St Athan Northern Access Road

FCA Appendix E and F

Welsh Government

February 2017

Quality information

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1. Introduction

This technical note has been produced to describe the methodology used to produce the hydraulic model for the St Athan Northern Access Road scheme. An ESTRY-TUFLOW model was provided by Natural Resources Wales (NRW) in November 2016, which was extended to include the Boverton Brook watercourse north of the Proposed Scheme. This extended model was then used to assess the impacts of the proposed scheme on the floodplain and the risk posed to the scheme from fluvial flooding. Mitigation measures were then designed and tested through iterative representation within the hydraulic model to ensure there was no increased risk of fluvial flooding to surrounding areas as a result from the proposed scheme. Where possible, mitigation measures have been designed to provide a decrease in fluvial flood risk downstream.

1.1 Commission

AECOM was commissioned by the Welsh Government (WG) to produce a Flood Consequence Assessment (FCA) for the development of a new Northern Access Road (NAR) at St Athan. The proposed NAR concerns the construction of a new highway, at a length of 2km, which will improve access to manufacturing facilities at MoD St Athan and unlock the region for development.

2. Received Model

In 2014 an ESTRY-TUFLOW model of the Boverton Brook inclusive of the Boverton Brook and Llanmaes Brook was constructed. The aim of this model was to understand the flood hazard in the Boverton area and produce flood risk and flood hazard maps for Boverton. The received model extents are shown in Figure E1, which includes Llanmaes Brook, Boverton Brook, River Hoddnant, Ham Tributary and Afon Cul-huw. According to the Boverton Model User Report[1] for this model a 2m grid resolution was used, which resulted in a simulation completing in approximately 6 hours.

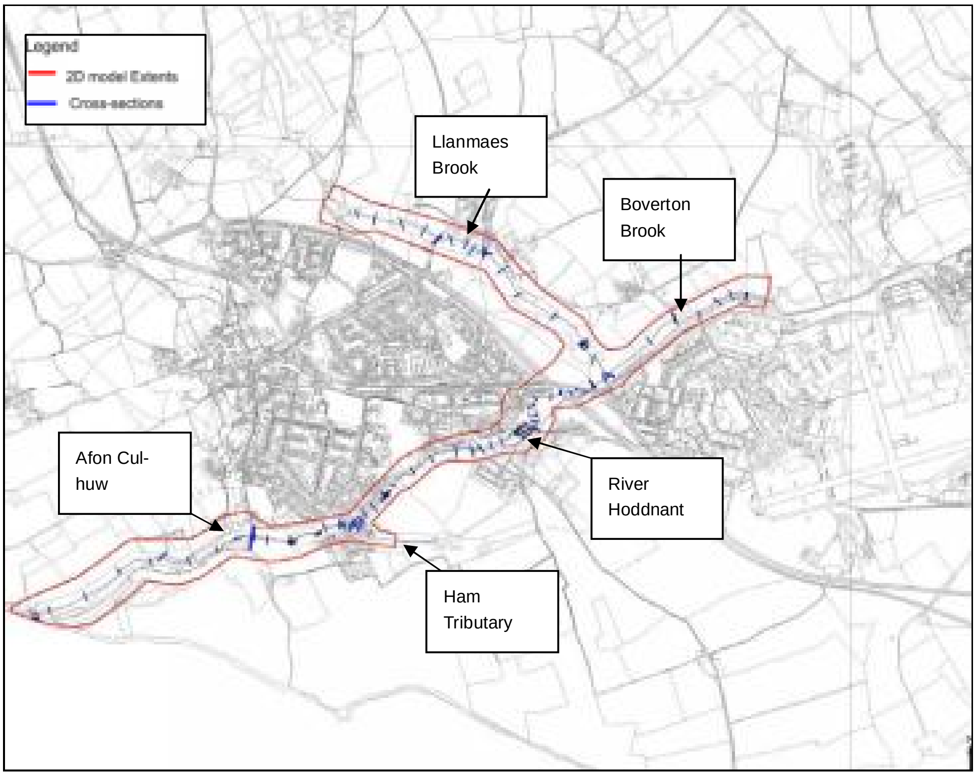


Figure E1- Received Model Extents (NRW, 2014)

[1] JBA consulting (2014) Boverton Flood Study-Model User Report

3. Boverton Brook Model

3.1 Model software

To assess the impact of the proposed scheme on the floodplain, the received model was extended approximately 1km north along the Boverton Brook. The updated 1D-2D model was constructed and simulated using ESTRY and TUFLOW (2016-03-AC-ISP-w64).

3.2 Model Extent

The 1D- 2D model was extended approximately 1km upstream, as shown in Figure E2. The model extension included the addition of:

- 46 additional cross-sections within the model extension at the upstream extension of Boverton Brook; and
- 7 additional culverts within the upstream model extension of Boverton Brook.

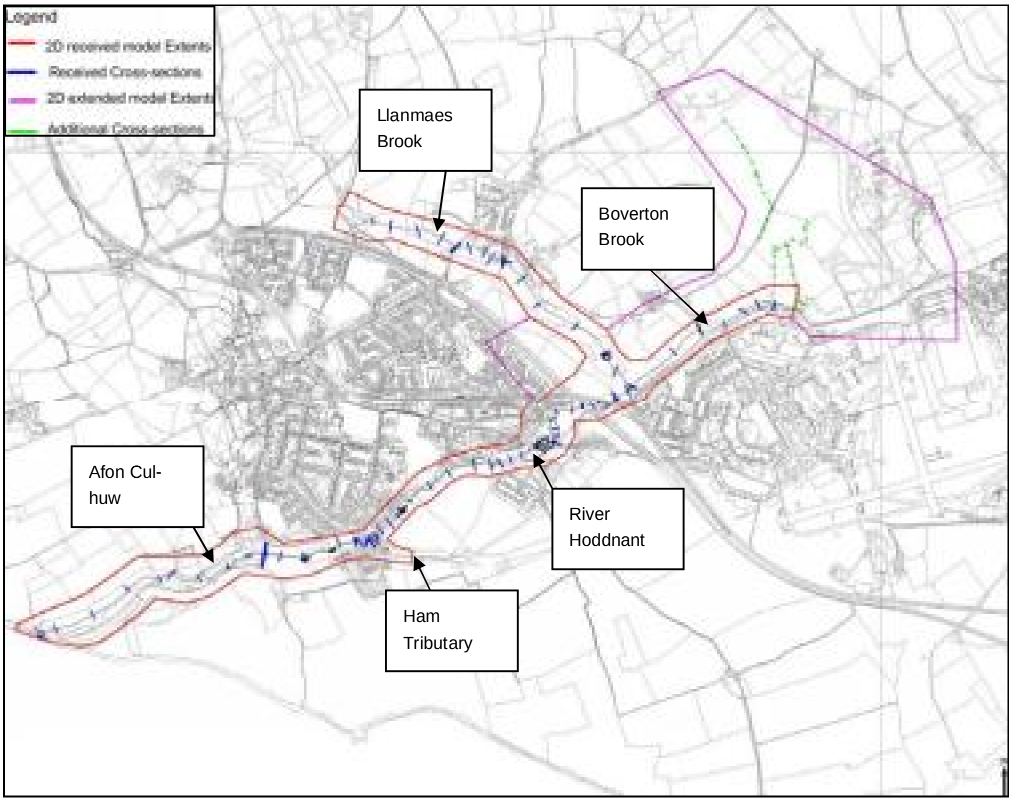


Figure E2 - Extended Model Extents

3.3 Roughness Coefficients

The existing NRW model is adjudged to have paid particular care in determining roughness coefficients throughout the model. As such, the specified roughness within the provided model area has not been adjusted, except for where a change in land-use is proposed within the development (i.e. highway construction).

A site visit was conducted on 2nd November 2016 to review the survey requirements for the extended Boverton Brook hydraulic model. It was observed on site that the reach of the Boverton Brook watercourse that forms the extended model region was heavily vegetated throughout (Figure E3). Therefore, a Manning's roughness coefficient of 0.067 was used throughout for all natural channels. This figure was based on coefficients used for similar cross-sections within the received model and typical Manning's coefficients for vegetated channels[2].

Figure E3 - Heavily Vegetated Banks as Observed on Site Visit (02/11/16)

A Manning's Roughness Coefficient of 0.014 was used for the seventeen culverts that were added to the proposed scenario, in order facilitate flow beneath the NAR. This value is consistent with the value used in the received model and is representative of smooth construction materials and unobstructed flow. To assist in presentation of chosen roughness coefficients used throughout the channel and floodplain, Table E1 details the specification adopted within the latest version of the hydraulic model.

Table E1. Manning's Roughness Coefficients

1D or 2D roughness element	Surface Type	Manning's Roughness Coefficient
2D	Roadside	0.02
2D	Road	0.02
2D	Mixed Vegetation	0.08
2D	Building	0.3
2D	Rail	0.3
2D	Natural Surface	0.04
2D	Manmade Surface	0.017
2D	Stability Patches	0.1
1D	Extended channel cross-sections	0.067
1D	Additional culverts	0.014

[2] http://www.fsl.orst.edu/geowater/FX3/help/8_Hydraulic_Reference/Mannings_n_Tables.htm

3.4 Upstream Inflows

Upon receipt of the model, the NRW Flood Risk Analysis team expressed that the hydrology used within the hydraulic model is current and should be adopted within any updates to the model. To provide a conservative estimate of inflows at the upstream extent of the updated Boverton Brook model the hydrological inflows from the received model were applied. These are considered conservative as altering the location 1km upstream of the existing inflow location, the receiving catchment will be slightly smaller and so flows will be reduced. The upstream inflow to Boverton Brook was therefore moved to the upstream extents of the extended model.

The extended Boverton Brook has three upstream boundaries; as a result, the inflow hydrograph flows for Boverton Brook were divided between the three catchments, proportionally to their catchment size. The location of the revised model inflows is shown in Figure E4.

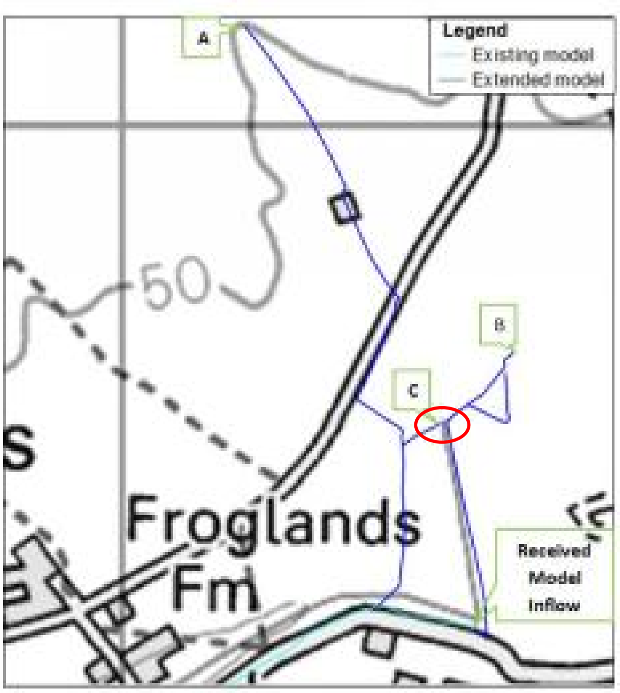


Figure E4-Location of Extended Model Inflows

The proportions of flow to each of the new model inflow locations is 75% to location A, 20% to location B, and 5% to location C. Topographical survey information showed no link between the drainage ditch networks highlighted by the red circle in Figure E4.

3.5 Topography

The received model used LiDAR from 2011, the extended model was updated to include the latest LiDAR (2014). According to the modelling report associated with the 2014 NRW model, several LiDAR stability patches were added to the model in the form of increased roughness material patches and topographical amendments (zshapes) which is indicative of inherited difficulties with model stability. Comparisons of elevations from the old LiDAR and new LiDAR were made, as little difference was observed these stability patches were retained within the model and the new LiDAR updated accordingly.

The only exception to this is the stability patch at the upstream extent of the received model, which was removed. As more recent topography was provided as part of this commission, it was deemed to be more accurate, which superseded potentially less accurate estimates made during the previous model build.

3.6 Model Parameters

The majority of the parameters used within the 2014 NRW model were retained and used within the updated model. The only changes made were to proportionately increase the 2D model grid area to account for the upstream extension on the Boverton Brook.

All other aspects of the model were retained from the received model. This included the representation of structures within the 1D model, roughness coefficients (1D domain and 2D domain), downstream boundary within the 1D model, and model time step.

3.7 Formal Flood Defences

There are formal defence layers provided within the received model therefore the model is considered to represent a defended scenario. These defences include two storage areas on Llanmaes Brook.

The Frampton Lane Flood Storage is located in the upper Llanmaes Brook catchment near the village of Frampton (NGR 297354, 169647). The outfall is regulated from the flood storage area by a flapped culvert that allows water to back up and flood the storage area in times of high flows.

The second flood storage area is located between the confluence of Llanmaes Brook and Boverton Brook and the village of Llanmaes (NGR 298565, 168969). The scheme consists of a small earth embankment across Llanmaes Brook that is culverted beneath. Flows through the culvert are restricted by the size of the orifice which allows for some attenuation of water upstream of the structure. It is understood that this structure is designed to allow flood storage below 10,000m^3.

3.8 Model Runs

Annual Exceedance Probabilities (AEPs) of: 20%, 2%, 1%, 1% plus 30% climate change, 1% plus 75% climate change, and 0.1% were simulated. Climate change allowances were taken from the Welsh Government's 2016[3] guidance for FCAs. Boverton Brook and Llanmaes Brook are located within the Western Wales river basin district, the central estimate of potential change by the 2080s 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.

Blockage simulations of 1% AEP plus 30% climate change and 0.1% AEP were run with 67% and 100% blockage of the main culverts independently on Boverton Brook and Llanmaes Brook and are detailed in Section 4.3.6.

[3] http://gov.wales/topics/planning/policy/policyclarificationletters/2016/cl-03-16-climate-change-allowances-for-planning-purposes/?lang=en.

4. Model Results

4.1 Extended Baseline Model

All updates to the Boverton Brook model as discussed above were incorporated to form the new baseline model (Figure E2). As can be seen in Figure E5, the flood extents of the new baseline model has been extended north of the NAR, an increase in modelled area upstream when compared to the received model. This allows for a more appropriate assessment of existing and proposed risk as a result of the construction of the NAR, allowing water to flow out of bank earlier in the model than the previous build.

Figure E5 demonstrates the difference between the received model and the latest extended build, as part of this study. It can be seen that there are differences in depth observed on Llanmaes Brook, where no changes have been made to model inflows, these changes are a result of the extended model using updated LiDAR to form the digital terrain model. Interrogation of the received and updated DTMs showed that differences in land elevations were of the same magnitude as the differences in depths shown.

It should be noted that the extents of the depth difference map, in Figure E5, on the extended section of Boverton Brook are limited by the extents of the received model. The received model does not extend as far north or east as the new extended baseline model, so depth difference cannot be calculated and displayed in this region.

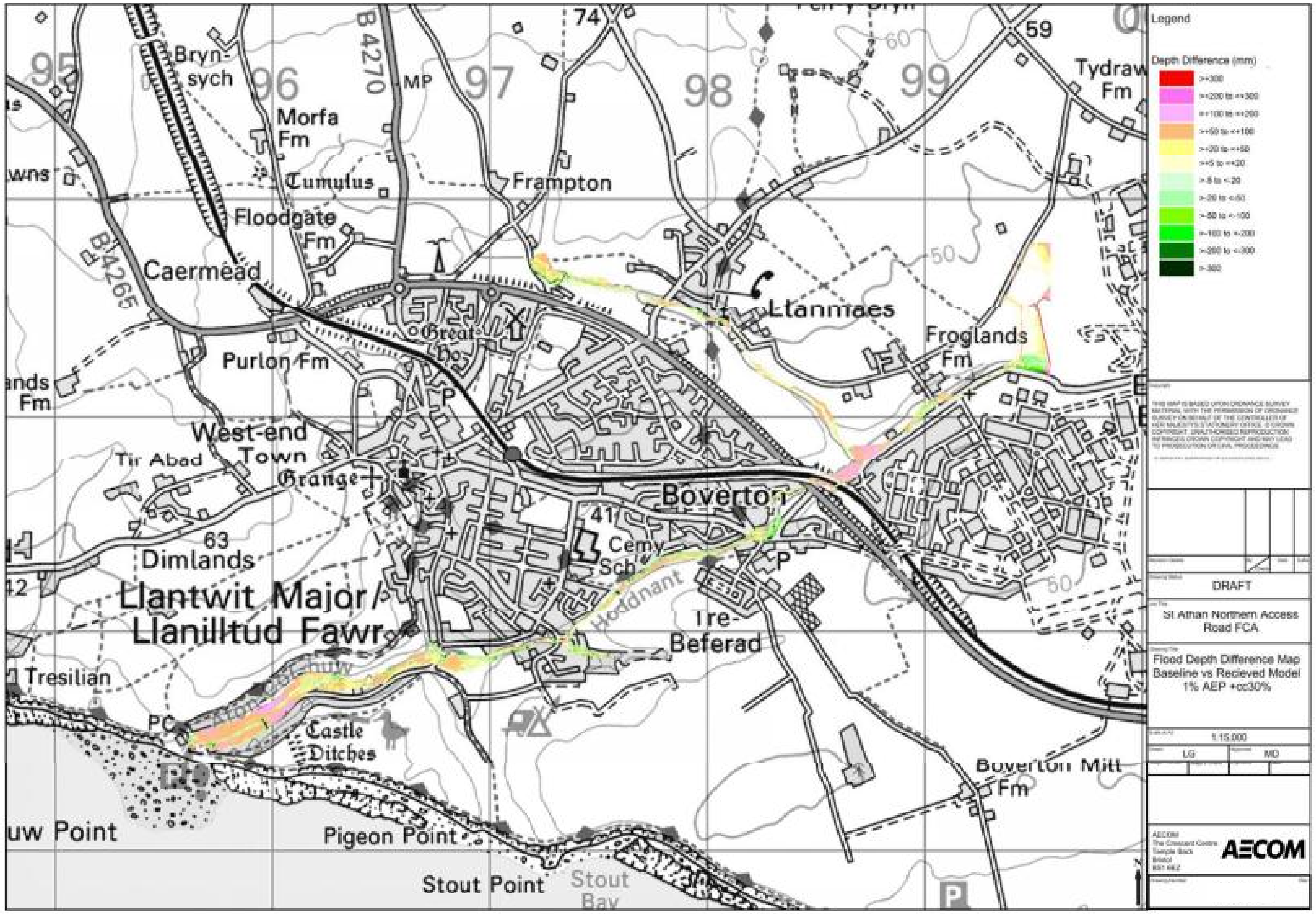


Figure E5 - Flood Depth Difference Map New Baseline vs Received Model 1% AEP+ cc30%

4.2 Proposed Model Scenario

In order to examine the effects of the proposed scheme on flood extents, the proposed NAR construction design and culvert arrangement was added to the model. 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. Proposed culverts were represented as 1D ESTRY culverts connecting to both 1D ESTRY watercourse elements (Llanmaes Brook and Boverton Brook) and 2D TUFLOW domain flood relief culverts. A materials patch was also created for the NAR region to represent the change in catchment roughness and land use (i.e. permeable rural region to road/highway).

Figure E6 shows the depth difference map as a result of inclusion of the proposed NAR scheme. The raised land of the NAR caused water to pond upstream of the road, and flood depths downstream of the NAR were reduced by a range of 5-100mm from the immediate downstream area of the NAR and throughout the village of Boverton. As a result of increased ponding upstream of the NAR the peak flow rate, at the railway crossing, was reduced from 2.4m^3/s to 1. 4m^3/s (~-40%).

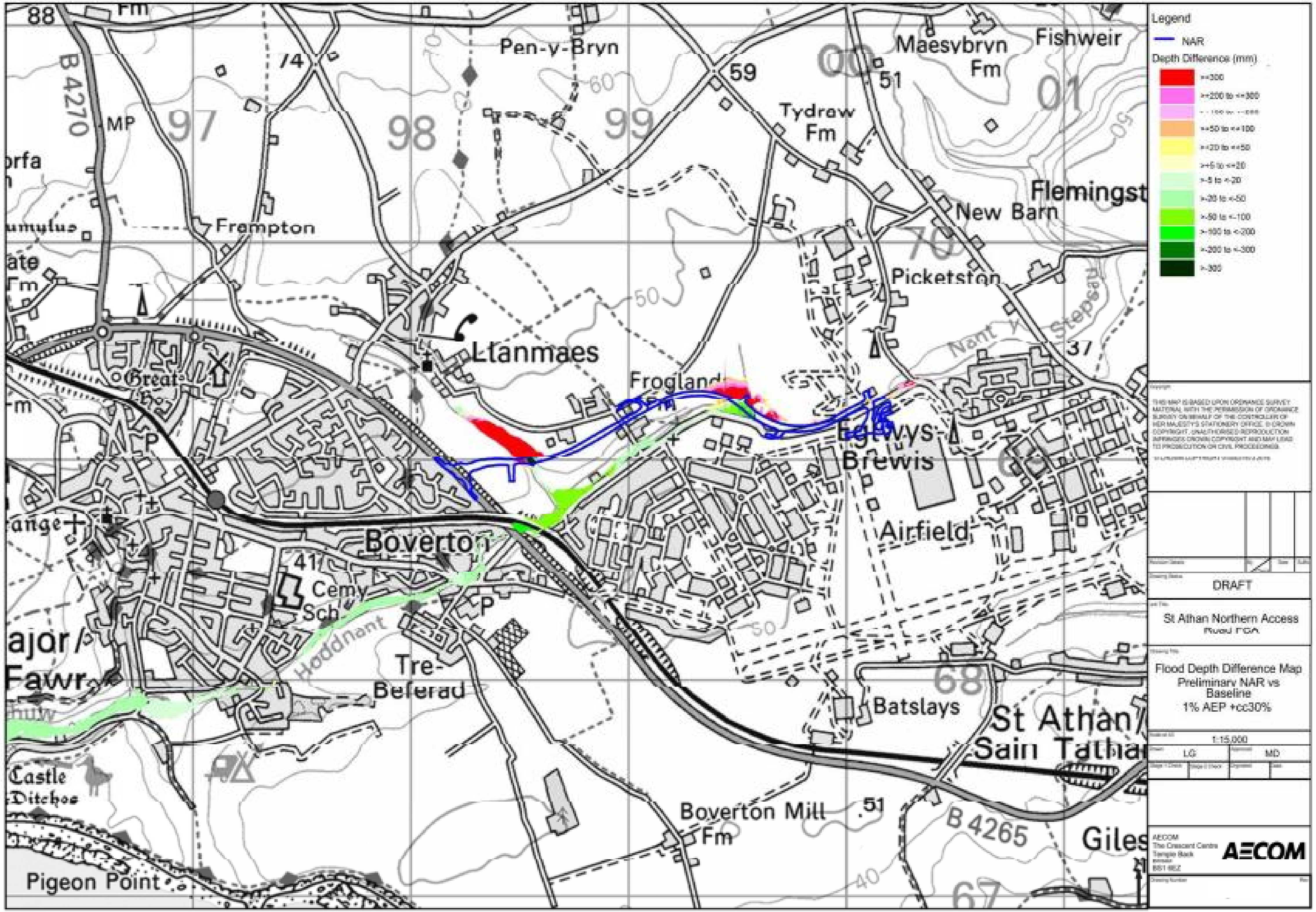


Figure E6- Depth Difference Map Proposed Scheme vs New Extended Baseline, 1% AEP +CC30% Event

4.3 Mitigation Options

4.3.1 Overview

As can be seen in Figure E7, the proposed scheme reduces the maximum flood depths observed downstream of the NAR. However, it can be seen that water overtops the NAR at Llanmaes Brook and the volumes of water contained upstream of the NAR were found to exceed 10,000m^3, these sites would therefore be classified as reservoirs. As neither of these situations are desired, a series of mitigation options were derived and then simulated.

The key considerations in the design of mitigation measures were to ensure:

- that the storage areas at Boverton Brook and Llanmaes Brook hold less than 10,000m^3 during a Q100 +CC30% event;
- 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 flood depths or extents through Boverton; that no overtopping of the road occurs during the Q100+ CC30% event; and
- that blockage of primary watercourse culverts are appropriately mitigated and do not result in detriment.

4.3.2 Initial Modifications to Design of NAR

Examination of model results for the proposed scheme showed that as a result of the NAR, additional water was flowing to the Nant-y-Stepsau from the Boverton Brook catchment. Therefore, an access spur off of the proposed scheme (as circled in dark blue in Figure E7) was realigned to act as a bund to prevent overland flow.

It was found that the road overtopped near to Boverton Brook for the 1% AEP plus 30% climate change event (area circled in pale blue in Figure E7). Therefore, the road was raised in this region from 42.5m to 43m AOD to prevent overtopping.

For simplification of design, it was determined that Boverton Brook will have one 0.6m diameter primary culvert as opposed to dual 0.6m diameter culverts in the previous proposed model build (Figure E6). The resulting depth difference map for the 1% AEP plus 30% climate change event are shown in Figure E7.

It can be seen in Figure E7 that these alterations resulted in a greater depth of water to the north of the NAR on the Boverton Brook. Examination of results found that the volume of water stored upstream of the NAR at the Boverton Brook was 16,000m^3 for the 1% AEP plus 30%. This is in excess of the desired maximum 10,000m^3.

The received model had a 500mm diameter circular culvert modelled to replicate the effect of a downstream sluice gate on a 1.0m diameter culvert within the Llanmaes Brook. This control structure and corresponding storage area was removed, and consistent culvert dimensions modelled. As a result of this, the depth and volume of water stored upstream of the NAR was reduced on the Llanmaes Brook (as seen in Figure E8).

Further optimisation runs of the culvert dimensions on both the Llanmaes and Boverton Brook were conducted. The optimisation of culvert dimensions for Llanmaes Brook and Boverton Brook is discussed further in Section 4.3.3.

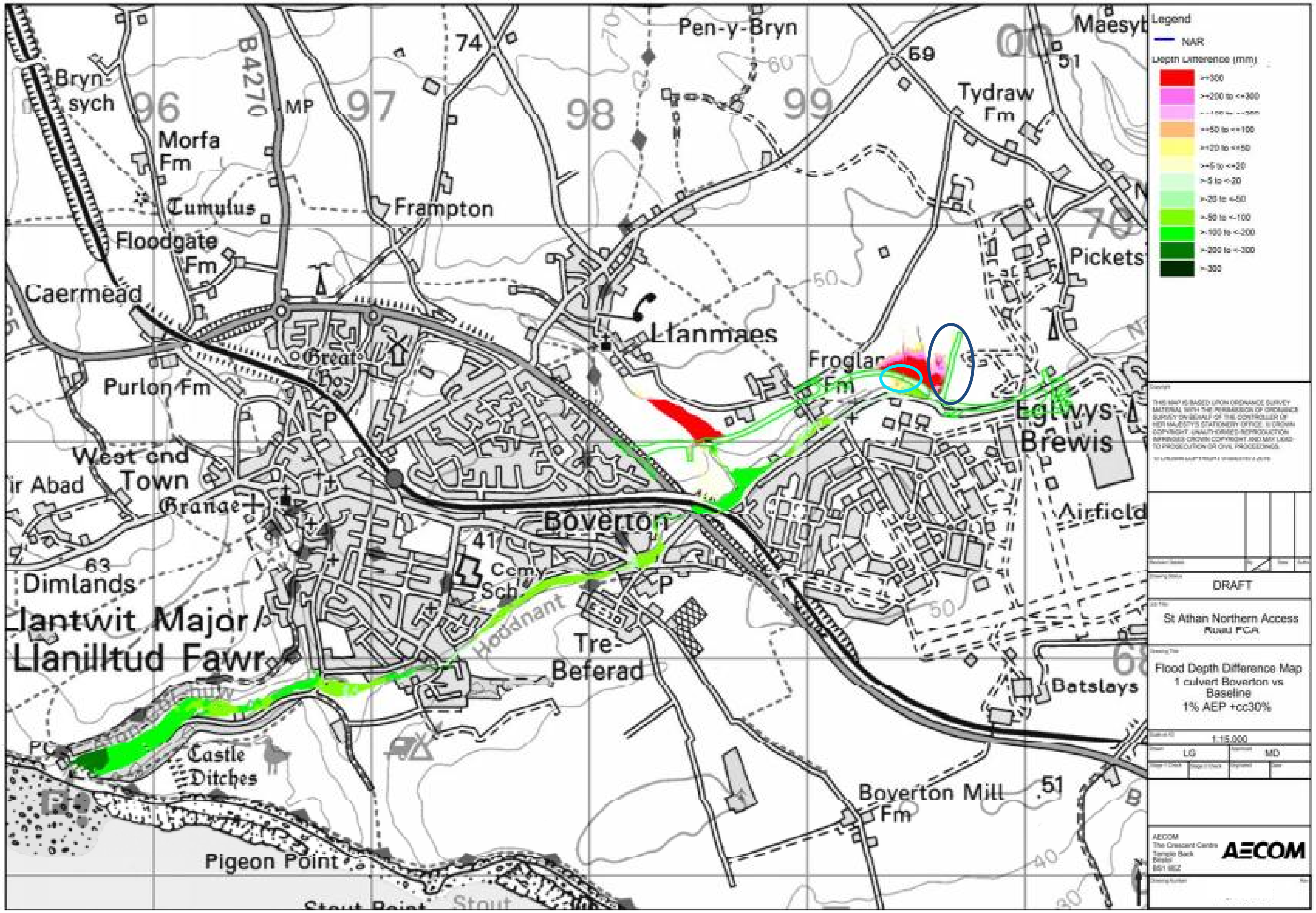


Figure E7- Depth Difference Map One 600mm Diameter Culvert Boverton Brook vs Baseline, AEP 1% +CC 30% event,

4.3.3 Optimisation of Culvert Dimensions

Different size circular culverts were simulated on the Llanmaes Brook and Boverton Brook as part of the culvert optimisation process. Table E22 below shows the culvert specifications and results from the culvert optimisation simulations. It can be seen in Table E2, that all culvert diameters tested show a reduction in maximum flow. However, only certain culvert diameters (Options 4-6) result in upstream storage volumes on both the Llanmaes and Boverton Brook being less than 10,000m^3. Therefore, in order to achieve both goals of downstream flow reduction and upstream storage size, the following culvert diameter ranges were recommended to be taken forward:

- Boverton Brook - Diameter 1.2-2.0m
- Llanmaes Brook - Diameter 1.6-2.0m

Table E2- Culvert Optimisation Process - Maximum Flows and Storage Areas (1%AEP +CC30% Event)

	Baseline	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
Llanmaes Culvert Diameter (m)	N/A	1.0	1.2	1.5	2.0	1.6	1.6
Boverton Culvert Diameter (m)	N/A	0.6	1.0	1.5	2.0	1.2	1.5
Llanmaes U/S Storage Area (m^3)	N/A	36,255	30,663	10,398	4,850	7,329	7,392
Boverton Brook U/S Storage Area (m^3)	N/A	15,271	12,006	4,850	2,255	6,833	4,851
Maximum flow at railway line (m^3/s)	1.22	1.18	1.00	1.17	1.22	1.18	1.18
Flow Difference (m^3/s)	N/A	-0.04	-0.23	-0.05	-0.01	-0.04	-0.04

In order for the depth difference of the proposed culverts to be examined further, final proposed culvert dimensions were selected to use in further modelling. At this point in the process, a design change request was made for the culvert specification on Llanmaes Brook, which required the removal of the 0.5m diameter flow constriction downstream of the NAR and the use of a box culvert, rather than a circular culvert previously tested in Table E2. The culvert dimensions selected were 1.5mx1.5m rectangular box culvert at Llanmaes Brook (design change request) and one 1.375m diameter circular culvert at Boverton Brook.

To check that these culvert dimensions met the scheme requirements, a series of depth difference maps were produced; where the baseline model flood depths were subtracted from the proposed option flood depths. It can be seen in Figure E8 that the proposed culvert diameters provide a decrease in flood depth of 5-50mm downstream for the 1% AEP +30%.

The result of the removal of the 0.5m diameter flow constriction on Llanmaes Brook enabled a slight reduction in flood depth and no flood storage upstream of the NAR (Figure E8). The culvert size of 1.5m x 1.5m does not constrict flow upstream and allows for greater conveyance. However, combined with the influence of the upstream storage on the Boverton Brook catchment, there is an overall decrease in flood depth and extents in the village of Boverton. It can be seen in Figure E9 that for 1%AEP +CC75% there is a large area of upstream storage on Llanmaes Brook and a greater decrease in flood depth and extents in Boverton.

Flood depth difference maps representative of this 1.5m x 1.5m box culvert on Llanmaes and 1.375m diameter culvert on Boverton for the 3.33%AEP event, and 1% AEP event, and 1%AEP + events are shown in Appendix F Figures F3-F5 as part of this document.

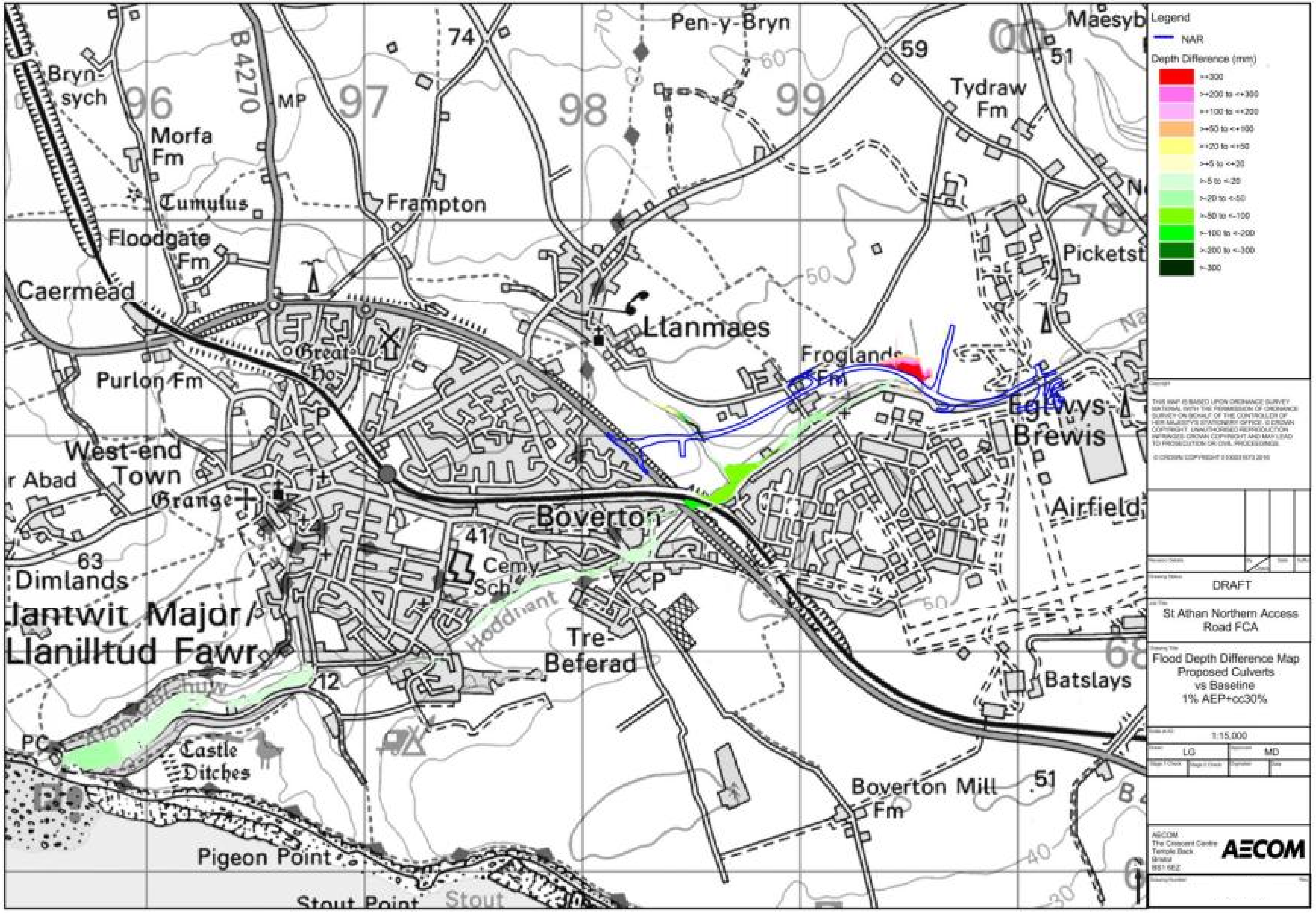


Figure E8- Flood Depth Difference Map Proposed Culverts vs Baseline, 1%AEP +CC30%

Comment [MD1]: Can we explain why there is no increase in flood depth on llanmaes brook, looks odd?

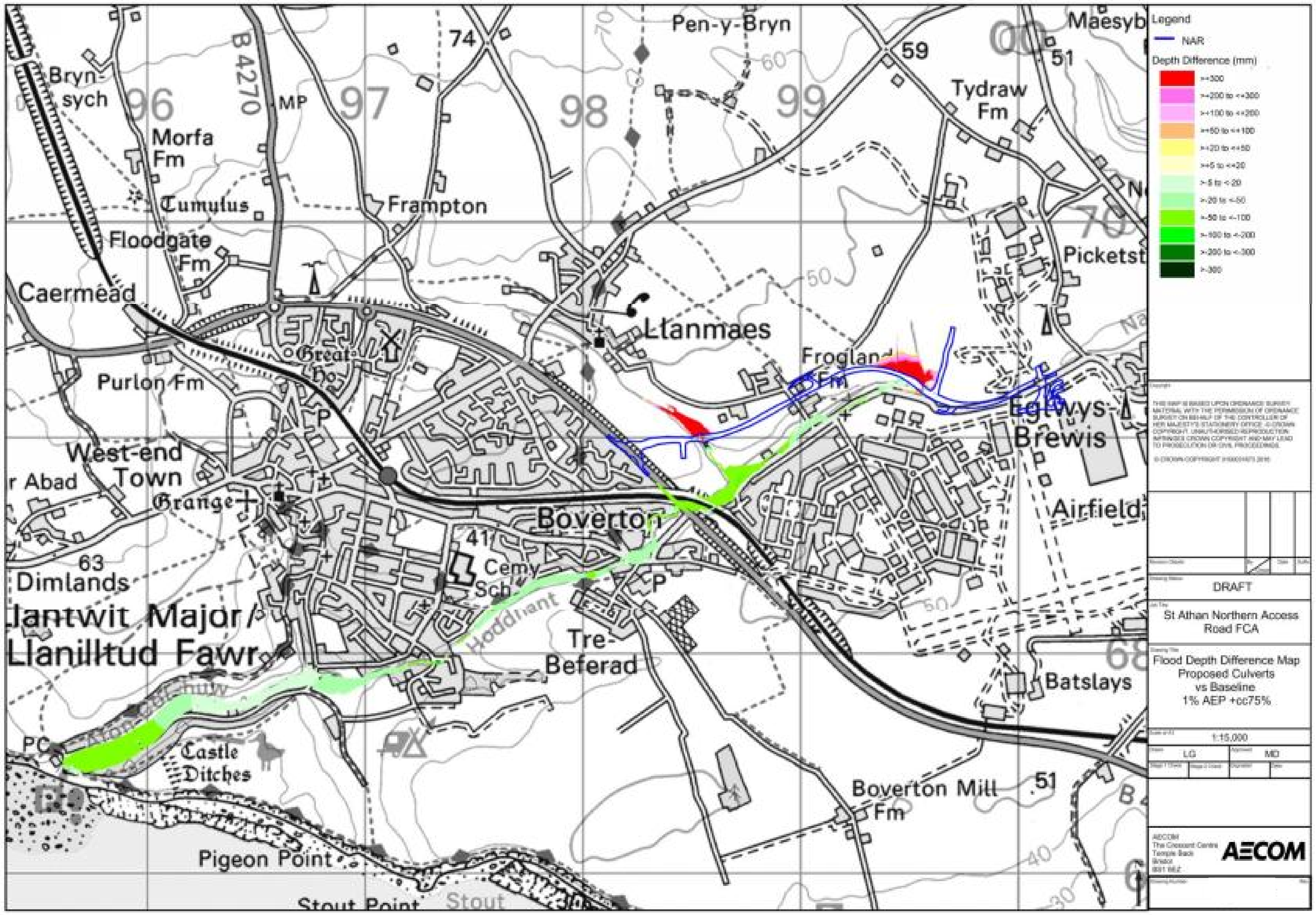


Figure E9- Flood Depth Difference Map Proposed Culverts vs Baseline, 1%AEP plus 30% climate change+CC75%

4.3.4 Blockage Simulations with the Proposed Culvert Dimensions

The culvert dimensions selected to facilitate modelling of blockage were:

- 1.5m by 1.5m rectangular box culvert at Llanmaes Brook;
- 1.375m diameter circular culvert at Boverton Brook.

Simulations were conducted to examine the effects of blockage of the proposed culverts on both Llanmaes and Boverton Brook. Simulations of 67% and 100% blockage were conducted for the 1%AEP plus climate change 30% allowance and for the 0.1%AEP events. This is in accordance with the latest guidance on blockage provided by NRW[4]. The depth difference maps of these events compared to no blockage event scenarios are shown in Figure E10 – Figure E13. Flood depths maps showing the extent and depth of flooding for each scenario are shown within Appendix F, Figures F7-F10.

It can be seen in Table E3 that for all simulations there are large areas of storage upstream of the NAR on both the Llanmaes Brook and Boverton Brook. To ensure that there is no detrimental flood risk or flood storage in excess of 10,000m^3, varying flood relief culverts were tested to determine an appropriate solution.

Table E3. Storage Volumes for Blockage Simulations, without flood relief culverts

Event	Llanmaes Storage Volume (m3)	Boverton Storage Volume (m3)
1%AEP +30%CC, 67% blockage	36,872	14,437
1%AEP +30%CC, 100% blockage	38,614	15,875
0.1%AEP, 67% blockage	38,667	15,358
0.1%AEP, 100% blockage	39,994	16,414

[4] NRW, Unpublished Guidance, 2015. Flood Risk Management: Modelling blockage and breach scenarios.

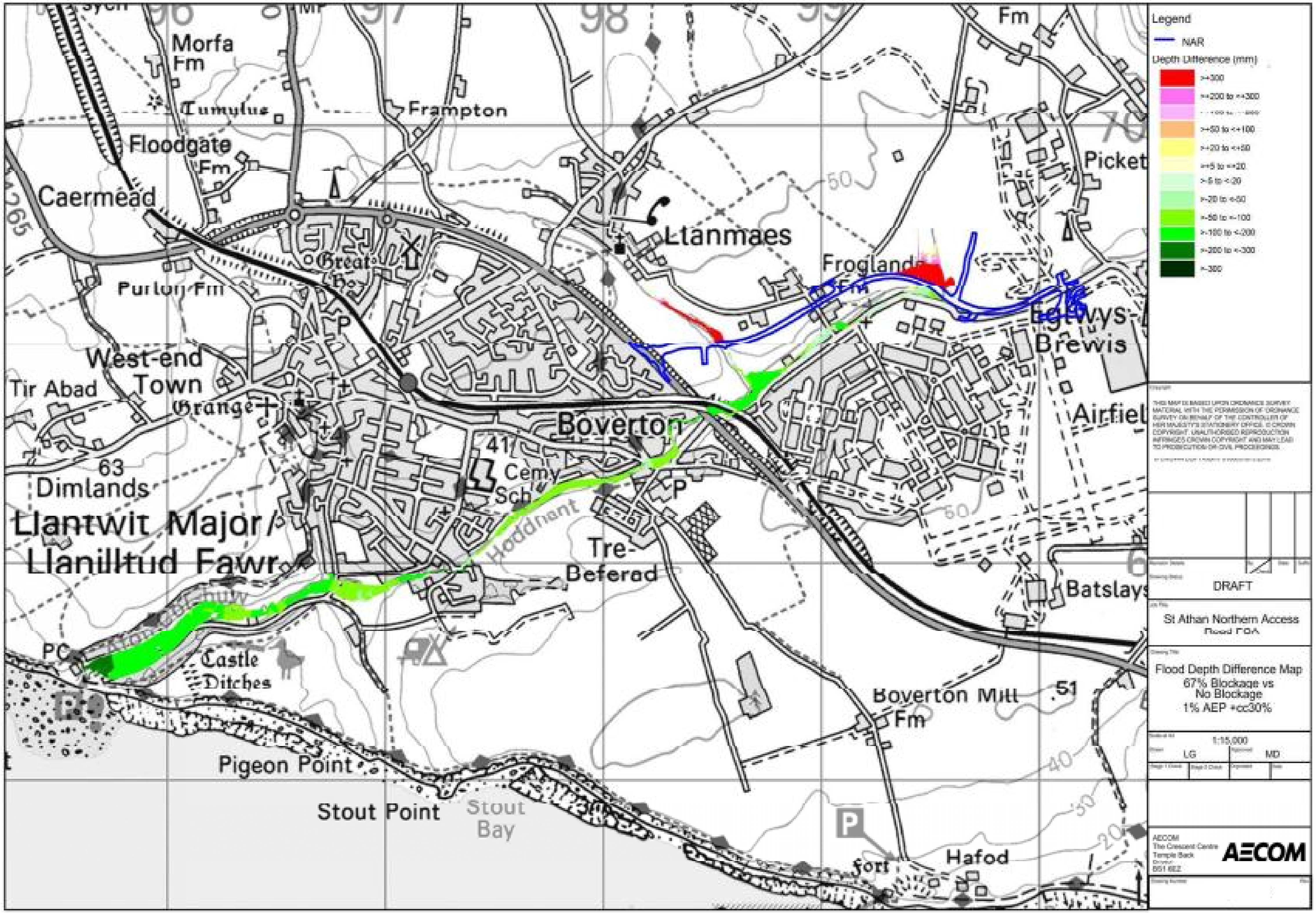


Figure E10- Flood Depth Difference Map, 67% Culvert Blockage vs No Blockage, 1% AEP plus 30% Climate Change Allowance

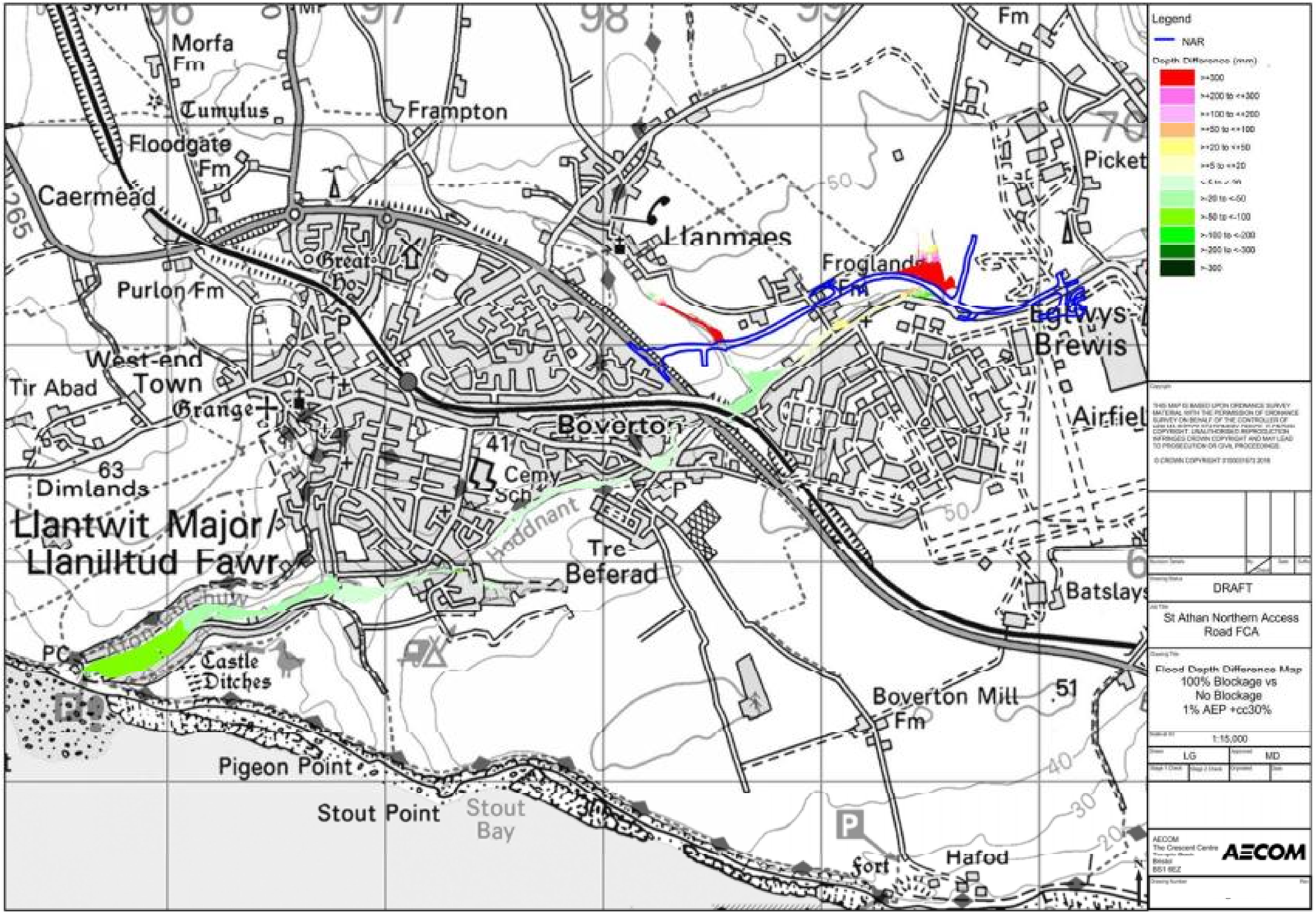


Figure E11-Flood Depth Difference Map, 100% Culvert Blockage vs No Blockage, 1% AEP +CC30%

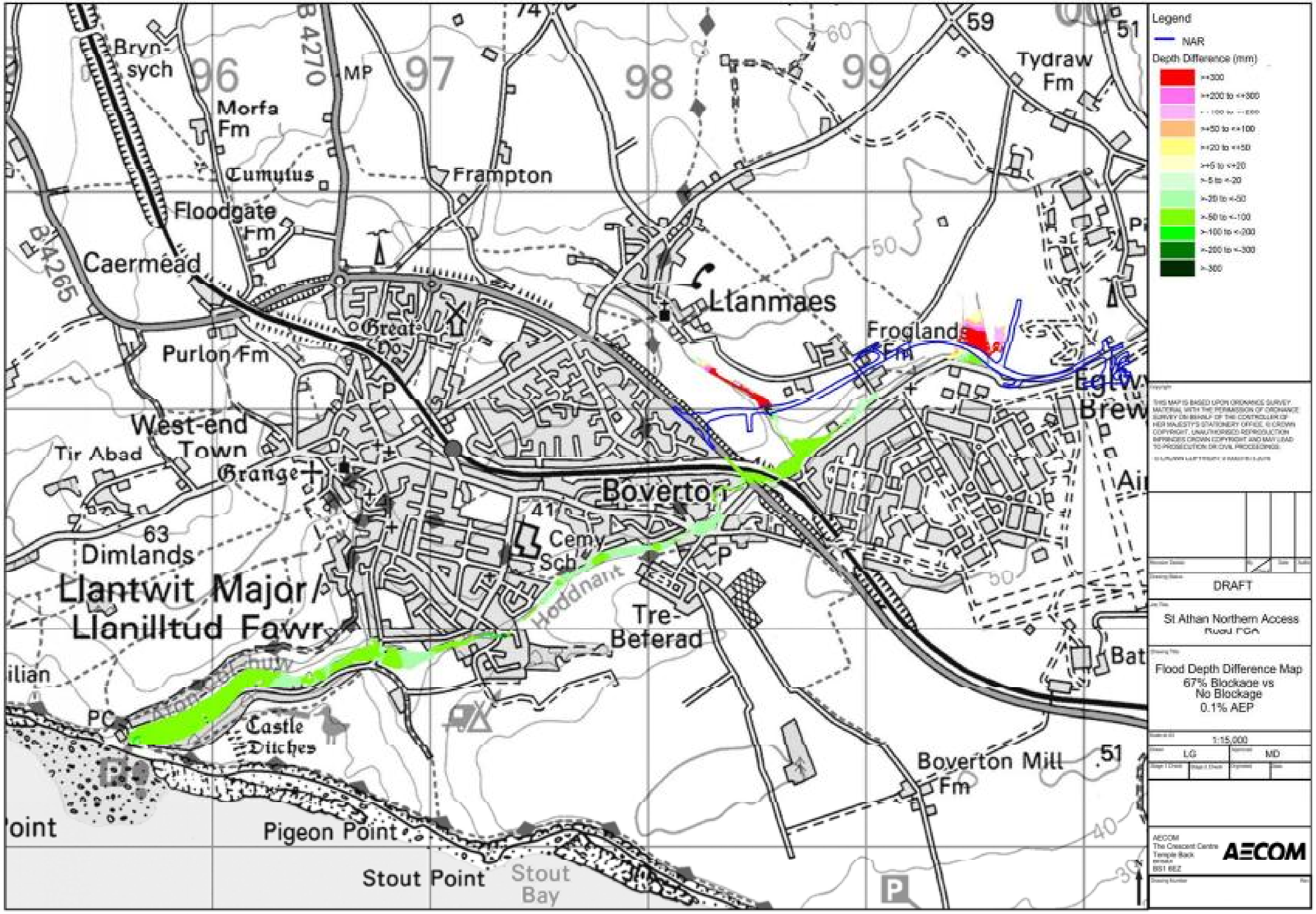


Figure E12-Flood Depth Difference Map, 67% Culvert Blockage vs No Blockage, 0.1% AEP

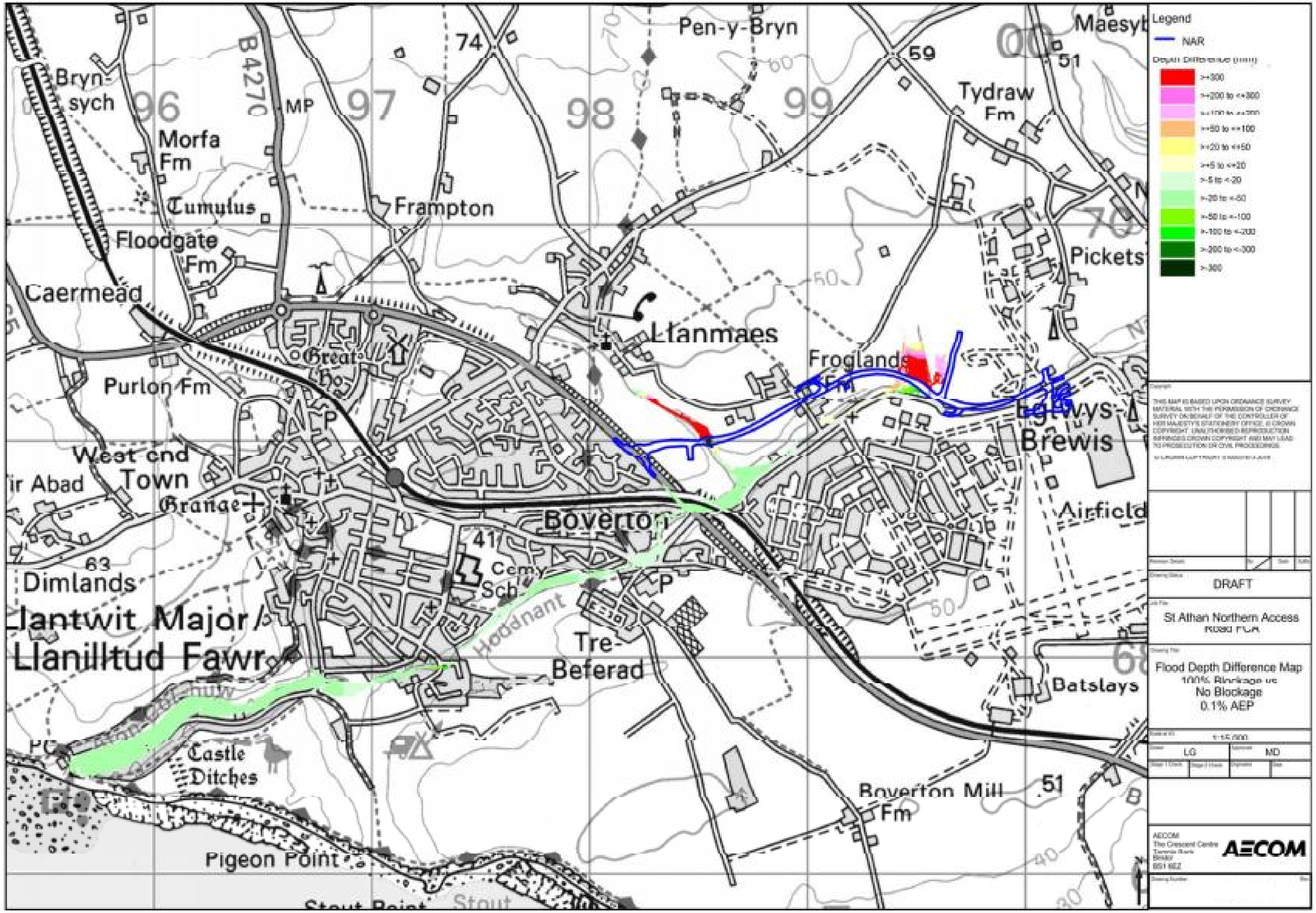


Figure E13-Flood Depth Difference Map, 100% Culvert Blockage vs No Blockage, 0.1% AEP

4.3.5 Blockage Simulations with Flood Relief Culverts

As discussed in section 4.3.5, the simulations of blockage to the main culverts (Llanmaes Brook and Boverton Brook) underneath the NAR resulted in large areas of storage upstream, as shown in Table E3. The volume of these storage areas were far in excess of 10,000m^3 on both the Llanmaes Brook and Boverton Brook. Therefore, flood relief culverts were conceptually specified and entered into the model.

The invert levels of the flood relief culverts were initially set to the maximum elevations of flood water upstream of the road for the unblocked 1%AEP plus 30% climate change event. However, as a result of simulating blockage scenarios with this assumption it was found that at these elevations, storage volumes on Boverton Brook exceeded 10,000 m^3 for the 100% blockage events. At the crossing of the NAR on Llanmaes Brook, the storage volume remained below 10,000m^3 without further amendments.

Interrogation of results found that the flood relief culverts on Boverton Brook were not fully utilised throughout the simulations. Widening of the culverts on Boverton Brook still resulted in storage volumes greater than 10,000m^3. Therefore, the invert levels of the culverts on Boverton Brook were lowered. Details of the modelled flood relief culverts are shown in Table 4.

Table E4- Proposed Flood Relief Culvert Dimensions

Culvert Parameter	Llanmaes Brook	Boverton Brook
Invert Level (mAOD)	2 at 39.69 and 2 at 39.89	42.5
Height (m)	1.1	0.5
Width (m)	2.1	3
Number of	4	4

Maps showing the maximum flood depths with the above flood relief culverts are shown in Appendix F, Figures F6-F9. The upstream storage volumes with the above flood relief culverts included were found to be 9,920m^3 on Llanmaes Brook and 9,190m^3 on Boverton Brook for 100% blockage for the 0.1% AEP event.

Results showing the percentage full of the culverts and maximum flood elevations during the event were interrogated to find the minimum culvert dimensions required. As the invert levels of the flood relief culverts are set high, the depth of water within the culverts were found to be lower than the soffits, and therefore the culvert width is the critical factor for conveyance. Table E5 summarises the minimum flood relief culvert dimensions required to ensure that upstream storage volumes do not exceed 10,000m^3.

Table E5- Minimum Required Dimensions of Flood Relief Culverts

Culvert Parameter	Llanmaes Brook	Boverton Brook
Peak Upstream Water Elevation (mAOD)	40.66	42.79
Road Elevation at FRC location (mAOD)	42	42.9 and 43.8
Invert Level (mAOD)	39.69 (x2) and 39.89 (x2)	42.5
Height (m)	1	0.4
Width (m)	2.1	3
Number of	4	4

As a result of including the specified flood relief culverts from Table E4, the storage volume on both the Llanmaes Brook and Boverton Brook was maintained below 10,000m^3 for all blockage scenarios. The storage volumes for each event are shown in Table 6.

Table E6- Llanmaes and Boverton Brook Storage Volumes for Blockage Events with Flood Relief Culverts Included

Event	% blocked	Llanmaes Storage Area (m^3)	Boverton Storage Area (m^3)
0.1% AEP	**100%**	9,920	9,190
	67%	8,970	7,840
1% AEP +CC30%	**100%**	8,360	7,560
	67%	7,420	6,240

Flood depth difference maps for each of these events are shown in Figure E14 – Figure E17. It can be seen that in the 0.1% AEP 100% blockage event, there is a 5mm increase in flood depth in a localised area within Boverton. It was agreed with NRW that this level of detriment downstream was acceptable as it is well within model tolerance and is for the most stringent of events modelled.

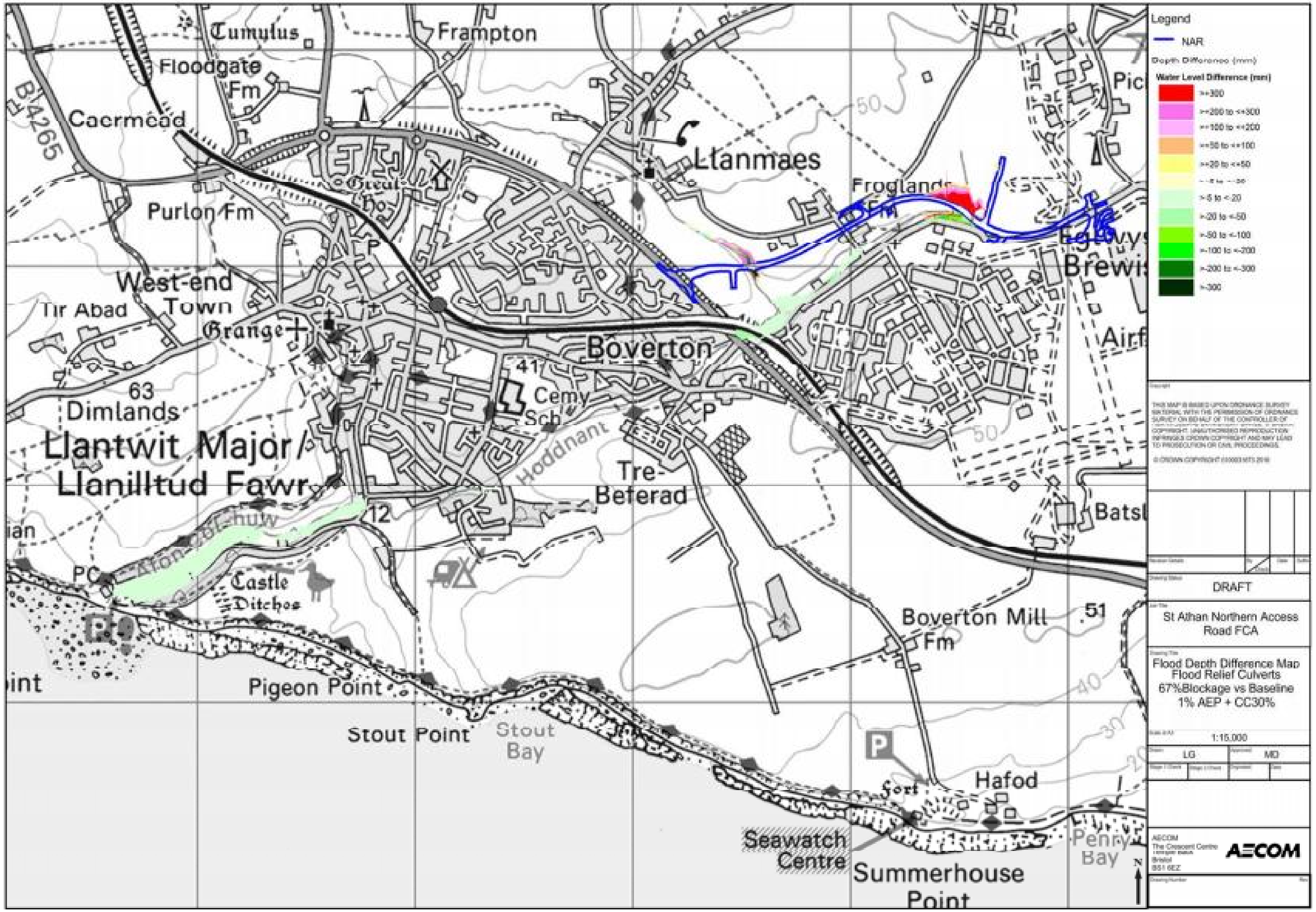


Figure E64 - Flood Depth Difference Map Proposed Scheme with Flood Relief Culverts 67% Blockage vs Baseline 1%AEP+CC30%

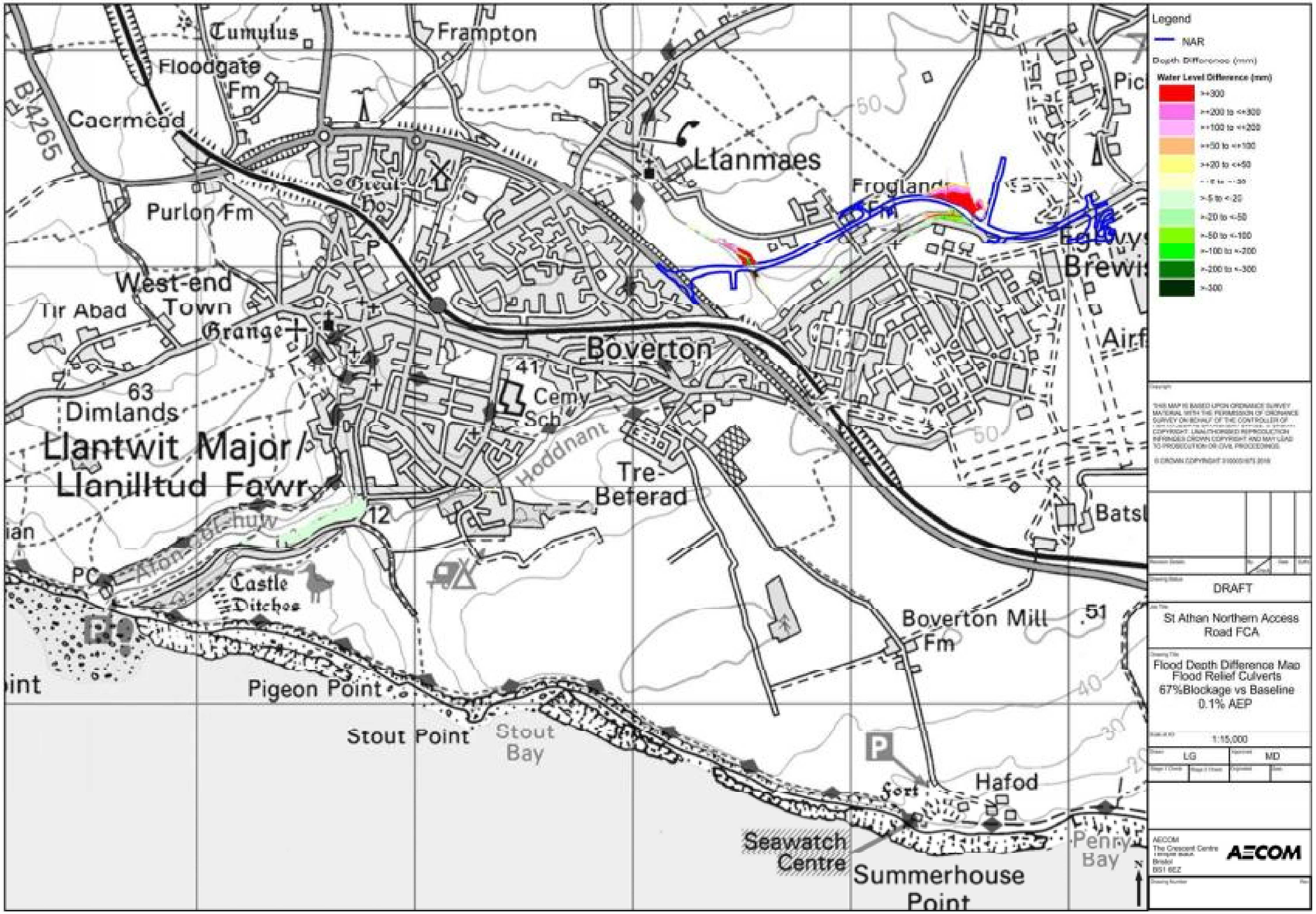


Figure E75 - Flood Depth Difference Map Proposed Scheme with Flood Relief Culverts 67% Blockage vs Baseline 0.1%AEP

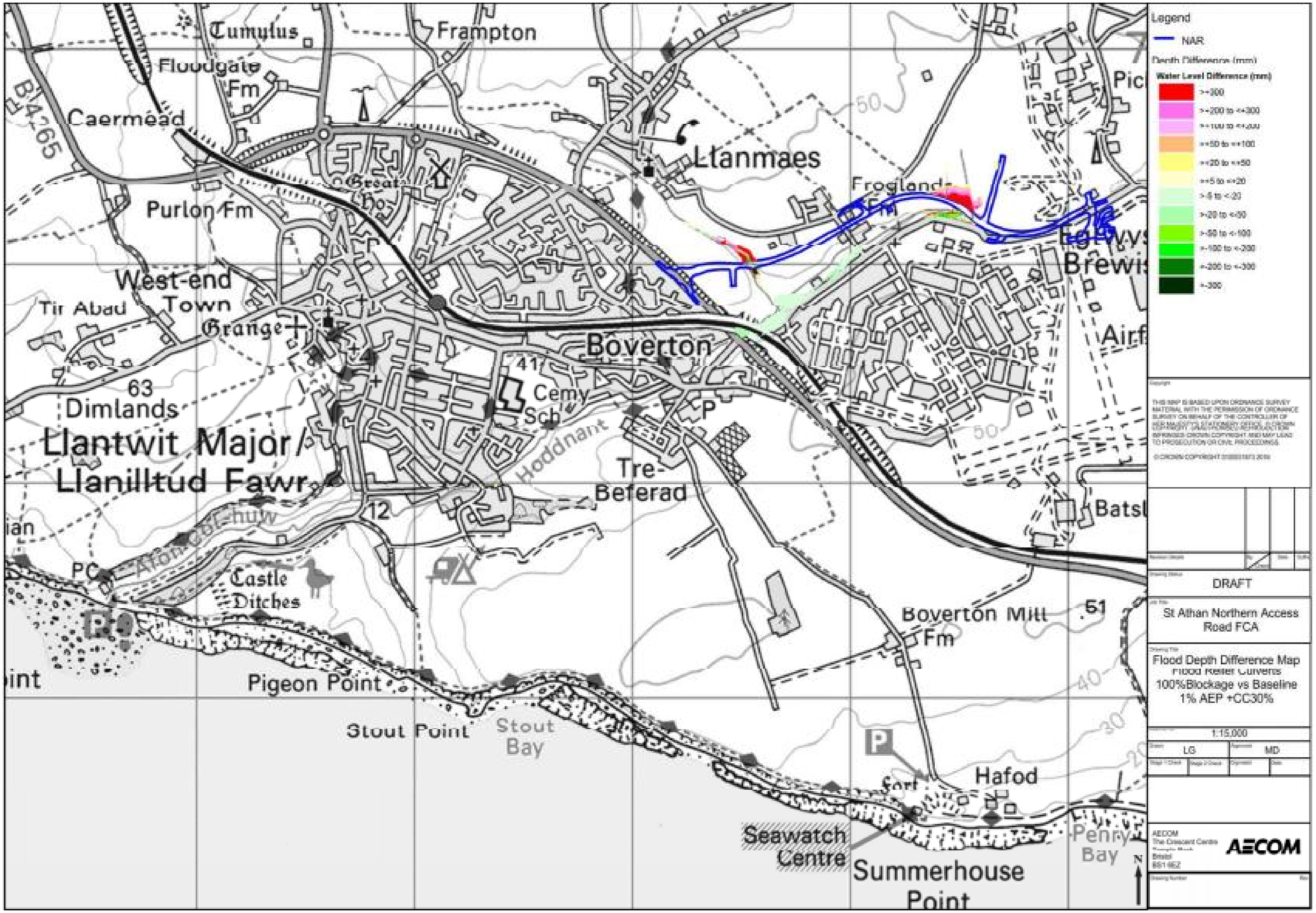


Figure E86 - Flood Depth Difference Map - Proposed Scheme with Flood Relief Culverts 100% Blockage vs Baseline 1%AEP+CC30%

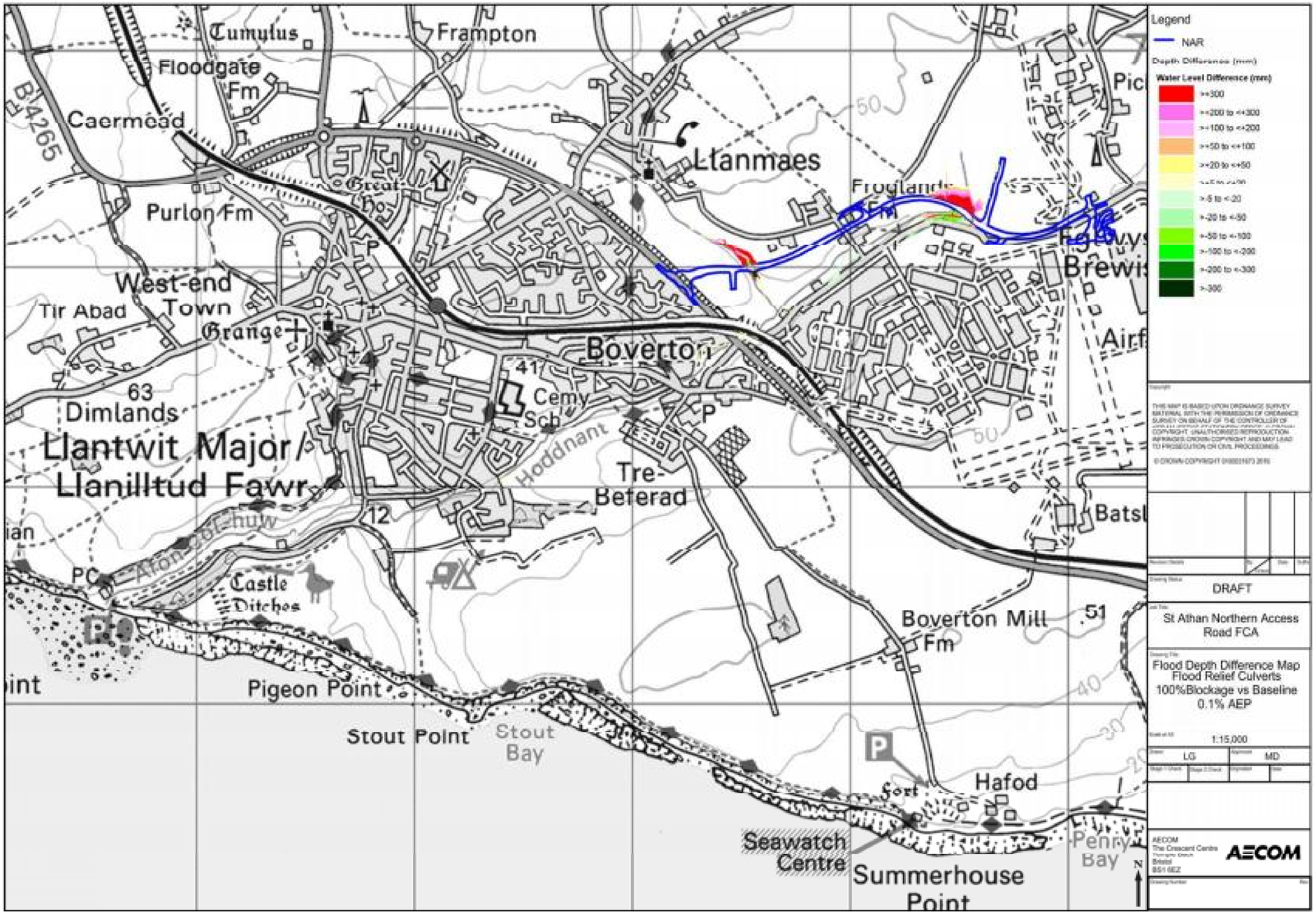


Figure E17- Flood Depth Difference Map Proposed Scheme with Flood Relief Culverts 100% Blockage vs Baseline 0.1%AEP

4.3.6 Flood Bunds, Highways Drainage and Pluvial Mitigation Measures

At this stage, designs of the highways drainage ditches and swales became available; these features are detailed in the drainage design specification in the drainage strategy report. These highways drainage elements include swales, culverts and infiltration basins. Which were added to the model using a series of 1D ESTRY culverts and channels and Z shapes. The location of these features is shown in Figure E18.

The flood bunds and pluvial mitigation measures were developed in tandem and therefore pluvial mitigation measures were incorporated into the fluvial model. Details of the pluvial mitigation measures are contained within Section 7 of the FCA and Appendix D.

It was decided that separate flood bunds are to be constructed to prevent long term hydrostatic pressure issues against the road embankment, therefore further modelling was conducted. The flood bunds were added to the hydraulic model by alterations to the DTM. Simulations were completed to assess the impact of the flood bunds on storage volumes and downstream flows. In order to allow space for surface water drainage features between the bunds and the NAR, the flood bunds were positioned at least 15m away from the NAR.

As a result of the hydrology used to drive the pluvial model, flows and storage volumes observed in the pluvial model were greater than those observed in the fluvial model. Therefore, in order to be conservative, the design of storage bunds and weirs was informed by the pluvial model.

The elevation of the flood bunds was set to the 1%AEP plus 30% climate change pluvial flood water elevations plus 0.5m to provide sufficient freeboard allowance. The culverts on both Llanmaes Brook and Boverton Brook (detailed in Section 4.3.3) were extended to the upstream face of the flood bunds to allow flow through the bunds and the NAR. The location of the modelled bunds, highways drainage features and pluvial mitigation measures are shown in Figure E18.

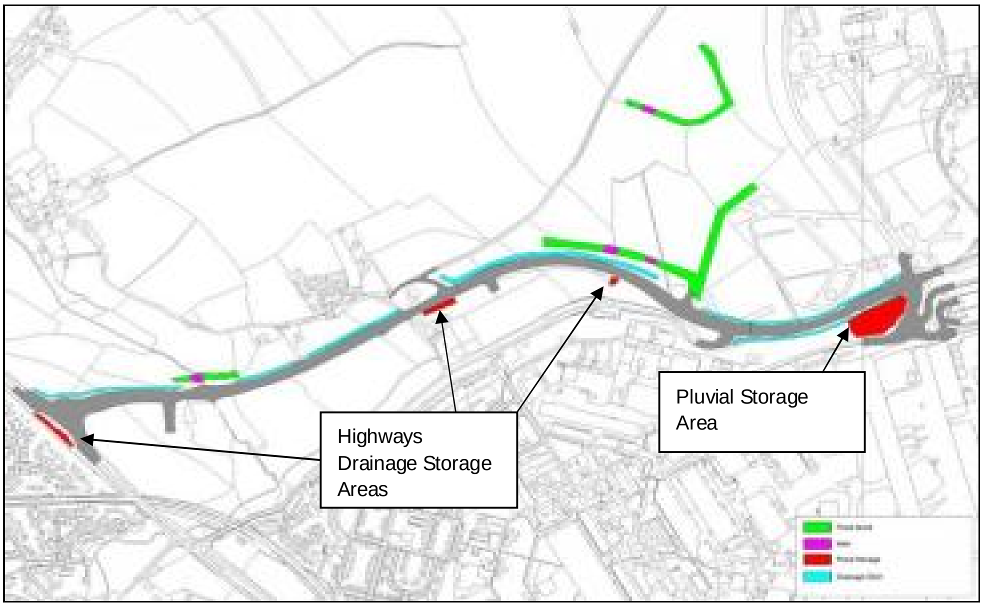


Figure E18 - Location of Flood Bunds (Green) and Highways Drainage Storage Areas (Red) and Pluvial Mitigation Drainage Ditches (Blue)

The more conservative pluvial model highlighted the need for an additional location of flood storage upstream on Boverton Brook. This was required as hydraulically, no solution could be reached which maintains storage below 10,000m^3 during the 1000yr event (0.1%) with 100% blockage without causing detriment. This additional flood storage area acts to slow the overland flow of water in the pluvial model and ensure that the volume of water stored at the downstream bund at Boverton is less than 10,000m^3 in the pluvial model and that no detriment is observed in Boverton in the fluvial model.

A 1.25m diameter culvert drains this upstream storage area, this culvert outfalls to the existing ditch network. Simulations of 100% blockage of this culvert were also completed.

The design of the bunds incorporates overspill weirs to allow overflow if the main culverts block or fail, conveying surcharged flow to the flood relief culverts. The overspill weirs were initially set to the level of water immediately upstream of the bunds in the 1% AEP plus 30% climate change pluvial event, these levels were then lowered to ensure storage volumes were maintained below 10,000m^3 for all events.

The weirs have been designed so that water overtops the flood bunds in a controlled manner and is channelled towards the flood relief culverts under the NAR. The flood relief culverts are designed to also take surface water away from the area in between the bunds and NAR at Boverton Brook in extreme pluvial events.

The dimensions of the flood bunds modelled are shown in Table 7

Table E7-Dimensions of Flood Bunds on Llanmaes and Boverton Brooks

Watercourse	Elevation of Crest (m AOD)	Width of Crest (m)	Elevation of weir (m AOD)	Width of Weir (m)
Llanmaes	41.25	2.00	40.52	20.00
Boverton	44.15	2.00	42.78 and 42.65	30.00 and.00 22
Boverton Upstream Flood Bund	46.39	2.00	45.49	28.00

The flood relief culverts were iteratively adjusted in size, number and elevation, with the final dimensions specified shown in Table 8.

Table E8- Finalised Dimensions of Flood Relief Culverts on Llanmaes and Boverton Brooks

Watercourse	Upstream Invert Elevation (m AOD)	Width (m)	Height (m)	Number of
Llanmaes	39.1 and 39.15	2.40	1.00	2 x 2.00
Boverton	42.12 and 42	3.00	0.50	2 x 2.00

The large volumes of water stored at Boverton for the 1%AEP plus 30% climate change pluvial event meant that the main culvert here had to be increased to 2m in diameter. Examination of pluvial results showed that this 2m diameter culvert 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. It was found that the culvert at Llanmaes could be reduced to 1.4m by 1.4m.

Model simulations were also run for AEPs of: 20%, 1%+CC30%, and 1%+CC75%.

In order to prove that this new alignment of flood bunds and culverts still met the design criteria outlined in section 4.3.1, model simulations were completed with 100% blockage of the three main culverts for the 1% AEP plus 30% climate change and 0.1% AEP event, the depth difference map is shown in Figure E19. It can be seen that the scheme now provides up to 20mm decrease in flood depth downstream in the most extreme events. This is a result of maximum downstream flows now being reduced by up to 0.18m^{3}s^{-1}.

The results of all simulations with flood bunds are summarised in Table E4.

Table E4. Summary of Results for Proposed Scenario with Flood Bunds

Event	Llanmaes Storage Volume (m^3)	Boverton Storage Volume (m^3)	Boverton Upstream Storage Volume (m^3)	Difference in Downstream Flow (m^{3}s^{-1})
20% AEP	1,554	710	1,697	-0.41
1% AEP+CC30%	5,443	2,012	3,934	-0.46
1%AEP+CC75%	6225	3045	4420	0.14
1%AEP+CC30% with 100% blockage on Llanmaes and Boverton NAR bund	7117	4662	3934	-0.26
1% AEP +CC30% with 100% blockage on Boverton upstream bund	N/A	1,722	4,934	-0.08
0.1% AEP with 100% blockage on Llanmaes and Boverton NAR bund	7,803	5,699	4,517	-0.30
0.1% AEP with 100% blockage on Boverton upstream bund	N/A	2,858	5,477	-0.18

It can be seen in Figure E19 below that there is detriment observed at Froglands Farm of an extra 0.01m depth for the 0.1% AEP with 100% blockage of the upstream Boverton flood bund culvert. There is no detrimental increase in the flood extent. This is the only event for which detriment is observed, all other simulations show betterment. As the detriment is not shown to be close to any building footprints, it has been considered as reasonable for such a rare event, pending future discussion with NRW. Depth difference grids for the other AEPs are shown in Figures to in Appendix F, Figures F10-F15.

It can be seen in table E9 above that storage volumes are below 10,000m^3 on Llanmaes Brook even for the 1%AEP plus 75% climate change event, as a conservative sensitivity to flow on the Llanmaes Brook catchment. Maximum downstream flows are also reduced for the 1% AEP plus 75% climate change event under the proposed design. This gives a degree of confidence that the mitigation options on Llanmaes Brook should be able to cope with an increase in flow if a separate flood relief scheme within Llanmaes village is constructed, although specific changes to flow hydrograph as a result of any future scheme for the village have not been provided to support this study.

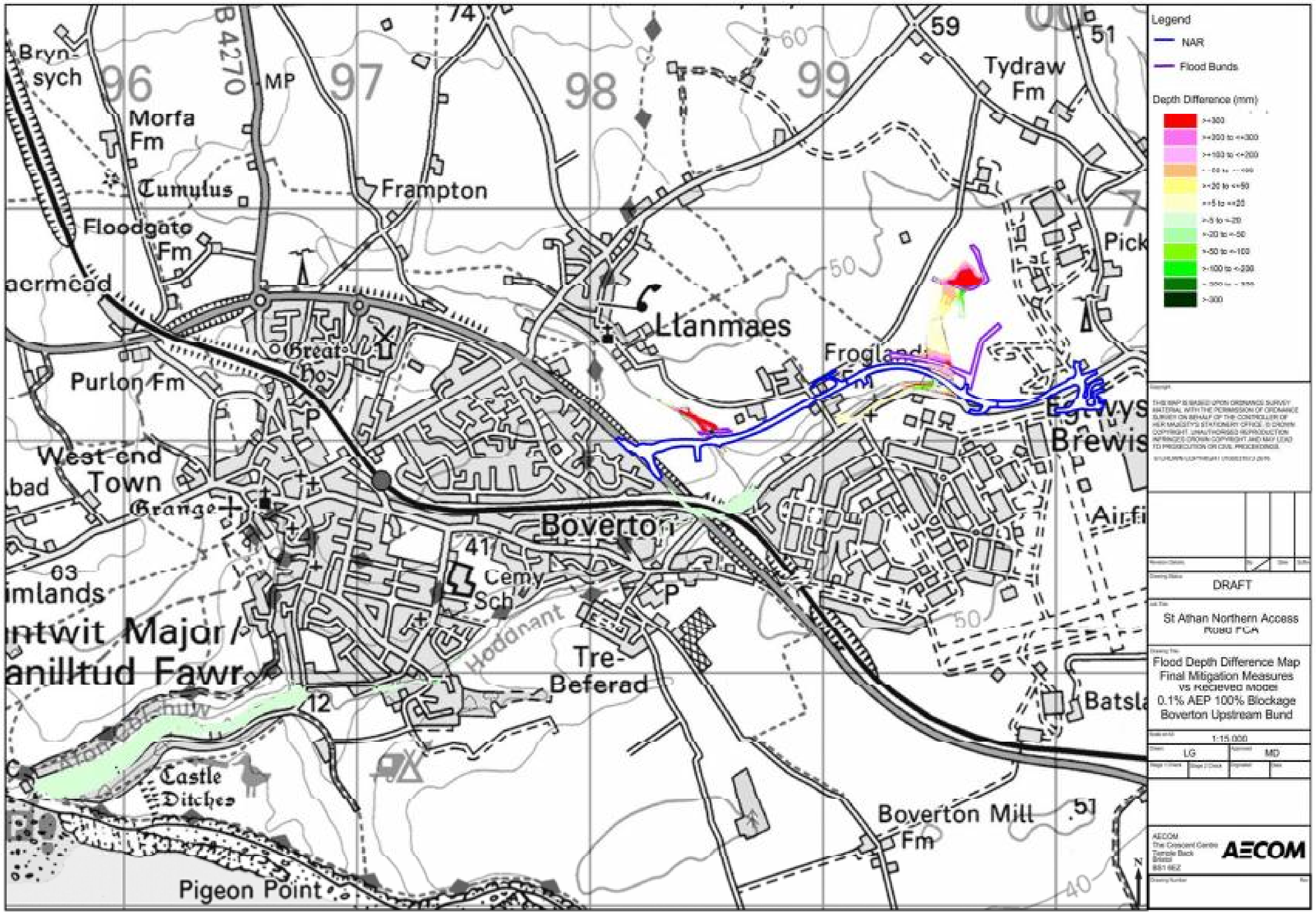


Figure E19-Flood Depth Difference Map, Proposed Scenario with Flood Bunds, 100% Blockage of Boverton Upstream Storage Area vs Baseline 0.1% AEP

4.3.7 Summary of Mitigation Measures

The following mitigation measures ensure that all of the design criteria outlined within section 4.3.1 are met:

- re-alignment of the access spur further eastwards in order to block overland flow paths to the Nant-y-Stepsau;
- one culvert on Llanmaes Brook with a cross sectional area within the range of 1.96-2.25m^2;
- one diameter culvert on Boverton Brook with a cross sectional area within the range of 1.13-1.48m^2;
- 41.25m AOD flood bund with 20m wide weir at 40.52mAOD on Llanmaes Brook;
- 44.15m AOD flood bund with a 30m wide western weir at 42.78mAOD and a 22m wide eastern weir at 42.65m AOD on Boverton Brook;
- 46.39mAOD upstream flood bund with a 28m wide 44.92mAOD weir on Boverton Brook, with a 1.25m diameter culvert at 44.92mAOD;
- two lots of two flood relief culverts on Llanmaes Brook with invert levels of 39.15 and 39.10mAOD, widths of 2.4m and heights of 1m; and
- two lots of two flood relief culverts on Boverton Brook with invert levels of 42 and 42.12mAOD, widths of 3m and heights of 0.5m.

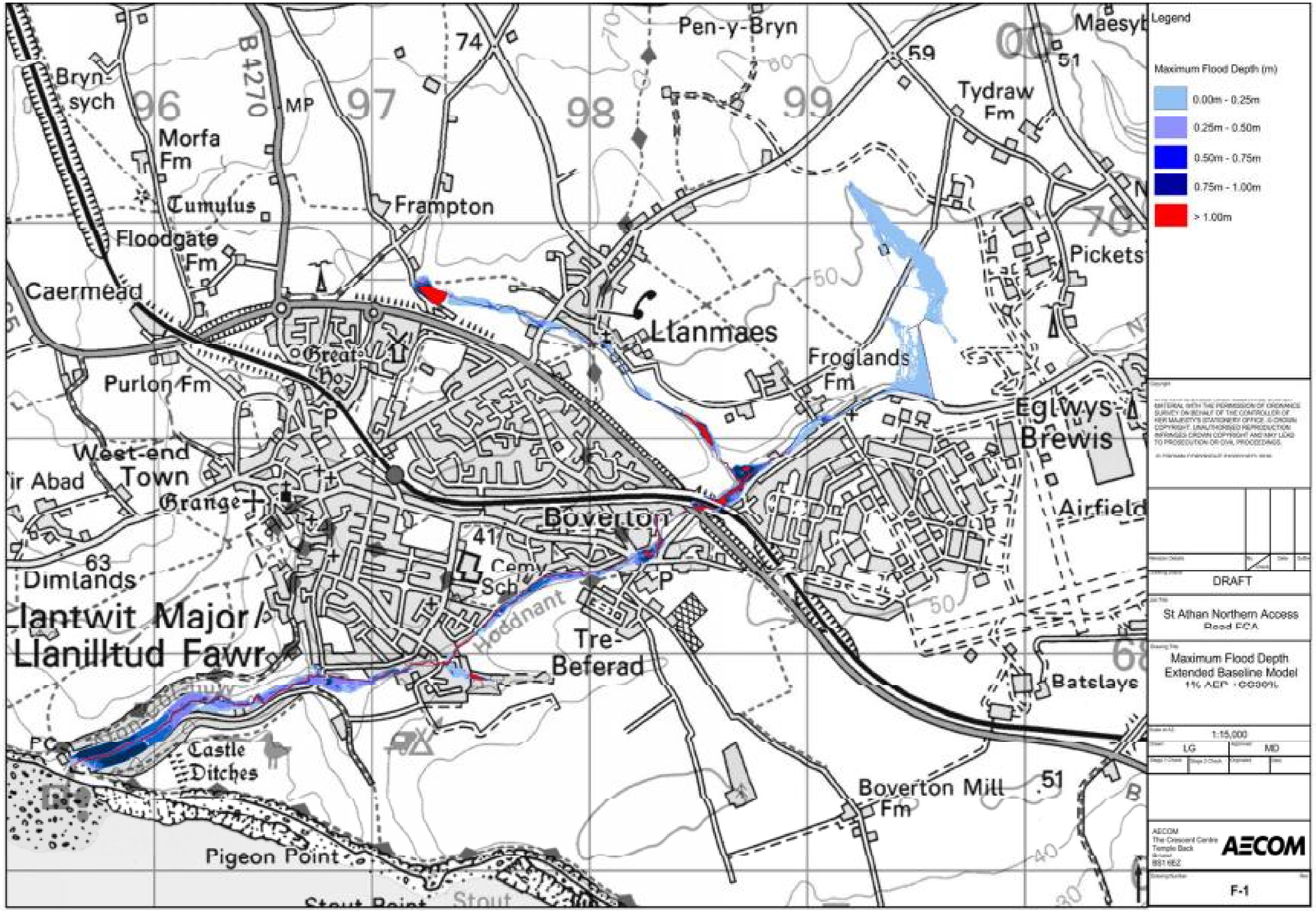
5. Conclusions and Recommendations

Following the model extension, the preliminary design of the NAR has been concluded. With the proposed NAR scheme crossing two watercourses and potentially displacing areas of the floodplain, 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 these compensatory measures have shown that even in 100% blockage scenarios, betterment is provided downstream and upstream storage volumes remain less than 10,000m^3.

Fluvial model simulations have also been run for a climate change scenario of +75% to examine the sensitivity of mitigation measures to increased flows at Llanmaes Brook. Upstream storage volumes and downstream flows for this scenario were found to be within design criteria. As the NAR scheme is likely to be designed and constructed in advance of the potential VoGC flood relief scheme at Llanmaes, the proposed NAR scheme design should be relayed back to VoGC at the earliest opportunity to ensure that their future design has no detrimental impact on flood storage.

It should be noted that the proposed elevations of flood bunds and weirs are very sensitive to changes in position of the flood bunds. It is therefore recommended that if any alterations to the positioning of flood bunds is made during detailed design that further modelling is conducted to determine the suitability of any proposed elevations of the weirs and bunds required.

Appendix F – Fluvial Modelling Results Figures



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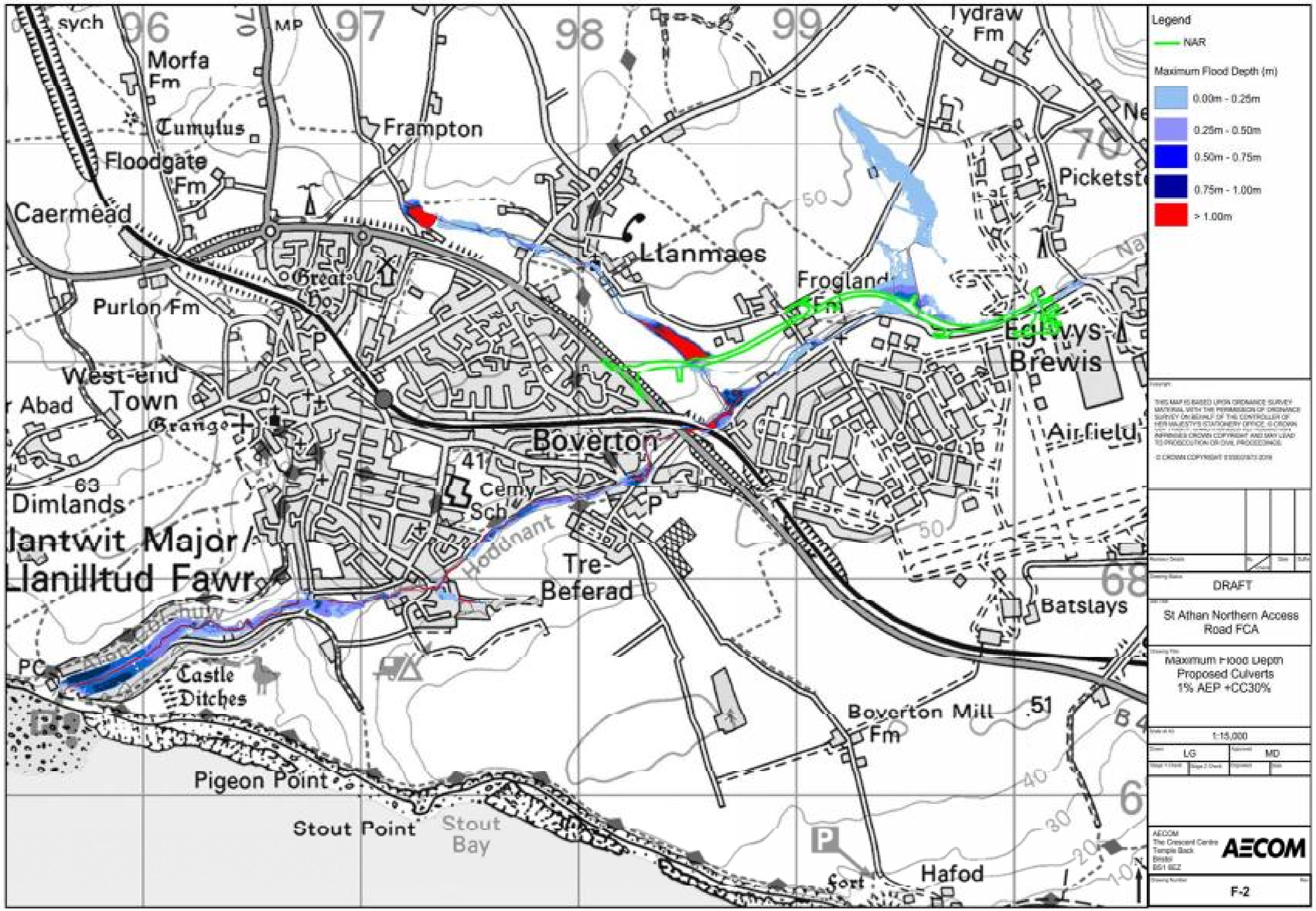
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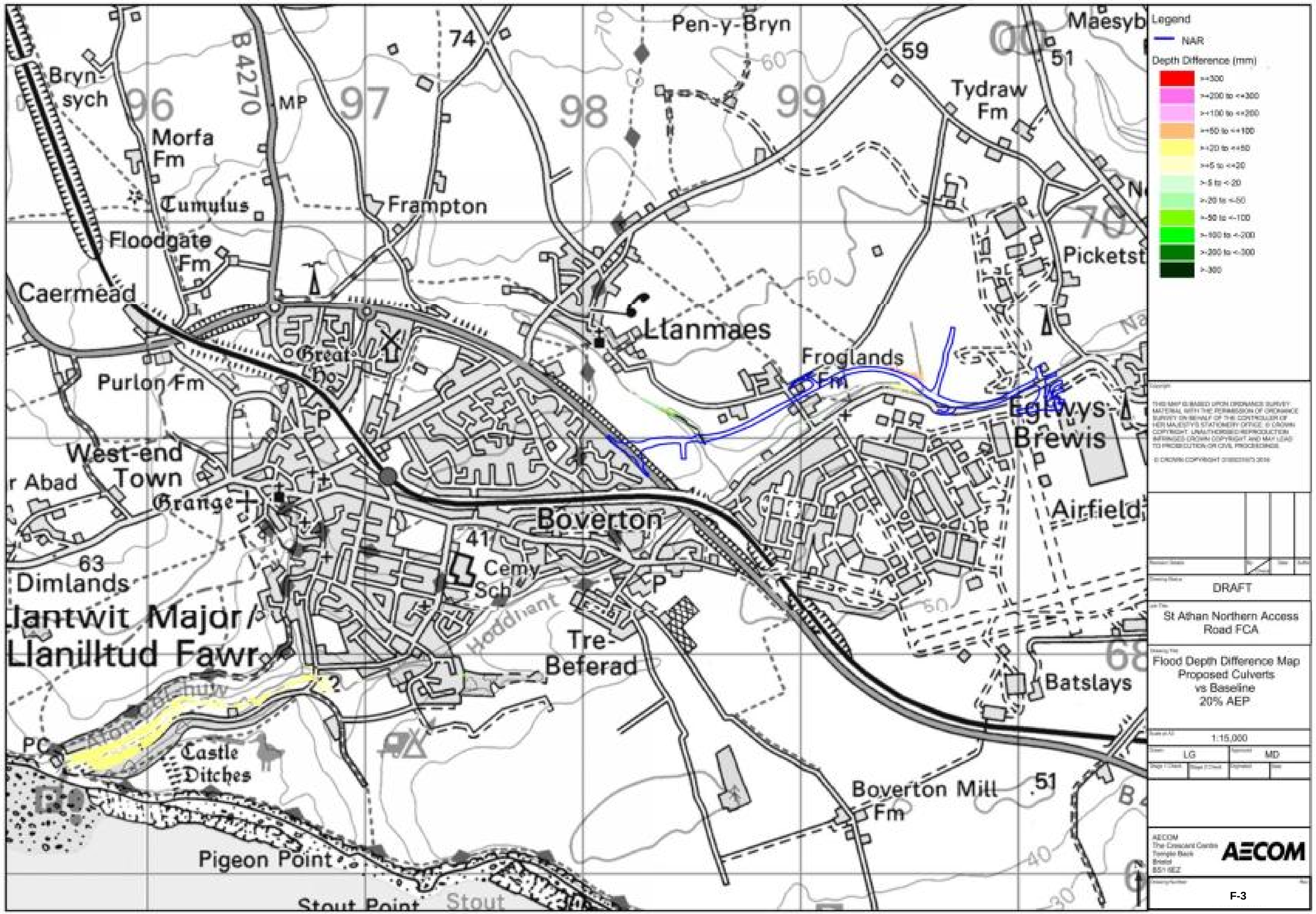
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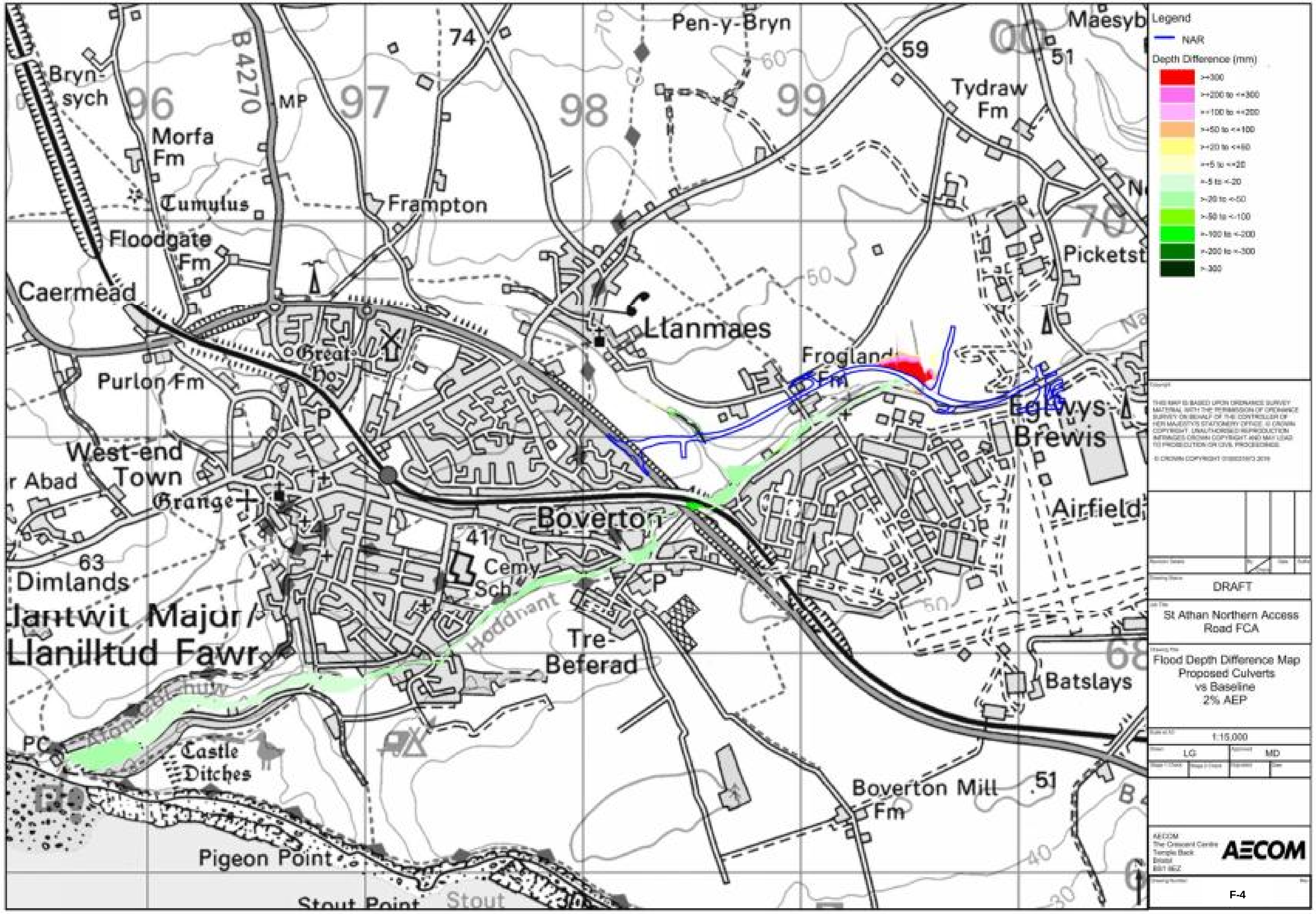
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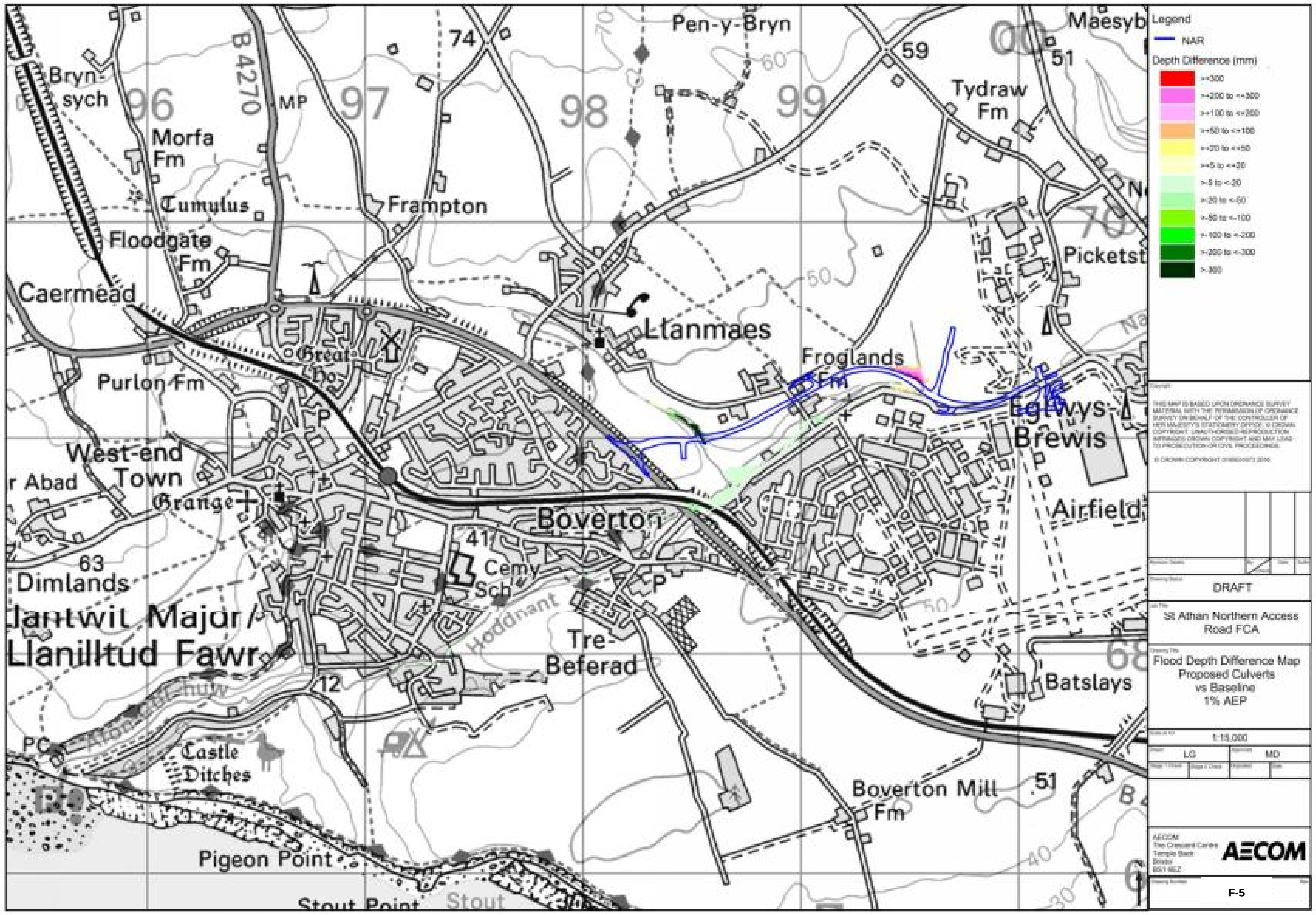
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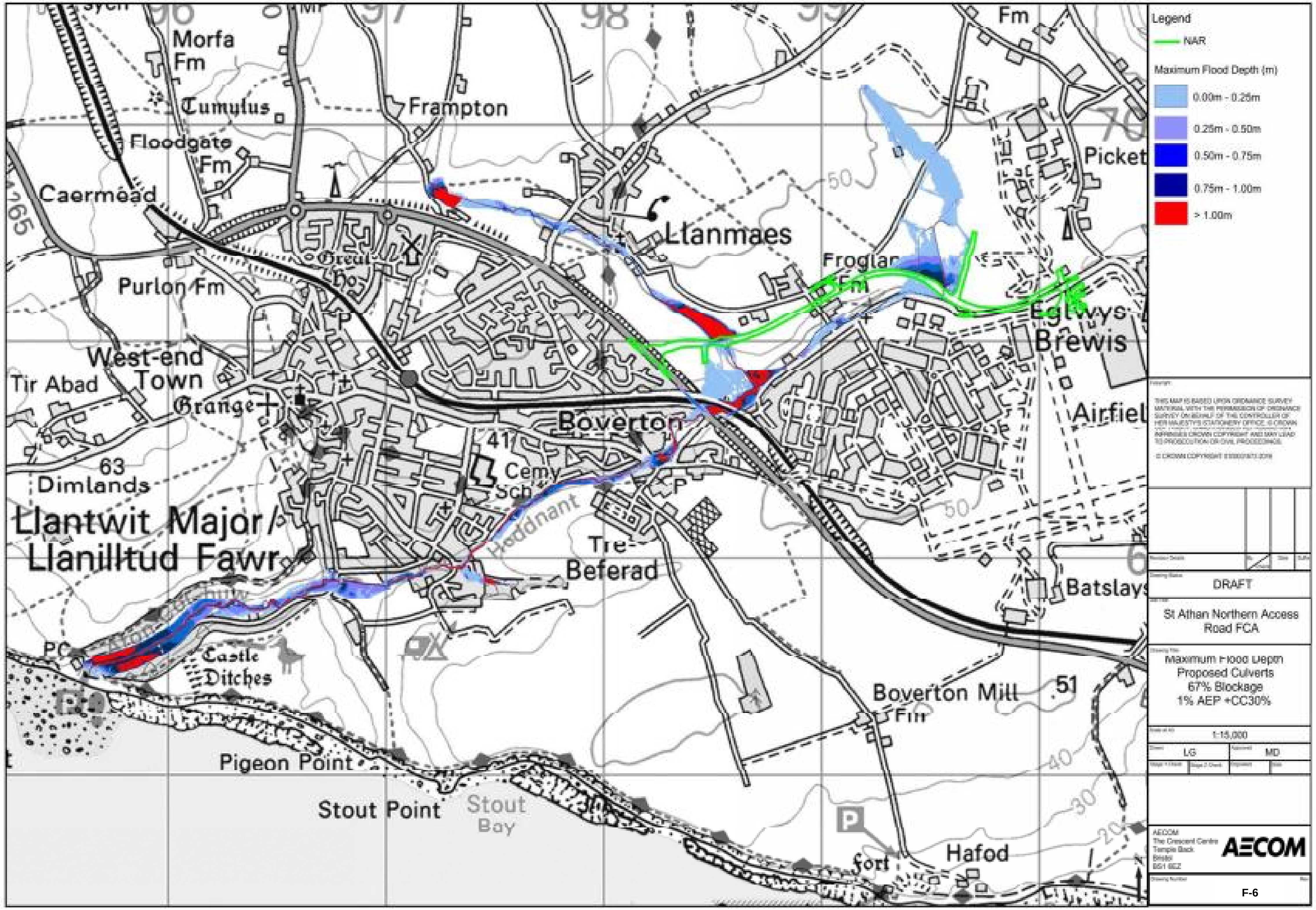
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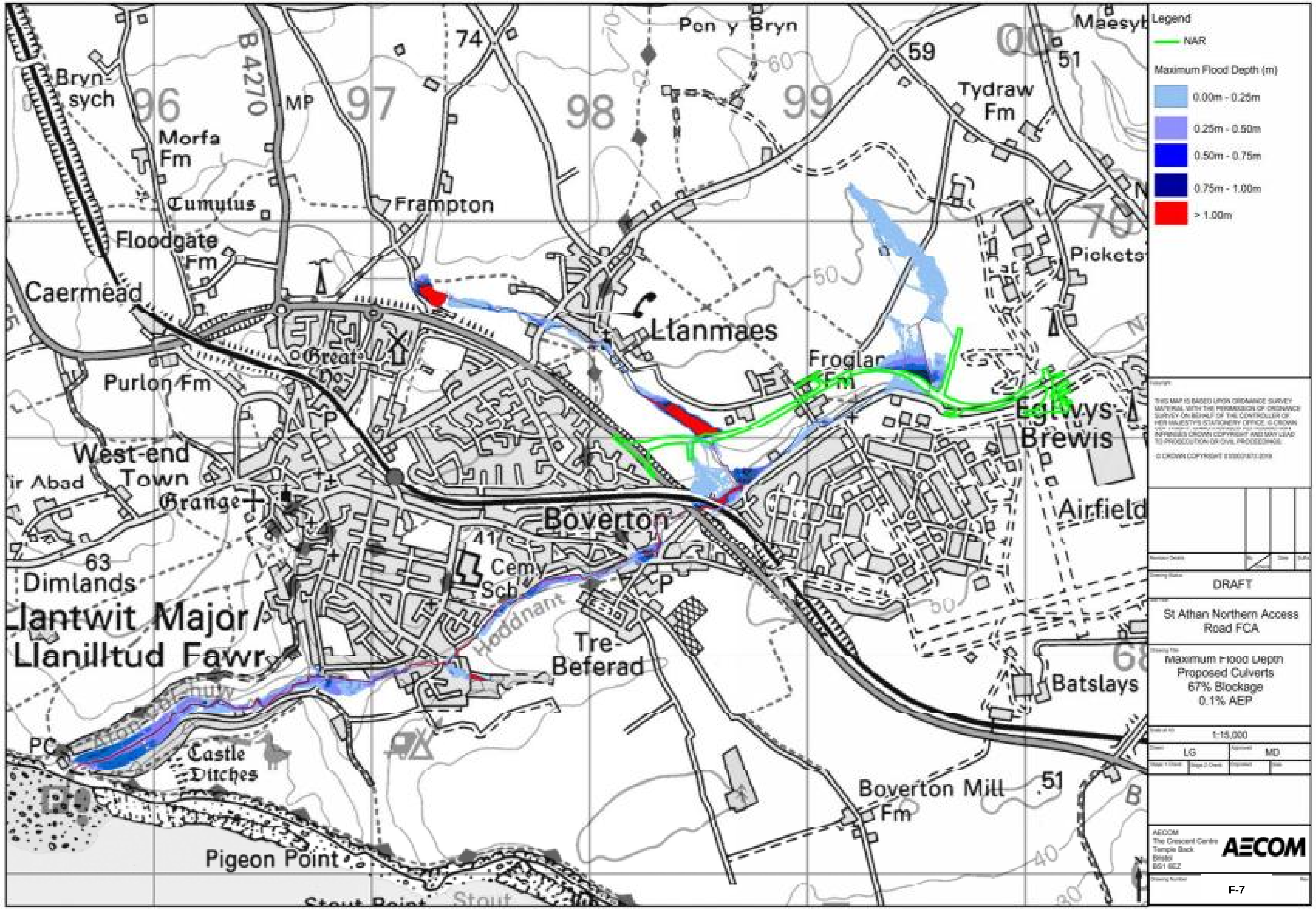
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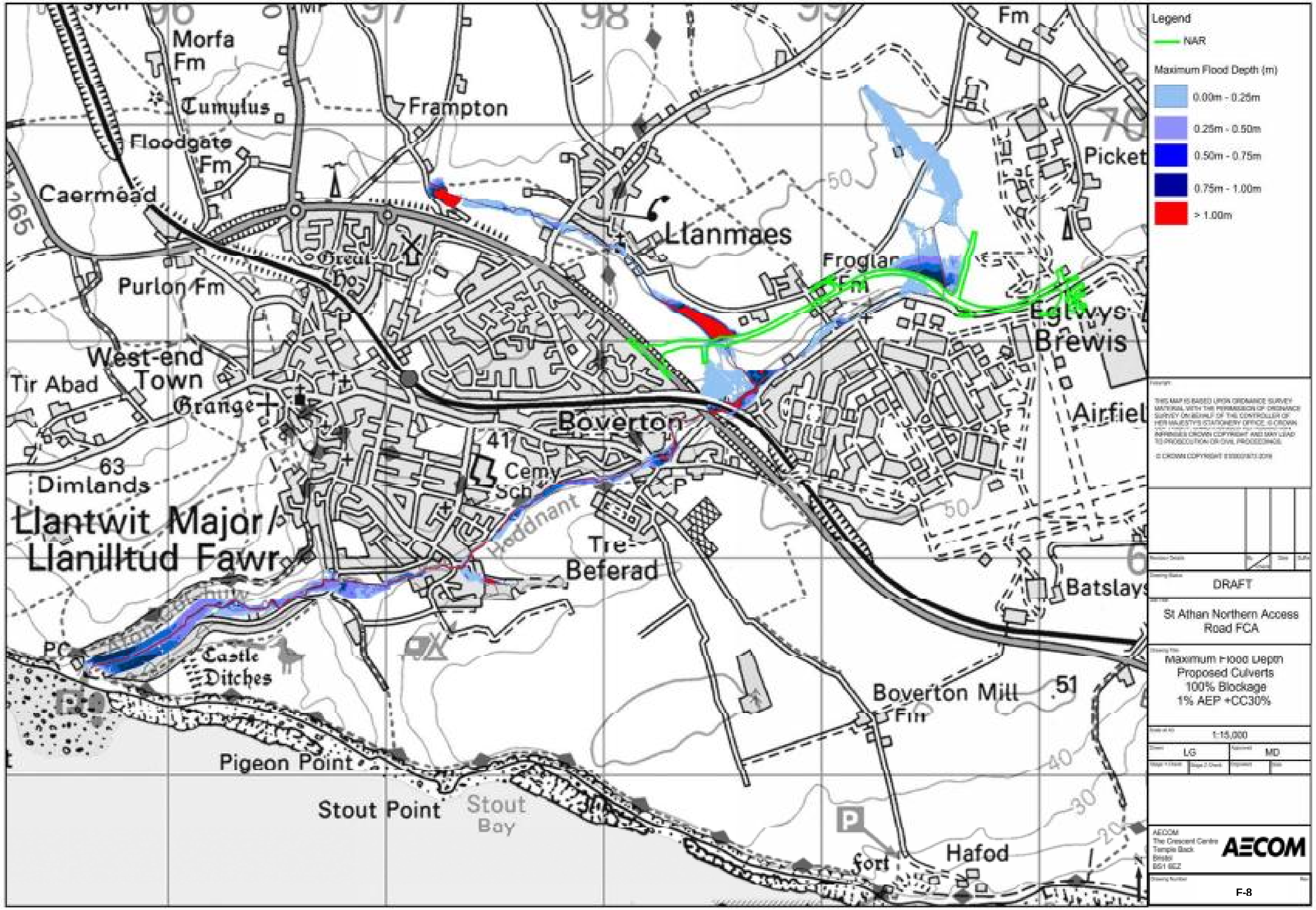

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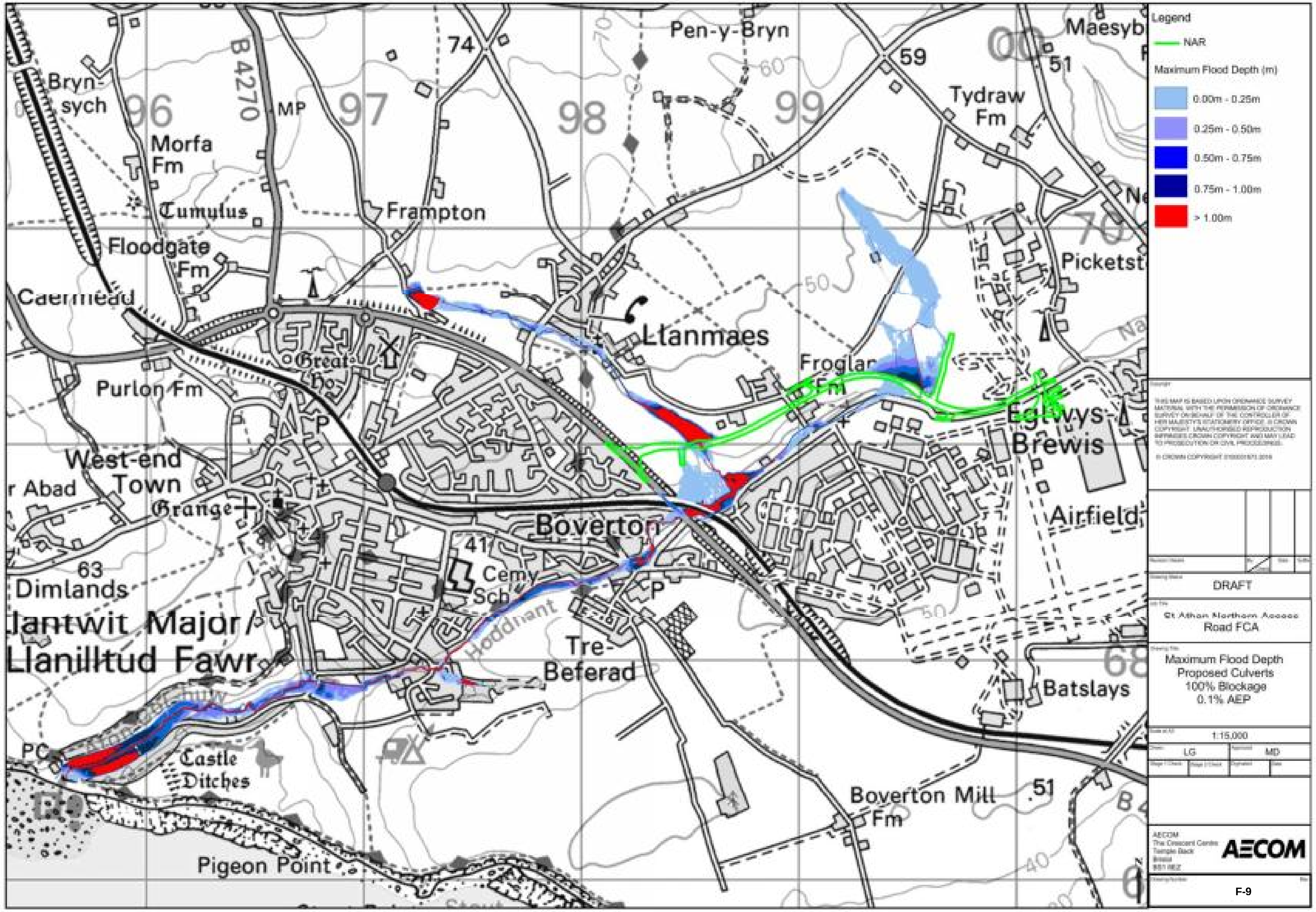

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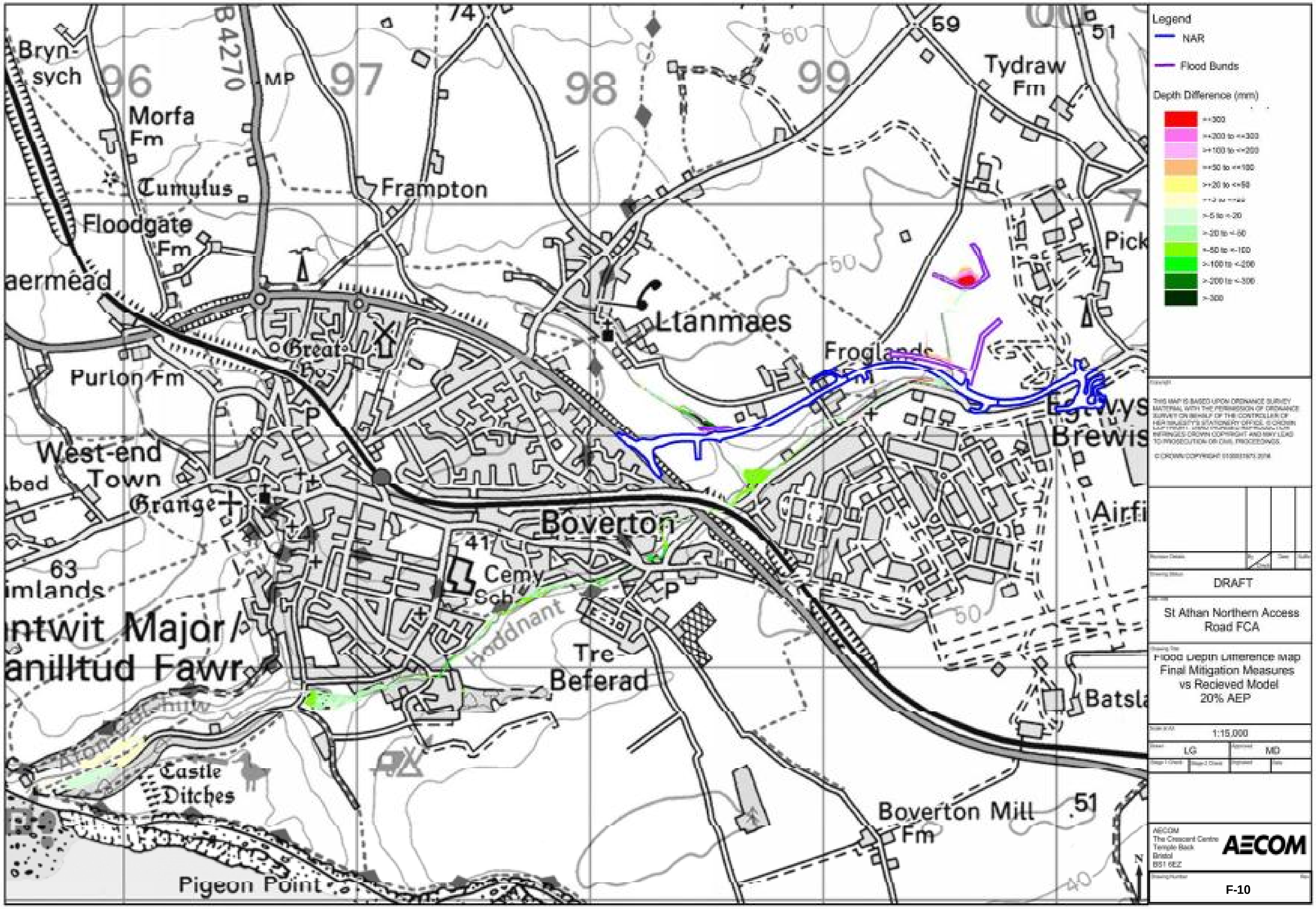
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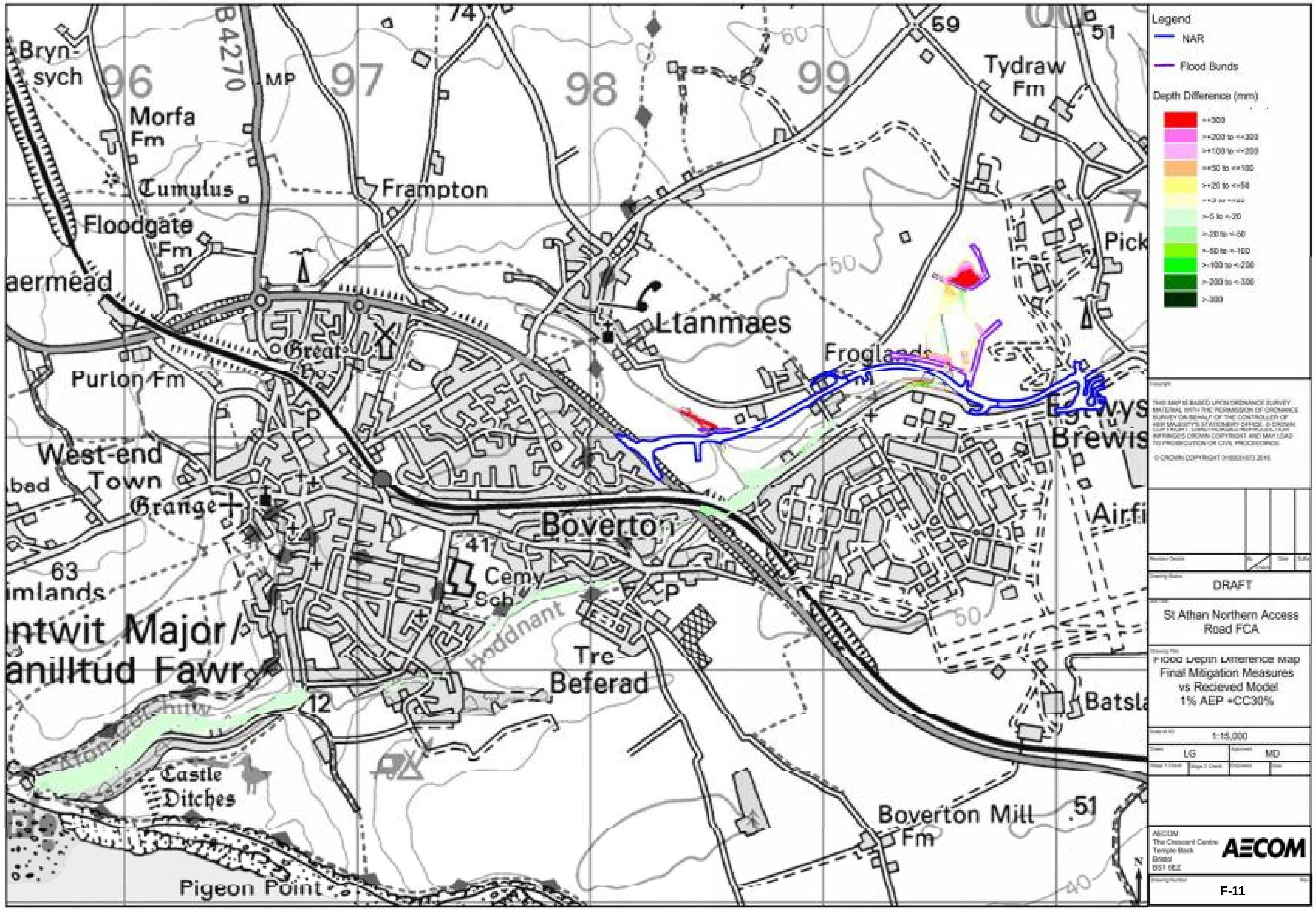
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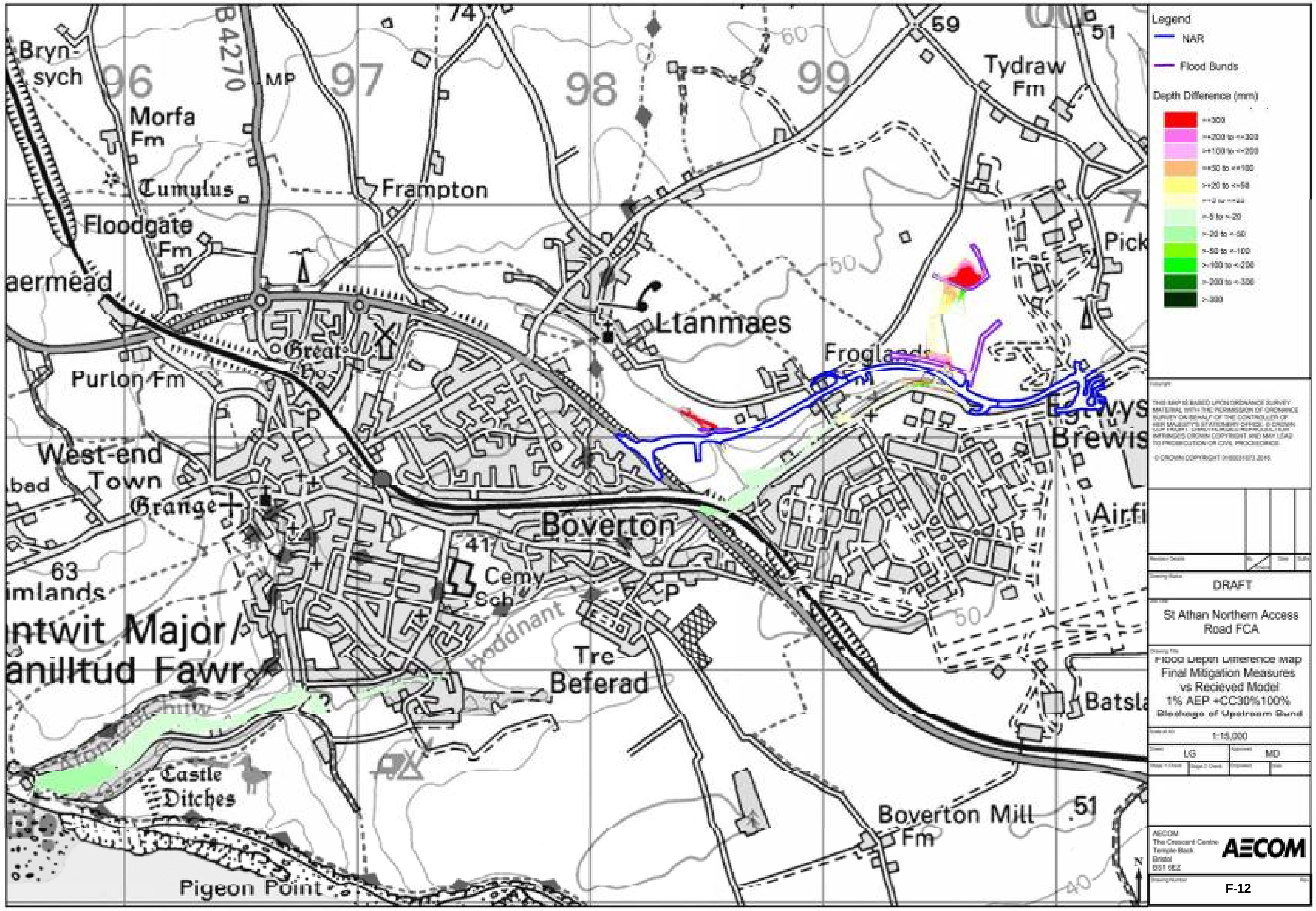
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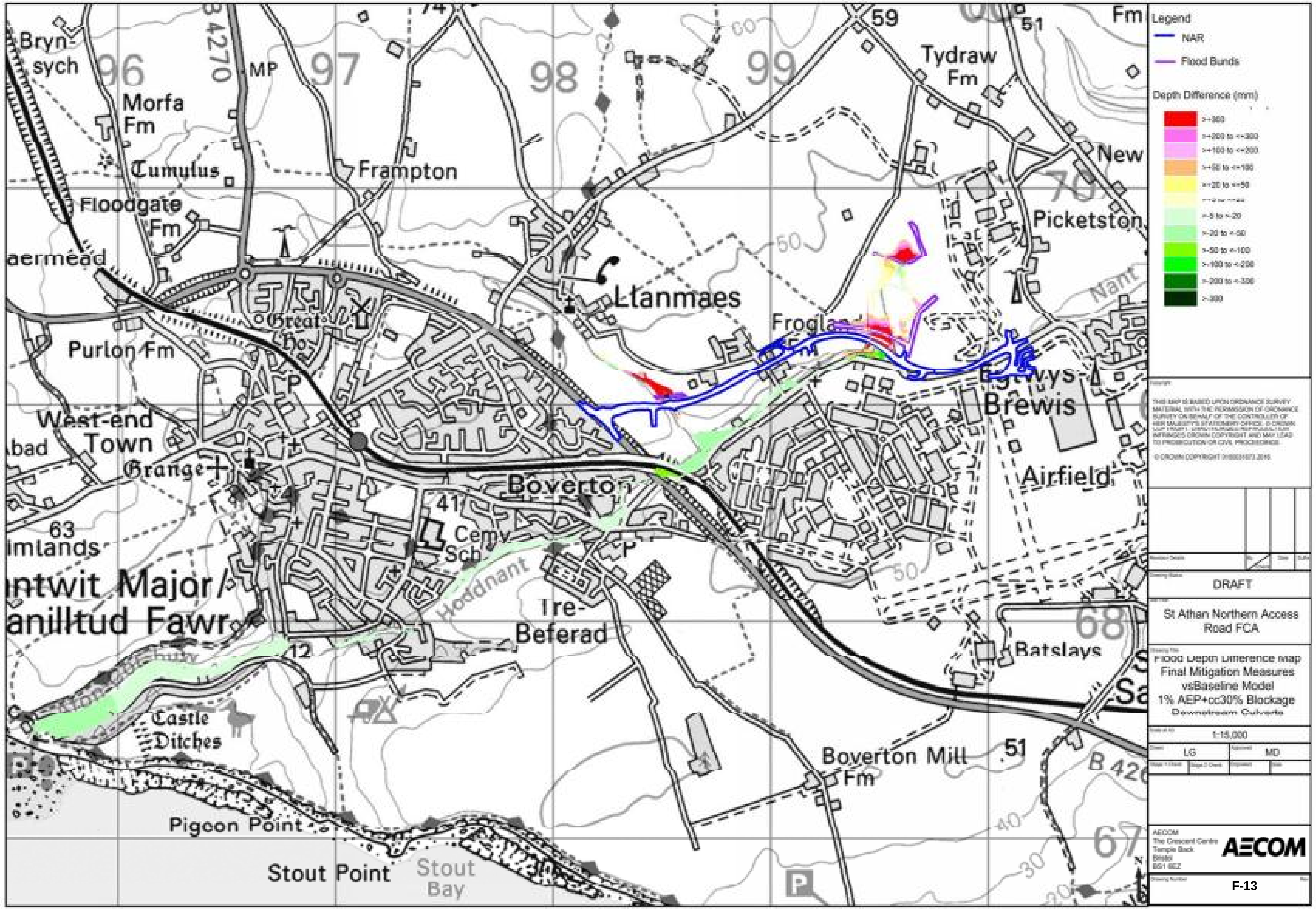
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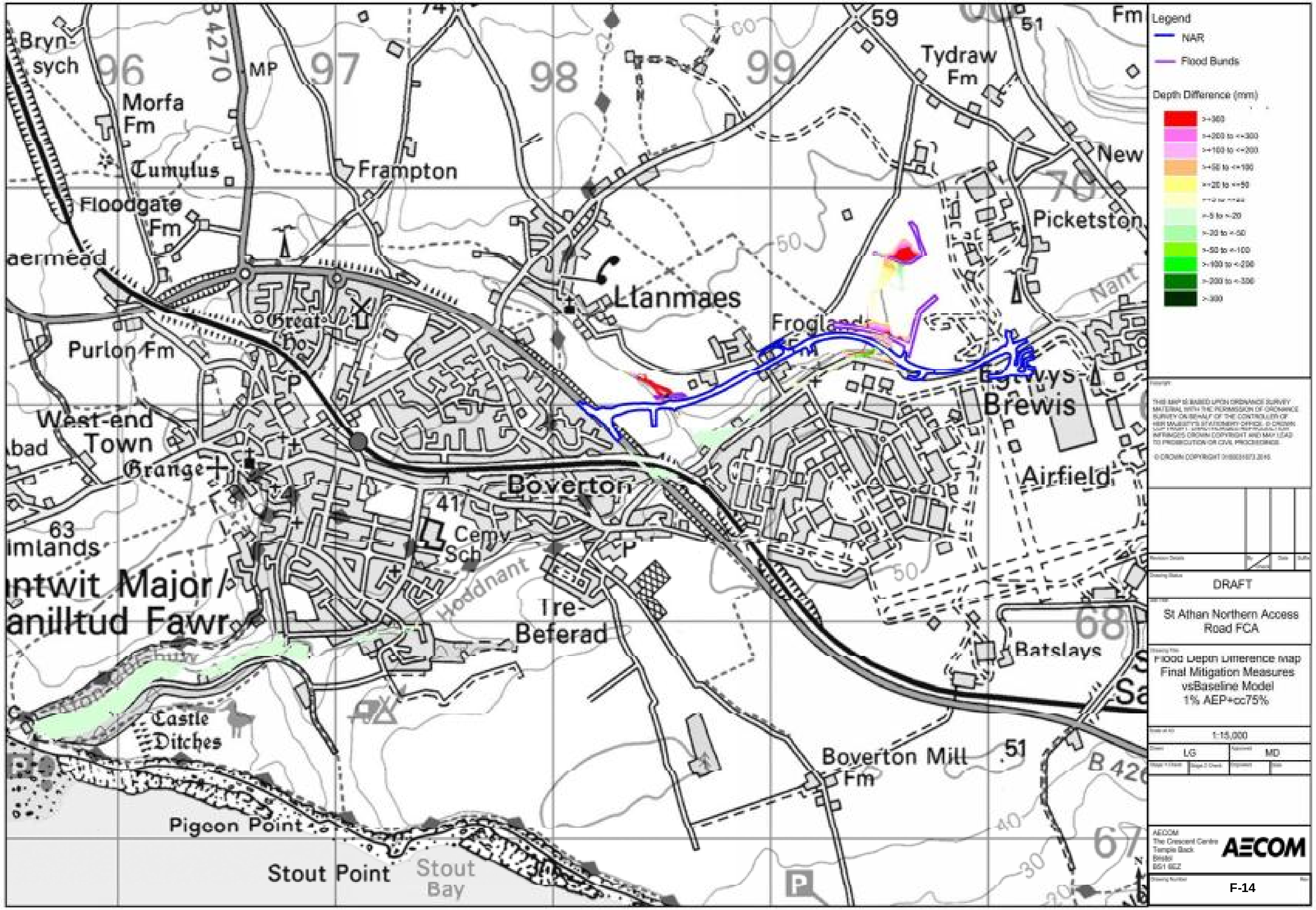

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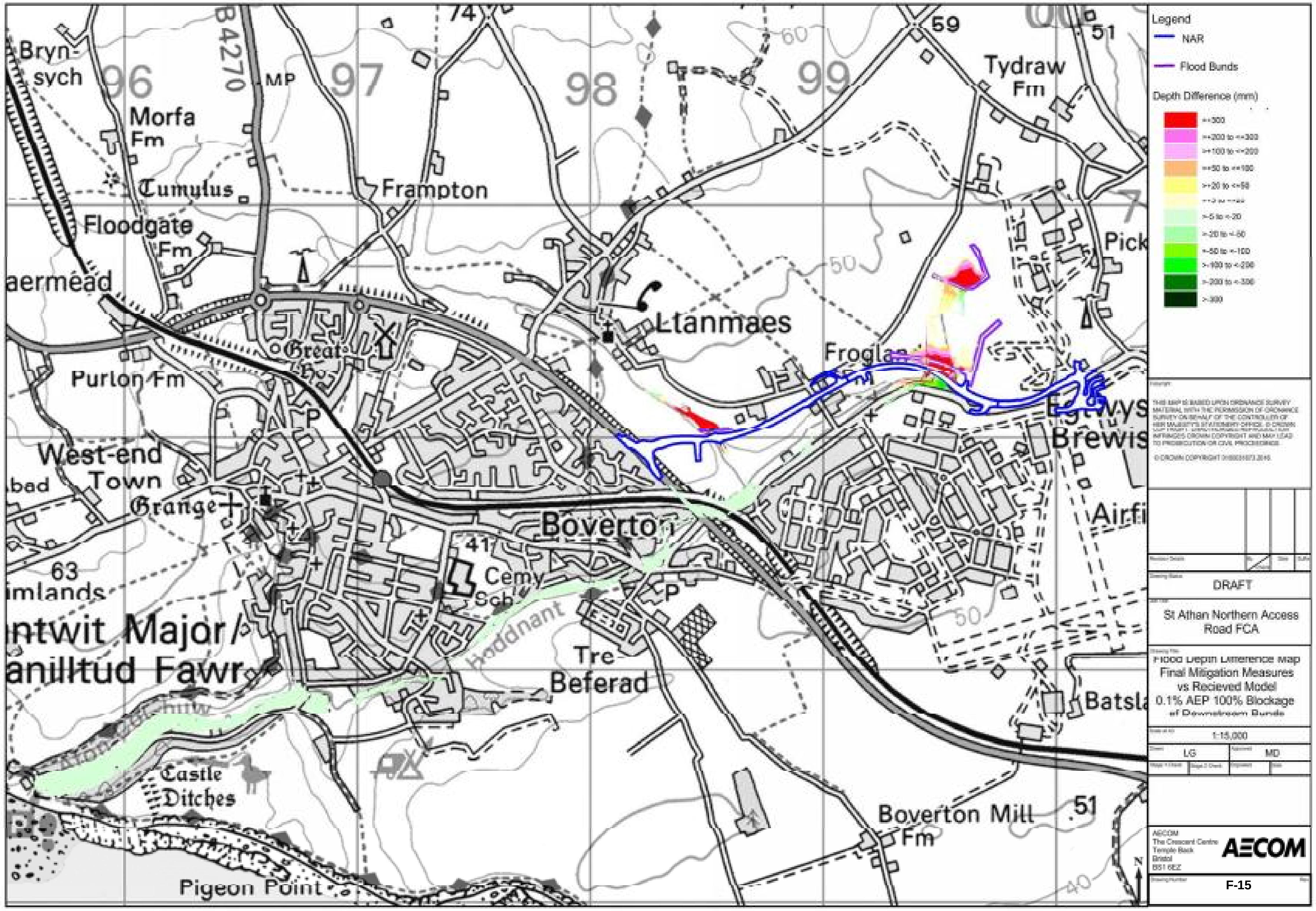
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Flood Depth Difference Map
Final Mitigation Measures
vs Recieved Model
0.1% AEP 100% Blockage
1:15,000
LG
MD
AECOM
The Crescent Centre
Temple Back
Bristol
BS1 6EZ
AECOM
F-15
Bryn-sych
Morfa Fm
Cumulus
Frampton
Floodgate Fm
Llanmaes
Tydraw Fm
Purlon Fm
West-end Town
Grange
Boverton
Cemy
Sch
Tre-Beferad
Castle Ditches
Boverton Mill Fm
Pigeon Point
Brewis
Batsl
Airfi
Pick
Frogl
Hoddnant

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