St Athan Northern Access Road

FCA Appendix D

Welsh Government

February 2017

Quality information

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1. Introduction

This technical note confirms the methodology used to produce the Direct Rainfall Assessment (DRA) for the St. Athan Northern Access Road scheme. An ESTRY-TUFLOW model was provided by Natural Resources Wales (NRW) which was extended to include the Boverton Brook watercourse north of the Proposed Scheme. The received model was updated as described in Appendix E and adapted to a new direct rainfall model to assess the flood risk from pluvial sources. Mitigation measures were then designed to ensure there was no increased risk of pluvial flooding to surrounding areas as a result from the proposed scheme.

1.1 Commission

AECOM was commissioned by the Welsh Government to provide a Flood Consequence Assessment (FCA) for the development of a new 2km Northern Access Road (NAR) at St Athan (referred to herein as the proposed NAR). The proposed NAR concerns the construction of a new highway which will improve access to manufacturing facilities at MoD St Athan and unlock the site for potential development.

1.2 Model Development

AECOM carried out a preliminary Direct Rainfall Assessment (DRA) in October 2016 prior to receiving the approved NRW ESTRY-TUFLOW hydraulic model[1]. This investigation was used as a basis to understand the overland flow routes within the Boverton Brook catchment and initial impacts of the proposed NAR. Once the NRW model was received, the fluvial model setup was incorporated into a new pluvial model described within this report to ensure that both methods of assessing flood mechanisms are consistent.

A Direct Rainfall Assessment (DRA) was carried out to form a baseline representation of existing surface water flow routes of the Boverton Brook and upper Nant y Stepsau catchment, subsequent effects of the construction of the proposed NAR, and mitigation measures required to manage pluvial flood risk appropriately.

The pluvial model of the proposed site has been developed sequentially as follows:

- A hydrological analysis was undertaken of the Boverton Brook catchment to form design rainfall inputs for events with an Annual Exceedance Probability (AEP) of 20%, 1%, 1% + 30% Climate Change, 1% + 75% Climate Change and 0.1%;
- Analysis to find the critical storm duration from 60, 180 and 360 minutes was conducted;
- Creation of a broad scale 'Bare Earth' hydraulic model of the catchment (determined by 2014 LiDAR) at a 4m grid resolution;
- Baseline scenario modelling;
- The baseline flood model was then updated with the preliminary designs of the proposed scheme, including new road levels and bank alignments. This was used to identify surface water flood risk to the NAR and surrounding area; and
- The model for the proposed scheme was used to assess flood mitigation measures in order to demonstrate in concept that flood levels can be effectively managed without increased risk to the proposed scheme and third parties.

[1] AECOM 2016 - St Athan Northern Access Road Preliminary Direct Rainfall Assessment

2. Hydrological Analysis

2.1 Rainfall Analysis

To provide rainfall inputs into the pluvial model, a hydrological analysis was undertaken for the Boverton Brook catchment. In line with the scope of works, design rainfall profiles were generated for events with an Annual Exceedance Probability (AEP) of 20%, 1%, 1% + 30% Climate Change, 1% + 75% Climate Change and 0.1% using the Microdrainage software package. For each AEP, hyetographs were created for storms with durations of 60, 180 and 360 minutes with a winter profile.

Climate change allowances were taken from the Welsh Government 2016[2] guidance for FCAs. Boverton Brook and Llanmaes Brook are located within the Western Wales river basin district, the central estimate of potential change to peak river flows is 30% for this region, and the upper end estimate is 75%. It was agreed with NRW that the central estimate should be used.

2.2 Rainfall Catchment Analysis

The Proposed NAR crosses the hydrological catchments of Boverton Brook and the upper catchment of Nant y Stepsau. This also includes the contributing rainfall catchment of Llanmaes Brook, a tributary of Boverton Brook (Figure 2-1).

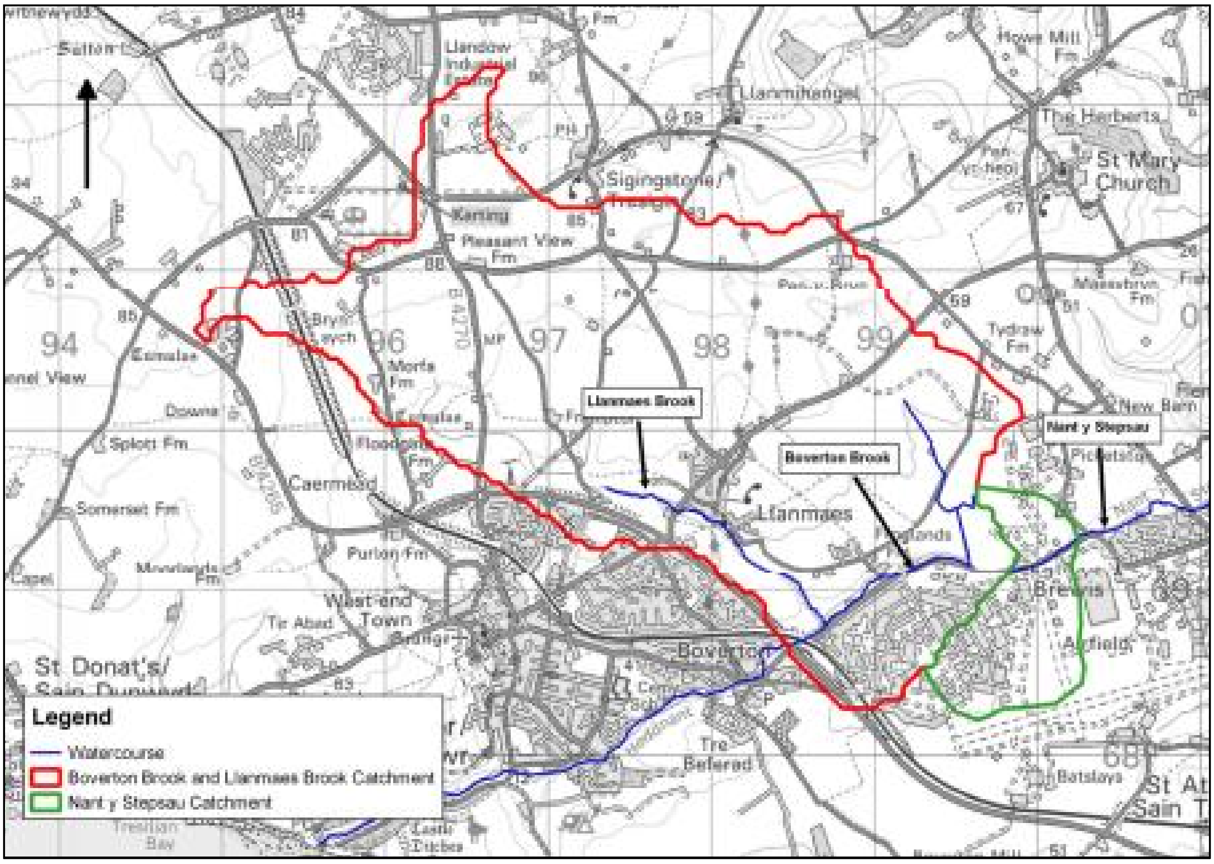


Figure 2-1: Boverton Brook Hydrological Catchment

2.3 Infiltration Losses

In order to calculate effective rainfall for application within a pluvial hydraulic model, it is necessary to account for losses attributable to infiltration and the capacity of the surface water drainage network within the catchment. Analysis of satellite imagery and land cover information within GIS demonstrated that the Boverton Brook catchment comprised of 95 % undeveloped land, with less than 5 % of the modelled area being characterised by

[2] Flood Consequences Assessments: Climate Change Allowances. Available from: http://gov.wales/topics/planning/policy/policyclarificationletters/2016/cl-03-16-climate-change-allowances-for-planning-purposes/?lang=en. Accessed 01/11/16

impermeable surfaces. Therefore the approach adopted assumed that all losses within the model domain were attributable to infiltration. Due to the rural nature of the modelled catchment, losses due to surface water drainage network were not represented.

Following the preliminary investigation in October 2016 by AECOM a runoff coefficient of 0.3 was selected based upon comparison of total rainfall volume and total runoff volume for the Boverton Brook catchment, calculated using the Revitalised Flood Hydrograph 2 (ReFH2) rainfall-runoff model. This analysis showed that approximately 30% of total rainfall contributed to surface runoff over the full storm duration. An example of the application of this runoff coefficient is shown within Figure 2-2, which shows total rainfall depth for the 0.1 % AEP plus climate change design event (60 minute storm duration), the depth of water lost to infiltration, and the resulting surface water runoff applied to the model domain. This same method was used to assess the runoff coefficient for the extended Boverton Brook catchment and confirmed to be consistent with the wider catchment.

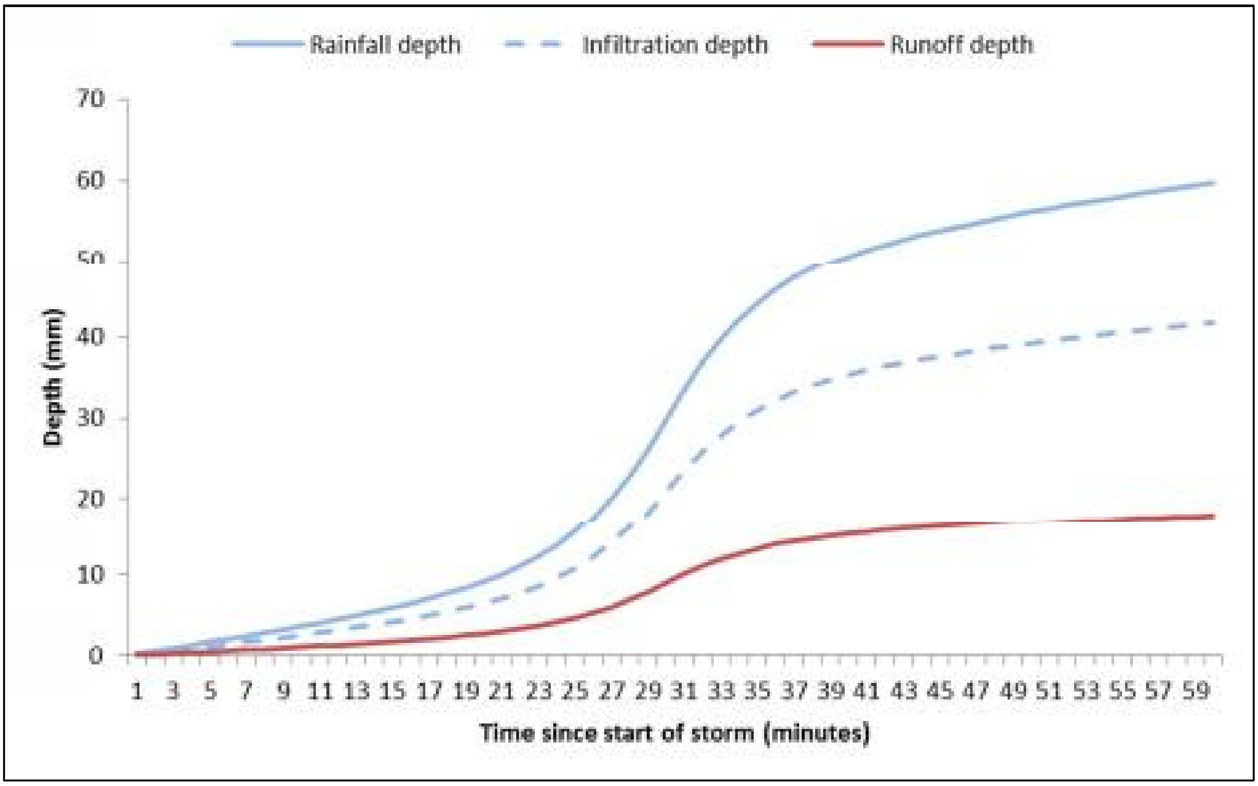


Figure 2-2: Calculation of the depth of surface runoff applied to TUFLOW domain through application of a runoff coefficient of 0.3 in order to account for infiltration (1 % AEP plus climate change design event, 60 minute storm duration)

The Entec 2009 Flood Consequence Assessment report indicates that the SPRHOST was adjusted from 11.7% (FEH CD value) to an SPR of 31.7%, based on the investigations into percentage runoff undertaken, which indicated a higher level of percentage runoff. This higher rate agrees with coefficients calculated as part of this investigation.

Overall, the hydrological analysis undertaken was considered to provide an appropriate estimate of surface water flood inundation throughout the contributing Boverton Brook catchment, when applied within the hydraulic model.

3. Baseline Scenario (Bare Earth)

A broad ‘Bare Earth’ direct rainfall hydraulic model was developed using the updated baseline fluvial model of Boverton Brook Brook and Llanmaes Brook described in Appendix E. To allow for a practical assessment of the overland flow regimes in the Boverton Brook and Nant y Stepsau Brook hydrological catchments, some changes were made to the model setup described in Appendix E. These changes are outlined in Sections 3.1 – 3.5.

3.1 Model Extent

The 1D-2D model was extended to incorporate the entire Boverton Brook hydrological catchment to the location downstream of the B4265 culvert (NGR 298454, 168667) and the partial Nant y Stepsau hydrological catchment to a location downstream of the MoD site (NGR 300305, 169363) (Figure 3-1). The grid resolution was increased from 2m in the fluvial model to 4m in the Direct Rainfall model to reduce the simulation time due to the larger model extent. The difference in grid resolution was tested as a sensitivity and deemed appropriate, especially given the rural nature of the primary site region.

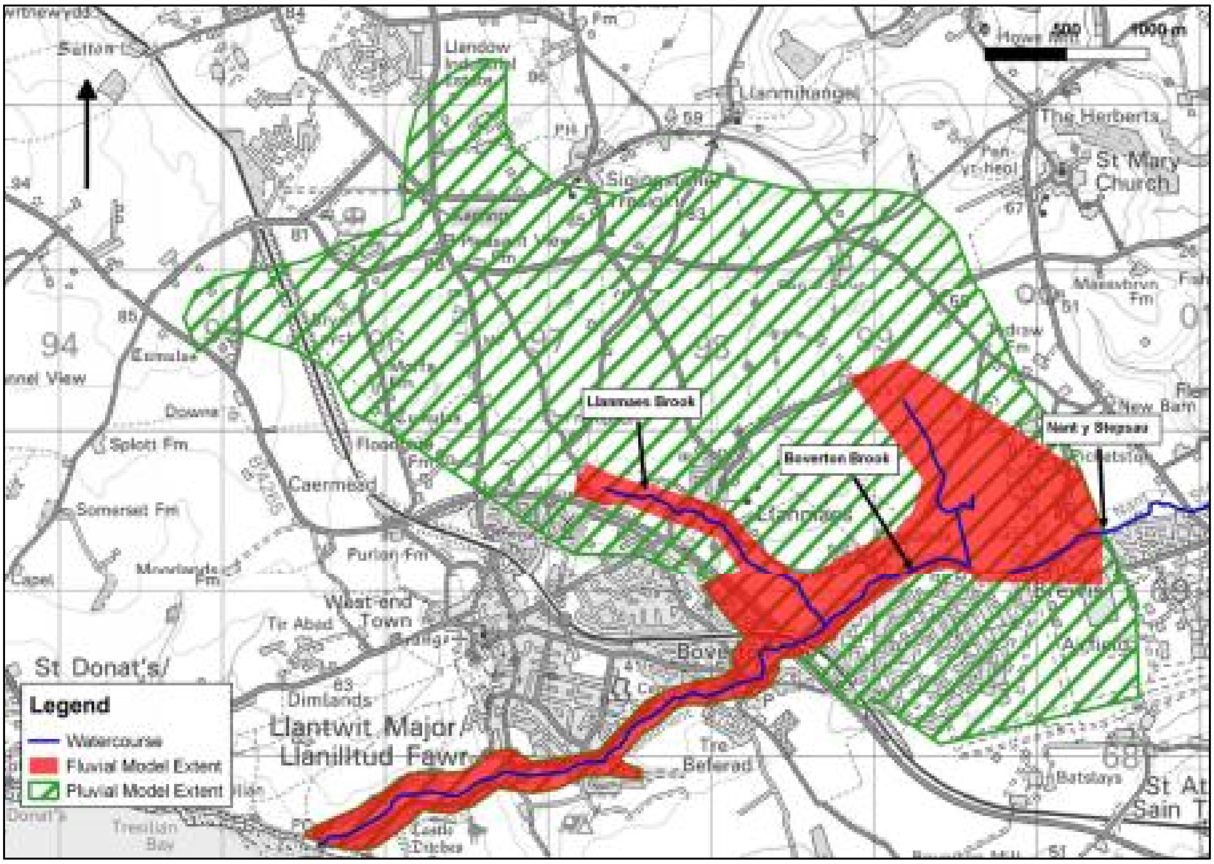


Figure 3-1: Extension of the pluvial 2D model domain

3.2 Topography

The extended topography was determined using LiDAR DTM obtained from NRW (2016), covering an area of approximately 20km^2 around the site. Due to a gap within the upper Boverton Brook catchment in this available LiDAR data (Figure 3-2), a topographic patch was introduced to represent the estimated fall of local terrain. This was achieved by digitising contours from OS 1:50000 mapping and using TUFLOW to interpolate between the contours to create the topographic surface for the missing LiDAR region only. In lieu of further additional data, this approach is considered appropriate given the size of area affected. However, it is recommended that any future development of the model procures surveyed data to address this gap.

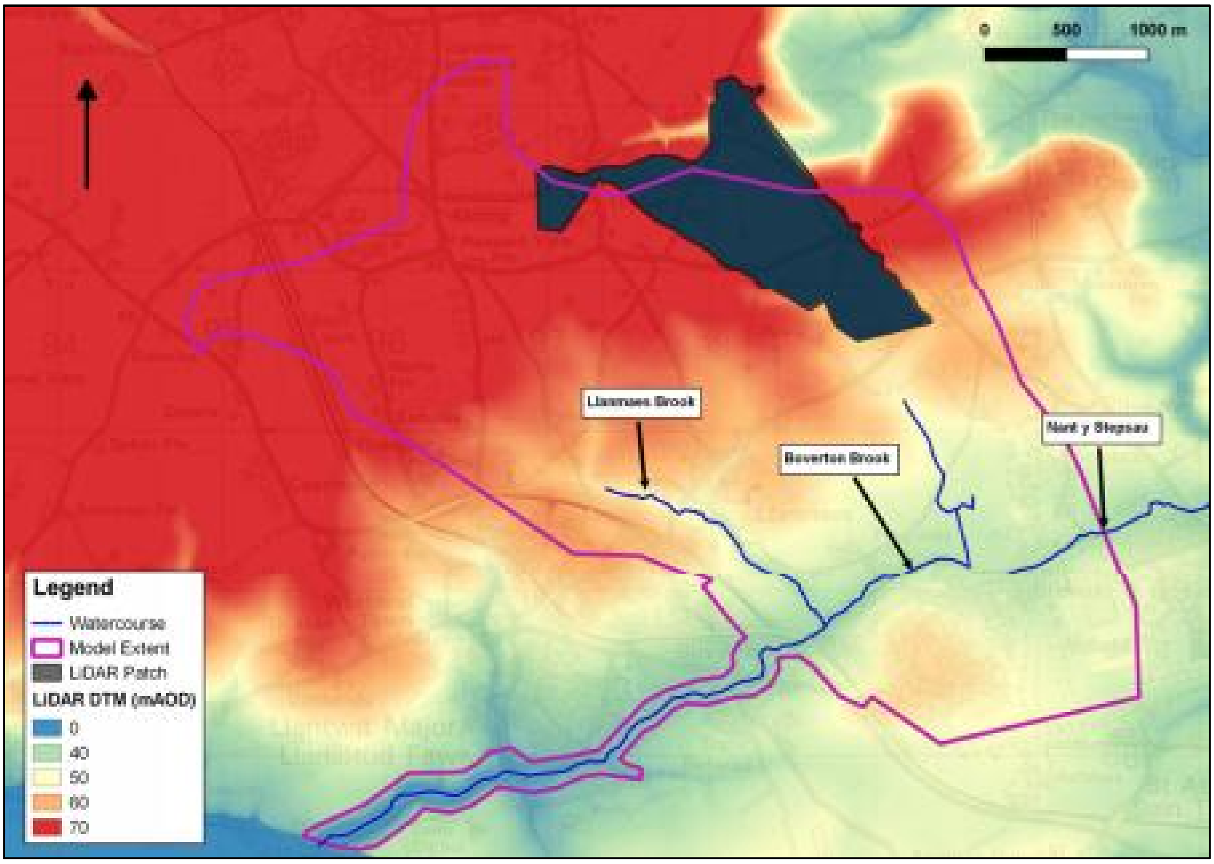


Figure 3-2: LiDAR DTM showing the location of the missing LiDAR data

3.3 Hydrological Inflows

To assess the overland flow routes within study area, a TUFLOW rainfall catchment was defined using the hydrological catchments described in Section 3.1. TUFLOW applies a specified rainfall hyetograph to grid cells within the defined rainfall catchment to analyse where surface water will flow.

To avoid the potential double counting of flows within the study area all 1D hydrological, inflows were removed from the fluvial model on Boverton Brook and Llanmaes Brook. This method means that the watercourses are dry at the beginning of the design storm event and allows all contributing flows from pluvial sources are accounted for and drive the eventual flows within local watercourses.

3.4 Roughness Coefficients

All Manning's Roughness Coefficients of the 1D and 2D domain were maintained from the Fluvial Model described in Appendix E. Where the model domain was extended, the same Manning's Roughness Coefficients were calculated using MasterMap polygons as the Fluvial model.

3.5 Critical Storm Duration

An assessment of Critical Storm Duration was performed during the October 2016 preliminary DRA. The critical duration is defined as the duration that gives the largest flow at the site of interest. Accordingly, the preliminary DRA was used to simulate the 60, 180 and 360 minute duration storms for the 100yr return period design rainfall event, including +30% for climate change. This model also included for no representation of infiltration or runoff coefficients to provide a worse case, fully saturated ground conditions throughout the catchment. A comparison of flood extent outlines demonstrated that the 60 minute storm duration was associated with the largest extent/depth of inundation and should be considered as the critical storm duration for the proposed site.

3.6 Model Runs

Simulations with Annual Exceedance Probabilities (AEPs) of: 20%, 2%, 1%, 1% plus 30% climate change, 1% plus 75% climate change, and 0.1% were conducted.

Blockage simulations of 1% AEP plus 30% climate change and 0.1% AEP were run with 100% blockage of the main culverts.

4. Baseline (Bare Earth) Model Results

Once the NRW fluvial model had been combined with the pluvial model and updated with the changes described in Section 3 the baseline model was simulated using 60 minute storm for the design events with Annual Exceedance Probabilities (AEPs) of: 20%, 1%, 1% plus 30% climate change, 1% plus 75% climate change, and 0.1%. This was inclusive of a 30% runoff coefficient applied to the rainfall catchment as described in Section 2.

The complete model results for these simulations can be found in Appendix D1.

4.1 Primary Flow Paths

The baseline model results show that there are a number of overland flow paths that enter Llanmaes Brook, Boverton Brook and Nant y Stepsau from the surrounding catchment that could potentially be impacted by the proposed NAR. Figure 4-1 shows the location of these key overland flow routes identified during the 1% + 30% Climate Change Flood Event. The results show that besides the Boverton Brook and Llanmaes Brook channels there are three large flow routes that are most pertinent to this study. These are Froglands Farm, the agricultural land between Froglands Farm and Boverton Brook and the flow route into Nant y Stepsau from the south.

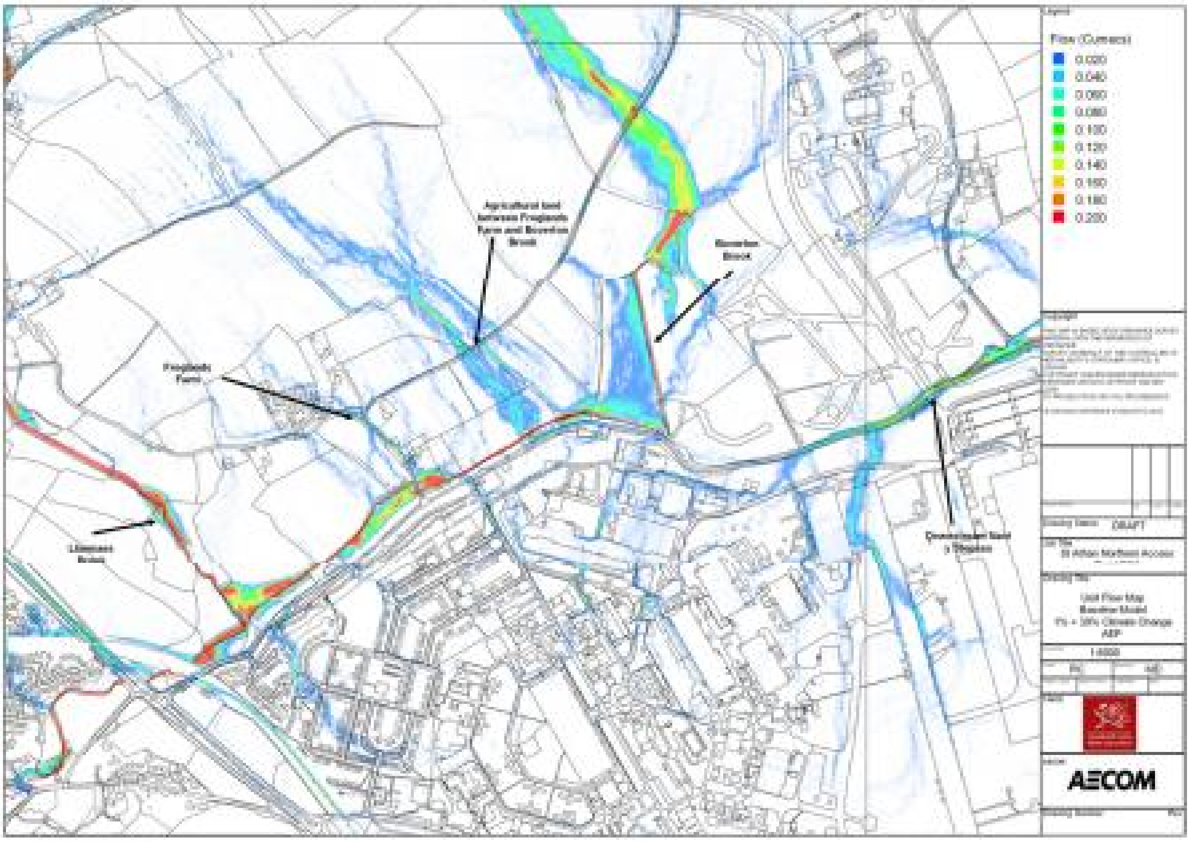


Figure 4-1: Baseline overland flow for the 1% + 30% Climate Change AEP event

To assess the magnitude of overland flow within the baseline model, 2D PO Lines were schematised in TUFLOW along the key flow paths described above and the model was re-simulated. PO lines calculate the cumulative magnitude of flow across the whole PO for each timestep of the model simulation.

Table 4-1 shows the maximum flow across the flow paths during the 1% + 30% Climate Change AEP event.

Table 4-1: Maximum overland flow, Baseline, 1% + 30% Climate Change AEP event

Location	Maximum Flow (m^3/s)
Froglands Farm	0.86
Fields between Froglands Farm and Boverton Brook	2.80
Downstream on Nant y Stepsau	2.19

It is noted that no assessment of the existing drainage systems of the MoD site to the south of Nant y Stepsau has been carried out as part of this investigation. As such, the flows entering Nant y Stepsau are considered to be a worse-case scenario where surface water runoff is not attenuated.

4.2 Flood Depths

An initial analysis of the results demonstrates pooling of maximum water to depths of over 1.0m at the confluence with Llanmaes Brook and the Froglands Farm bridge crossing during the 1% + 30% Climate Change AEP event. This area of higher depth is expected as this denotes the topographical depression within the 2D domain associated with the LiDAR DTM.

The model also predicts the flooding of the unnamed highway that runs along the south side of Boverton Brook to a depth of 0.45m during 1% + 30% Climate Change AEP event. Flooding of the highway in the Nant y Stepsau catchment suggests that at present the highway becomes inundated even in the 20% AEP flood event (Appendix D1).

Figure 4-2 shows the flood depths for the 1% + 30% Climate Change event

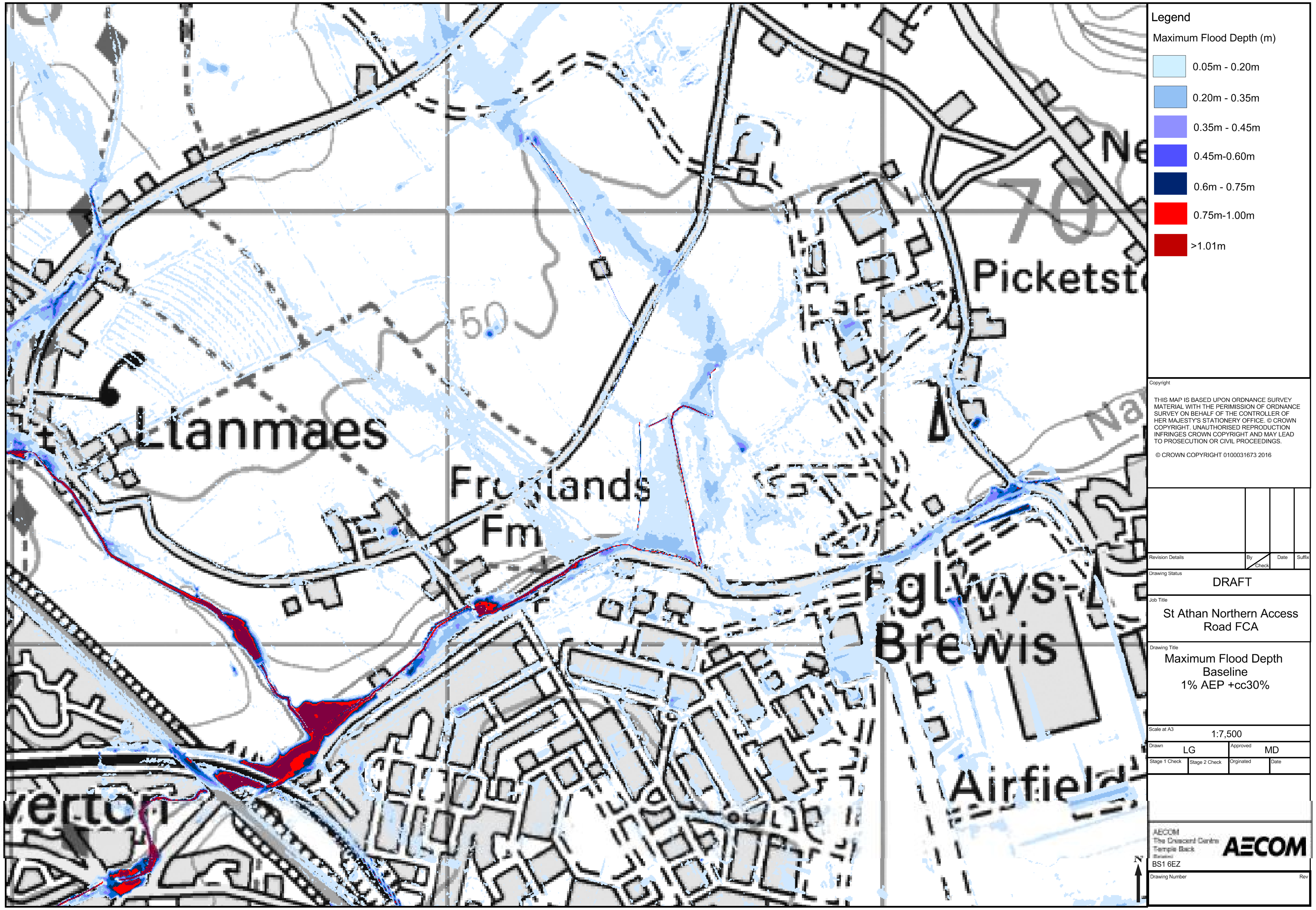


Figure 4-2: Maximum Flood Depth, Baseline Scenario, 1% + 30% Climate Change AEP

4.3 Downstream Channel Flows

To understand the downstream flows on Boverton Brook within the pluvial model, a 1D node immediately downstream of the railway culvert was chosen to extract in-channel flows (Figure 4-3). This location was chosen because it falls within the rainfall catchment and considered to account for all flows in the Boverton Brook and Llanmaes Brook catchment.

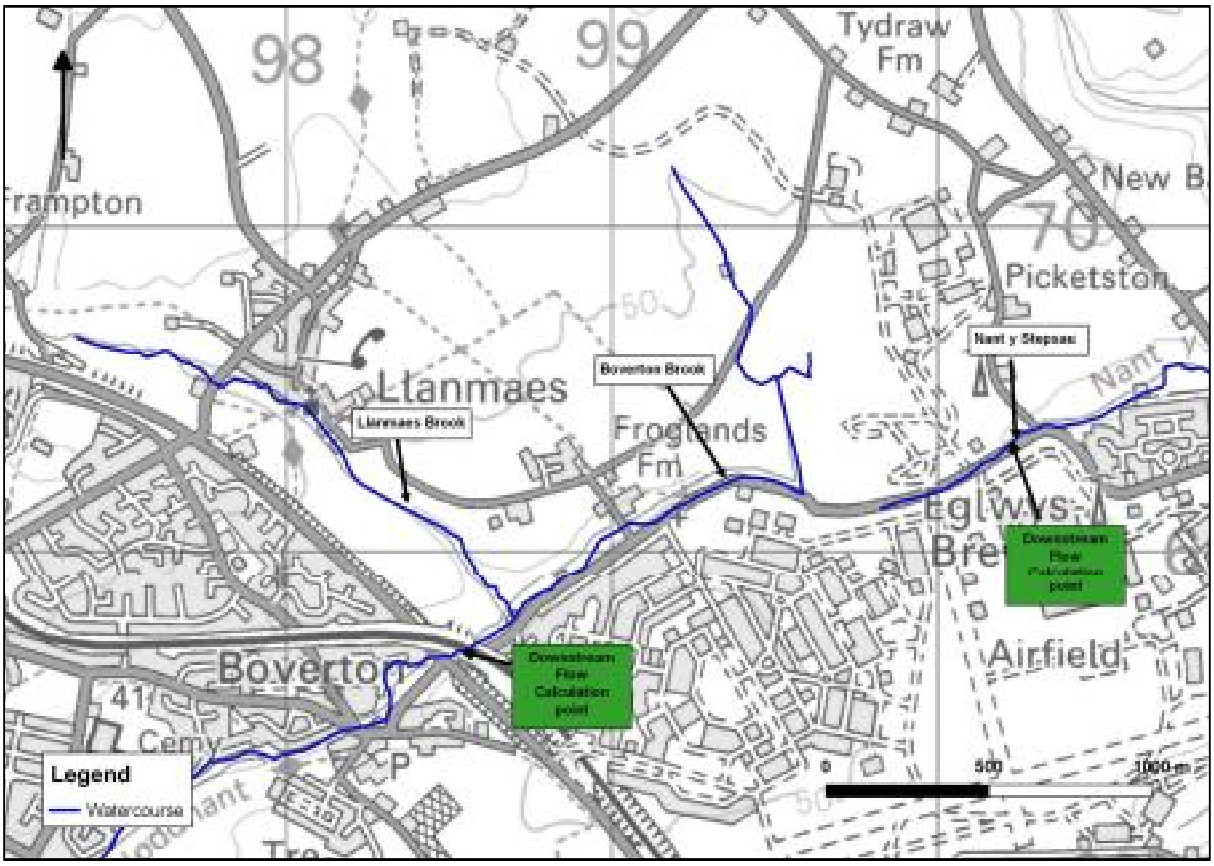


Figure 4-3: Location of flow estimations in the pluvial model

The flows within the pluvial model were compared with those from the fluvial model at the same location. Table 4-2 demonstrates that flows within the pluvial model are greater during the 1% + 30% Climate Change scenario and therefore provide a more conservative estimate of overall flow.

Table 4-2: Downstream baseline flows on Boverton Brook for 1% + 30% Climate change event

Model	Flow (m^3/s)
Fluvial	9.3
Pluvial	12.5

4.4 Baseline Model Verification

Anecdotal evidence from the flooding event of November 2016 demonstrates that during large rainfall events the highways around Frogland's Farm becomes inundated and act as conduits to flow. Further to this, local landowners suggest that the fields between Frogland's Farm and Boverton Brook become heavily inundated during large storm events.

This is consistent with the model results demonstrated in Figure 4-1

5. Proposed Scenario Model Results

To assess the impact of the proposed scheme on the overland flow routes within the study area, the NAR was added to the Baseline model and simulated for the 1% + 30% Climate Change AEP event. The NAR was incorporated through alterations to the DTM, these included regions of land raising and land lowering to reflect the design levels of the NAR. A materials patch was also created for the NAR region to represent the change in catchment roughness. Modifications were also made to both Llanmaes and Boverton Brook to remove the cross sections representing sections of open watercourse where the proposed NAR was located. Figure 5-1 shows the location of the proposed NAR and the location of the surrounding watercourses.

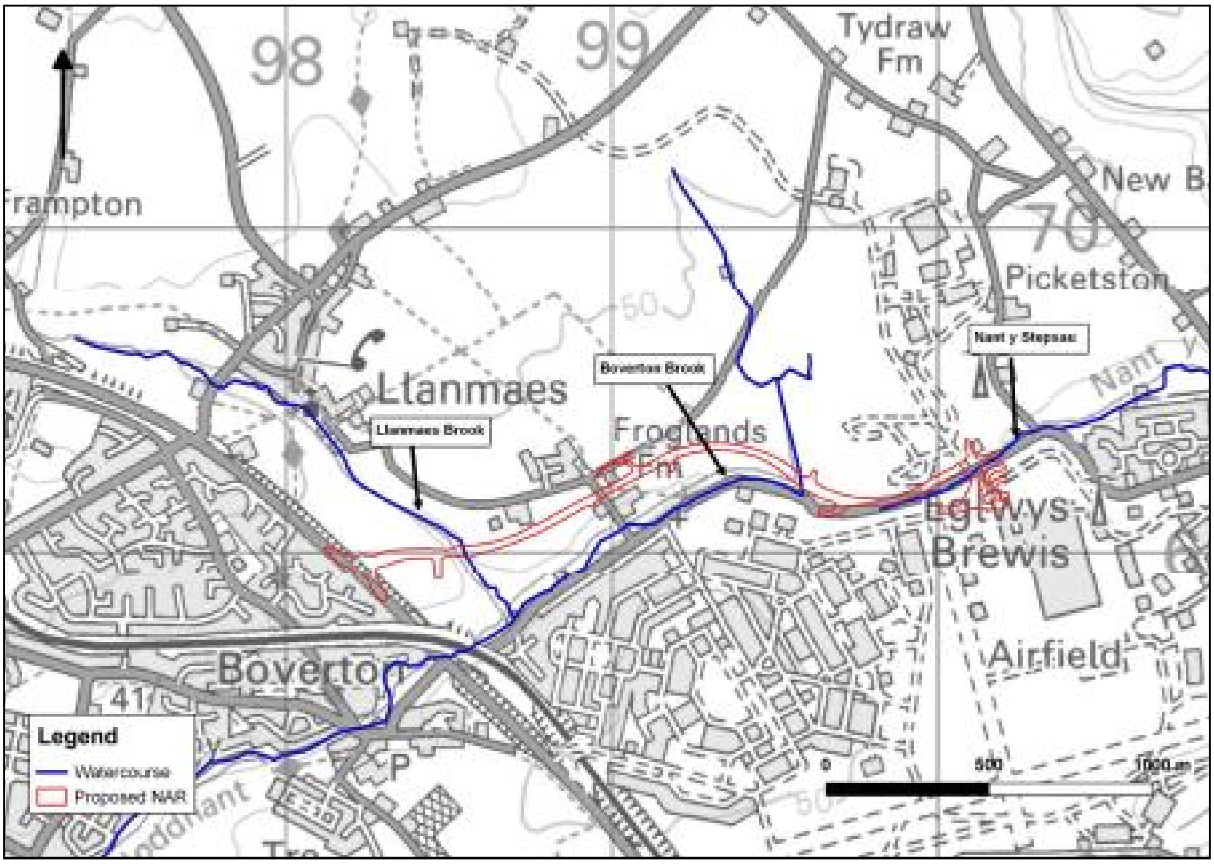


Figure 5-1: Location of the Proposed NAR

5.1 Flood Depths

The model results show that the Proposed Scheme intersects a number of primary flow paths identified in Section 4. Figure 5-2 demonstrates that without any flood mitigation measures there is an increase in flood depths on the north and upstream side of the NAR within the Boverton Brook catchment and on both sides of the NAR within the Nant y Stepsau catchment during the 1% + 30% Climate Change AEP event. This is most prevalent at Llanmaes Brook, Frogland's Farm, agricultural land between Froglands Farm and Boverton Brook, Boverton Brook and on the south side of the NAR along the primary course of Nant y Stepsau. Flood depths around Frogland's Farm reach approximately 0.6 - 0.8m during the 1% + 30% Climate Change AEP event.

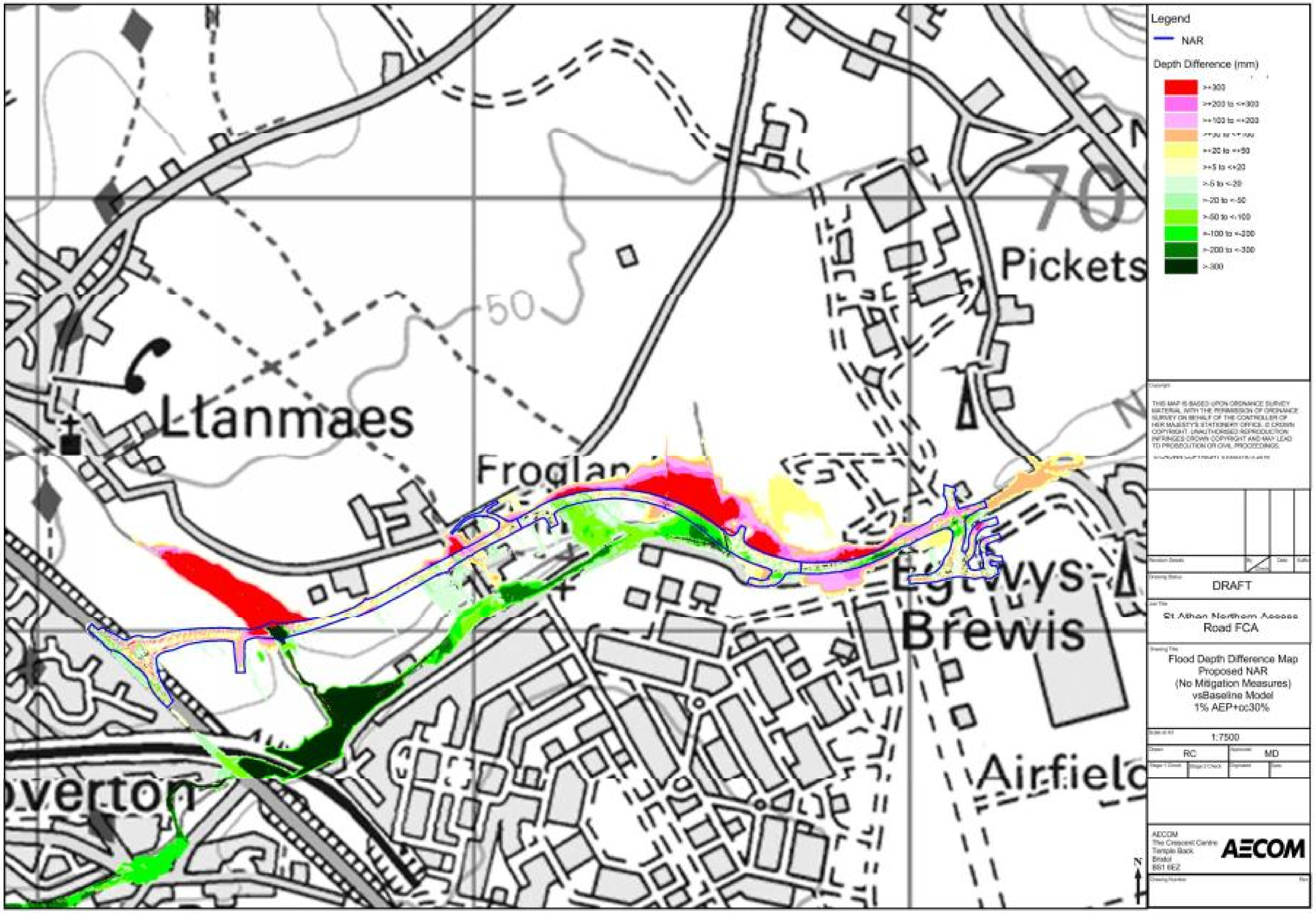


Figure 5-2: Flood Depth Difference Map, 1% + 30% Climate Change ,Proposed NAR (No Mitigation Measures) vs Baseline

Figure 5-2 demonstrates that there is an overall reduction of flood depths of up to 0.5m downstream of the proposed NAR. As a result of this ponding there is a decrease in peak flows directly downstream of the railway culvert from 12.5 m^3/s to 8.3 m^3/s for the Proposed NAR with no mitigation measures. These results are consistent with those found in the fluvial model described in Appendix E Section 4.2

5.2 Drainage Catchment Definition

The direct rainfall model was then used to identify and confirm the smaller drainage catchments described within the Drainage Strategy in Appendix G. For the purpose of this report it is assumed that any water falling onto the NAR is removed from the highway through the drainage network as described within the drainage strategy. This report will describe any flow from the surrounding area that may impact upon the NAR. Figure 5-3 provides an overview of the local drainage catchments.

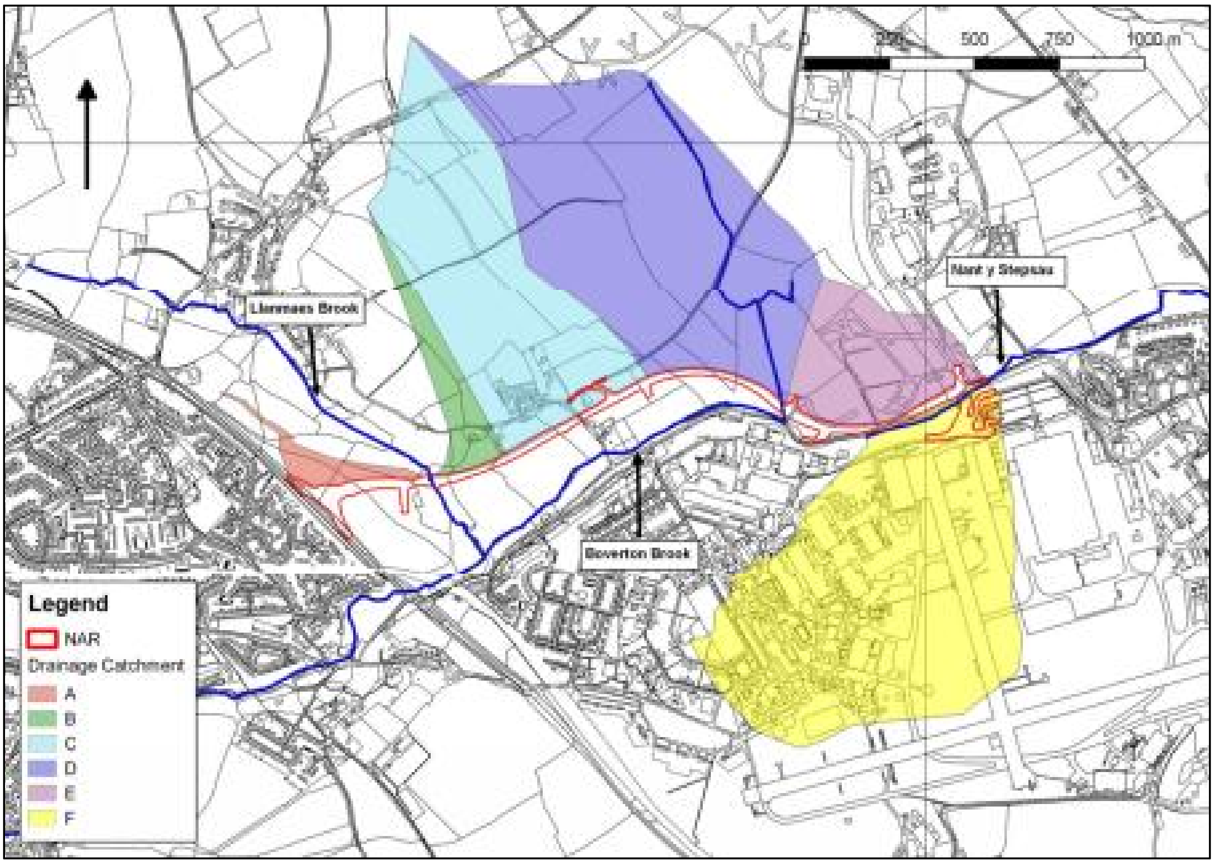


Figure 5-3: Approximate Local Drainage Catchment

6. Mitigation Options

6.1 Overview

It has been demonstrated in Section 5 that the proposed scheme reduces the maximum flood depths observed downstream of the NAR by 0.5m in the Direct Rainfall model for the 1% + 30% Climate Change AEP event. However, Figure 5-2 shows that at Llanmaes Brook, Froglands Farm, Boverton Brook and Nant y Stepsau there is an increase on flood depths on the north and south side of the NAR and also inundation of the highway. To address this, a series of flood mitigation options were developed in tandem with the fluvial model described in Appendix E and the Drainage Strategy described in Appendix G.

At this stage, the 1D-2D fluvial model was combined with the pluvial model with the inclusion of all the topographic and structural changes described in Appendix E once the development of the flood storage areas had been completed. Through an iterative process it was found that the pluvial model produced larger storage volumes for an equivalent return period event than the fluvial model at Boverton Brook and Llanmaes Brook. As such, the most conservative approach has been taken and the final flood storage areas have been designed using the pluvial model results. These were then verified by the fluvial model to ensure that in both models the following requirements have been met:

- Any flood storage areas should hold a volume of less than 10,000m^3 in all events including blockage scenarios;
- that no additional water is discharged into the Nant-y-Stepsau as a result of construction of the proposed scheme;
- to ensure no increase in flows through Boverton; and, that no overtopping of the road occurs during the Q100+ CC30% event.

The drainage of the NAR highway and embankments will not be considered further in this report (Appendix G). Mitigation options have been developed in tandem with the Drainage Strategy to ensure that highways drainage and overland drainage are kept separate from one another.

6.2 Mitigation Measures

A series of mitigation options were developed to address the criteria set out in Section 6.1. Figure 6-1 shows an overview of the proposed flood mitigation methods and the approximate drainage catchments.

The development of the flood storage areas and culvert optimisation on Llanmaes Brook and Boverton Brook has been described in detail within Appendix E (Section 4.3.6). For the purpose of the report, this will not be repeated here, however the development of surface water flood mitigation measures are described in further detail in Section 6.2.1 – 6.2.5

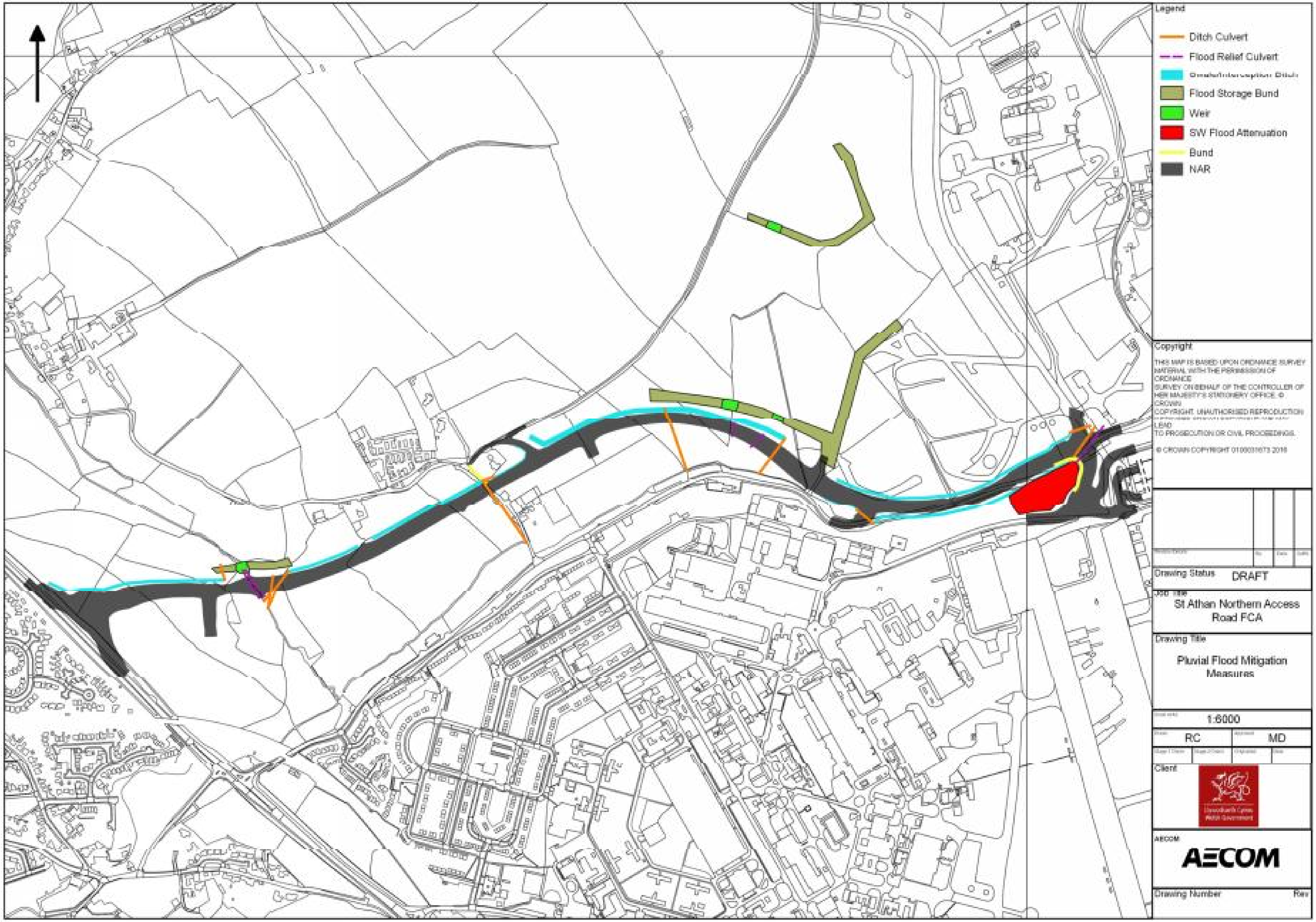


Figure 6-1: Overview of Flood Mitigation Measures

6.2.1 Overland Drainage Ditches

A series of swales and interception ditches were designed to convey surface water along the north side of the NAR to prevent ponding of water along the embankment, flooding of the NAR and erosion of the NAR embankment. These were schematised using 1D ESTRY elements connected to the 2D domain to ensure that the hydraulic capacity of the ditches was correctly represented when using a 4m model grid. All elements are considered to have a Manning's Roughness value of 0.067 which is consistent with the drainage channels within Boverton Brook. All swales and interception diches are located within Welsh Government owned land.

Figure 6-2 shows the location of the surface water swales and interception ditches and Table 6-1 shows the dimensions of these the ditches and swales.

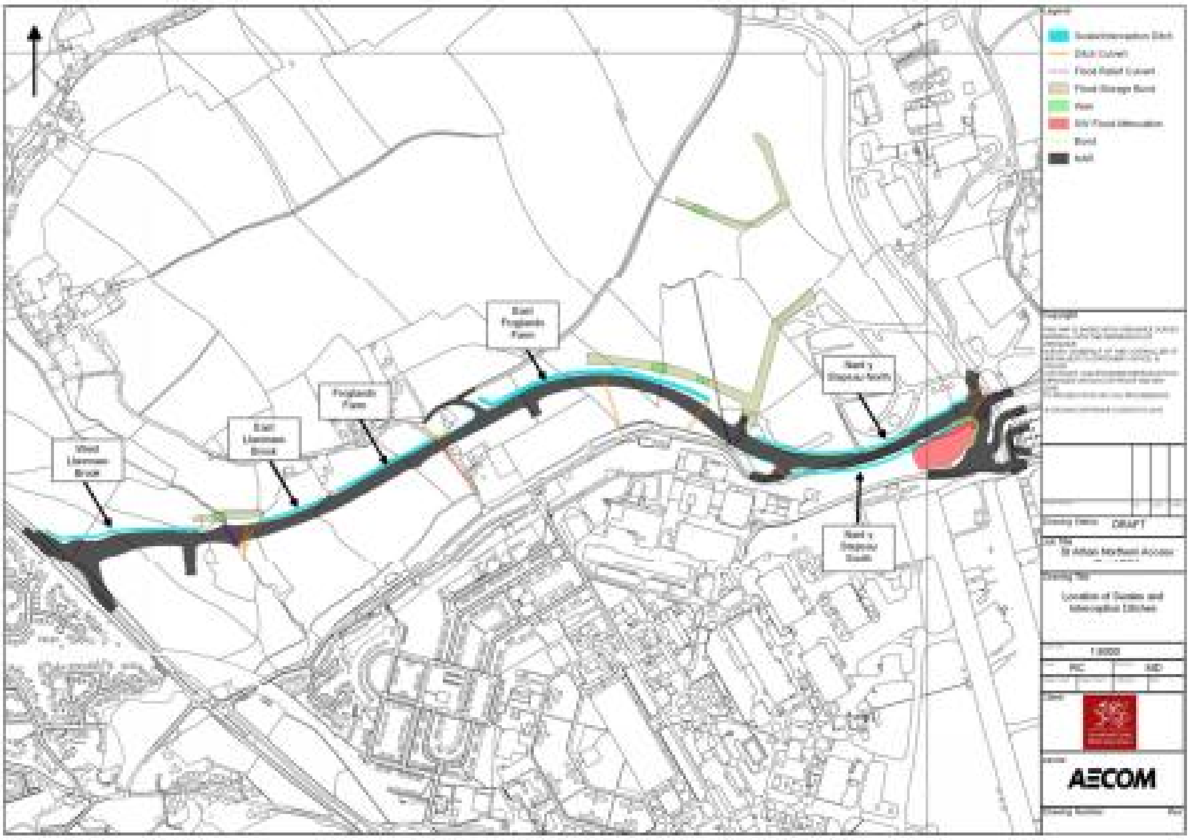


Figure 6-2: Location of surface water swales and interception ditches

Table 6-1: Specification of swales and interception ditches

Location	Catchment	Depth (m)	Base Width (m)
West Llanmaes Brook	A	0.6	1
East Llanmaes Brook	B	0.6	1
Froglands Farm	C	1	6
East Froglands Farm	C/D	1	2
Nant y Stepsau (North)	E	0.6	1
Nant y Stepsau (South)	F	0.6	2

It is noted that that the Froglands Farm swale is oversized to allow for capacity to store water in large flood events. This will ensure there is no flood risk to the surrounding property as a result of the proposed NAR.

6.2.2 Ditch Culverts

To ensure the continued conveyance of water along the swales and interception ditches a series of culverts were schematised using ESTRY 1D culvert elements at the downstream extent of the ditches. Figure 6-3 shows the location and capacity of these culverts. Each culvert was assigned a Manning's Roughness value of 0.014 which is consistent with all culverts within the received NRW fluvial model.

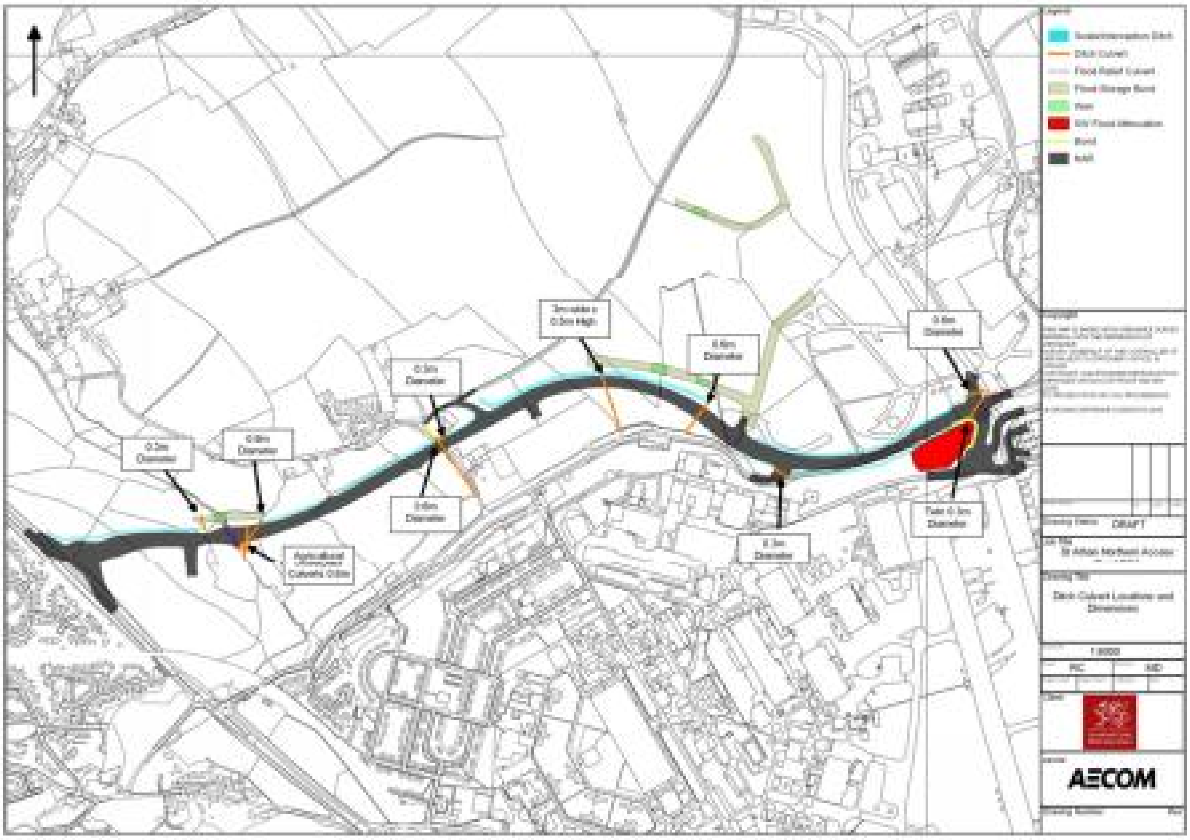


Figure 6-3: Ditch Culvert Location and Dimensions

It is noted that there are two culverts located within the East Froglands Drainage Ditch. The overland flow path identified in Section 4.1 demonstrated that the magnitude of flow entering this drainage ditch is in the order of 2.8m^3/s during the 1% + 30% Climate Change AEP event. Therefore a larger 3m wide by 0.5m culvert was located at the upstream extent of the ditch to remove a significant proportion of this flow and direct it towards Boverton Brook. This ensures that overland flow from the ditch does not interfere with the functionality of the flood relief culverts (Appendix E).

6.2.3 Flood Storage Areas

In addition to the three flood storage areas at Boverton Brook (two areas) and Llanmaes Brook (one area) described in Appendix E, initial pluvial results showed that a further flood storage area was required at Nant y Stepsau to accommodate overland flow routes from Catchment F to the south of the NAR (Figure 4-1). Figure 6-4 shows the location and arrangement of the Nant y Stepsau flood storage area. The baseline scenario shows that at present it is predicted that the highway becomes inundated to a depth of 0.3m during the 1% + 30% Climate Change AEP event (Figure 4-2). To prevent the inundation of the proposed NAR and control the flows entering Nant y Stepsau downstream of the NAR, an attenuation basin and low level flood bund was stamped into the topography using a z-shape. The attenuation basin is set to a base level of 40.2m AOD and bund is set to 41.25m AOD. The latter is set to the maximum flood level of the 1% + 30% Climate Change with 100% blockage of the primary culvert to ensure no flooding of the highway during this event (see Section 6.2.4).

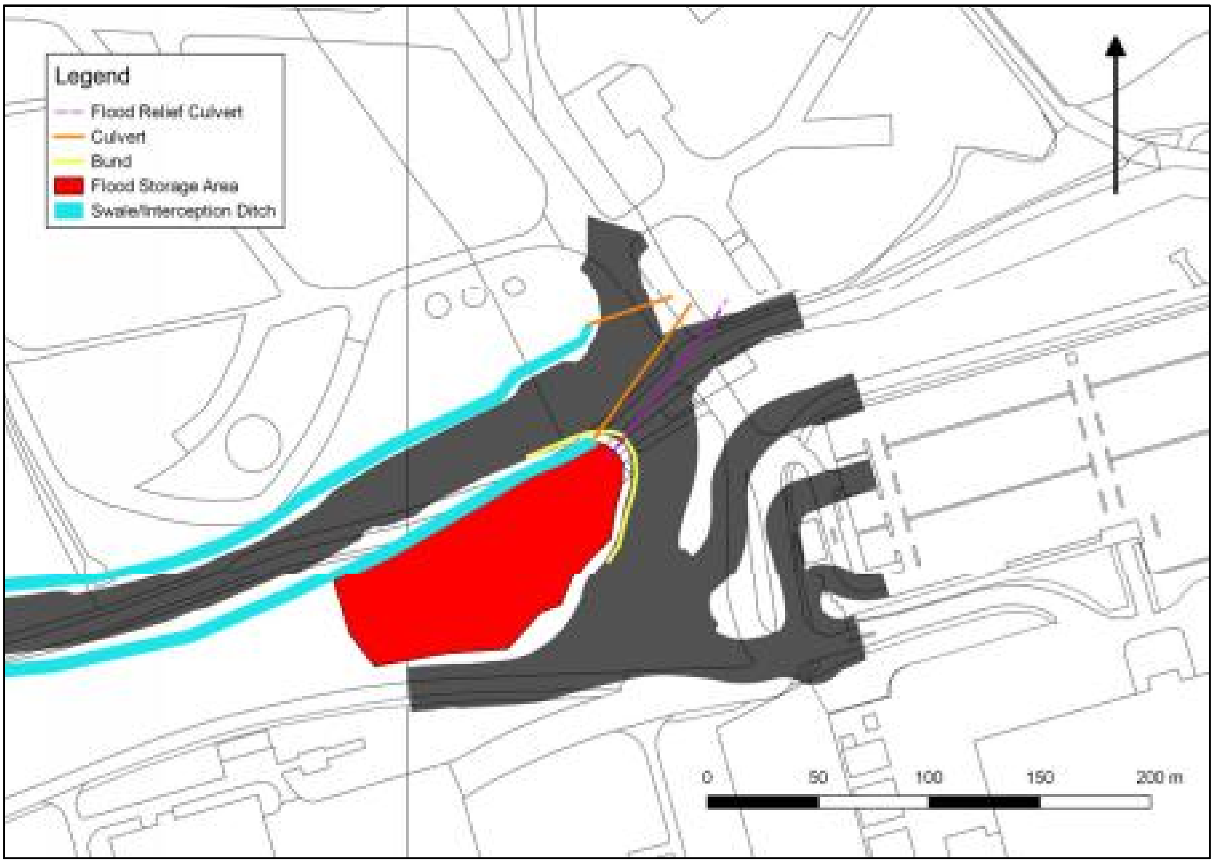


Figure 6-4: Nant y Stepsau Flood Storage Area

A detailed specification of the flood storage areas, weir levels for Llanmaes Brook and Boverton Brook can be found in Appendix E.

6.2.4 Flood Relief Culverts

During the development of flood mitigation measures it was decided that flood relief culverts would be required at Frogland's Farm and the flood storage area at Nant y Stepsau to ensure that there was no additional flood risk in the event of a culvert blockage (Section 8). Table 6-2 details the specification of the flood relief culverts

Table 6-2: Specification of Flood Relief Culverts

Flood Relief Culvert	Culvert Type	Number of culverts	Dimensions (w x h) (m)	Upstream Invert (m AOD)
Froglands Farm	Circular	1	0.6	41.6
Nant y Stepsau	Rectangular	3	1 x 0.3	40.4

A detailed specification of the flood relief culverts on Llanmaes Brook and Boverton Brook can be found in Appendix E.

6.2.5 Topographic Changes

To ensure that there is no increase in flood risk to the Froglands Farm property, a 1.0m high bund was added to the west and north side of the property using a z-shape. This bund would form the highway boundary and not encroach on private land.

7. Mitigation Options Results

The finalised flood mitigation measures were incorporated into the pluvial model and simulated using 60 minute storm for the design events with Annual Exceedance Probabilities (AEPs) of: 20%, 1%, 1% plus 30% climate change, 1% plus 75% climate change, and 0.1%. This was inclusive of a 30% runoff coefficient applied to the rainfall catchment as described in Section 2. A complete set of results can be found in Appendix D2.

The model results for the Proposed Scenario with flood mitigation measures were then compared to the baseline results to assess the impact to flood risk to and from the NAR. Figure 7-1 shows that there is an overall reduction in flood depths of up to 150mm for the 1% + 30% Climate Change AEP event when compared to the Baseline scenario for the land downstream of the proposed NAR. This is most pronounced along the Boverton Brook channel where there is presently storage within the floodplain. Notably there is a reduction of between 0.01 – 0.03m to the east of the Froglands Farm and to the properties to the south of Froglands Farm. There is also no flooding of the NAR highway at Nant y Stepsau that was described within the baseline scenario.

This reduction in flood depths is observed in all Annual Exceedance Probability events (Appendix D2). This demonstrates that the flood mitigation measures will result in a reduction of flood risk downstream of the NAR.

There is an expected increase in flood depths around the designated flood storage areas and drainage ditches at Llanmaes Brook, Boverton Brook and Nant y Stepsau (Figure 7-1). Beyond the eastern end of the upstream storage at Boverton Brook there is an increase in flood depths of up to 70mm during the 1% + 30% Climate Change event however, given the severity of the flooding event, the location within agricultural fields this is not considered to be a significant increase in flood risk.

The upstream flood storage areas were then assessed to ensure that the volumes remained below the 10,000m^3 desired limit. To calculate the flood storage a polygon was drawn around the maximum flood extent. This was defined as the extent to which the maximum water level remains the same upstream of the flood bund. This method ensures that all flood water abutting the flood bund as a continuous water body is calculated. Once defined, a buffer added around this to ensure all flood volumes were included. The Region inspection tool in MapInfo was used to calculate the total volume within the polygon based upon the maximum depths within each grid square. The same polygon was used for both the fluvial and pluvial models. Figure 7-2 shows the location of the polygons when compared to the flood depths.

Table 7-1 shows a comparison of the flood storage volumes during 1% + 30% Climate Change AEP event between the fluvial and pluvial hydraulic models. It can be seen that the volumes within the pluvial model are significantly larger than those found in the fluvial model. This suggests that the pluvial model provides a more conservative estimate of the final volumes within the storage areas.

Table 7-1: Comparison of flood storage volumes between the pluvial and fluvial model

Flood Storage Location	1%+30% Climate Change Pluvial Storage Volume (m^3)	1%+30% Climate Change Fluvial Storage Volume (m^3)
Llanmaes Brook	6,442	5,443
Boverton Brook Upstream	6,550	3,934
Boverton Brook	5,311	2,012
Nant y Stepsau	7,041	N/A

A further assessment was carried out for blockage scenarios of the main culverts to ensure that no storage area increased over 10,000m^3 for a 100% blockage in the 1% + 30% Climate Change and 0.1% AEP events. This is further described in Section 8.

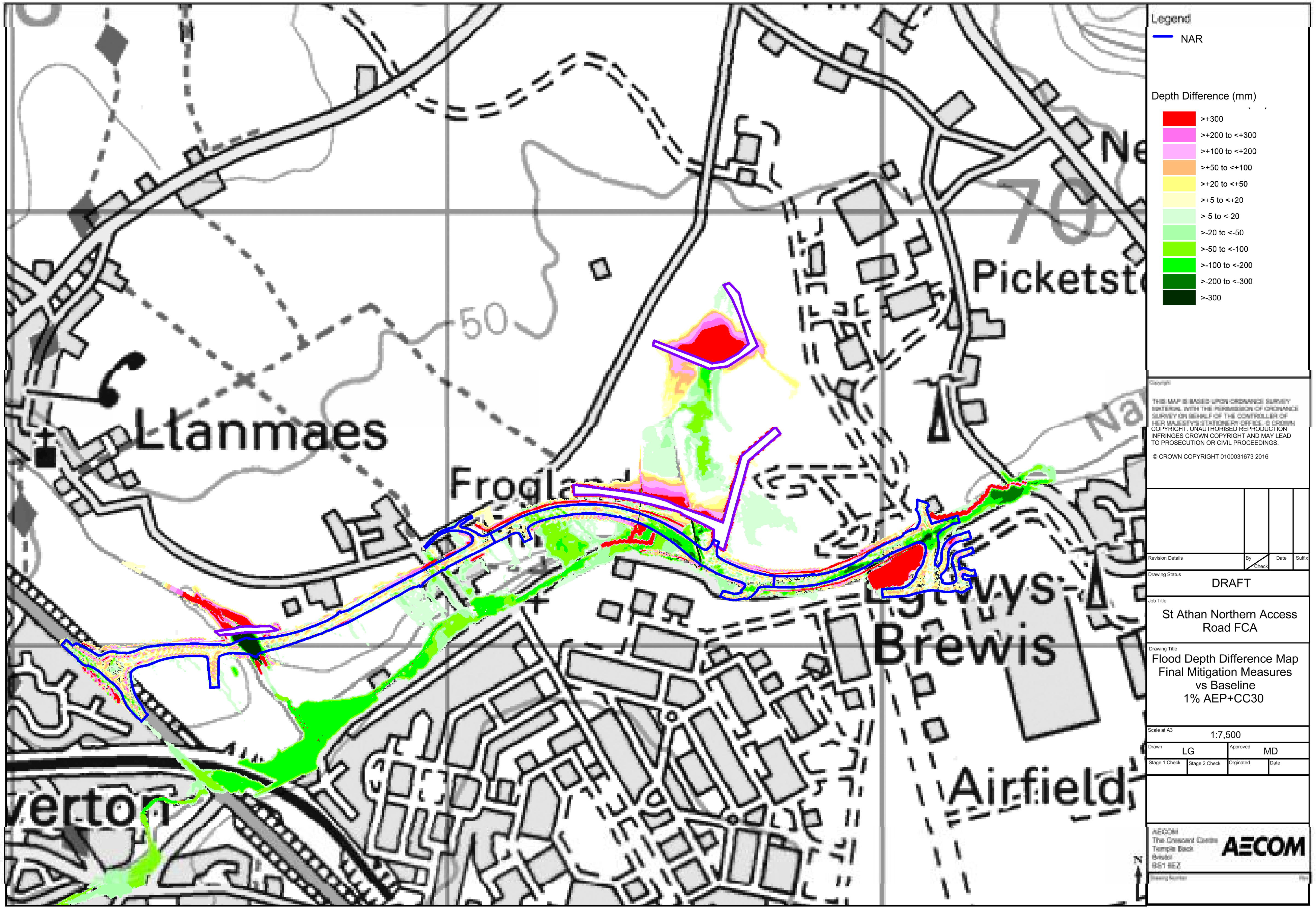


Figure 7-1: Flood Depth Difference Map, 1% + 30% Climate Change, Final Mitigation Measures vs. Baseline

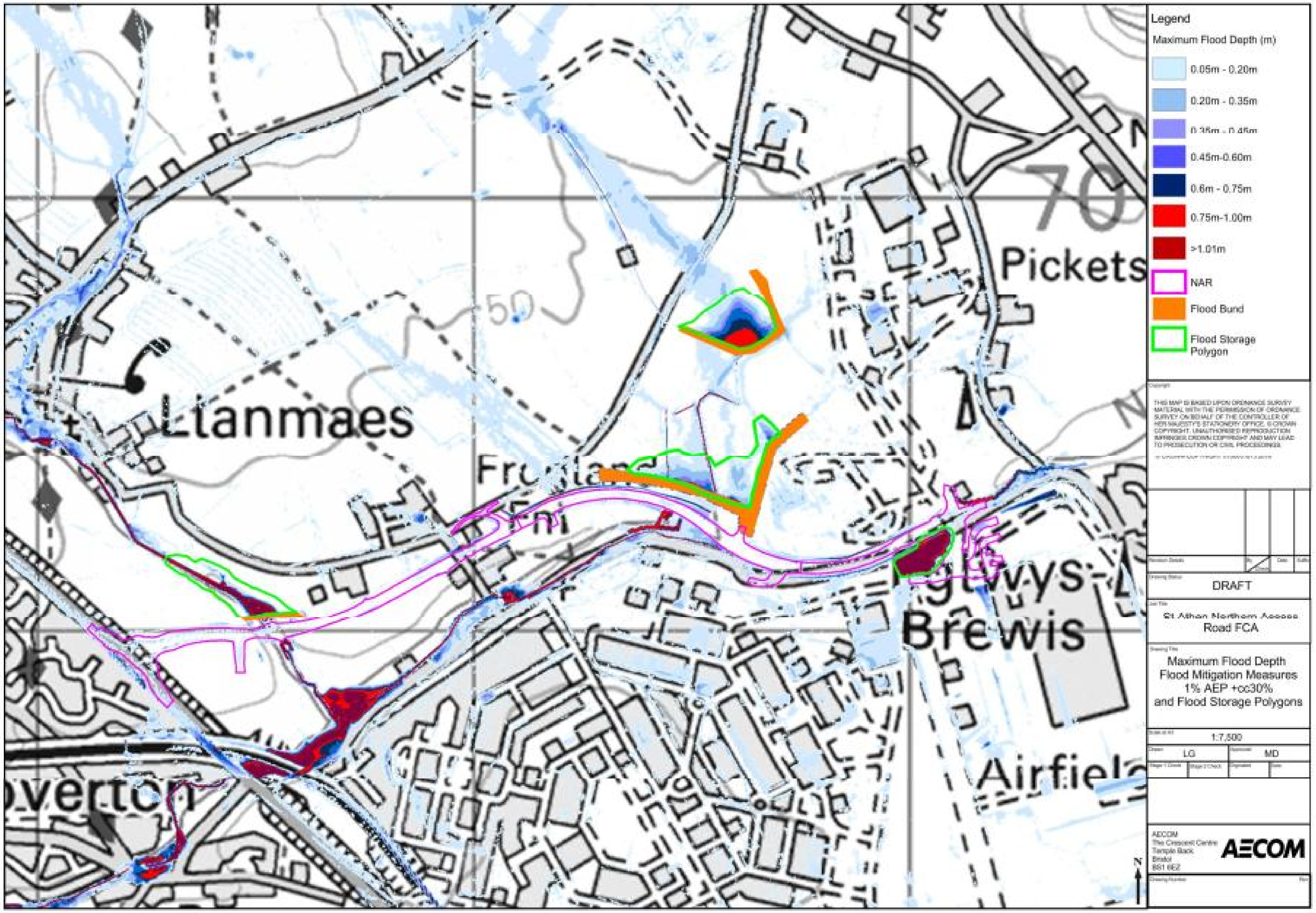


Figure 7-2: Maximum Flood Depth, 1% + 30% Climate Change, Flood Mitigation Measures and Flood Storage Polygons

The downstream flows were then compared to the Baseline scenario on Boverton Brook and Nant y Stepsau. Figure 7-3 shows that the peak flow of the downstream hydrograph at the B4265 road bridge is reduced during the 1% + 30% Climate Change event from 12.5m^3/s to 10.9m^3/s. Whilst the Direct Rainfall model cannot provide an estimate of flow outside of the rainfall catchment described in Section 2 it is anticipated that this reduction in peak flow at the B4265 would also result in lower flows further downstream on Boverton Brook. This can be verified in the fluvial model results in Appendix E.

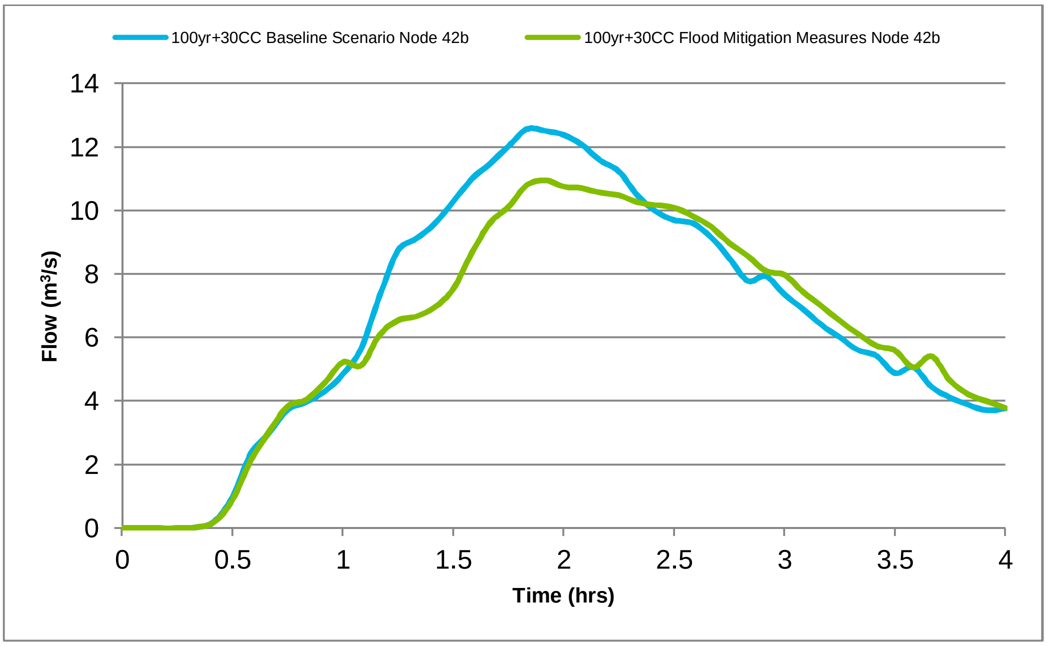


Figure 7-3: Comparison of downstream flow 1% + 30% Climate Change Flood Mitigation vs Baseline

The downstream flows on Nant y Stepsau were assessed using 2D PO lines and used to compare the downstream impact of the Proposed NAR on the watercourse. The results show that there is a reduction in peak flow on Nant y Stepsau downstream of the NAR from 2.18 m^3/s to 0.76 m^3/s during the 1% + 30% Climate Change AEP event. This indicates that the Proposed Flood Mitigation measures will have benefit on Nant y Stepsau further downstream.

Table 7-2 summarises the key results from the final mitigation scenarios

Event (AEP)	Llanmaes Storage Volume (m^3)	Boverton Storage Volume(m^3)	Boverton Upstream Storage Volume (m^3)	Nant y Stepsau Storage Volume(m^3)	Difference in Downstream Flow Boverton Brook (m^3/s)	Difference in Downstream Flow Nant y Stepsau Brook (m^3/s)
20%	1216	2789	1793	2495	-0.84	-0.13
1% + CC30%	6442	5311	6550	7041	-1.61	-1.42
1% + CC75	7965	6988	7888	7450	-1.92	-1.47
0.1%	8674	7815	8588	7569	-1.07	-1.48

Examination of pluvial results, showed that the 2m diameter culvert that drains the Boverton downstream bund reached a maximum capacity of 75%, as the capacity of the channel upstream limits the flow reaching the culvert. Therefore, it is possible that a culvert with a smaller cross sectional area may be sufficient at this location.

8. Blockage Scenarios

8.1 Overview

To ensure that the flood mitigation measures meet the design criteria outlined in Section 6.1, a 100% blockage scenario was simulated for different culverts for the 1% + 30% Climate Change and 0.1% AEP flood event. This testing is in accordance with the NRW Modelling Blockage and Breach Scenario Guidelines 2015[3]

A 100% blockage of a culvert was simulated by setting the pBlockage attribute on the 1d_nwke to 100. The following combination of blocked culverts was simulated.

- Llanmaes Brook main culvert + Nant y Stepsau main culvert
- Boverton Brook main culvert
- Upstream Boverton Brook Storage culvert
- Froglands Farm culvert + East Froglands Drainage Ditch main culvert

Figure 8-1 shows the location of the blocked culverts.

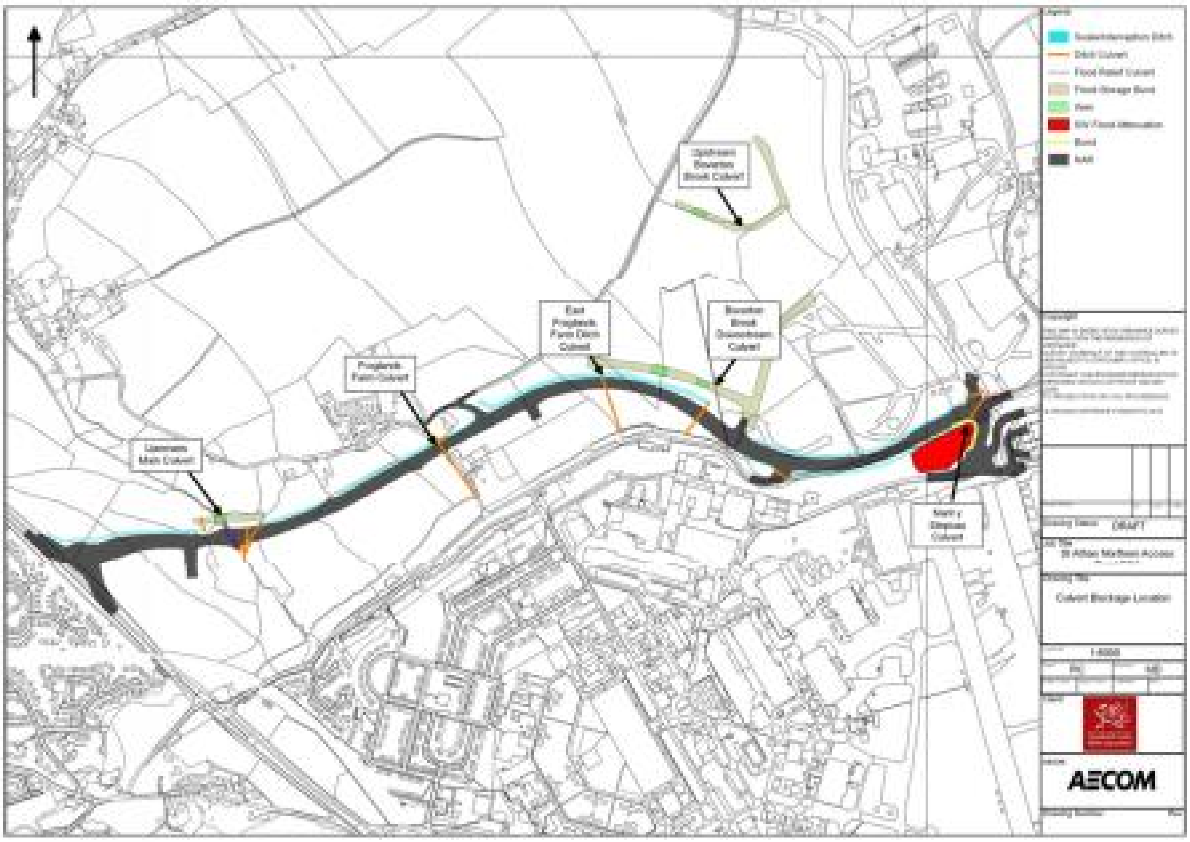


Figure 8-1: Culvert Blockage Locations

A complete set of the blockage simulation results can be found in Appendix D3.

8.2 100% Blockage

The model results show that for all blockage scenarios there remains a downstream betterment of up to 150mm even for the most extreme event of 0.1% + 100% blockage. Figure 8-2 shows the comparison of the 0.1% AEP event with 100% blockage of the Llanmaes and Nant y Stepsau culvert. During the 100% blockage of the Nant y Stepsau culvert during the 0.1% AEP event the water level rises over the bund and floods the road to a depth of 150mm. This only occurs in the most extreme event and blockage scenario and the flood water is contained

[3] Flood Risk Management: Modelling blockage and breach scenarios. Natural Resources Wales February 2015

within the highway before discharging back in to the watercourse to the east. Given the water is contained within the highway and does not flow towards any properties or infrastructure, this flooding is considered to be proportional to the event.

For all blockage scenarios there is an expected increase in the flood volumes within the flood storage areas as a result of additional backing up of water. Table 8-1 shows that for the most extreme event, 0.1% AEP with 100% blockage, all of the storage areas show a flood volume below 10,000m^3.

Table 8-1: Flood Storage Volumes for Blockage Scenarios

Storage Location	0.1% + 100% Blockage (m^3)	1%+ 30%CC +100% Blockage (m^3)	1%+ 30%CC No Blockage (m^3)
Llanmaes Brook	9642	7694	6442
Boverton Brook	9664	6950	5311
Upstream Boverton Brook	9181	7355	6550
Nant y Stepsau	7588	7121	7041

A 100% blockage scenario of the Froglands Farm and east Froglands Farm ditch culvert was carried out to assess any impact on flood risk downstream of NAR or to the residential properties at the Frogland's Farm. For both the 1% + 30% Climate Change and 0.1% AEP event the results show a reduction in flood depths downstream of the NAR (Figure 8-2). This includes a reduction in flood depths of 0.11m at the properties to the south of Froglands Farm during the 0.1% AEP plus 100% blockage scenario. During this flood event, the flood relief culverts at Boverton show that they are at 66% and 51% capacity for the east and west one respectively. This demonstrates that there is enough capacity in the flood relief culverts in the event of a blockage of the upstream ditch culvert during the extreme event whilst still displaying betterment downstream.

Figure 8-2 also shows there is an increase in flood depths of 0.2m within the highway to the west of Froglands Farm property during the 0.1% plus 100% blockage scenario. This increase in flood depth is confined to the highway owned by the Welsh Government and does not encroach on the private property to the east. During the same scenario for the 1% + 30% Climate Change AEP event the model results show a reduction in flood depths at the same location. Given that an increase in flooding occurs only during the most extreme event with 100% blockage, the flood water is confined to the highway and there continues to provide significant benefit downstream and the increase in flood risk at this location is considered to be low.

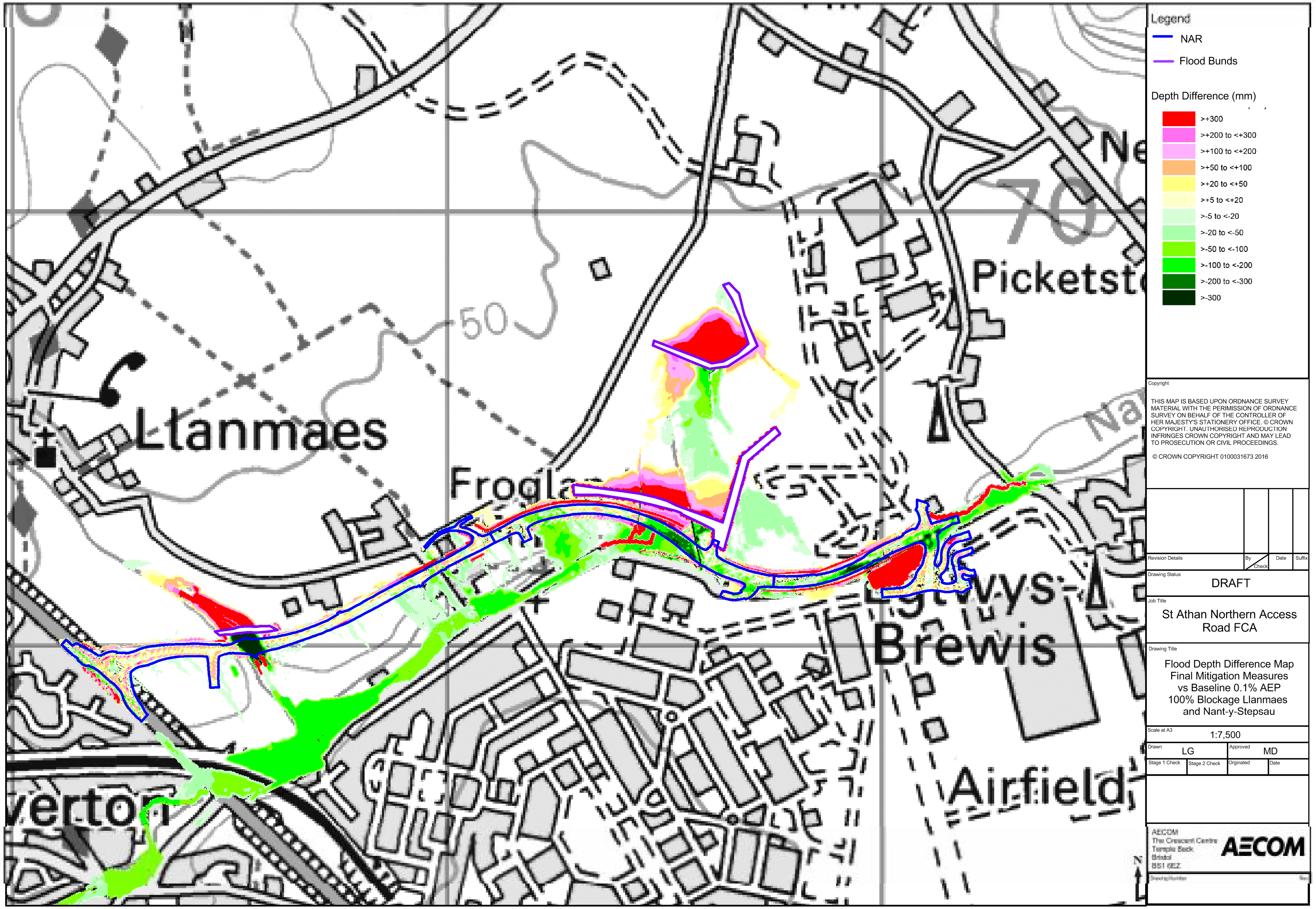


Figure 8-2: Flood Depth Difference, 0.1% AEP + 100% Blockage of Llanmaes and Nant y Stepsau

A

8.3 Summary

An analysis of the 100% blockage scenarios for the 1% + 30% Climate Change and 0.1% AEP event demonstrate that with the mitigation measures described in Section 6 the following criteria have been met:

- Any flood storage areas should hold a volume of less than 10,000m^3 in all events including blockage scenarios;
- that no additional water is discharged into the Nant-y-Stepsau as a result of construction of the proposed scheme; and,
- to ensure no increase in flows through Boverton; and, that no overtopping of the road occurs during the Q100+ CC30% event.

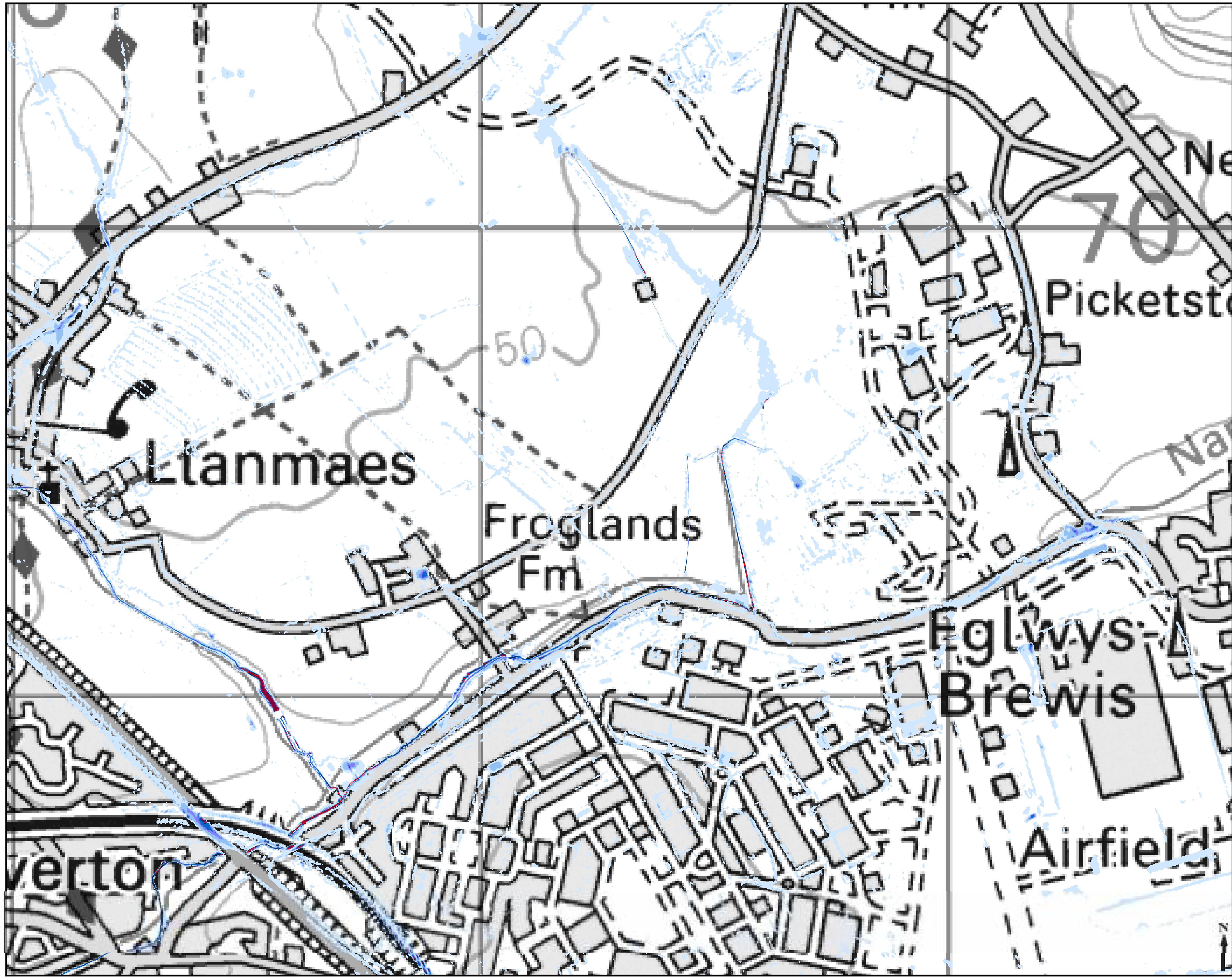
9. Conclusion and Recommendations

Following the combination of the fluvial and pluvial models to analyse the impact of the proposed NAR on surface water flood risk, the preliminary design of the NAR has been concluded. The proposed NAR crosses Boverton Brook, Llanmaes Brook and Nant y Stepsau and intersects overland flow routes. To address the impact of the NAR on these flow routes mitigation measures in the form of upstream storage areas with flood bunds containing overspill weirs, culverts, and flood relief culverts have been proposed. Results from these simulations which model the mitigation measures have shown that even in 100% blockage scenarios, flood levels downstream of the proposed scheme are not increased beyond the baseline results and upstream storage volumes remain less than 10,000m^3.

The mitigation measures have been designed using the pluvial flood storage volumes which are shown to be more conservative than the fluvial model results described in Appendix E. Given that the fluvial hydrology has been verified and accepted by NRW, using this more conservative approach gives confidence that the proposed mitigation measures are robust.

Overland flow routes at Froglands Farm have been managed through the inclusion of interception swales and culvert beneath the proposed NAR. These measures are shown to reduce flood depths on the highway to the west of the property during all design events and reduce flood depths to properties downhill of Froglands Farm. It is recommended that all culverts are regularly maintained to ensure full functionality during all events.

Appendix D1 – Pluvial Baseline Modelling Results Figures



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- 0.6m - 0.75m
- 0.75m-1.00m
- >1.01m

Revision Details	By / Check	Date	Suffix

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Drawing Title: Maximum Flood Depth Baseline 20% AEP

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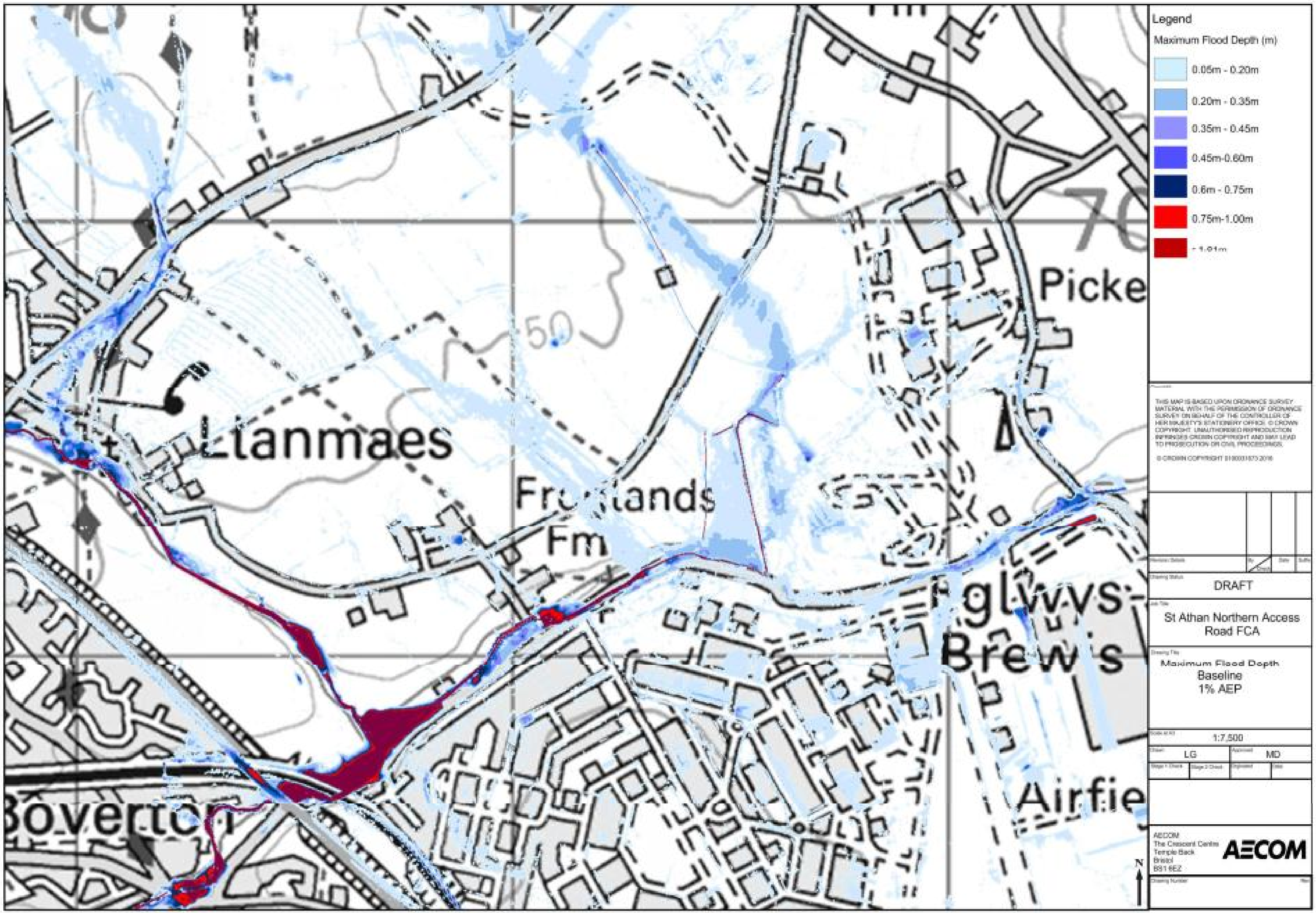
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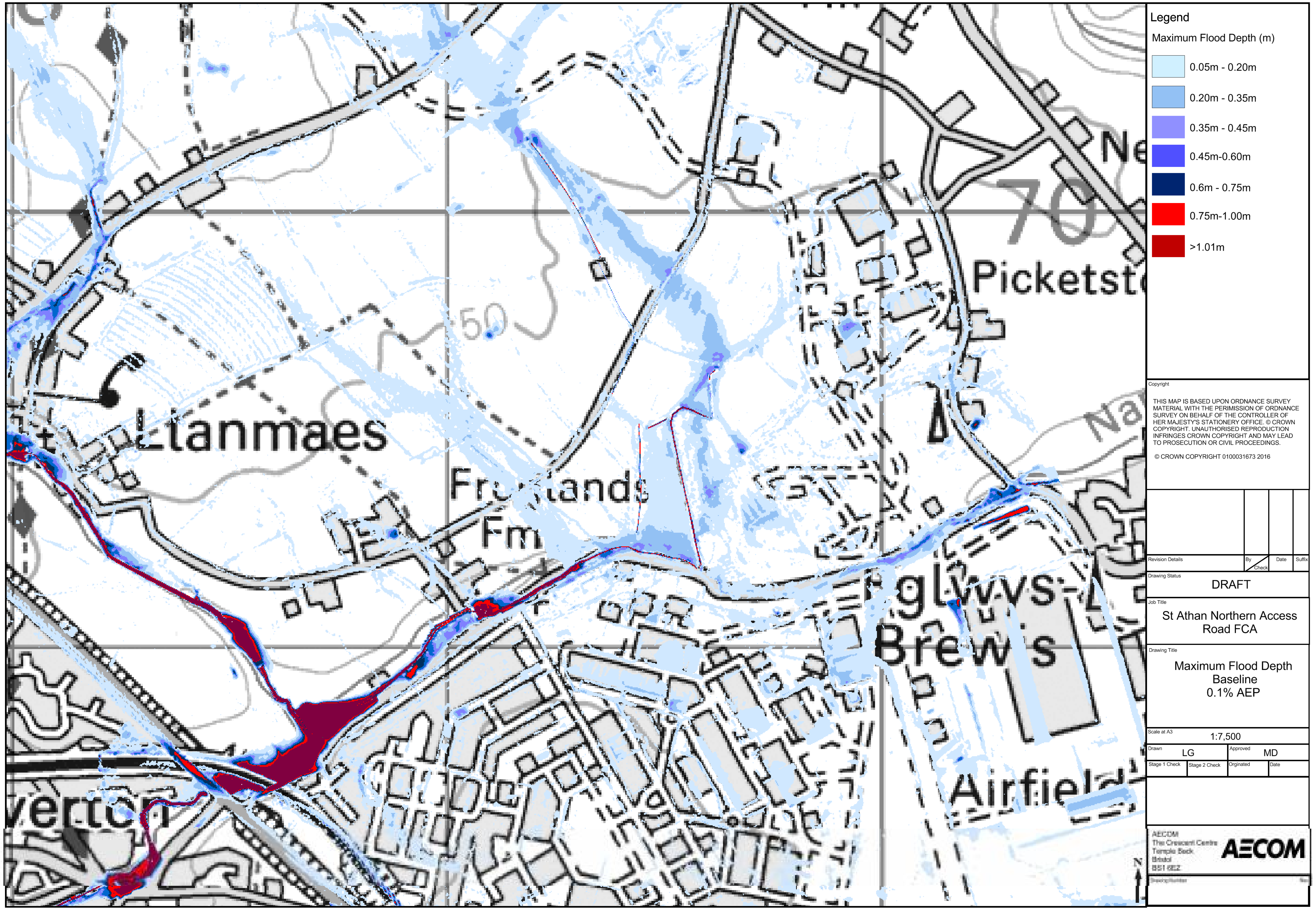
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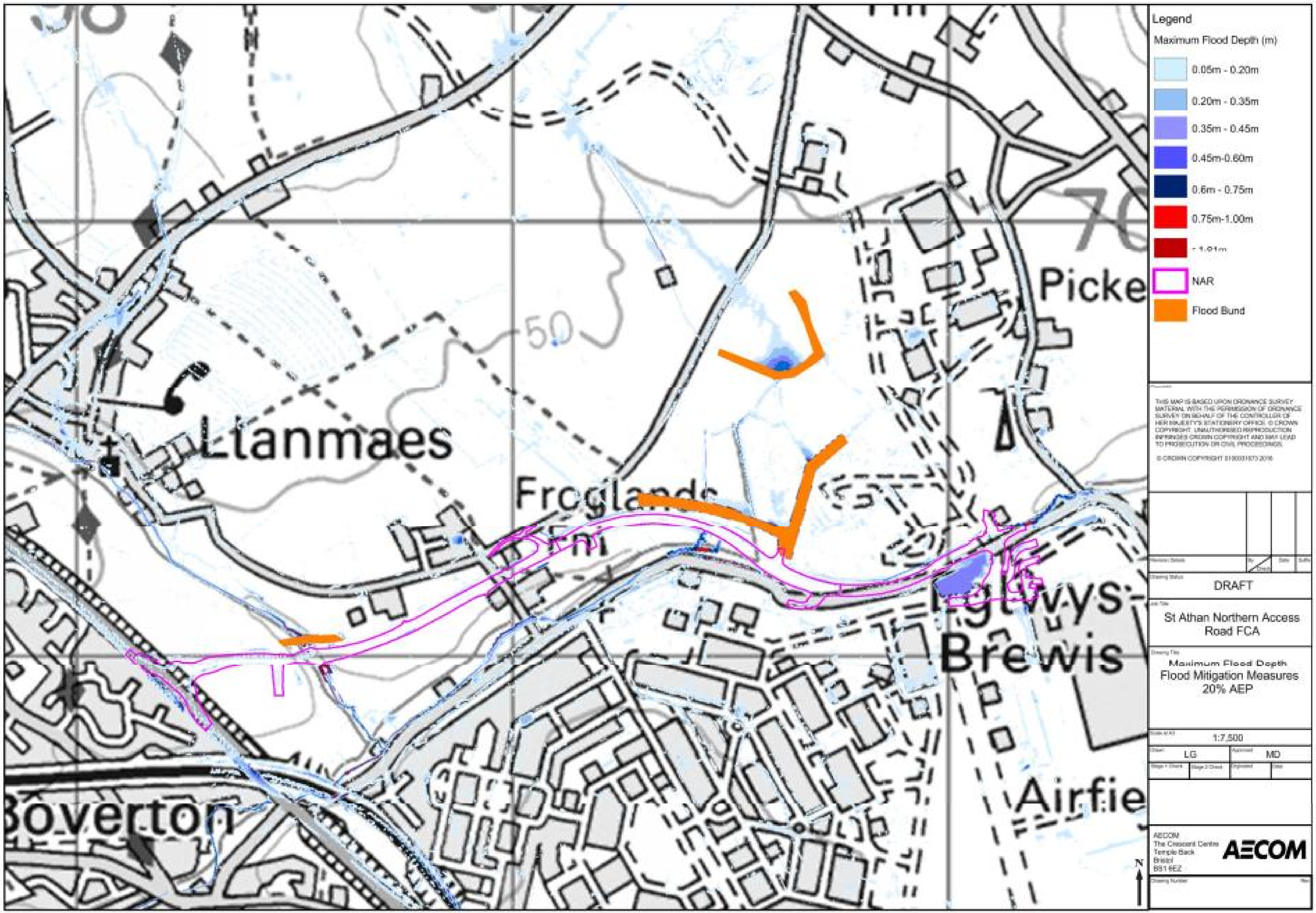
Appendix D2 – Pluvial Mitigation Measures Modelling Results Figures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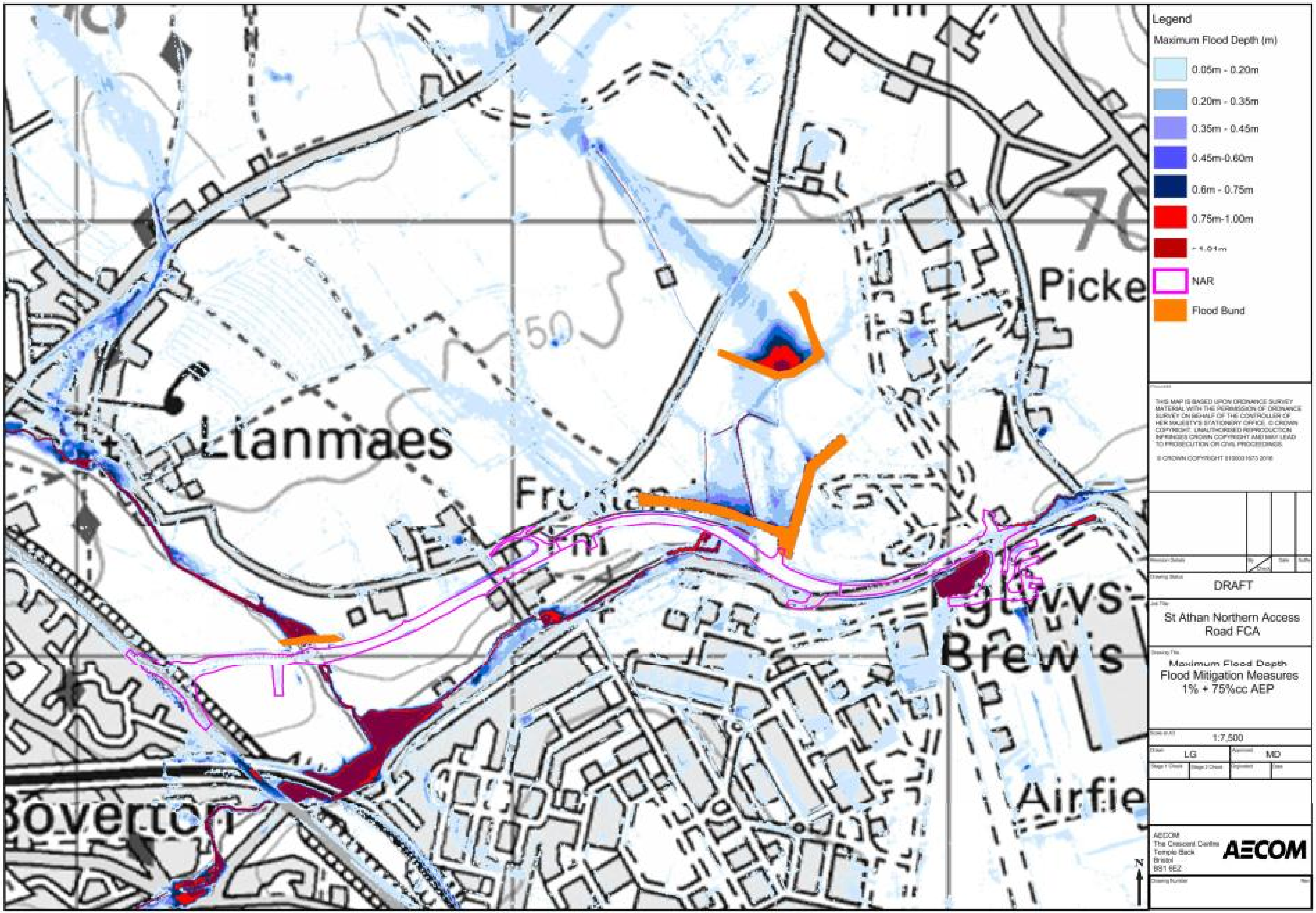
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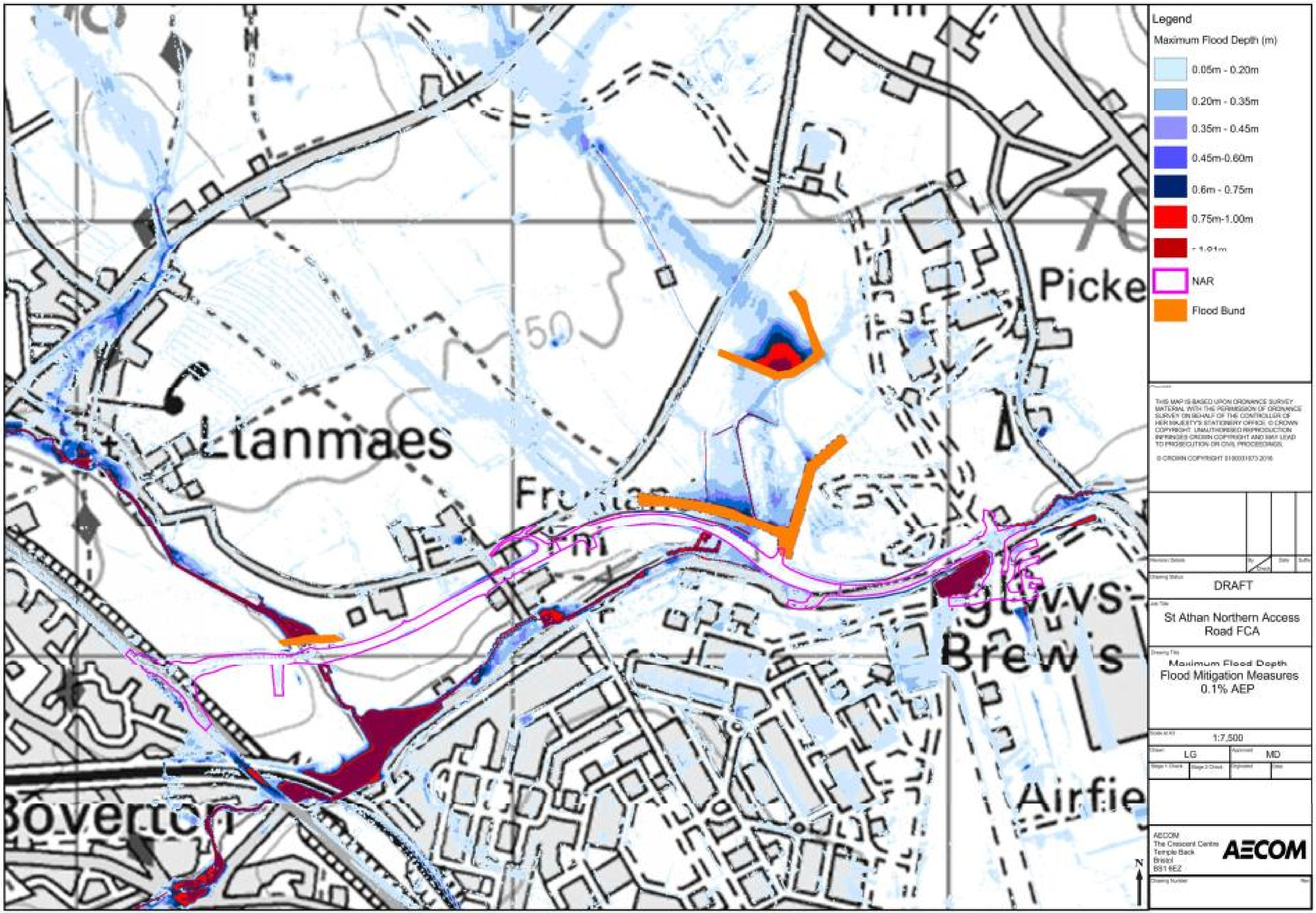
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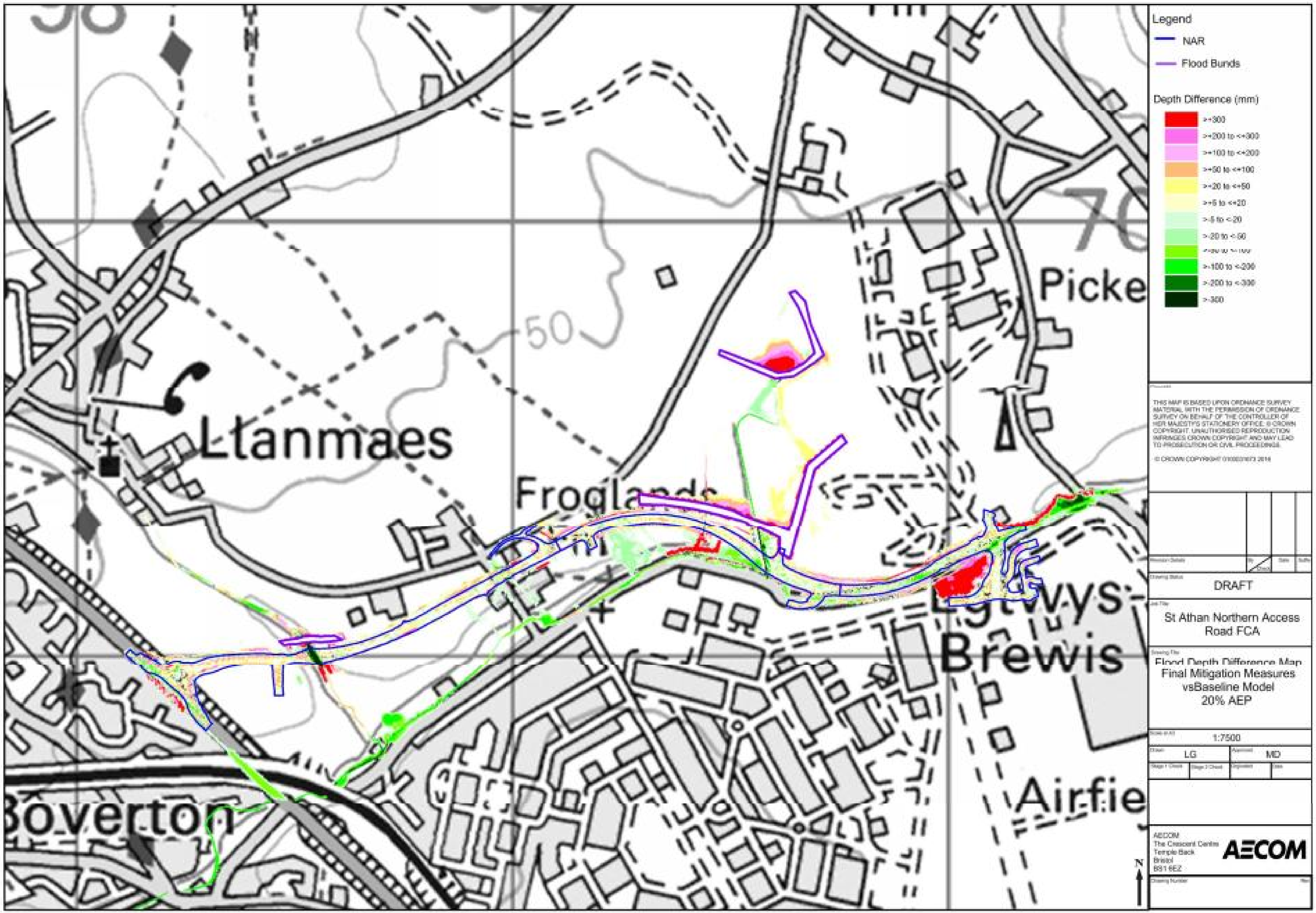
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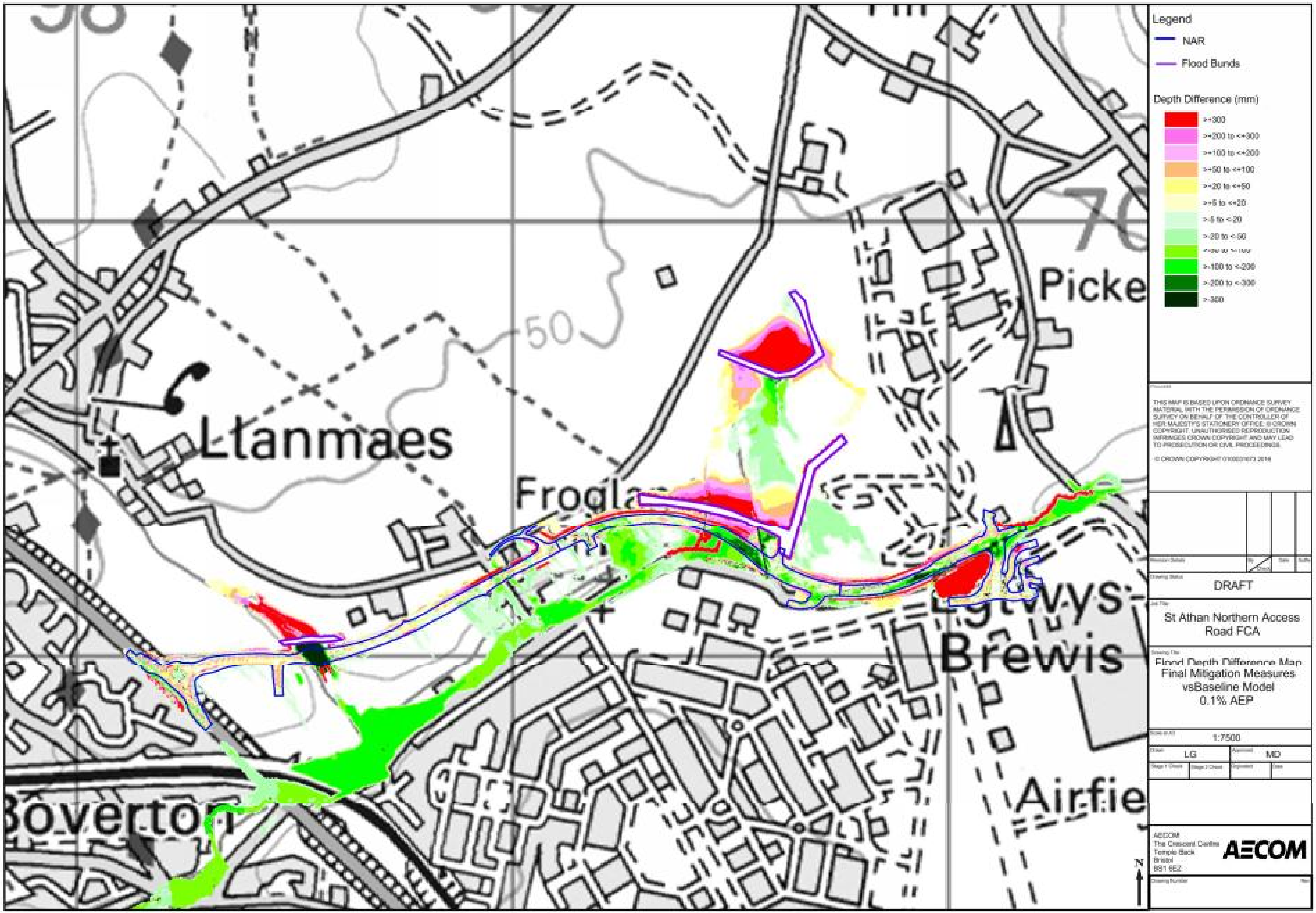
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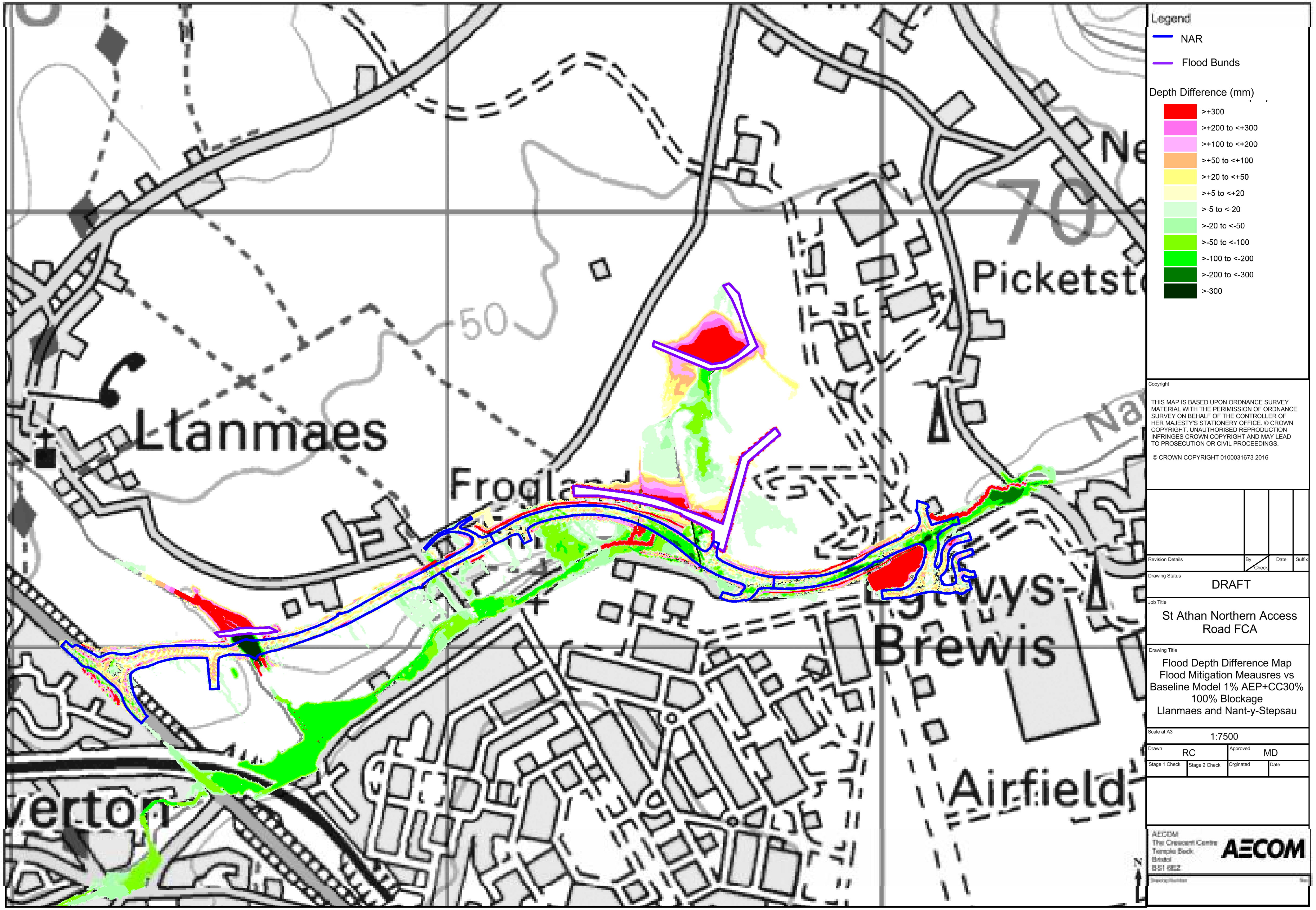
Appendix D3 – Pluvial Blockage Modelling Results Figures



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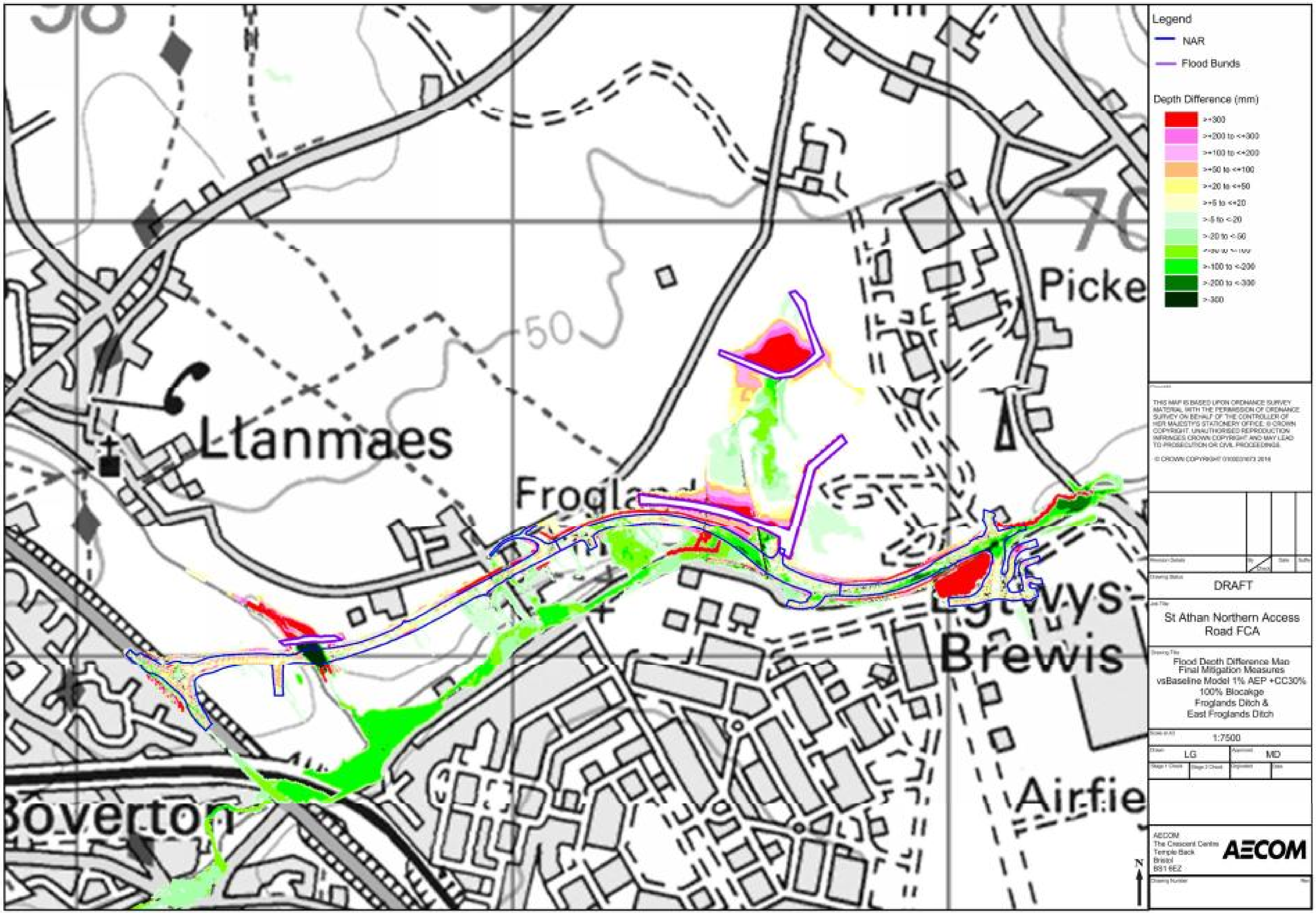
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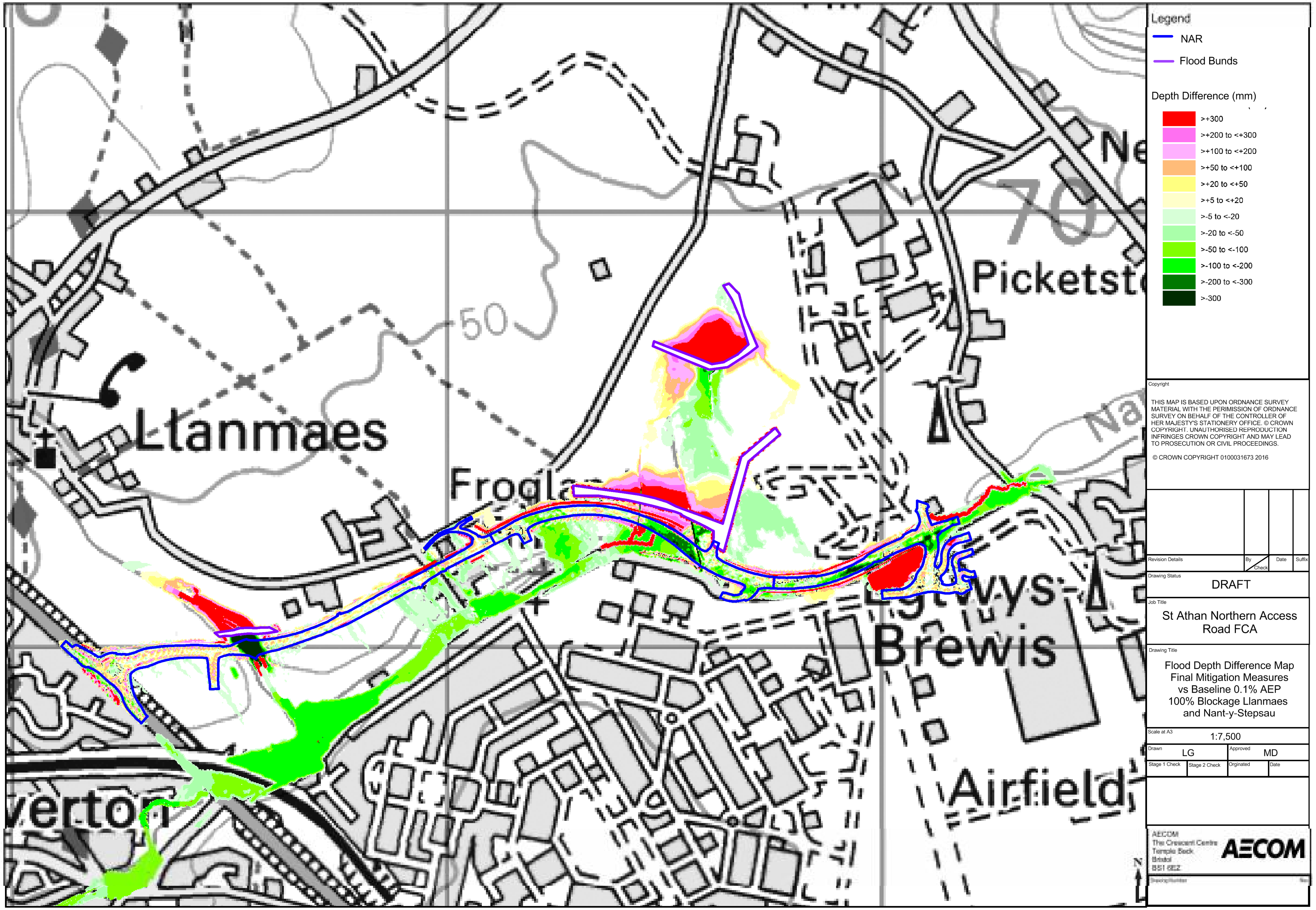
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