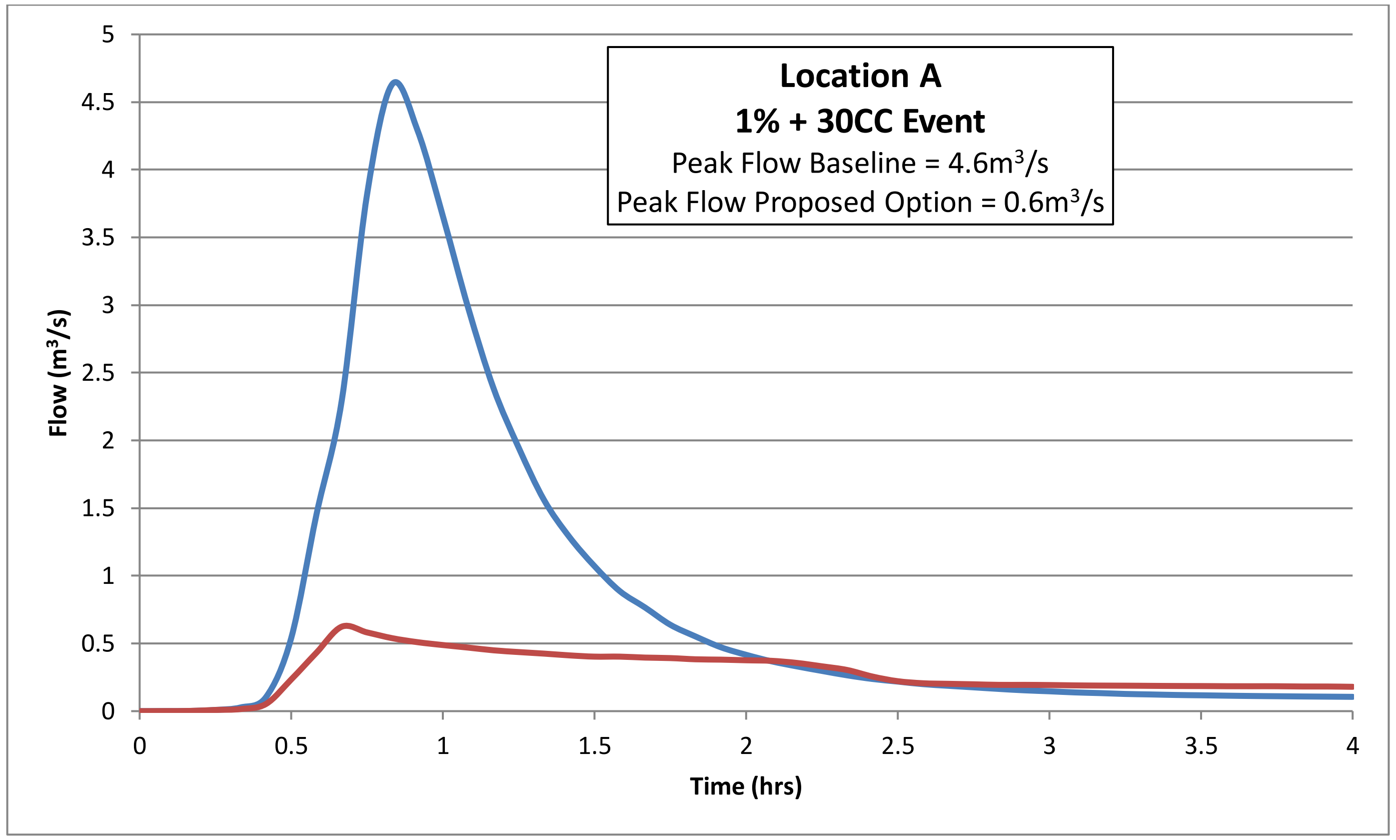

Figure 6-5: 2D PO Flow, Proposed Option vs Baseline, 1% AEP + 30%CC, Upstream of Llanmaes (Location A)

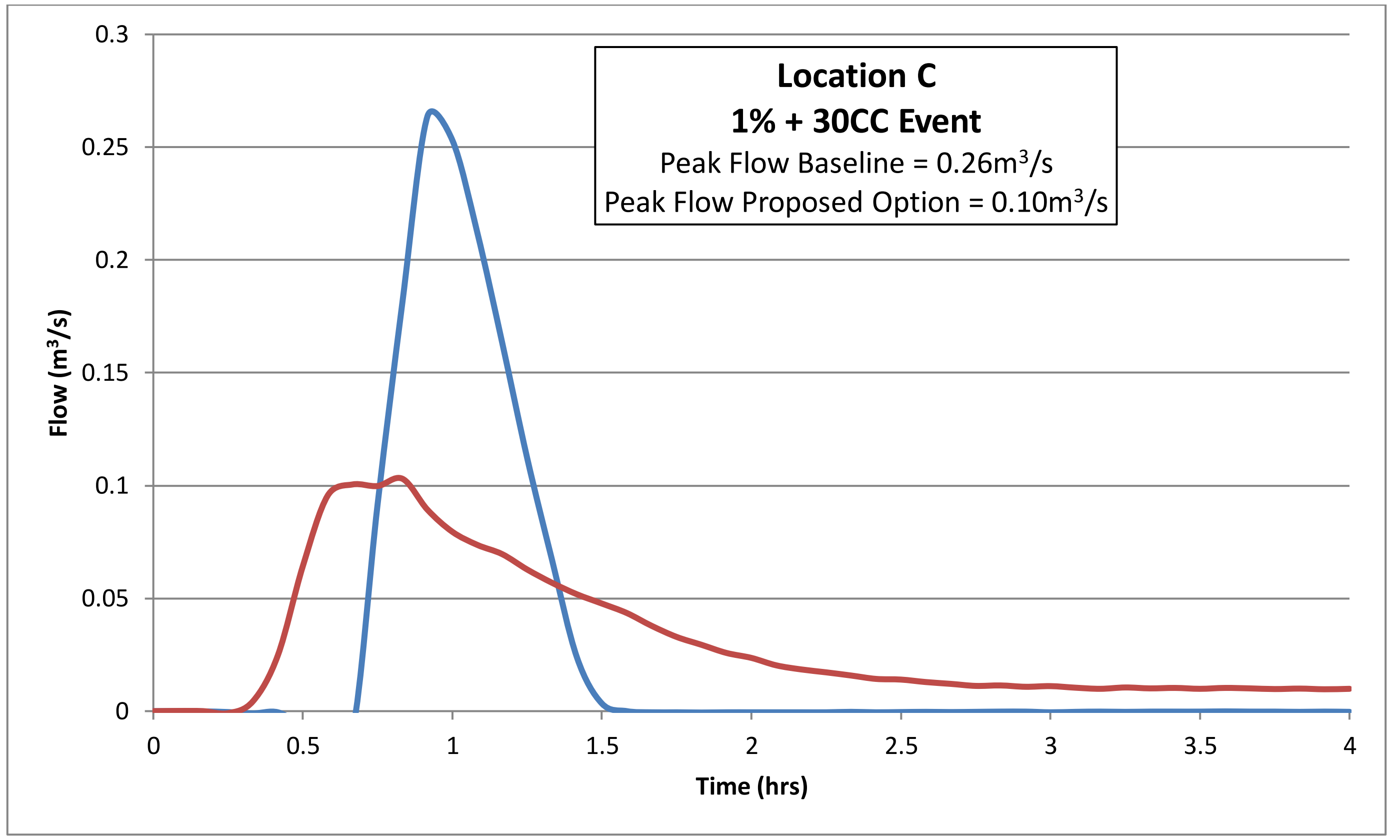

Figure 6-7: 2D PO Flow, Proposed Option vs Baseline, 1% AEP + 30%CC, West Road (Location C)

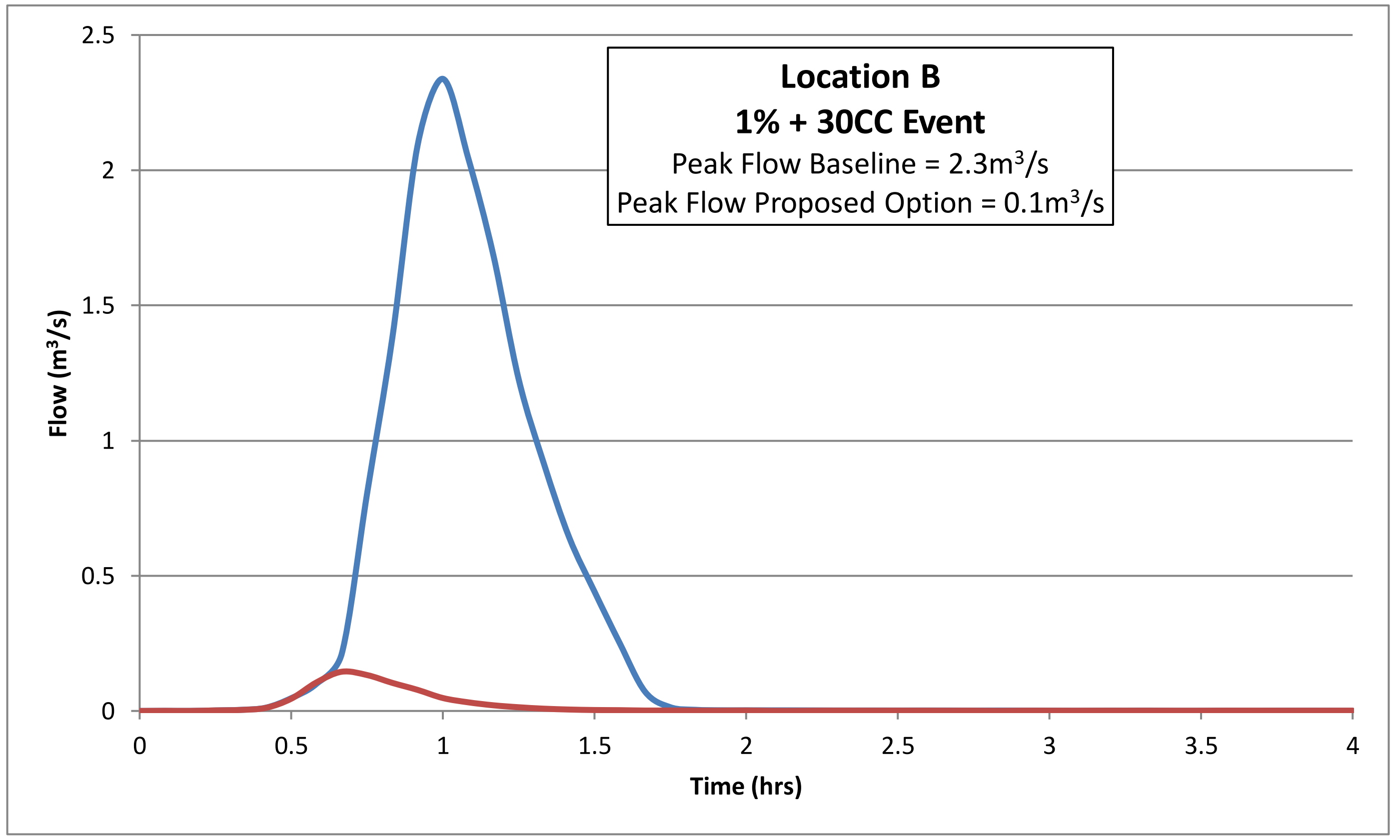

Figure 6-6: 2D PO Flow, Proposed Option vs Baseline, 1% AEP + 30%CC, Tyle House Close (Location B)

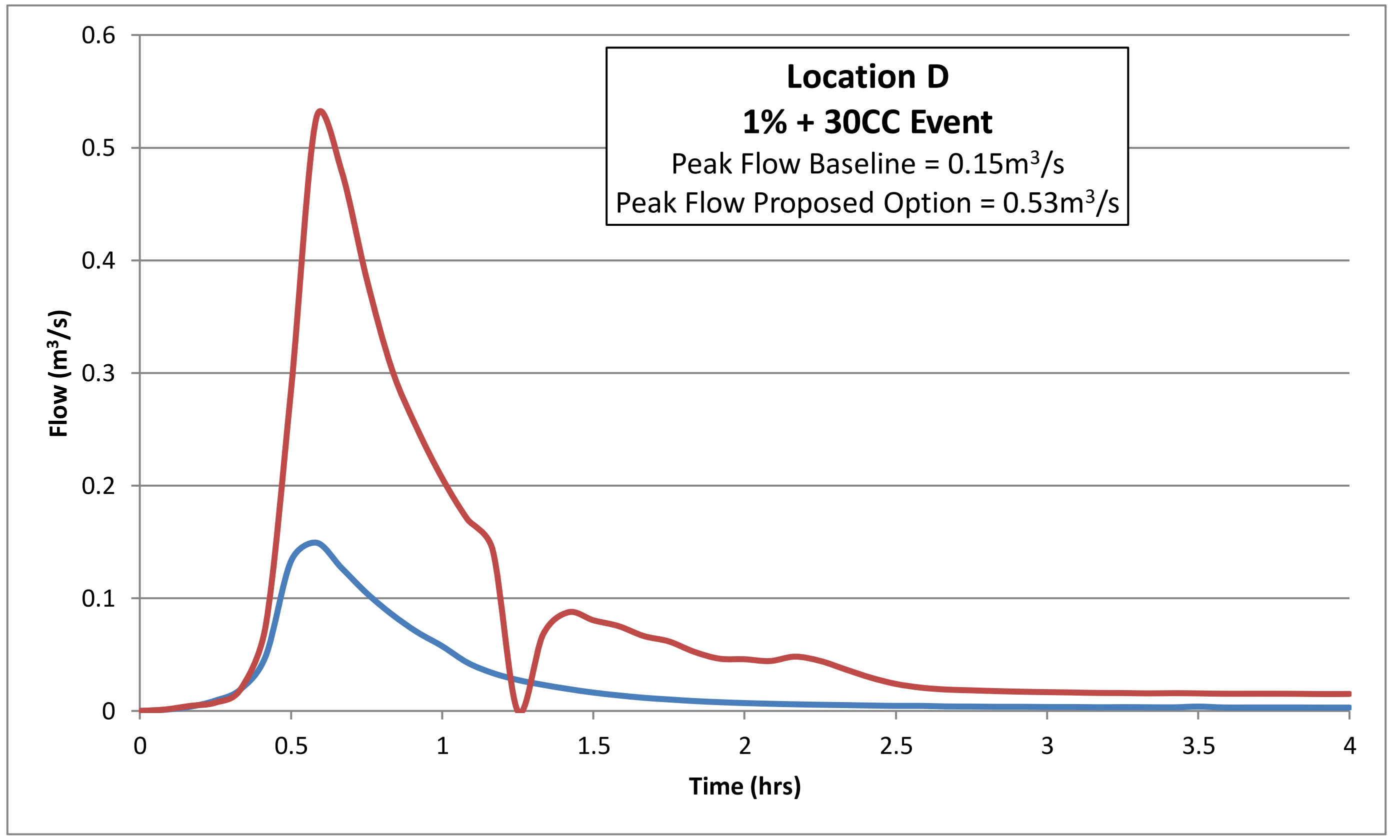

Figure 6-8: 2D PO Flow, Proposed Option vs Baseline, 1% AEP + 30%CC, West Road at Llanmaes Brook (Location D)

6.1.3 Flood Depths

It has been demonstrated that the Proposed Option provides a significant reduction in the overall flood depths throughout Llanmaes across all simulated AEP events. However, due to the volume of water entering Llanmaes and limited capacity of the unnamed watercourse channel the results show that all flood risk could not be mitigated against for some properties, although this is not exacerbated by the introduction of the Proposed Scheme. Figure 6-9 and Figure 6-10 shows the maximum flood depths maps for the 20% AEP and 1% AEP +30% climate change scenario respectively.

During the 20% AEP event the maximum flood depths within Llanmaes can be seen within West Road where road re-profiling has lowered the highway to create formalised flow paths (Figure 6-9). The maximum flood depths are shown to be between 0.2m-0.3m within a small number of cells along the side of Gadlys Lane and West Road. The large depth of flooding within these cells is believed to be the result of an 'Edge Effect' and is considered to be as a result of the model representation and grid cell definition rather than a 'true' flood depth. The actual flood depths along these roads are thought to be in the region of 0.1-0.2m, in line with the remainder of the road surface.

This 'Edge Effect' can be attributed to a combination of a marked change in topography at the edge of the road, combined with a larger than desired grid cell size. At the edge of the road these factors, combined with the very shallow water depths observed within direct rainfall models, lead to an over elevated water surface level. Furthermore, in this instance West Road is already lower than the LiDAR levels to the north and through lowering the road in the Proposed Option the 'Edge Effect' has been amplified. This means that whilst there will be flooding within the highway it is expected that these maximum flood depths would be lower than the maximum depths shown, and would be 0.1-0.2m, broadly in line with the majority of the road surface.

The Proposed Option can be seen to be functioning well during the 20% AEP event (Figure 6-9) with inundation of the highway and properties at Gadlys Lane around The Croft, Tyle House Close and Low Road being all but removed. It is noted that flood depths around Tara House have been reduced significantly during this event. The greatest flood depths on West Road are demonstrated to be confined to areas of the highway away from the properties at risk showing that the road re-profiling is functioning as intended. The West Road ditch is also shown to be conveying water off the highway and into Llanmaes Brook.

During the 1% AEP + 30% climate change scenario, the maximum flood depths are observed at the Village Green (0.5m–1m) and within the West Road, Gadlys Lane and Low Road where depths are approximately 0.2-0.3m (Figure 6-10). Flooding is mainly confined to highways and public open space as intended within the design of the Proposed Option. Inundation of Tyle House Close has been reduced significantly and mostly removed from the highway and properties. Flood depths of between 0.2-0.4m are evident around Tara House caused by a combination of overtopping of the unnamed watercourse immediately upstream of Tara House and out of bank flow from Llanmaes Brook. These are reduced from the Baseline scenario which demonstrated flood depths of 0.4-0.5m during the 1% AEP + 30% climate change event.

Figure 6-9 and Figure 6-10 show that although there is a general reduction in flood depth there are some properties that experience flooding during the 20% AEP and 1% AEP + 30% climate change event (Section 6.1.4). Through assessment of the Proposed Option, the maximum flood depths inundating properties benefitting from the scheme have been reduced by 0.1-0.2m within the 1% AEP + 30% climate change scenario, when compared with the baseline. This flooding is considered to be residual risk and flood depths of this magnitude can be mitigated through Property Level Resilience (PLR) measures such as flood doors, smart airbricks etc. This approach is recommended from a constructability and feasibility perspective to allow the Proposed Option to be considered in earnest, providing a wider benefit to the community.

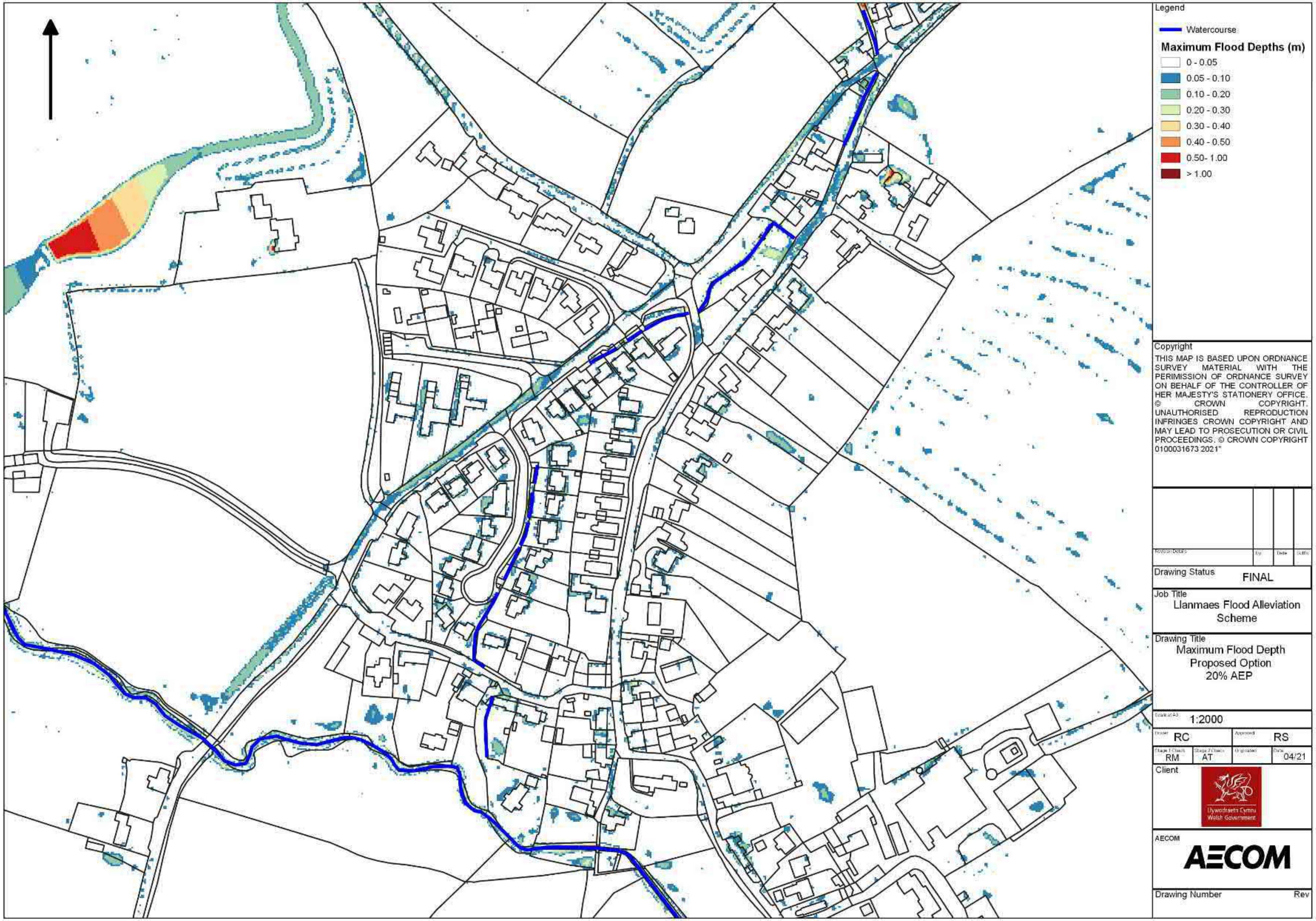

Figure 6-9: Maximum Flood Depths 20% AEP Proposed Option Results

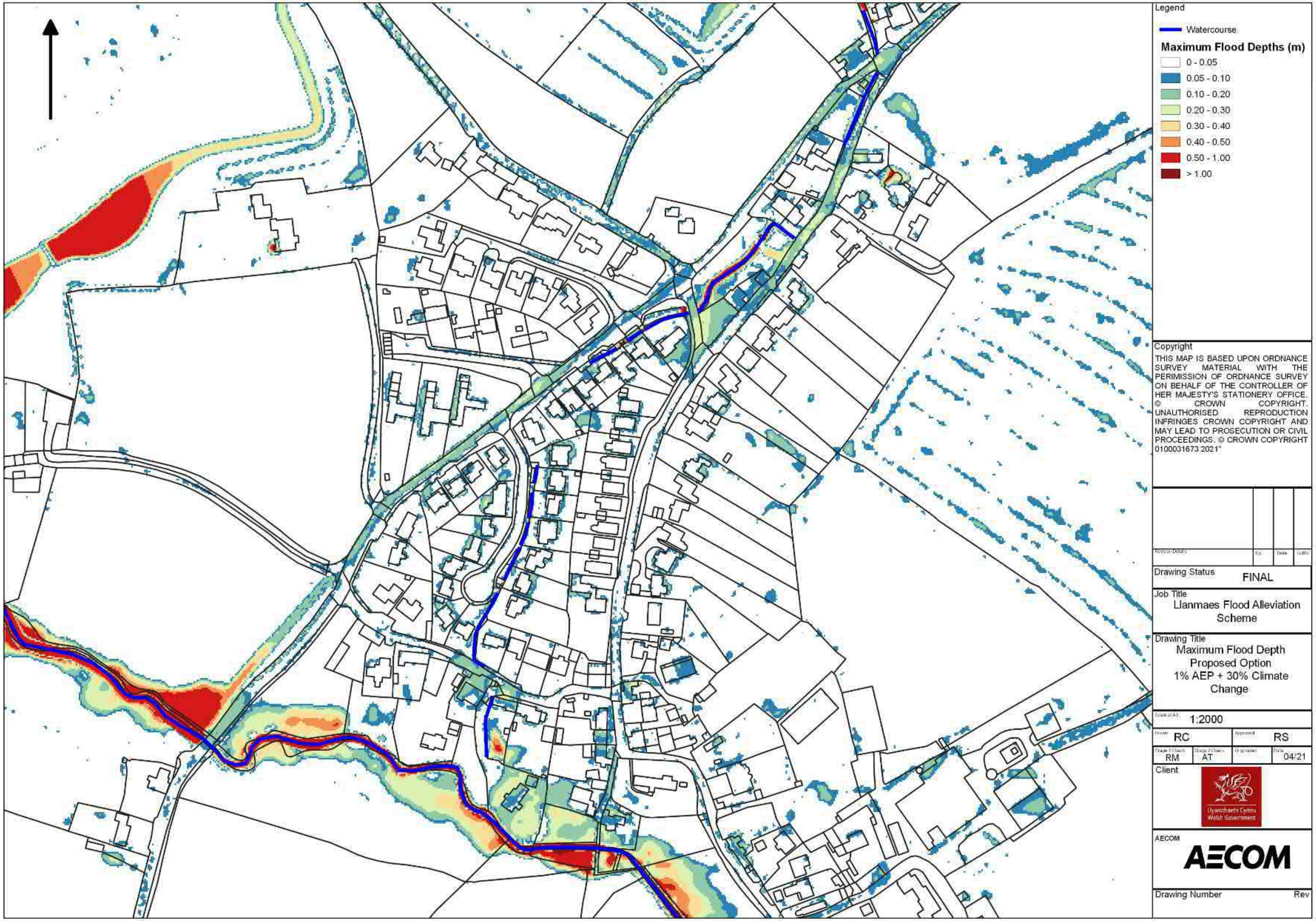

Figure 6-10: Maximum Flood Depths 1% AEP + 30%CC Proposed Option Results

During the extreme 0.1% AEP event, the largest maximum flood depths within Llanmaes are within the Village Green and public highways (Appendix D16) where flood depths between 0.3-0.4m are observed. The Proposed Option reduces the overall inundation level of properties to between 0.2-0.4m which could now be managed through adoption of PLR.

Further discussion on the functioning of the attenuation storage areas and ditches is found in Section 6.3.

6.1.4 Properties at Risk and Residual Risk

In order to understand the benefits of the Proposed Option, the number of properties which experience internal flooding within the Baseline model are compared against the Proposed Option model for all AEP's. The identification method of flooded properties is the same as that specified in Section 4.1.4. A broad sensitivity assessment of estimated threshold levels of properties within Llanmaes was carried out and is discussed in Section 7.2. Table 6-2 shows the number of properties affected by flooding in the Baseline and Proposed Option scenarios during the simulated events.

Table 6-2: Comparison of Properties Affected by Flooding - Baseline and Proposed Option Model

Annual Exceedance Probability (AEP)	Baseline - Inundated Properties	Proposed Option - Inundated Properties	Inundated Properties – Reduction (Complete Removal)
20%	19	14	-5 (-26%)
10%	27	16	-11 (-41%)
5%	31	17	-14 (-45%)
2%	45	21	-24 (-53%)
1% + 30% CC	61	26	-35 (-57%)

It can be seen that there is a reduction in the number of properties that are estimated to flood across all AEP events. This is most pronounced during the 1% AEP + 30% climate change event where 35 properties are completely removed from inundation in comparison to the Baseline scenario.

6.2 Flood Hazard Mapping

As part of the Proposed Option, road re-profiling and flood storage is recommended and has been shown to provide significant benefit to the level of flood risk within residential property footprints throughout Llanmaes. However, there is an associated increase in flood depths where these mitigation measures have been proposed. To understand how the Proposed Option has changed the risk posed to members of the public, Flood Hazard Maps have been created for the Baseline and Proposed Option model results. The Flood Hazard Rating used within this report is based upon the October 2005, Defra/EA produced 'Flood Risk Assessment Guidance for New Development (Phase 2)'[14]. The full set of results can be found in Appendix E.

Figure 6-11 shows that during the 1% AEP + 30% climate change Baseline scenario there are large areas of Gadlys Lane, West Road, Low Road, Tara House and the Village Green that are considered to be 'Danger to Most'. On Gadlys Lane, north of the Croft there is a small area of 'Danger for All' showing significant risk to even rescue response units. This is as a result of the depth and velocity of the flooding at Gadlys Lane during the 1% AEP + 30% climate change event.

The Proposed Option model results show that during the 1% AEP + 30% climate change event, there is a large reduction in Flood Hazard Rating throughout Llanmaes with West Road and Low Road reduced to 'Very Low Hazard' (Figure 6-12). The areas of 'Danger to Most' are now confined mainly to the attenuation storage areas, ditches and the Village Green as per the intended Proposed Option design however there remains some residual risk to parts of Gadlys Lane due to the volume of water entering Llanmaes.

[14] Defra/Environment Agency, 2005 'Flood Risk Assessment Guidance for New Development (Phase 2)', FD2320/TR2. Available from: http://evidence.environment-agency.gov.uk/FCERM/Libraries/FCERM_Project_Documents/FD2320_3364_TRP_pdf.sflb.ashx.

Although the Proposed Option shows a significant benefit to Llanmaes it is noted that through developing the scheme there is a formalisation of the overland flow path through Llanmaes along West Road and within the Village Green. As such, a Designers Risk Assessment has been produced by AECOM to facilitate discussions with VoGC and NRW. Mitigation measures such as, but not limited to, communication to residents of risks, parking restrictions, road signage and rainfall gauge warning systems could be implemented to help reduce the risk to these areas.

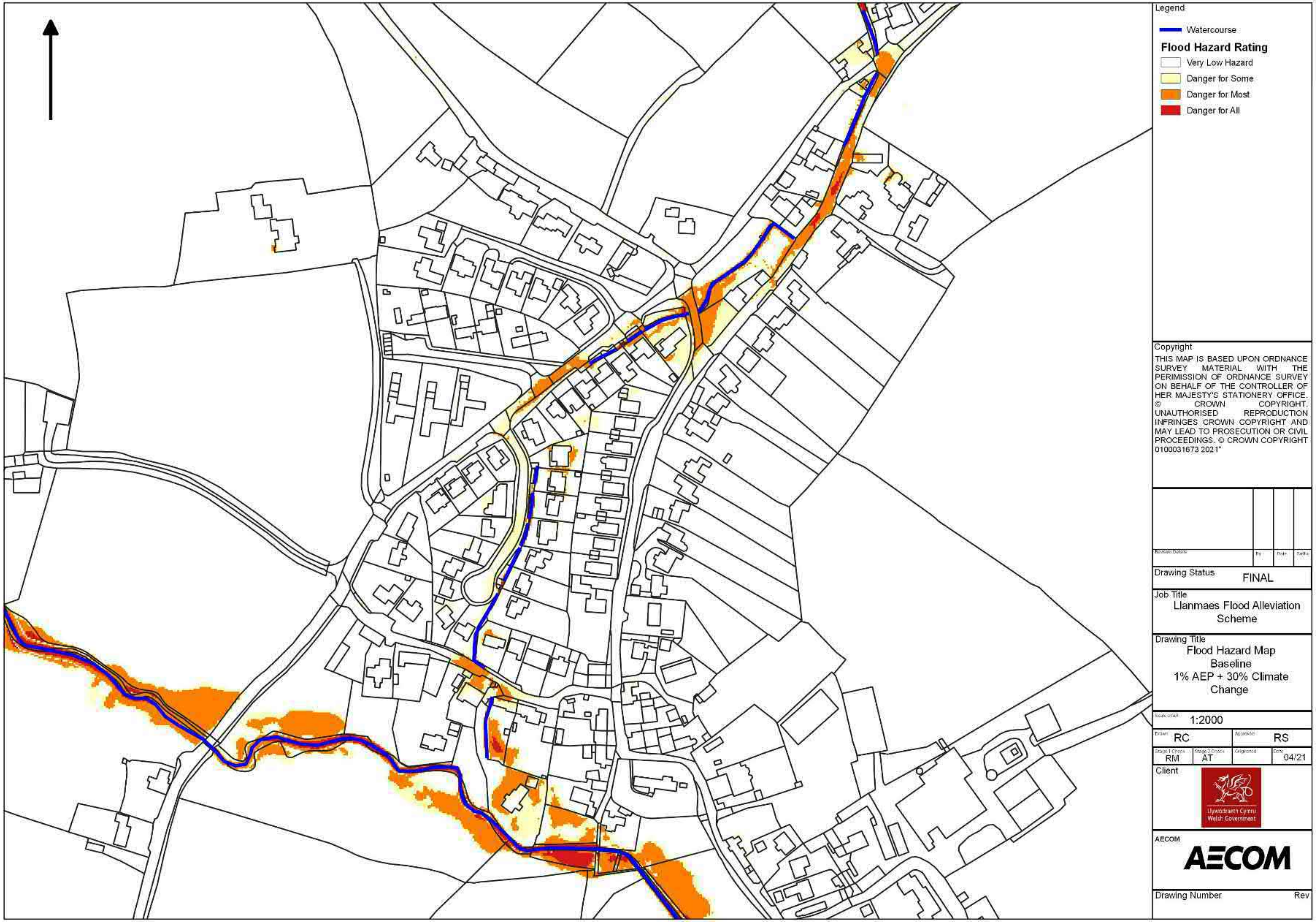

Figure 6-11: Flood Hazard Map. Baseline 1% AEP + 30%CC

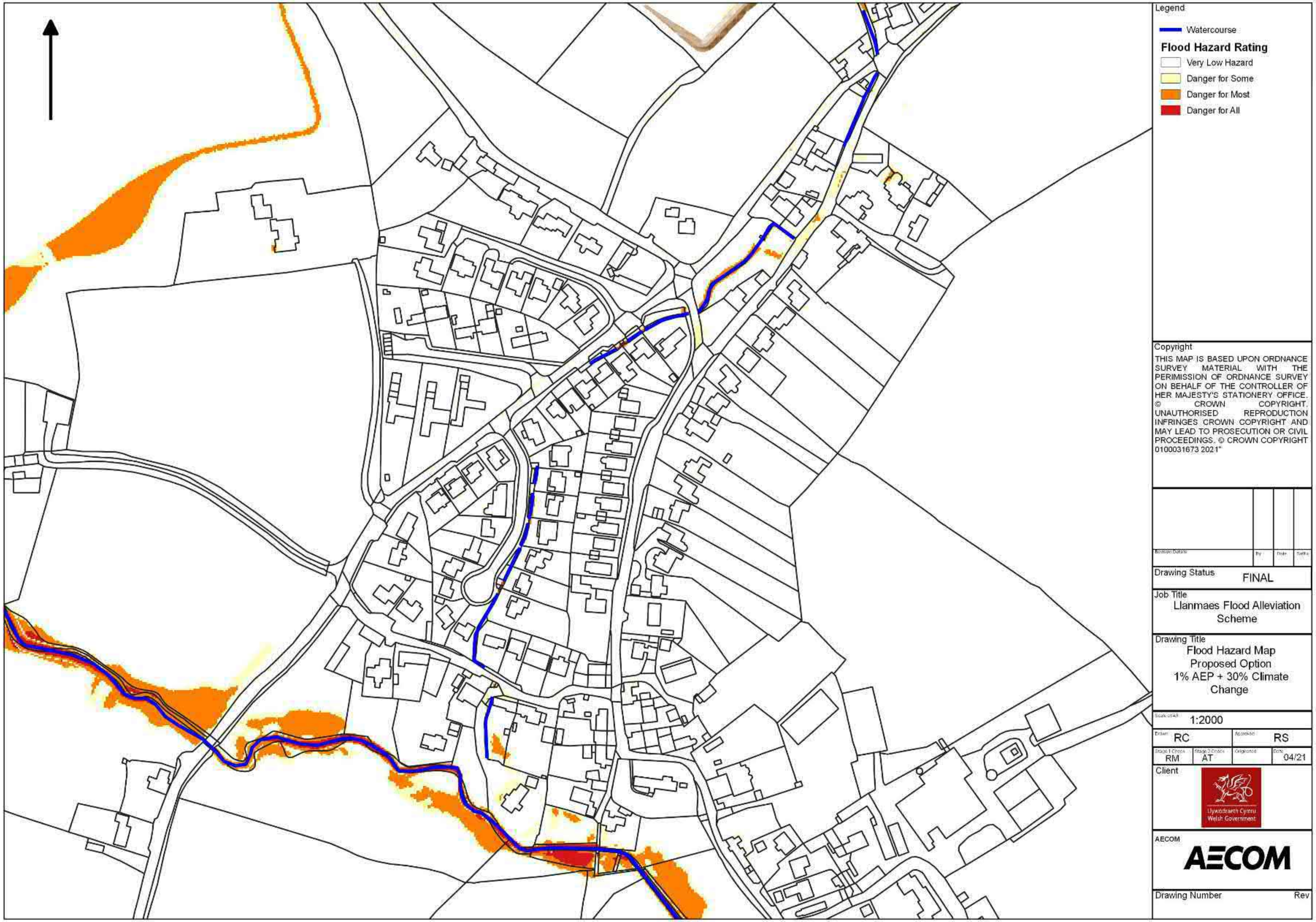

Figure 6-12: Flood Hazard Map. Proposed Option 1% AEP + 30%CC

6.3 Attenuation Storage Volumes and Ditches

6.3.1 Attenuation Storage Volumes

The reduced flooding within Llanmaes shown in the Proposed Option is primarily as a result of the implementation of flood storage areas upstream of the village. The flood storage areas have been designed to attenuate flood flows up to the 1% AEP + 30% climate change scenario inclusive of a minimum 0.3m freeboard. Figure 6-13 shows the location of the storage areas and Table 6-3 shows the maximum storage and flood depths provided by the flood bunds.

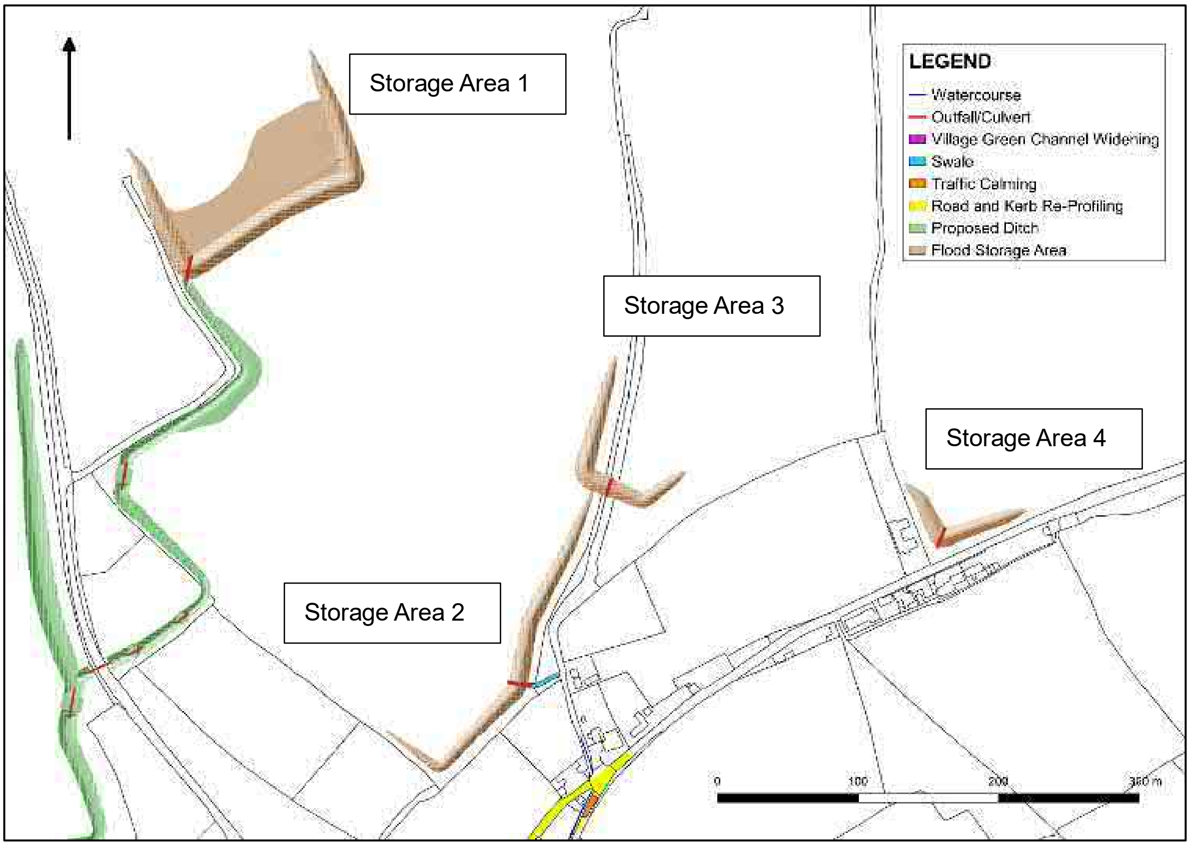

Figure 6-13: Flood Storage Area Classification

Table 6-3: Comparison of maximum storage and water depth in the proposed storage areas

Storage Area	Attribute	20% AEP	1% + 30%CC AEP	0.1% AEP
1	Maximum Storage Volume	$1100m^3$	$4700m^3$	$6700m^3$
	Maximum Flood Depth	0.60m	1.10m	1.30m
2	Maximum Storage Volume	$550m^3$	$2600m^3$	$3800m^3$
	Maximum Flood Depth	0.50m	0.95m	1.05m
3	Maximum Storage Volume	$300m^3$	$1000m^3$	$1400m^3$
	Maximum Flood Depth	0.60m	1.20m	1.40m
4	Maximum Storage Volume	$50m^3$	$150m^3$	$200m^3$
	Maximum Flood Depth	0.25m	0.55m	0.65m

It can be seen in Table 6-3 that all storage areas are below 10,000m^3 and are therefore not considered to be reservoirs under the Reservoir Act[15] (1975). A sensitivity simulation has been carried out on the potential blockage of Storage Areas 1 and 2, due to the provision of the largest volume of storage, and is described further within Section 7.4.

6.3.2 Ditches

Three ditches are included within the Proposed Option design and are shown in Figure 6-14. Ditch 2 is designed as the outfall for Bund 1 to divert flow west around Llanmaes into Ditch 1. Ditch 1 is designed to intercept overland flow from Sigingstone Lane and the agricultural fields to the north of the village and divert it away from flood risk receptors in the village. The third is the West Road ditch (Ditch 3) which collects highway runoff from the scheme and acts as the outfall through an agricultural field into Llanmaes Brook.

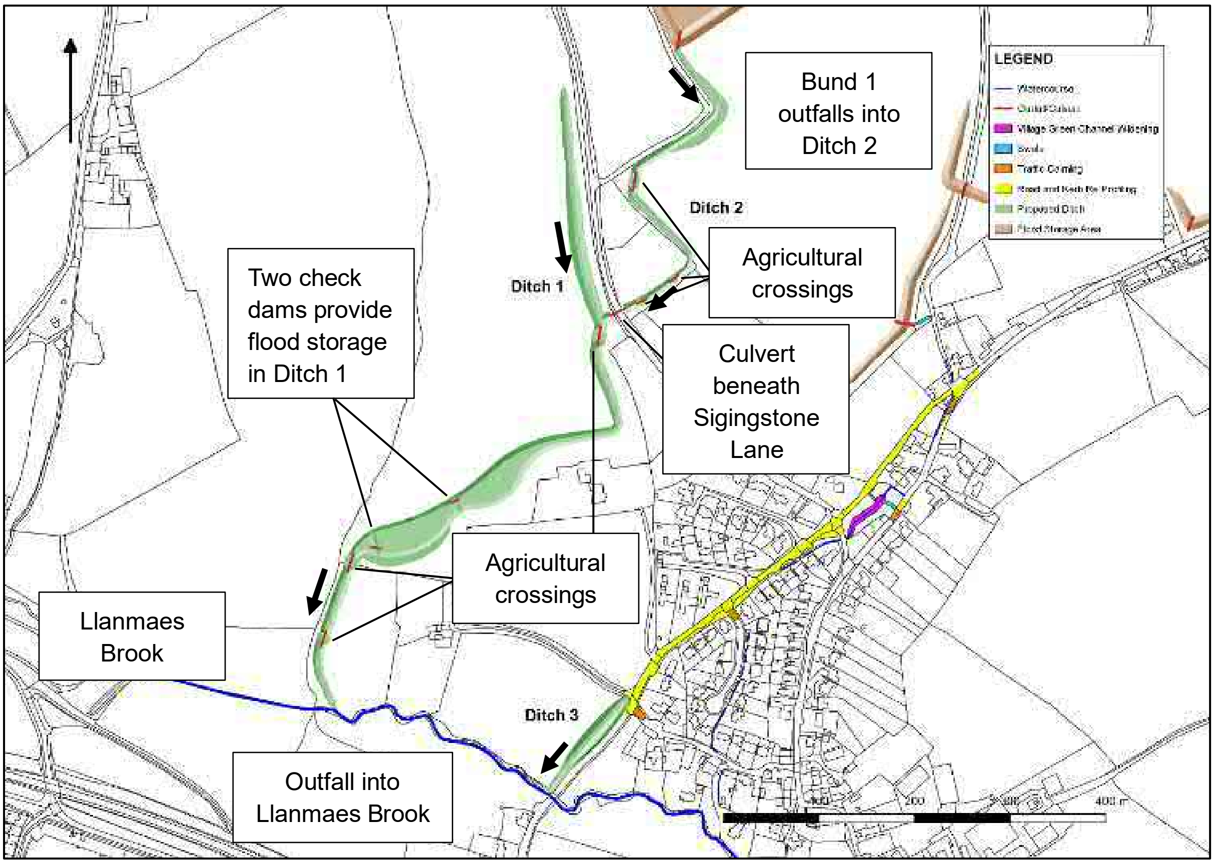

Figure 6-14: Proposed Ditch Locations

Through the design process it was found that by diverting surface water from the agricultural fields and Sigingstone Lane around the north side of the village there was an elevated concentration of flow entering Llanmaes Brook upstream of the West Road bridge (Section 6.5). To reduce the volume of water entering Llanmaes Brook from the cut off ditch, check dams have been incorporated into the design to store water during large magnitude events.

Table 6-4 shows the surface water stored within Ditch 1 during the 20%, 1% + 30% climate change and 0.1% AEP events. It can be seen that a maximum of approximately 4650m^3 is stored in Ditch 1 in the 0.1% AEP but is also effective at storing water during lower order magnitude events too.

The residual flood risk impact of the ditches is discussed further in Section 6.5.

[15] HMSO 1975, The Reservoirs Act 1975

Table 6-4: Flood Storage within Ditch 1

Annual Exceedance Probability (AEP)	Flood Storage within North Ditch
20%	1900m^3
1% + 30%CC	4050m^3
0.1%	4650m^3

6.4 Downstream Impact

To understand the impact the Proposed Option would have on Llanmaes Brook downstream of Llanmaes, hydrographs were compared at a node upstream of the NAR (006c) and downstream of the NAR (003a). Figure 6-15 shows the location of the node points where flow results have been compared.

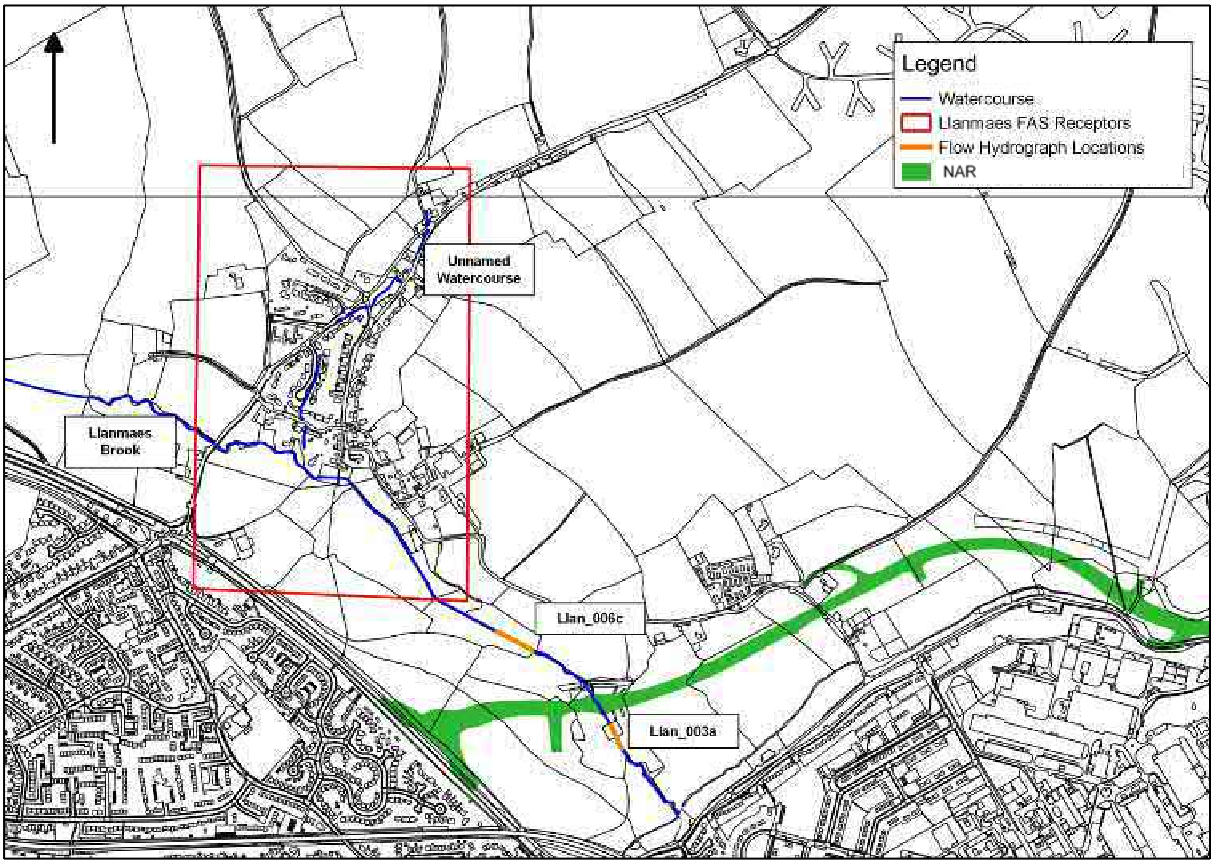

Figure 6-15: Location of extracted downstream model results

The flow hydrographs demonstrate that for the 1% AEP + 30 climate change event there is a reduction in the overall size of the downstream hydrograph on Llanmaes Brook whereby the initial peak of the hydrograph, associated with the unnamed watercourse through Llanmaes, is significantly reduced by the storage areas upstream of the village (Figure 6-16). The maximum peak flow upstream of the NAR is reduced from 12.0m^3/s to 10.0m^3/s whilst the downstream maximum peak flow is reduced from 12.1m^3/s to 8.8m^3/s (Figure 6-17). It is noted that for the Proposed Option, the flow difference between upstream and downstream of the NAR is 1.2m^3/s indicating that it is having a benefit on the functionality of the NAR storage area (Table 6-5). Model results show that the Proposed Option provides a reduction in peak flow on Llanmaes Brook across all AEP's

This reduction in the overall volume of water passing onto Llanmaes Brook will provide a cumulative flood risk benefit to Boverton and to the standard of protection afforded by the NAR flood storage area.

Table 6-5: Comparison of Peak Flow Upstream and Downstream of the NAR, 1% AEP + 30% climate change

Node	Baseline Peak Flow	Proposed Option Peak Flow
Upstream of NAR (006c)	12.0m³/s	10.0m³/s
Downstream of NAR (003a)	12.2m³/s	8.8m³/s

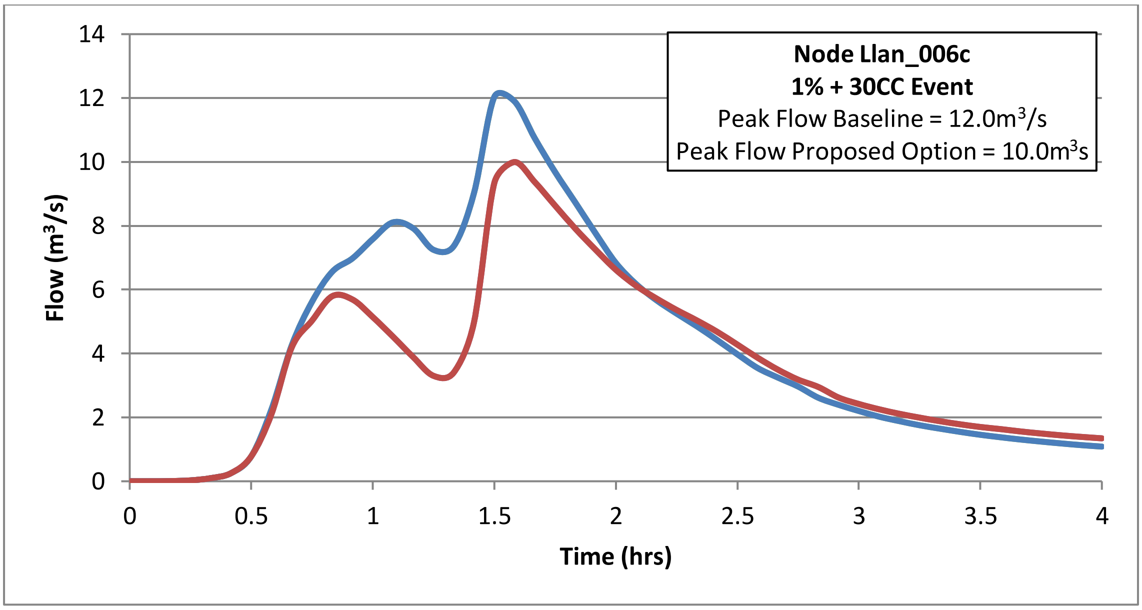

Figure 6-16: Flow Comparison Upstream of NAR, 1% AEP + 30%CC (Node Llan006c)

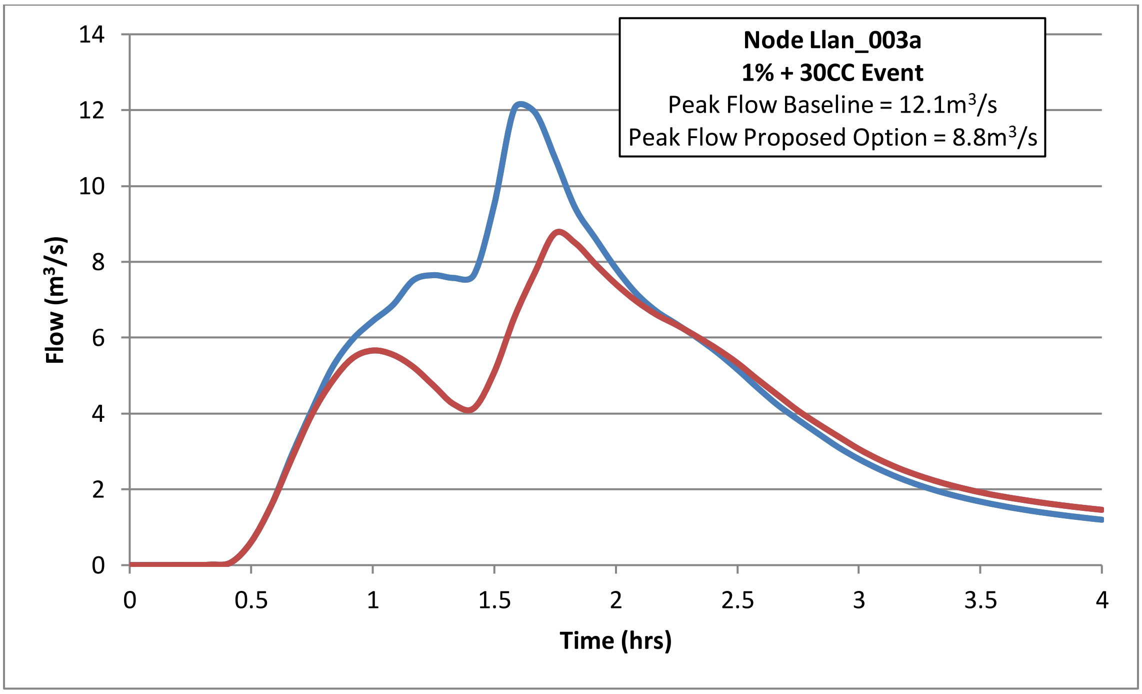

Figure 6-17: Flow Comparison Upstream of NAR, 1% AEP + 30%CC (Node Llan003a)

6.5 Residual Flood Risk

It has been demonstrated throughout this report that the Proposed Llanmaes FAS has a positive reduction in flood depths to sensitive receptors through Llanmaes (Sections 6.1.1 and Section 6.1.3) and an overall reduction in the flow hydrograph downstream of the village (Section 6.4) for all the design events. This reduction is primarily the result of the implementation of the attenuation storage areas to the north of the village. However, the scheme also relies on the formalisation of two flow paths which outfall into Llanmaes Brook in order reduce the overall volume conveyed by the existing flow path through the village (Figure 4-1).

These interventions consist of Ditch 1 and Ditch 2 that intercept overland flow from the north of Llanames and the road re-profiling of West Road that maintains a flow path through Llanmaes within the highway to protect properties from flooding. A consequence of these two new outfalls is that for an approximate 500m reach of Llanmaes Brook from the Ditch 1 outfall to the existing outfall of the unnamed watercourse there is an increase in the peak flows on Llanmaes Brook which results in the increase in flood depths in agricultural fields described in Section 6.1.1. Table 6-6 shows a comparison of the peak flow from within the channel and floodplain on Llanmaes Brook between the Proposed Option and Baseline scenario. It can be seen that during the 20% AEP and 1% AEP + 30% climate change there is general increase in peak flow of 0.1m^3/s between the Ditch 1 outfall and upstream of Tara House as a result of the scheme.

It has been demonstrated in Section 6.4 that there is an overall reduction in the volumes and peak flows downstream of Llanmaes and therefore this means the increase in flow on Llanmaes Brook between the outfalls represents a redirection of flood risk away from properties to an area of lower risk. The justification for this is as follows:

- The hydraulic model does not consider infiltration into the ditch which is a conservative approach. It is likely that some water would be lost to the ground and the outfall would be less than currently observed;
- There is no increase in flood extents from the baseline results and all observed increased flood depths are contained within the baseline floodplain (existing);
- There is no change in flood risk to significant receptors and all increases to flood depths are within agricultural fields; and
- The pass-on peak flow and total volume has been reduced from Llanmaes Brook (Section 6.4) which should have a positive influence on the effectiveness of the standard of protection afforded by downstream receptors.

Table 6-6: Comparison of Peak Flows on Llanmaes Brook Between North Ditch Outfall and Upstream of Tara House, 1% AEP + 30%CC

Node		Baseline Peak Flow	Proposed Option Peak Flow
Upstream of West Road Bridge (016a)	20% AEP	0.3m^3/s	0.3 m^3/s
	2% AEP	2.6 m^3/s	2.6 m^3/s
	1% AEP + 30%CC	9.3 m^3/s	9.4 m^3/s
West Road Bridge	20% AEP	0.4 m^3/s	0.5 m^3/s
	2% AEP	2.6 m^3/s	2.6 m^3/s
	1% AEP + 30%CC	9.1 m^3/s	9.2 m^3/s
Upstream of Tara House (013a)	20% AEP	0.5 m^3/s	0.6 m^3/s
	2% AEP	2.6 m^3/s	2.6 m^3/s
	1% AEP + 30%CC	9.2 m^3/s	9.2 m^3/s

Based on this assessment, we recommend that VoGC liaise with the relevant landowners to ensure that this part of the FAS can function as intended. A change in the flow regime of Llanmaes Brook for this length of Main River may require a Flood Risk Activity Permit agreement with NRW.

7. Sensitivity

Sensitivity testing is undertaken on all hydraulic models in order to document how the relationship of model outputs can be apportioned to different sources of model parameter variance. This is achieved by altering key parameters within the model and observing the change in model results at specific locations within the model.

Sensitivity testing of the Baseline and Proposed Option model were undertaken for the 1% AEP + 30% climate change event throughout this study (except Structural Blockage which was 0.1% AEP) and involved adjustments to the following parameters:

- Manning's Roughness Coefficients (+/-20%);
- Structural Blockage (100%);
- Percentage Runoff (+40% and +50%); and
- Boverton Brook Inflow.

The full model results for the sensitivity test are provided in Appendix F.

7.1 Manning's Roughness Coefficient (+/-20%)

Manning's Roughness Coefficient sensitivity tests were conducted by applying +/-20% Manning's Roughness Coefficient to the model. It should be noted that upon testing, application of the -20% Manning's Roughness Coefficient resulted in model instability and the simulation could not be completed. The Manning's Roughness Coefficient was then reduced by -10%, which simulated and is discussed below. However due to the failure of the simulation during the -20% Manning's Roughness Coefficient scenario and issues raised in Section 3.3, the model is considered to be sensitive to lowering of the Manning's Roughness Coefficient. It is noted that this sensitivity analysis has been carried out using the model iteration from Stage 4 (Section 5.1.2) of this study. The alterations to the model at Stage 5 and 6 (Section 5.1.2) are not considered to be significant enough to affect the conclusions drawn from this sensitivity test.

Flood depth difference maps were prepared which compare the maximum flood depth results for the sensitivity simulation and the Proposed Option simulation. Figure 7-1 shows that for the 1% AEP + 30% climate change event with -10% Manning's Roughness Coefficient there is an increase in flood depths of between 0.2-0.3m on Tyle House Close and 0.0-0.1m along the banks of Llanmaes Brook. This is primarily caused by an increase in the speed at which water enters the unnamed watercourse through Llanmaes and Llanmaes Brook and ultimately an increase in flow in the watercourse channel. This overwhelms the driveway culverts on Tyle House Close and results in an increase in out of bank flooding from the unnamed watercourse through Llanmaes. The increase in flood depths is mainly confined to highways and open areas however there is an increase in flood depths at Tara House. There are no additional properties put at risk of flood that are currently demonstrated in the Proposed Option model as a result of lowering the Manning's Roughness Coefficient by 10%.

When the Manning's Roughness Coefficient is increased by 20% there is a general decrease in flood depths on Low Road and along Llanmaes Brook of 0.0-0.1m during the 1% AEP + 30% climate change (Figure 7-2). This is caused by a slowing of overland flow entering the unnamed watercourse through Llanmaes and Llanmaes Brook which ultimately reduces the flow within the channel. There is therefore more capacity in the culverts network in Llanmaes and the river channel on Llanmaes Brook to convey water away. This does not reduce the number of properties at risk of flooding that are currently demonstrated in the Proposed Option model but does reduce the level of inundation of properties along Low Road and around Tara House.

The sensitivity testing of raising and lowering the Manning's Roughness Coefficient has demonstrated that there is no increase or decrease in the number of properties at risk of flooding when compared to the Proposed Option results described in Section 6.

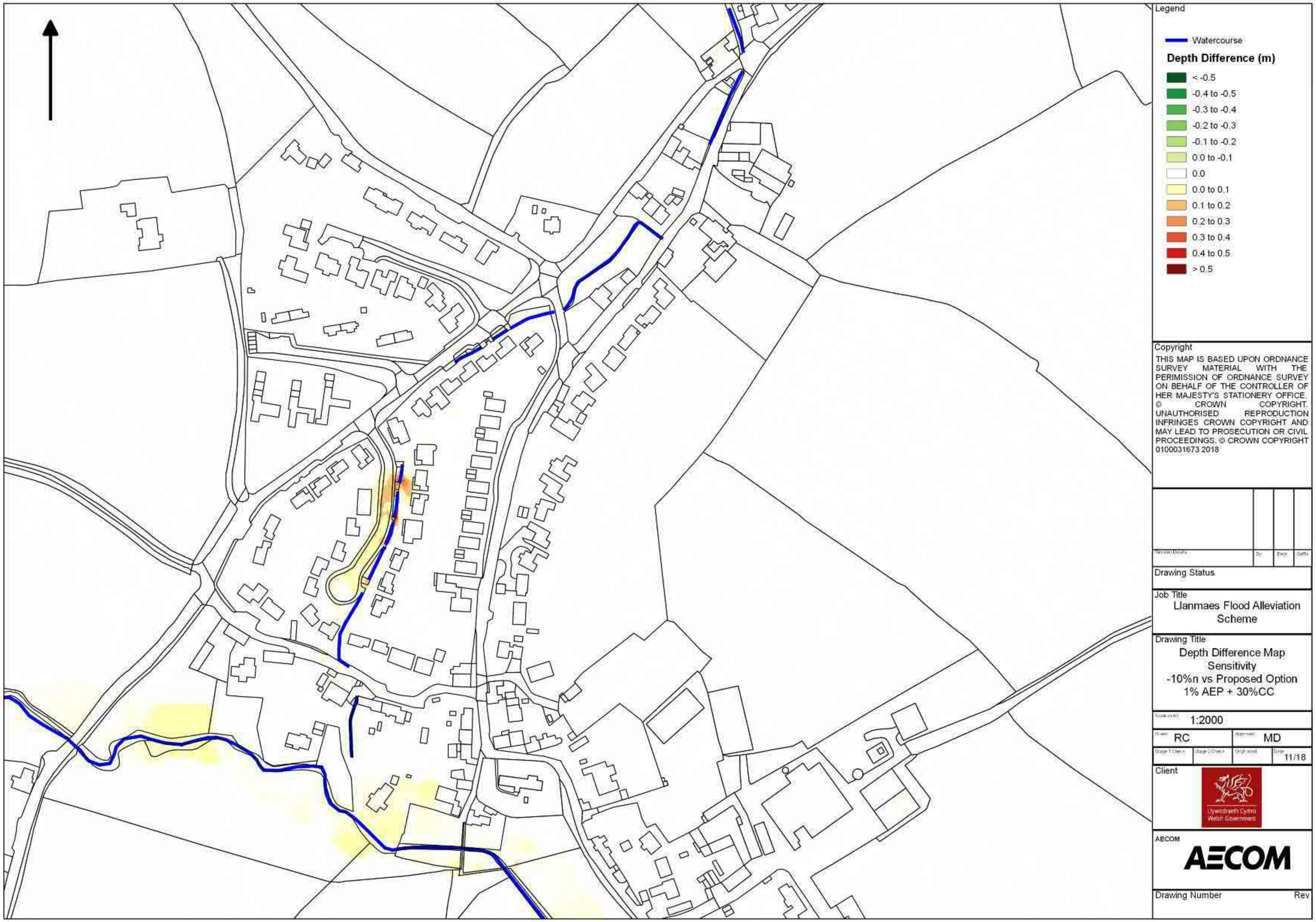

Figure 7-1: Maximum Flood Depth Difference -10% Manning's Roughness Coefficient Sensitivity (1% AEP + 30%CC Scenario)

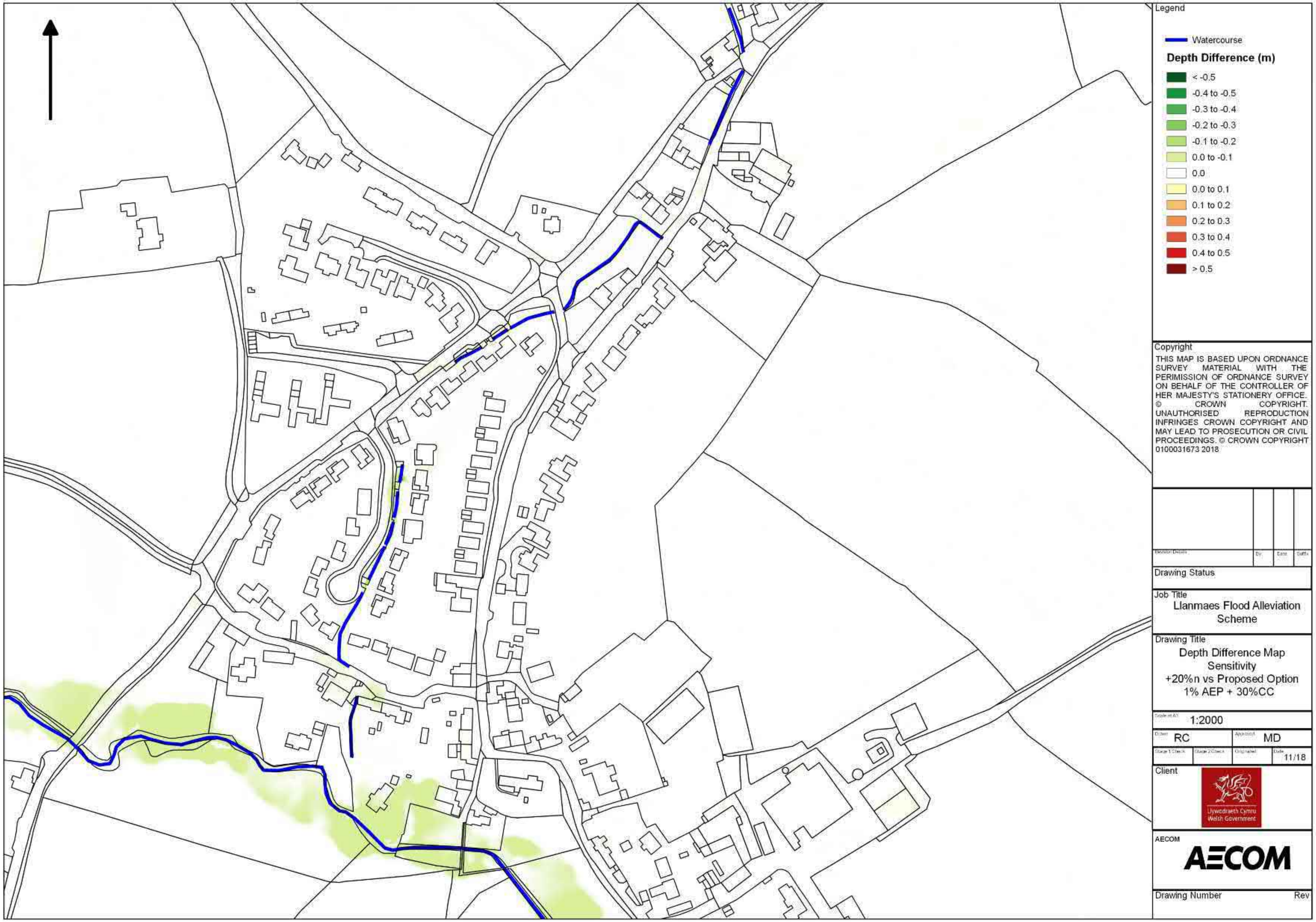

Figure 7-2 Maximum Flood Depth Difference +20% Manning's Roughness Coefficient Sensitivity (1% AEP + 30%CC Scenario)

7.2 Structural Blockage

A sensitivity simulation was undertaken to assess the impact of blockage to the primary outfall pipes of all of the upstream storage areas (Storage Area 1-4, Figure 6-13). In accordance with NRW guidance this was undertaken using the extreme 0.1% AEP event for the worst case scenario.

Figures 7-3 shows that there is an associated increase in the depth of water held within all flood storage areas of between +0.1m and +0.2m during the 0.1% AEP event as a result of the blockage of the outfall pipes. In all storage areas the water is held within the bund and the flood relief culvert is activated only within Flood Storage Area 3 due to the available freeboard above the maximum 1% AEP +30% climate change peak flood level. Table 7-1 shows that for both blockage scenarios the volume of water held back is below 10,000m^3 and is therefore below the definition of a reservoir according to the Reservoir Act (1975).

It is noted that there is a small increase in the maximum flood depths to a property to the west of Flood Storage Area 4. This is a consequence of overland flow by passing the west arm of the bund. It is recommended that either the elevation of the flood relief culvert is lowered or the bund is extended to the north to tie into higher ground to provide additional storage. There are no other residual impacts within Llanmaes village.

Table 7-1: Upstream Storage Volumes for Blockage Scenario

Storage Area	0.1% AEP No Blockage	0.1% AEP 100% Blockage Storage
1	6700m^3	8100m^3
2	3800m^3	4950m^3
3	1400m^3	1900m^3
4	200m^3	340m^3

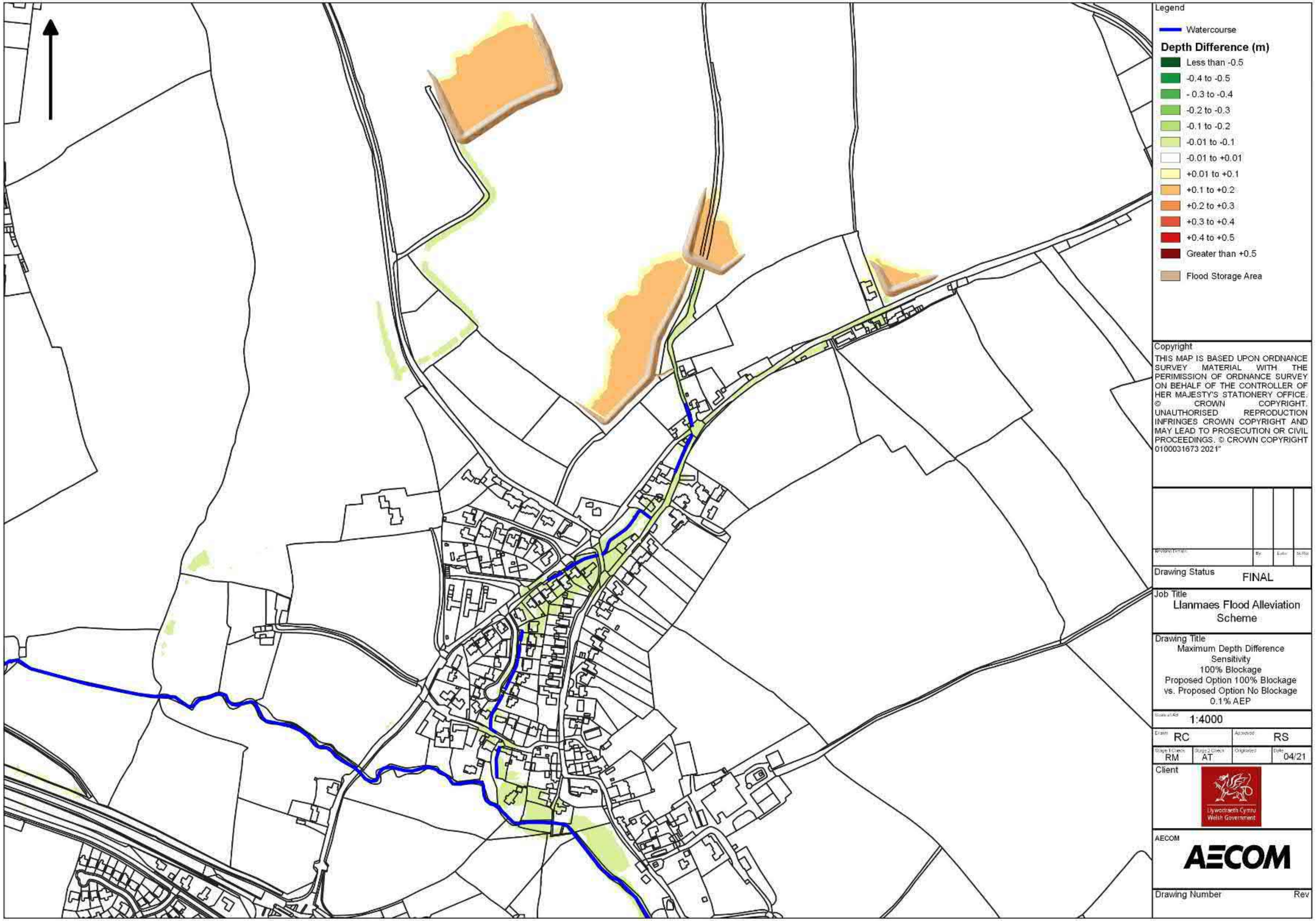

Figure 7-3: Maximum Depth Difference - 100% Blockage - Proposed Option, 0.1% AEP

7.3 Percentage Runoff

The hydrological analysis undertaken in Section 2 found that a surface percentage runoff value of 30% was suitable for the Llanmaes Brook catchment, which is consistent with the findings of previous studies undertaken in the area[16],[17]. To assess the uncertainty in this assessment and ground variability within the catchment, a sensitivity simulation was undertaken using the Baseline and Proposed Option models to investigate the impact to flood risk with an increase in the catchment surface percentage runoff to +40% and +50%. This means that the Llanmaes Brook catchment is modelled to be effectively less permeable and rainfall cannot infiltrate into the ground as readily during the sensitivity simulations.

The sensitivity analysis was undertaken for the +40% and +50% runoff by reducing the 1% AEP + 30% climate change rainfall hyetograph (excluding any infiltration losses) by 60% and 50% respectively. Figure 7-4 shows the comparison of the sensitivity rainfall hyetographs compared to the 1% AEP + 30% climate change with a 30% surface percentage runoff value used throughout this study. This demonstrates a significant increase in effective peak rainfall from 6.0mm to 8.1mm and 10.1mm in the 40% and 50% surface percentage runoff scenarios respectively. The latter is significantly larger than the 0.1% AEP hyetograph (with 30% water percentage runoff) used in this study (8.4mm).

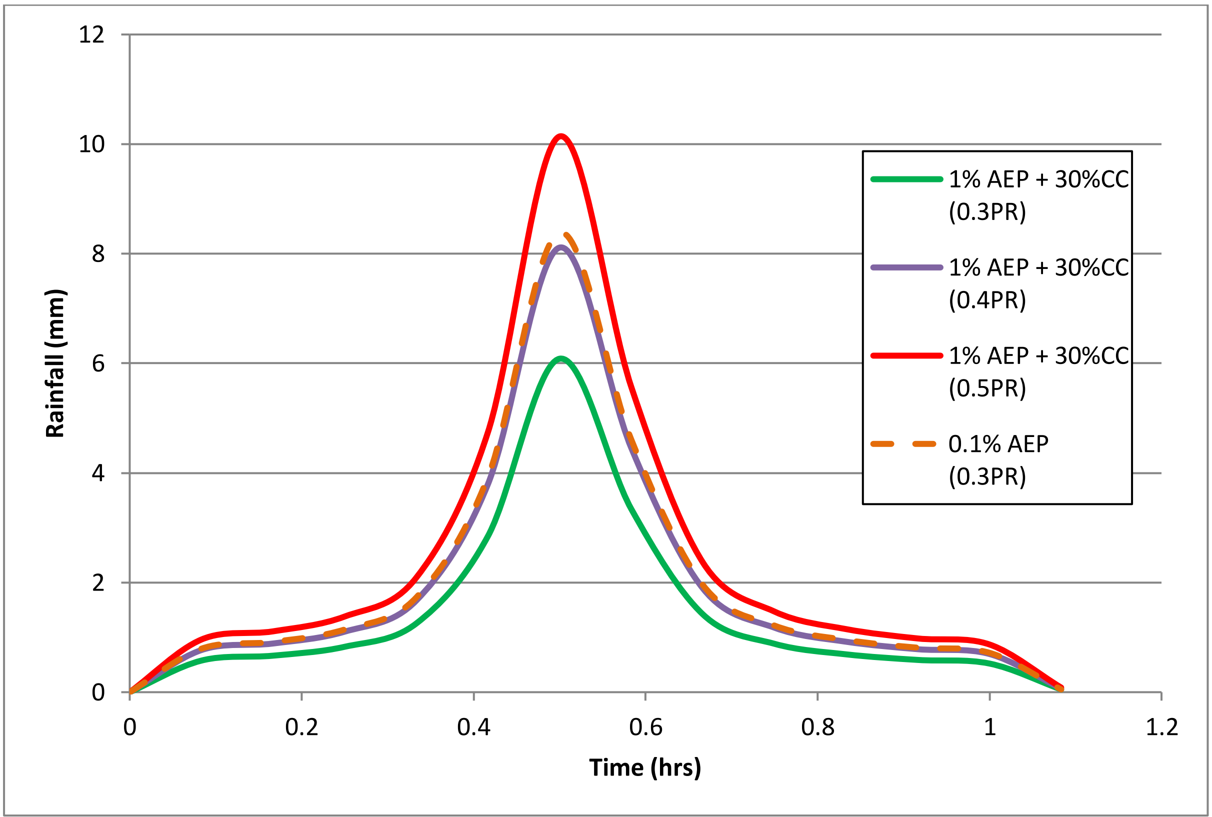

Figure 7-4: Comparison of Rainfall Hyetographs for Sensitivity Simulations

To assess the impact of increased runoff on the efficiency of the Proposed Option, a maximum flood depth difference map between the Proposed Option and Baseline scenario was plotted for the 40% and 50% percentage runoff scenarios. Figures 7-5 and 7-6 show that for both scenarios the magnitude of the overall benefit provided by the Proposed Option is commensurate with the 30% surface percentage runoff value used in this study. The areas of intended increased flooding, i.e. at attenuation storage areas, ditches and highways, remains the same and the Proposed Option continues to provide benefit downstream of Llanmaes.

[16] Entec 2009 Flood Consequence Assessment
[17] AECOM 2017 – St. Athan Northern Access Road Flood Consequence Assessment

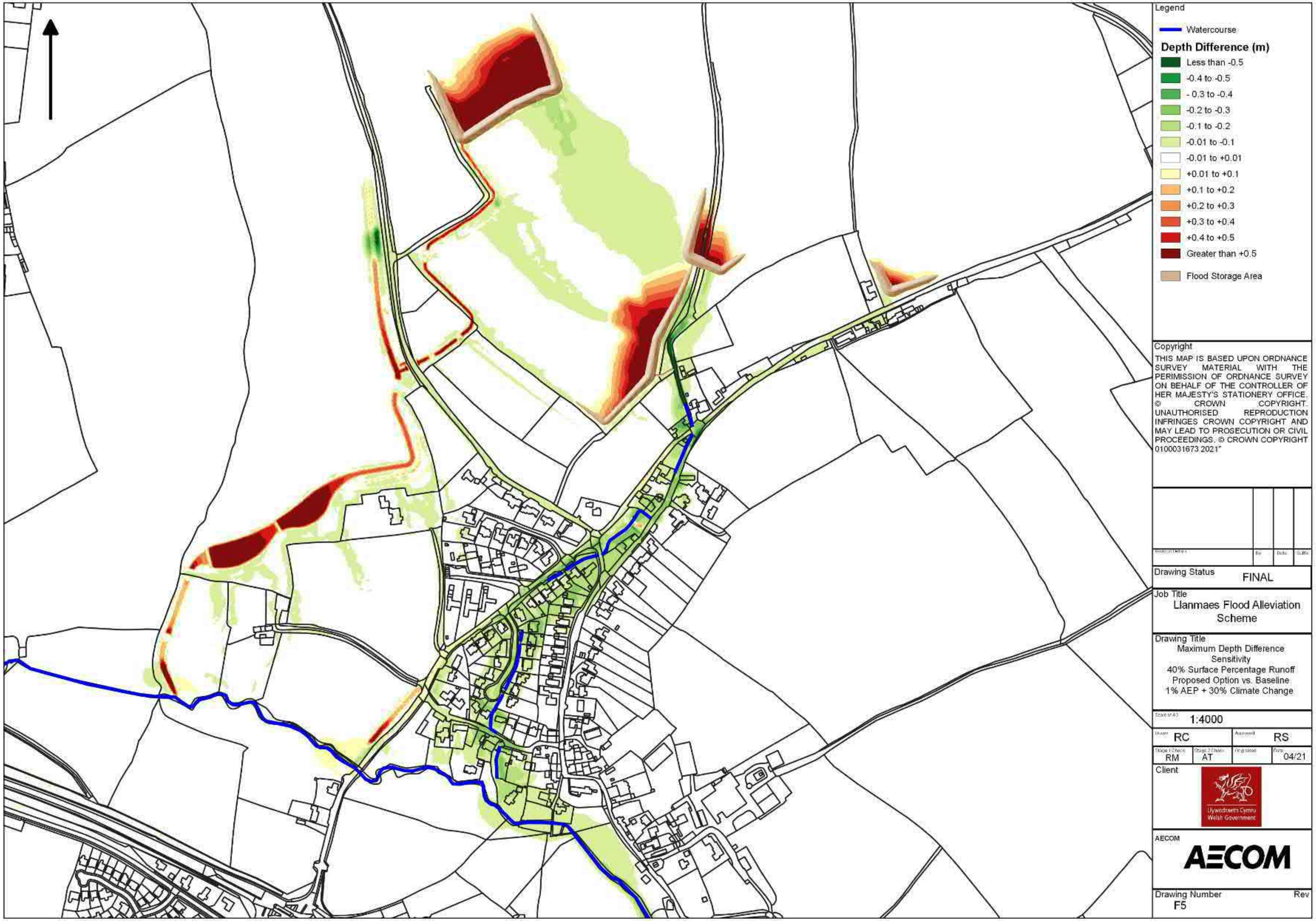

Figure 7-5: Maximum Depth Difference – 40% Surface Percentage Runoff Sensitivity, 1% AEP + 30%CC

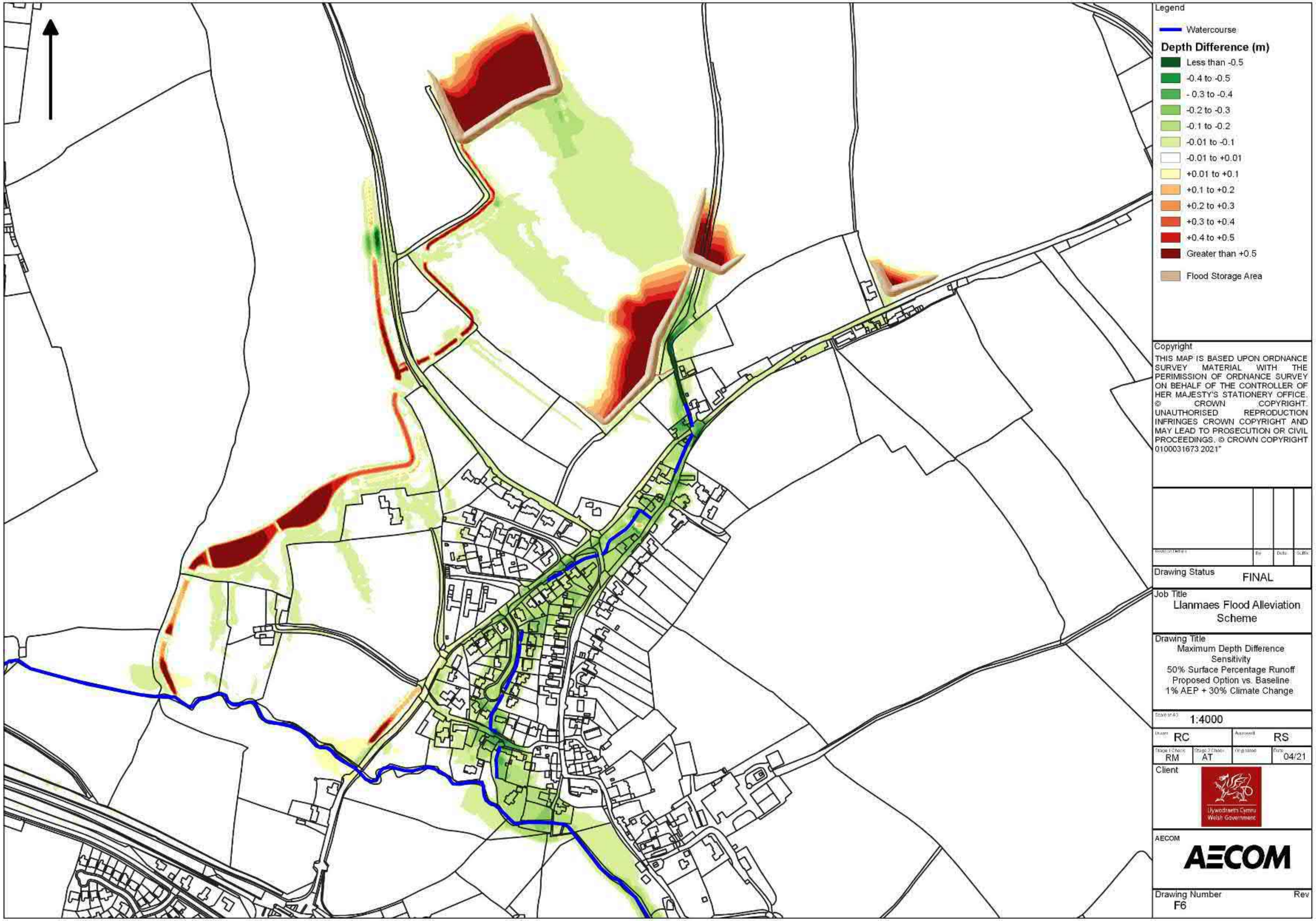

Figure 7-6: Maximum Depth Difference – 50% Surface Percentage Runoff Sensitivity, 1% AEP + 30%CC

As expected, with an increase in surface percentage runoff in the Llanmaes Brook catchment there is an associated overall increase in the flood depths for both the Baseline and Proposed Option sensitivity scenarios (Appendix F). Table 7-2 shows the number of inundated properties for the Baseline and Proposed Option for each sensitivity scenario. It has been demonstrated that the catchment percentage runoff does not increase the number of inundated properties in the Baseline scenario significantly.

The number of inundated properties in the Proposed Option scenario increases and there is a reduction in the overall benefit of the scheme from -57% down to -41% in the 50% surface percentage runoff scenario. The areas affected by increased flooding are at the Village Green, Tyle House Close, Low Road and along Llanmaes Brook (Appendix F) where the additional overland flow increases flood depths. However, it is noted that the maximum flood depths remain at a level that could be mitigated with Property Level Protection. This shows that the efficiency of the Proposed Option is sensitive to a catchment surface percentage runoff where it is tested as being greater than 40% but maintains flooding at a manageable level. A full presentation of flood depths in the sensitivity analysis can be found in Appendix F.

Table 7-2: Comparison of the number of flooded properties in PR sensitivity simulations

Annual Exceedance Probability (AEP) and Scenario	Baseline - Inundated Properties	Proposed Option - Inundated Properties	Inundated Properties – Reduction (Complete Removal)
1% + 30%CC (30% Percentage Runoff)	61	26	-35 (-57%)
1% + 30%CC (40% Percentage Runoff)	69	35	-35 (-49%)
1% + 30%CC (50% Percentage Runoff)	75	44	-31 (-41%)

The increased volume of water within the catchment as a result of greater surface runoff has the ability to affect the proposed attenuation storage volumes. Table 7-3 shows the attenuation volume associated with the Proposed Option during the sensitivity analysis. The maximum volume stored at the largest attenuation storage area (Storage area 1) increases from 4700m^3 to 8250m^3 during the 50% percentage runoff scenario. This demonstrates that the Proposed Option has the capacity to be effective even when there is increased runoff within the catchment and is maintained below the Reservoir Act (1975) threshold. However, the increase in storage volume is approximately 100% which shows that the attenuation volumes are sensitive to the catchment percentage runoff values.

Table 7-3: Comparison of attenuation storage volumes for PR Sensitivity simulations

Storage Area	1% AEP + 30%CC 30% Runoff	1% AEP + 30%CC 40% Runoff	1% AEP + 30%CC 50% Runoff
1	4700m^3	6600m^3	8250m^3
2	2600m^3	3750m^3	4850m^3
3	1000m^3	1350m^3	1750m^3
4	150m^3	250m^3	300m^3

The percentage runoff sensitivity analysis has demonstrated that the hydraulic model is sensitive to an increase in the value chosen for percentage runoff within the catchment. This has been shown to primarily impact the number of properties at risk of flooding at the Village Green - Tyle House Close, Low Road and Tara House - and also the attenuation storage volume in the proposed storage areas. However, it has been demonstrated that the Proposed Option is effective and provides benefit even with an increase in catchment percentage runoff up to 50%. Therefore,