St Athan Northern Access Road, FCA

Flood Consequence Assessment
Final Report

Welsh Government

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Quality information

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1. Executive Summary

This report presents the findings of a Flood Consequence Assessment (FCA) undertaken by AECOM Limited for the Welsh Government . This report has been prepared in support of a planning application for the construction of a highway associated with the redevelopment of the St. Athan Ministry of Defence (MoD) site.

The St. Athan development site is located within the administrative district of the Vale of Glamorgan, approximately 8 miles west of Barry and 12 miles south east of Bridgend. To support this development, vehicular access improvements are to be made connecting the B4265 to the redevelopment site through construction of a new Northern Access Road (NAR). The proposed NAR crosses two watercourses, Boverton Brook and Llanmaes Brook and intersects the upper Nant y Stepsau catchment to the east, This FCA will focus on the highway improvements and to clearly document associated impacts and subsequent mitigation options.

The village of Llanmaes is located upstream of the proposed NAR and has historically suffered from surface water flooding. At the time of writing, Vale of Glamorgan Council (VoGC) is currently investigating the benefits of constructing a flood alleviation scheme in Llanmaes. The town of Boverton is located downstream of the proposed NAR and has suffered frequent fluvial flooding in the past. A key aspect of this FCA is to demonstrate that the proposed NAR has no detrimental effect on the flood risk to the town of Boverton.

This FCA has been prepared following consultation with Natural Resources Wales (NRW) and conforms to the requirements of *Technical Advice Note 15 (TAN15): Development and Flood Risk.* The Welsh Government's accompanying TAN15 development advice maps, alongside the NRW flood maps and more detailed flood mapping prepared as part of this FCA have been used to inform the assessment of flood risk.

TAN15 requires that all potential flood sources that could affect the proposed development be considered. An initial assessment of flood risk to and from the proposed NAR from all sources shows:

- There is no risk of tidal flooding;
- The risk of fluvial flooding is considered to be medium to low;
- The risk of surface water flooding is considered to be medium;
- The risk of sewer flooding is considered to be negligible;
- The risk of groundwater flooding is considered to be low; and
- The risk of flooding from artificial sources is considered to be negligible.

Hydraulic modelling has been undertaken to further assess the pluvial and fluvial flood risk to and from the proposed NAR and present flood mitigation options to manage this flood risk. The proposed NAR links the B4265, north of the Llantwit Major Railway line to the St.Athan MoD site. The access road crosses two watercourses, Boverton Brook and Llanmaes Brook, and passes adjacent to areas of Flood Zone C2, as shown in Figure 1-1. As such, fluvial and pluvial flood modelling has been undertaken to inform the design of these watercourse crossings and assess the flood risk to and from the proposed NAR. A third watercourse, Nant Y Stepsau, is located east of the proposed NAR. The highway intersects the upper Nant Y Stepsau catchment; discharges downstream of the NAR to the Nant Y Stepsau have been restricted to baseline flows. Therefore, the fluvial and pluvial representation through hydraulic modelling of this watercourse has not been deemed as a requirement of this FCA. It should be highlighted here that although there is no direct assessment of the Nant Y Stepsau, the surface water drainage plan describes how the highways drainage outfall controls outflow to the Nant Y Stepsau.

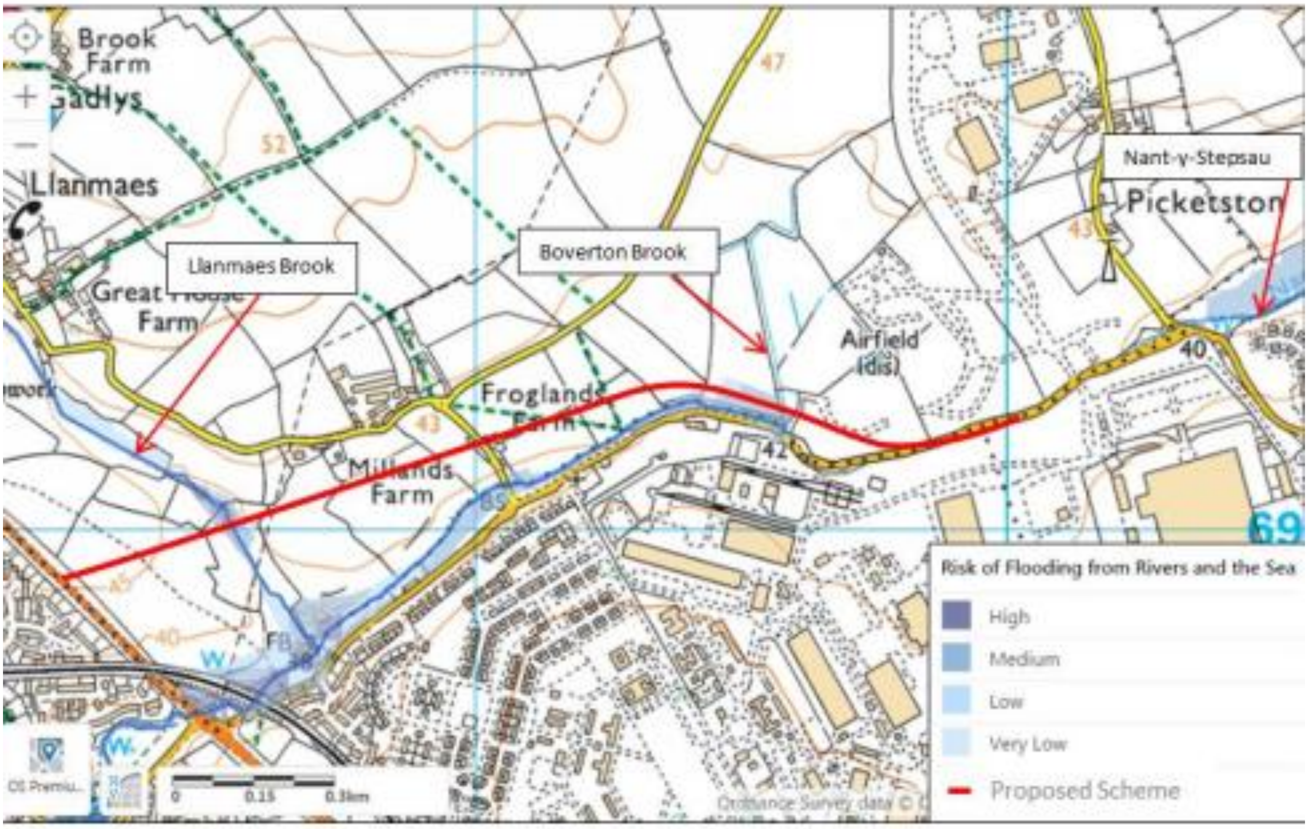

Figure 1-1- Natural Resources Wales Risk of Flooding from Rivers and Sea Map

(Adapted from NRW flood risk maps)

As shown in Figure 1-1, the majority of the proposed NAR is located within TAN15 Flood Zone A (land assessed being at a very low risk of flooding, i.e. as having less than a 0.1% probability of flooding from fluvial or tidal flooding in any given year). However, where the proposed NAR crosses Llanmaes Brook and Boverton Brook, the proposed NAR is located within Flood Zone C2 (land considered to be at at greater than or equal to 0.1% probability of flooding). As a result, to ensure compliance in demonstrating no detrimental impacts as a result of the NAR construction, both the flood risk to and from the site from pluvial and fluvial sources has been considered in this FCA.

NRW provided AECOM with an ESTRY-TUFLOW hydraulic model of Boverton Brook, Llanmaes Brook and the River Hoddnant that was developed in 2014[1]. In agreement with NRW, this model was updated and extended to include the upstream extents of Boverton Brook, to include the total area required for the proposed NAR and drainage design to assess the fluvial and pluvial flood risk. Pluvial and fluvial hydraulic models were developed in tandem to provide a robust assessment of flood risk to and from multiple sources on both Llanmaes and Boverton catchments. Design simulations were assessed for events with an Annual Exceedance Probability (AEP) of 20%, 1%, 1% + 30% Climate Change, 1% + 75% Climate Change and 0.1%;

The climate change allowances used within this report were taken from the Welsh Government 2016 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, prior to the commencement of this FCA, that the central estimate should be used.

A baseline (present day) pluvial and fluvial hydraulic model was developed to assess the present day flood risk at the site. The pluvial hydraulic model demonstrates that besides the Boverton Brook and Llanmaes Brook watercourses, there are three large overland 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. The pluvial model also predicts the flooding of the unnamed highway that runs along the south side of Boverton Brook to

[1] Boverton Flood Study 2014, JBA Consulting

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.

Following the creation of the baseline scenario the flood risk of the proposed NAR scheme with no mitigation measures was then assessed and compared to the baseline scenario. It is demonstrated that during the 1% + 30% Climate Change scenario with no mitigation measures in place has shown that the proposed NAR presents a barrier to overland flow routes and flow within Boverton Brook and Llanames Brook. This results in: storage of water of over 10,000m^3 upstream of the proposed NAR; flooding of the proposed NAR; and an increase in flood depths around Frogland's Farm. However, given the storage of large volumes upstream of the NAR the results demonstrated there is a subsequent reduction in flood depths and flows downstream of the NAR where no mitigation measures are in place.

A series of flood mitigation measures were then iteratively developed using the fluvial and pluvial hydraulic models in tandem to mitigate against the flood risk posed by the proposed NAR. 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 provides additional confidence that the proposed mitigation measures are robust, given that there is an exceptionally strong dependence between fluvial and pluvial flood events in this catchment.

Mitigation measures in the form of upstream storage areas with flood bunds containing overspill weirs, culverts, flood relief culverts, interception ditches and swales have been specified. Overland flow routes at Froglands Farm, an area which has experienced flooding in the past, have been proactively 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.

The proposed mitigation measures were then simulated for a series of blockage scenarios on key culverts withiin the design,

By incorporating these flood mitigation measures it has been shown through hydraulic modelling that:

- the proposed scheme is not at risk of flooding up to and including the 1% AEP + 75% Climate Change event. This is in excess of the 1% + 30% Climate Change event that NRW require the proposed scheme to be designed to demonstrating future resilience to large climate changes;
- the proposed scheme provides betterment downstream of the NAR and reduces flood depths and peak flows at Boverton and the properties at Froglands Farm. This demonstrates that the scheme provides overall benefit to flood risk in the area;
- there are no additional flows into the Nant y Stepsau watercourse as a result of the proposed scheme;
- all proposed flood storage areas have a volume less than 10,000m^3 and therefore will not be classified as reservoirs under the requirements of the Flood and Water Management Act (2010);
- the proposed scheme does not increase flood risk downstream during extreme blockage scenarios demonstrating that the scheme design is robust against failure of primary culverts;

The presence of otters has been noted on both the Llanmaes and Boverton Brook. Otters are protected under UK and European law, in order to ensure the effects on otters are mitigated in the NAR design a series of otter ledges and underpasses are required. As such it is recommended that steps and hedges are used to encourage the passage of otters over the flood bunds in high flow incidences. Separate animal underpasses should be provided on both Llanmaes Brook and Boverton Brook, these should be positioned outside of the flood extents. This is a result of a lack of 0.75m of clearance and headroom in any of the culverts.

Through discussions with NRW and VoGC, AECOM have been made aware of VoGCs desire to increase the resilience of Llanmaes against the effects of flooding. No scheme details have been provided to date. As the construction of the NAR is due to commence in advance of any scheme at Llanmaes, Welsh Government have made a decision to provide downstream flows at Llanmaes to inform a solution guideline. It is the Welsh Government's understanding that further studies of flooding at Llanmaes are due to commence and that consultancy against the scheme design and hydraulic model associated with the NAR should be consulted. As such, to assist VoGC in designing and introducing an effective flood alleviation scheme in Llanmaes and to ensure that the proposed NAR mitigation measures operate effectively, it is recommended that the flows in Llanmaes Brook immediately downstream of Llanmaes Village should not exceed 8.5m^3/s during the 1% +30% Climate Change allowance Annual Exceedance Probability Event (AEP). This is the maximum flow that the mitigation measures for the proposed NAR scheme have been designed for.

The surface water management of the NAR is discussed within the Drainage Strategy report, which has been supplied as part of the overall planning application for the NAR. Surface water management by SuDS has been identified to maintain runoff from the highway to greenfield rates provided by NRW. A 30% increase in rainfall intensity due to climate change has been incorporated into the design of the surface water drainage system. The highway has been tested for exceedance events of 1% +75% Climate Change AEP and 0.1% AEP to assure that flooding is kept to a minimum in extreme events. The SuDS features include dry swales and infiltration trenches with control features limiting the flow rate into Llanmaes Brook, Boverton Brook and Nant Y Stepsau to the greenfield runoff rate.

2. Introduction

2.1 Commission

This report presents the findings of a Flood Consequence Assessment (FCA) undertaken, in conjunction with the Drainage Strategy Report, by AECOM Limited on behalf of the Welsh Government. This FCA has been prepared in support of a planning application for the Northern Access Road (NAR) to serve the Aerospace Business Park in St. Athan.

The NAR will provide a link from the B4265 near Llantwit Major in the west to Eglwys Brewis Road in Picketston in the east (as shown in Figure 2-1). When constructed, the new access road will be situated between Boverton and Eglwys-Brewis, to the north of the existing Eglwys-Brewis Road, within the Vale of Glamorgan Council (VoGC) administrative area. The NAR will pass between Froglands Farm and Rose Cottage.

Proposals for major development at St. Athan received outline planning permission in 2009 for a mixed-use, regeneration-led scheme, involving substantial new development of the existing site and the adjoining land. The purpose was to provide a Defence Technical College for the Ministry of Defence (MoD) and an expanded Aerospace Business Park for the Welsh Government, whilst part of the site, West Camp, was to remain as an operational military base. These developments required a new access road. The projects received outline planning permissions in December 2009 as part of which detailed permission was granted for the NAR.

The Defence Technical College did not proceed and the planning permissions have since expired. Nevertheless, the Welsh Government remains committed to the Aerospace Business Park and the NAR is considered essential in order to deliver the economic and social benefits associated with the Cardiff Airport St Athan Enterprise Zone.

The NAR will serve existing and proposed development at St. Athan including:

- The Aerospace Business Park, which occupies a large part of the former RAF camp, including the operational runway;
- The proposed Aston Martin car manufacturing facility, which will occupy the existing super hangar building on the Aerospace Business Park; and
- The proposed residential development on land lying south of the proposed NAR and between it and Eglwys Brewis Road.

The NAR will not serve the MoD camp at St Athan, which will continue to be served via its existing access road at Main Gate.

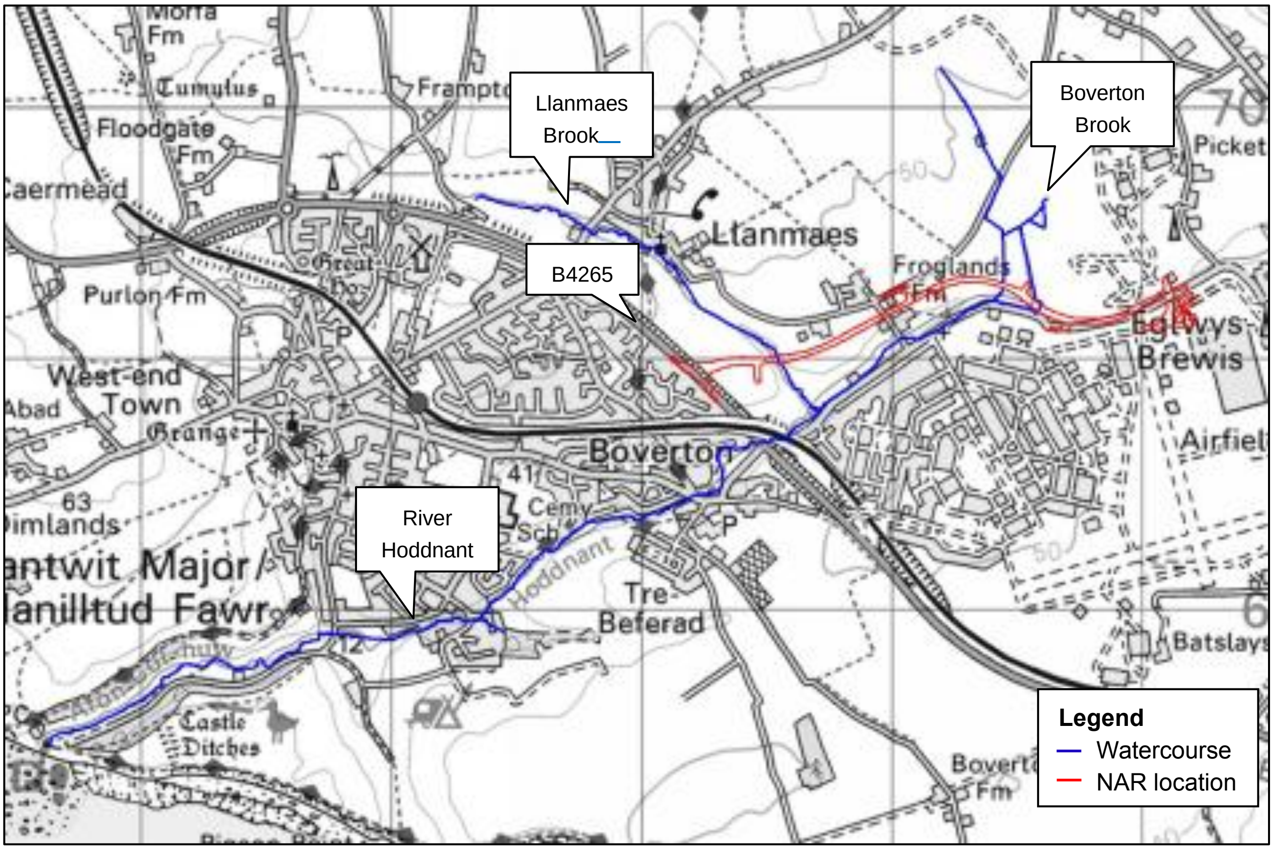

Figure 2-1- Site Location Map

2.2 Background

In 2009, Entec were commissioned to produce an FCA to accompany the outline planning permission for the entire proposed development at St Athan. This FCA included the assessment of flood risk from all sources to and from the development of the NAR. The recommendations of this FCA with regard to the NAR were to divert the upper ditches of the Boverton Brook adjacent to the NAR at Picketston and to form a bridge at Llanmaes Brook.

In flood risk terms, (without appropriate mitigation measures in place) the proposed scheme has the potential to increase impermeable surfacing (highway), present a constriction to existing watercourse flows (Llanmaes Brook and Boverton Brook crossings) and also compartmentalise existing surface water runoff conveyance routes throughout the catchment. As the region has a history of frequent flood events, these factors are of the utmost importance when considering scheme impacts and to assist in deriving suitable mitigation options.

As shown in Figure 1-1, the majority of the proposed scheme is within Flood Zone A (considered to be at little or no risk of fluvial or coastal/tidal flooding). However, in some regions, the proposed scheme falls within the extent of the 3.3% AEP flood outline of Boverton Brook and Llanmaes Brook. These areas of the proposed scheme are therefore classified as being located in TAN15 Flood Zone C2 (indicates that only ‘less vulnerable’ development should be considered, subject to the application of the justification test, including acceptability of consequences)[2]. Special attention has therefore been made to the potential impact of the proposed scheme on the floodplain i.e. the loss of floodplain storage as a result of construction of the new highway.

This Flood Consequence Assessment (FCA) comprises one of a number of documents supporting the environmental assessment of the proposed scheme.

[2] Planning Policy Wales (2004) Technical Advice Note 15: Development and Flood Risk, Publications Centre Wales;

2.3 Aim and Objectives

An initial FCA has been undertaken in accordance with Technical Advice Note 15 (TAN15). According to TAN 15, planning applications for development proposals located in Flood Zone C2 should be accompanied by a FCA, outlining how the proposed development meets the justification test and acceptability criteria. An FCA has therefore been undertaken to determine the risks of flooding that could result from the proposed scheme and subsequent appropriate flood risk mitigation measures.

In order to achieve the above, the following objectives are required to be met:

- Collect and review existing flood risk data including topographic data, surface water drainage, NRW information, scheme proposals and the VoGC Strategic Flood Consequence Assessment (SFCA);
- Assess and interpret available information to identify potential sources of flood risk including groundwater, surface water and infrastructure failure;
- Update and extend an existing hydraulic model of Boverton Brook to include the proposed scheme to assess the impact of the proposed scheme on flood extents and depths, identifying suitable mitigation measures;
- Summarise the proposed surface water drainage strategy to demonstrate that surface water from the site can be managed in a sustainable manner; and,
- Provide recommendations for appropriate flood risk mitigation measures and produce an FCA [this report], in full accordance with TAN15, to accompany the planning application.

2.4 Site Visit and Consultation

A site visit was undertaken on the 2nd November 2016 by AECOM staff to assess the survey requirements for the extended Boverton Brook hydraulic model, ground truth the existing Boverton hydraulic model and specify additional survey requirements. Following the site visit, a topographic survey of the study area was undertaken by AECOM and updated in November 2016 to incorporate upstream extents of the Boverton Brook watercourse.

The following data was requested and supplied by NRW as part of the FCA:

- 2014 Boverton Brook Flood Study hydraulic model including all results outputs;
- 2014 Digital Terrain Model (DTM) data for the study area was provided at a 2m grid resolution (most recently flown and complete at the time of writing)

A Technical Note detailing the proposed hydraulic modelling methodology was produced by AECOM in November 2016 and confirmed by NRW as being acceptable in December 2016 to appropriately determine the flood risk to and from the proposed NAR. Further information regarding the hydraulic modelling methodology is presented in Appendix D and E.

3. Site and Surrounding Area

3.1 Existing Site

Figure 3-1 shows an overview of the study area upstream of Bovertonand the location of the proposed NAR. A full description of the concept masterplan can be found in Appendix A.

The existing site and surrounding area is predominately agricultural fields from the B4265 towards Picketston. Three residential properties, Old Froglands, Rose Cottage, Froglands Farm and Millands Farm Caravan Park are within close proximity to the proposed development. The town of Boverton and Llantwit Major is located to the south west of the development site and the village of Llanmaes is located 600m to the north-west. The area in and around MoD St. Athan has been targeted for development opportunities in the future.

Three watercourses are located within the study area (Section 3.2) which are Boverton Brook, Llanmaes Brook and Nant y Stepsau. As shown in Figure 1-1, the majority of the study area is located with Flood Zone A and is considered to be at little or no risk of fluvial flooding. The river corridor along Boverton Brook and Llanmaes Brook can be seen to be within Flood Zone B and C2. Eglwys-Brewis Road the area around Froglands Farm Road Bridge is known to have flooded in the past from Boverton Brook.

Figure 3-1- Overview of the Study Area

3.2 Local Water Features

There are a number of local water features, depicted in Figure 3-2 that border the site and that the proposed scheme will cross:

- Boverton Brook is a tributary of the River Hoddnant where the confluence is downstream of the town of Boverton; it is classified as Main River by NRW to NGR 299503,169192. Upstream of this, where the Boverton Brook bisects the proposed NAR, Boverton Brook is classified as Ordinary Watercourse by NRW;
- Llanmaes Brook is a tributary of Boverton Brook, it is classified as Main River by NRW and flows north to south through Llanmaes village;
- A series of field drains and ordinary watercourses feed into the Boverton Brook, these branch out over agricultural fields to the north of the proposed scheme; and,
- Upper Nant y Stepsau to the east of the site is classified as an ordinary watercourse.

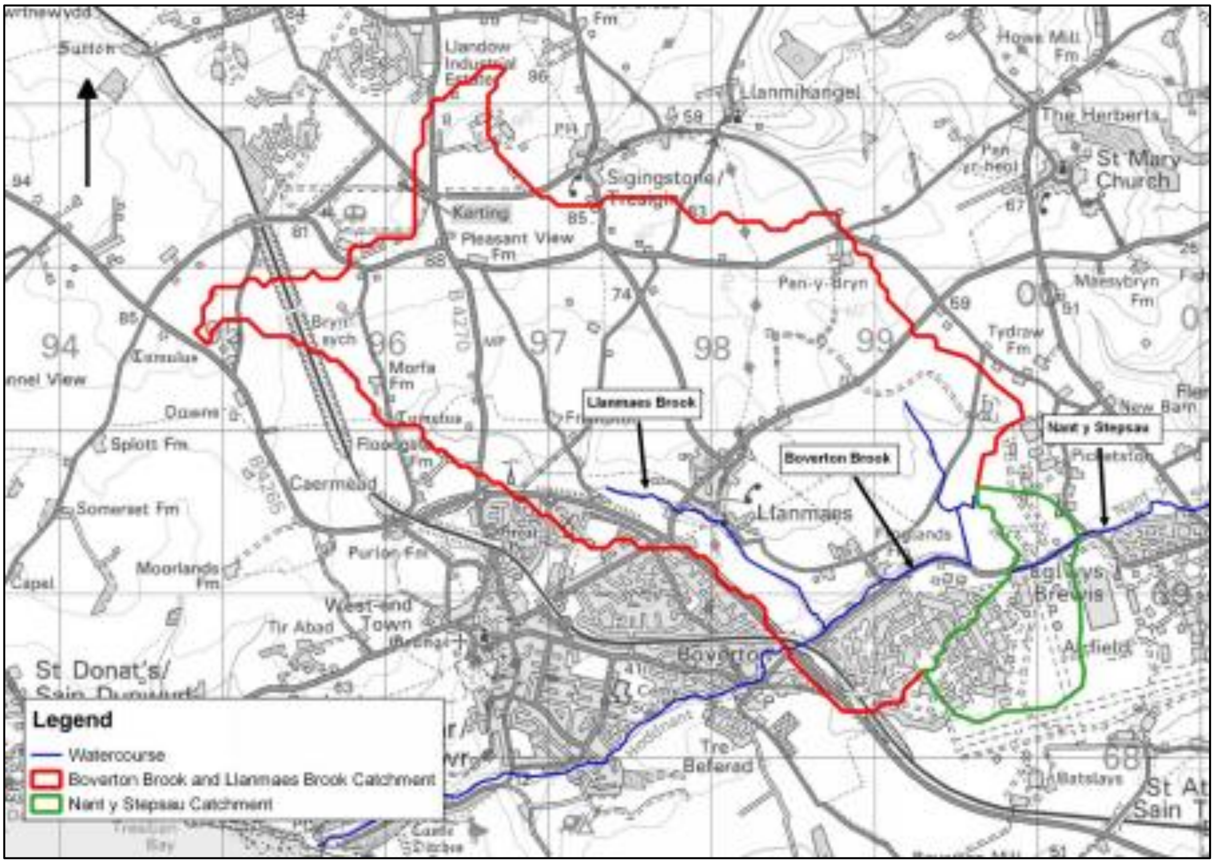

Figure 3-2- Boverton Brook, Llanmaes Brook and Nant y Stepsau Catchments

3.2.1 Exisitng Flood Defence Structures

Two flood storage areas are located on Llanmaes Brook to help alleviate the risk of flooding to the town of Boverton downstream. 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 0.50m diameter orifice which allows for small-scale attenuation of water upstream of the structure.

3.3 Geology

The 1:50,000 scale geological map of Bridgend - Sheet 262[3] shows that the site is underlain by Porthkerry Member Limestone and Mudstone Formation. These rocks are interbedded and formed approximately 190 - 200 million years ago, in the Jurassic Period.

The solid geology is overlain by small regions locally around the Boverton Brook of head and alluvium (formed of clay, silt, sand and gravel).

A detailed Ground Investigation (GI) was carried out as part of the wider planning application. Between November 2016 and January 2017, as part of this study, a series of trial pits were dug and boreholes drilled. Table 2-1 shows the anticipated geology for the site, strata thicknesses are based on on the four rotary boreholes formed as part of this GI. Groundwater was encountered at 0.7-1.3m..

Table 3-1 Summary of Geology

Stratum	Depth To Stratum	Geological Map Description/ Anticipated Presence	Thickness (m)
Made Ground	Ground Level	Soft slightly gravelly silty Clay.	0.20-0.65
Probable Alluvium	0.2-0.45	Silty/ gravelly/ sandy Clay. Appears to be only present in proximity to the watercourses in the area	0.10-2.20
Distinctly Weathered Porthkerry Member	0.35-1.30	Interbedded limestone with clay bands	0.01-1.7*
Partially Weathered Porthkerry Member	0.70-2.40	Interbedded limestone with clay bands	0.10*-7.80
Porthkerry Member	2.40	Interbedded limestone with clay bands	5.60*

**Base of Stratum not proven, greater thickness may be present.*

Source: AECOM, 2017. St Athan Northern Access Road, Factual Ground Investigation Report. Hydrogeology

NRW classifies zones around potable groundwater abstraction points as Groundwater Source Protection Zones (SPZ) and these are designed to limit potential pollution activities. The site is not in a SPZ and there are no SPZ limits within 1km of the site.

Welsh Government holds two groundwater abstraction licences within 1km of the site, at RAF St. Athan. There is one discharge consent to groundwater on the site and nine other discharge consents within 1km of the site.

The Geo Environment Report[4] indicates that the site is located within a Secondary A Aquifer. The Porthkerry Limestone form a permeable layer capable of supporting water supplies at a local rather than a strategic scale, and in some cases forming an important source of base flow to rivers. Therefore, it is unlikely there will be any significant restrictions on surface water runoff to ground.

3.4 Proposed Development

The proposed Northern Access Road (NAR) will link the B4265, east of Llantwit Major, and the Aerospace Business Park. The access road will run from the B4265 0.5km northwest of the existing Boverton highway junction (NGR 298204, 168928) and run laterally eastwards for 2km (NGR 300128, 169274). There will be a number of slip road junctions from the new highway to allow for future potential development. Figure 3-1 shows the location of the proposed development.

[3] BGS (British Geological Survey), Geology of Britain Viewer (1974): Grid Reference 299491,169228. Available at: http://mapapps.bgs.ac.uk/geologyofbritain/home.html
[4] AECOM, 2016. St Athan Northern Access Road Phase 1 Geo-Environmental Assessment.

There will be a series of swales, ditches and attenuation basins that will form part of the proposed highways drainage scheme. The proposed feature layout is shown within the drainage strategy report..

The existing watercourse crossings that bisect the proposed NAR embanked highway alignment are:

- Llanmaes Brook at (NGR 298537, 169015) – Mitigation: Pipe culvert and flood relief culverts. This watercourse is NRW Main River;
- Boverton Brook at Picketston (NGR 299595, 169215) – Mitigation: Pipe culvert and flood relief culverts. The catchment area here is 1.5km^2 , designated as an Ordinary Watercourse at this crossing location; and
- Minor field drains – Mitigation: Interception conveyance ditches and various pipe culverts.

It is noted that the Llanmaes Brook crossing will be located immediately upstream of the existing smaller scale Llanmaes Brook flood storage area. It is anticipated that this crossing will act as the control structure for flood water attenuation on Llanmaes Brook to ensure that there is no increase in flood risk, downstream of the proposed NAR.

AECOM is aware that Vale of Glamorgan Council (VoGC) are undertaking a study of Llanmaes Brook which is understood to include a proposed flood relief culvert through Llanmaes village to reduce flood risk within the village. It was intended that VoGC would provide hydraulic modelling results to AECOM to allow comparison of the maximum design flows from VoGC with those presented in this FCA. This would ensure that any flow conveyed downstream of Llanmaes as a result of any scheme would not have a detrimental impact on the downstream solution at the NAR or other third party regions. To date, no data relating to this study has been provided that is suitable to enable this comparison.

In lieu of this information, and in order to ensure that a robust solution was achieved, all fluvial and pluvial mitigation measures were tested for higher flows than those originally stipulated by NRW. The results of this FCA,will be shared with VoGC and the maximum flows downstream of Llanmaes village of 8.5m^3/s during the 1% +30% Climate Change allowance Annual Exceedance Probability Event (AEP)are provided as a constraint on the VoGC scheme at Llanmaes. This will ensure that a robust solution is found for both the NAR and VoGC scheme. Therefore, the conclusions of this report and the subsequent modelling undertaken, are considered to remain applicable.

4. Policy Context

4.1 National Policy

4.1.1 TAN15

Technical Advice Note 15 (TAN15) provides guidance which supplements the policy set out in Planning Policy Wales (PPW)[5] in relation to development and flooding. A precautionary framework is set out which advises caution in respect of new development in areas at high risk of flooding and this is used as a guide for planning decisions. The overall aim of the precautionary framework is to direct new development away from those areas that have a high risk of flooding; and development will only be justified in these areas if it meets the criteria and tests specified in this guidance.

The operation of the precautionary framework is governed by a Development Advice Map (DAM) made up of three zones (Table 3.1) which are used to trigger the appropriate planning test and definitions of vulnerable developments.

The DAMs are based on the best available information considered adequate to determine when flood risk needs to be taken into consideration with future development (Table 4-1).

Table 4-1-Flood Zone designations, their associated flood risk definition and use within the precautionary framework

Flood Zone	Definition	Use within the precautionary framework
A	Little or no risk of fluvial/ tidal flooding	Justification test is not applied and do not need to consider further
B	Areas known to have flooded historically evidenced by sedimentary deposits.	Used as part of the precautionary approach to indicate where site levels should be checked against the extreme (0.1% annual probability) flood. No need to consider flood risks further if site levels are greater than the extreme flood level
C	Based on Environment Agency extreme flood outline (0.1% annual probability)	Indicates that flooding issues should be considered as an integral part of the decision making by the application of the justification test, including FCA
C1	Areas of Zone C which are developed and served by significant infrastructure, including flood defences	Indicates that development can take place subject to the application of the justification test, including acceptability of consequences
C2	Areas of Zone C without significant flood defence infrastructure	Indicates that only 'less vulnerable' development should be considered, subject to the application of the justification test, including acceptability of consequences. Emergency services and highly vulnerable development should not be considered.

Source: TAN 15.

The precautionary framework identifies the vulnerability of different land uses to flooding, and classifies proposed uses accordingly as detailed in Table 4-2. This is because certain flooding consequences may not be acceptable for particular development types.

Table 4-2 Development Categories

Flood Zone Definition	Use within the precautionary framework
Emergency Services	Hospitals, ambulance stations, fire stations, police stations, coastguard stations, command centres, emergency depots and buildings used to provide emergency shelter in time of flood.
High vulnerable development	All residential premises (including hotels and caravan parks), public buildings (e.g. schools, libraries, leisure centres), especially vulnerable industrial development (e.g. power stations, chemical plants, incinerators), and waste disposal sites.
Less vulnerable development	General industrial, employment, commercial and retail development, transport and utilities infrastructure, car parks, mineral extraction sites and associated processing facilities, excluding waste disposal sites.

Source: TAN15, 2004

[5] Welsh Government (2016) Planning Policy Wales, Edition 9 (November, 2016);

Table 4-2 highlights that transport infrastructure is classified as 'Less Vulnerable'; the proposed NAR is located within DAM Zone A and C2.

For a less vulnerable development to be justified within DAM Zone C2, according to TAN15[6] it must be demonstrated that:

I. *its location in (DAM) Zone C2 is necessary to assist, or be part of, a local authority regeneration initiative or a local authority strategy required to sustain an existing settlement; or,*

II. *its location in DAM Zone C2 is necessary to contribute to key employment objectives supported by the local authority, and other key partners, to sustain an existing settlement or region;* and,

III. *it concurs with the aims of PPW and meets the definition of previously developed land (PPW fig 2.1); and,*

IV. *the potential consequences of a flooding event for the particular type of development have been considered, and in terms of the criteria contained in Sections 5 and 7 and Appendix 1 found to be acceptable.*

This FCA will demonstrate that the proposed NAR will be located within DAM Zone A.

4.1.2 Design Manual for Roads and Bridges (DMRB)

Transport Wales and other highway authorities have a responsibility to keep trunk roads and local roads free from flooding (relevant legislation includes the Highways Act 1980 and the Land Drainage Acts 1991 and 1994).

The DMRB primarily refers to the former PPS25 (now superseded by the NPPF) for FCA and flood mitigation guidance, and emphasises the need for consultation with NRW early in the design process.

The DMRB offers guidance on hydraulic design of highway drainage systems, and assessment, and guidance on mitigation techniques for roads (and embankments) that encroach into floodplains.

More detailed discussion of highway surface water management and sustainable drainage is provided in the Drainage Strategy report.

4.2 Local Policy

4.2.1 Vale of Glamorgan Local Development Plan (2011 – 2026)

The Local Development Plan[7] contains detailed policies that, when adopted will be used in the assessment of all planning applications that come before the council, and guide any new development that is likely to take place. The proposed NAR is within the St Athan-Cardiff Airport Enterprise Zone, Strategic Employment Site and Strategic Opportunity Area. Land for the proposed NAR has been allocated by VoGC in the emerging Local Development Plan.

Local Development Plan policies relevant to water and flood risk are summarised below:

- **MD1 – Location of new development**: this policy seeks to ensure that development will minimise or avoid areas of flood risk.
- **MD8 – Environmental protection**: this policy seeks to ensure that development does not increase flood risk.

4.3 Evidence Base

4.3.1 Strategic Flood Consequence Assessment (SFCA)

No strategic flood consequence assessment is available from VoGC at the time of writing.

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[6] Planning Policy Wales, 2004. Technical Advice Note 15: Development and Flood Risk.
[7] Vale of Glamorgan Local Development Plan 2011-2026, Deposit Plan, Written Statement (November 2013). http://www.valeofglamorgan.gov.uk/Documents/Living/Planning/Policy/LDP-2013/01-LDP-Deposit-Plan-Written-Statement-2013.pdf;

4.3.2 Preliminary Flood Risk Assessment

VoGC developed a preliminary flood risk assessment[8] which examined the areas within the Vale of Glamorgan that have historically suffered from flooding and areas that are at risk of flooding. This report highlighted that areas in Llanmaes and areas around Froglands Farm suffered from flooding in October 1998. The area which flooded around Froglands Farm is in close proximity to the proposed NAR scheme.

4.3.3 Local Flood Risk Management Strategy

In 2012, VoGC developed a Local Flood Risk Management Strategy[9], this document highlights the responsibilities of VoGC as Lead Local Flood Authority (LLFA) with respect to flooding from; surface water, ordinary watercourse and groundwater. This report also outlines the priority for investigation of surface water catchments. Both Llanmaes and St Athan are stated as having a medium investigation priority, with 18 and 22 properties identified as being at risk of surface water flooding respectively. The timescale for delivery of measures to reduce the risk of surface water flooding is 50 years for medium priority areas.

[8] Vale of Glamorgan Preliminary Flood Risk Assessment, 2011.
[9] Vale of Glamorgan Council Local Flood Risk Managemement Strategy, 2012. Available online: http://www.valeofglamorgan.gov.uk/en/living/highways_and_engineering/Flooding/Flood-and-Coastal-Erosion/Local-Flood-Risk-Management-Strategy.aspx

5. Sources of Flooding and Flood Risk

5.1 Overview

TAN15[1] requires that all potential flood sources that could affect the proposed development be considered. This chapter primarily focuses on the fluvial flood risk posed to the proposed site location, but also considers the flood risk posed to the site from other sources.

5.2 Tidal

Tidal flood sources include both the sea and estuaries. The assessment of tidal flood risk takes into account the site's distance from the Severn Estuary (approximately 2.5 km) and minimum ground levels on site (approximately 42 m AOD) (see Appendix D). This assessment identifies that there is no tidal flood risk posed to the development site and is not considered further within this FCA.

5.3 Fluvial

The proposed NAR crosses both Boverton Brook and Llanmaes Brook, a tributary of Boverton Brook. A third watercourse is located at the east end of the proposed NAR, Nant y Stepsau. A series of field drains act as conduits for overland flow from the surrounding agricultural fields and outfall in to Boverton Brook. Areas within the proposed development site have suffered from fluvial flooding in the past, specifically land around Froglands Farm. This area is a low point and key conveyance route, and the capacity of the bridge located immediately downstream of Froglands Farm may be exceeded at times of high flow.

An approximate outline of the fluvial flood extent from the October 1998 flood event has been taken from the Vale of Glamorgan Preliminary Flood Risk Assessment and is shown in Figure 5-1 below.

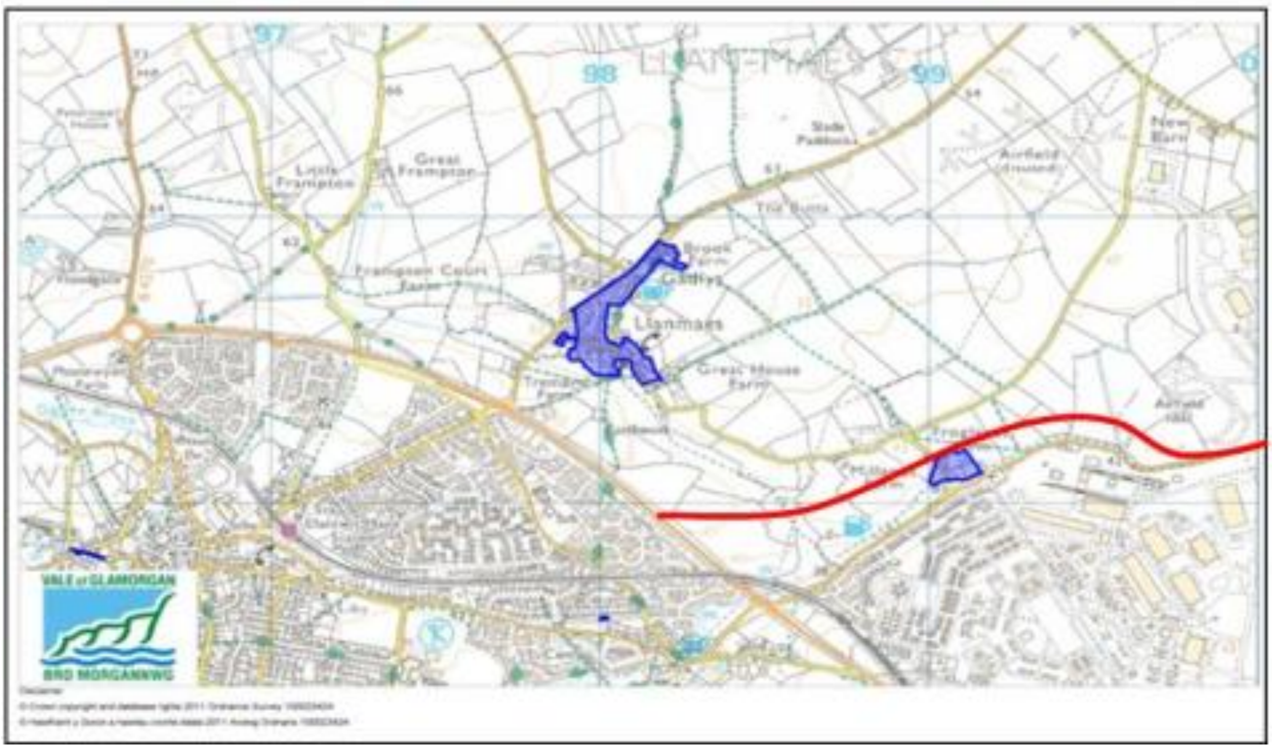


Figure 5-1-Extent of Flooding 28th October 1998, Vale of Glamorgan Preliminary Flood Risk Assessment, 2011.

The publicly available NRW Flood Map is provided in Figure 5-2. The Flood Map presents the undefended fluvial flood extents for land at a high (land assessed as having a greater than 1 in 30 annual probability of river flooding (3.3%)), medium (3.3 to 1%) and low risk (1 to 0.1%). Figure 5-2 includes the proposed road development boundary (red line) as superimposed.

The NRW Flood Map shown in Figure 5-2 shows that the location of the watercourse crossings of the proposed NAR are considered to be at medium to high risk of flooding.

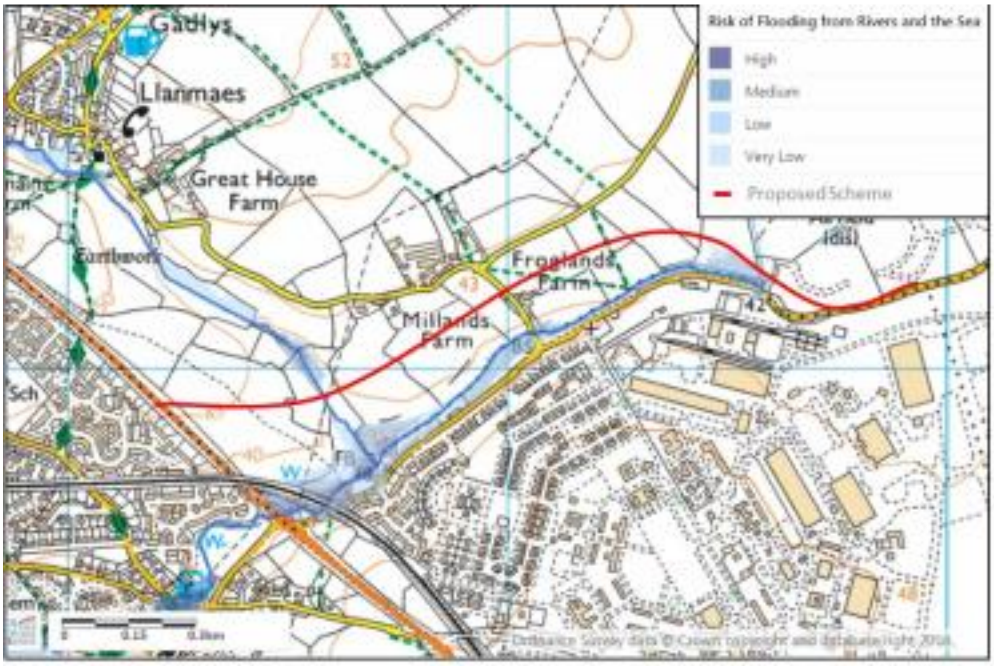


Figure 5-2- Natural Resources Wales Risk of Flooding from Rivers and Sea Map (Adapted from NRW flood risk maps.

Taking the above information into account, the risk posed from fluvial flood sources to the proposed highways development is considered to be medium to low as a result of the proposed highway being designed above existing ground level in areas near to the flood extents. However, the proposed scheme will encroach upon the floodplain where it crosses Llanmaes Brook and Boverton Brook. As a result of these issues, additional modelling work has been conducted to understand the associated risks and develop mitigation measures – this is discussed further in Section 7.

5.4 Overland Flow

Overland flow results from rainfall that fails to infiltrate the surface. This is exacerbated where the permeability of the ground is low due to the type of soil and geology (such as clayey soils) or urban development. Surface water flow may also occur in areas where steep topography can rapidly convey water that has failed to penetrate the surface or where the ground may already be saturated.

The British Geological Survey historic boreholes[10] and AECOM Ground Investigation Report[11] indicate that clay soils are present at the site in areas surrounding the watercourses. Therefore, infiltration of rainwater may be limited, resulting in higher surface water runoff rates compared with more permeable soils (such as sandy soils).

[10] BGS borehole record SS96NE51 and ST06NW54. Available at: http://mapapps.bgs.ac.uk/geologyofbritain/home.html.
[11] AECOM, 2017. St Athan Northern Access Road, Factual Ground Investigation Report.

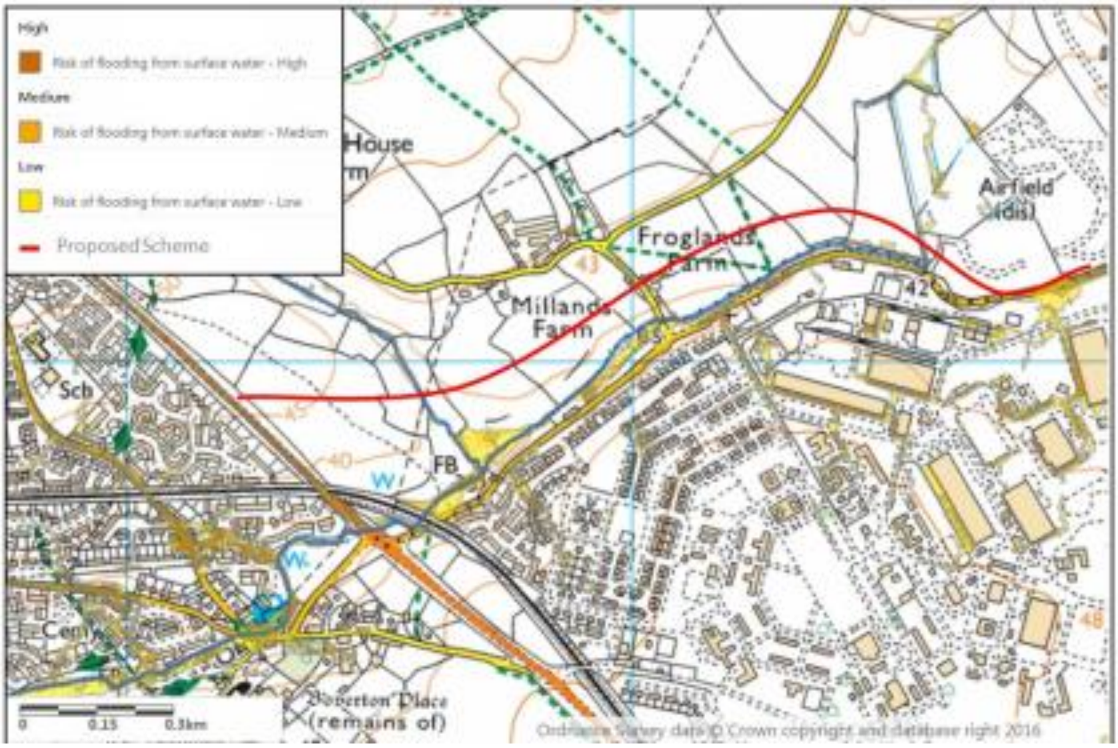


Figure 5-3-Natural Resource Wales Surface Water Flood Risk Map (Adapted from NRW flood risk maps.)

It can be seen in Figure 5-3 that the area to the south of the proposed scheme (along the existing road) and to the east of the proposed scheme where the NAR is proposed to re-join the existing highway is at medium to low risk of surface water flooding.

Taking into account the information above, the risk posed from surface water / overland flow is considered to be medium. The proposed scheme will affect the land drainage network and overland flow paths that contribute to the areas of surface water flood risk. Therefore a hydraulic model was undertaken and mitigation measures developed - this is discussed in Section 6. Drainage designs provided in the Drainage Strategy report demonstrate how it is intended to reduce the existing level of flood risk to the proposed development and manage highways drainage effectively.

5.5 Sewer Flooding

Flooding can occur as a result of infrastructure failure e.g. blocked sewers or failed pumping stations. Sewer flooding can occur when the system surcharges due to the volume or intensity of rainfall exceeding the capacity of the sewer, or if the system becomes blocked by debris or sediment.

The proposed scheme is located within agricultural fields and the existing highway. As proposed scheme ground levels (embanked highway) are above existing ground levels, the risk of sewer flooding posed to the development area is considered to be negligible and not considered further within this FCA.

As described above, the NAR Drainage Strategy states that the existing highway pavement and drainage collection systems would be replaced as part of proposed scheme, and detailed drainage design including analysis of the impact on sewers would take place during later project phases.

Overall, the risk of sewer flooding to the proposed scheme is considered to be negligible.

5.6 Groundwater

Groundwater flooding occurs where groundwater levels rise above ground surface levels. The geology has a major influence on where this type of flooding takes place; it is most likely to occur in low-lying areas underlain by permeable rocks (aquifers).

The superficial and bedrock geology underlying the site has been classified as a minor aquifer, it is an important source of base flow to rivers, but not considered significant for water supply at a strategic scale.

Boreholes available from the GI report that were constructed to aid the planning application for the proposed scheme indicate that groundwater is typically encountered at depths between 0.70m and 1.30m across the site. However, the regions of clay soil located above these groundwater bearing soils are likely to form an impermeable layer, preventing shallow groundwater from rising above ground surface levels.

Based on the above information, groundwater flooding is considered to present a low risk to the proposed development area as the majority of the road is to be constructed above the existing ground level.

5.7 Artificial Sources

Artificial flood sources include raised channels such as canals or storage features such as ponds and reservoirs. The NRW Flood Risk from Reservoirs Map (Figure 5-4) indicates that the nearest area at risk to the proposed scheme is located along the River Thaw, approximately 1.8 km away.

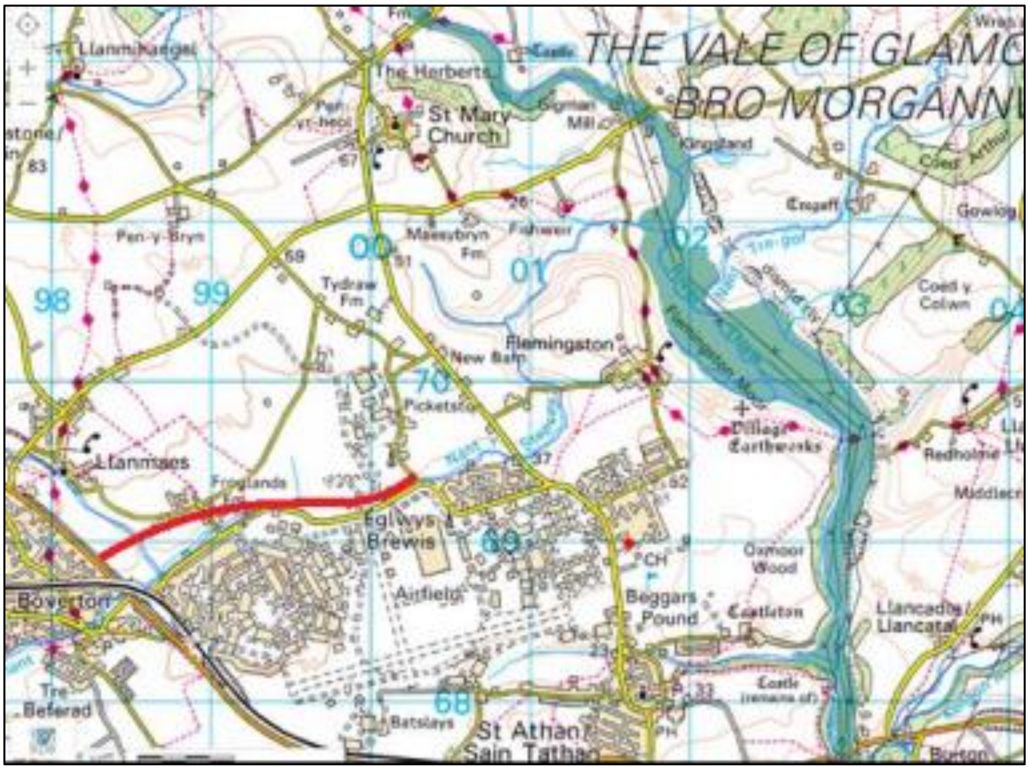


Figure 5-4- Natural Resources Wales Risk of Flooding from Reservoirs Flood Map- Approximate proposed scheme location shown in red.

Adapted from NRW flood risk maps.

As the proposed development area is located outside of maximum flood extent, combined with the low likelihood of a reservoir breach occurring, the risk from this flood source is negligible and not considered further within this FCA.

5.8 Summary

- There is no risk of tidal flooding;
- The risk of fluvial flooding is considered to be medium to low;
- The risk of surface water flooding is considered to be medium;
- The risk of sewer flooding is considered to be negligible;
- The risk of groundwater flooding is considered to be low; and
- The risk of flooding from artificial sources is considered to be negligible.

Mitigation measures to further reduce the level of flood risk posed to the site and surrounding areas are provided in Section 6 and 7 of this FCA.

6. Hydraulic Modelling and Conceptual Assessment of Pluvial Mitigation Measures

6.1 Overview

Hydraulic modelling has been used to assess the pluvial and fluvial flood risk to the existing site, the effects of the proposed scheme, and the determination of mitigation measures required to manage fluvial flood risk appropriately. The pluvial and fluvial hydraulic modelling was carried out in tandem is described in detail within Sections 6 and 7 respectively.

AECOM carried out a preliminary Direct Rainfall Assessment (DRA) in October 2016 prior to receiving the approved NRW ESTRY-TUFLOW Boverton Brook hydraulic model. 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 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 using the updated NRW fluvial model (Section 7.2);
- 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.

A detailed hydraulic modelling report and full modelling results from the pluvial modelling process can be found in Appendix D.

6.2 Baseline (Bare Earth) Model

A broad ‘Bare Earth’ direct rainfall hydraulic model was developed using the approved NRW ESTRY-TUFLOW Boverton Brook model in tandem with the fluvial hydraulic modelling. The received NRW model was first extended to create an updated baseline fluvial model of Boverton Brook and Llanmaes Brook described in Section 7 and then adapted to develop the pluvial baseline model.

6.2.1 Received Model

NRW provided AECOM with the latest hydraulic model of Boverton Brook, inclusive of Llanmaes Brook. The hydraulic model was constructed using ESTRY-TUFLOW (1D-2D) in 2014. The model was extended with additional cross section survey data and updated using the most current NRW LiDAR (2014) as described in Section 7.2. To fully assess the overland flow routes that may be impacted by the proposed NAR, 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).The extent of the pluvial model is shown in Figure 6-1. Further details of the updates made to the model are contained within Appendix E, and Appendix D Section 3.

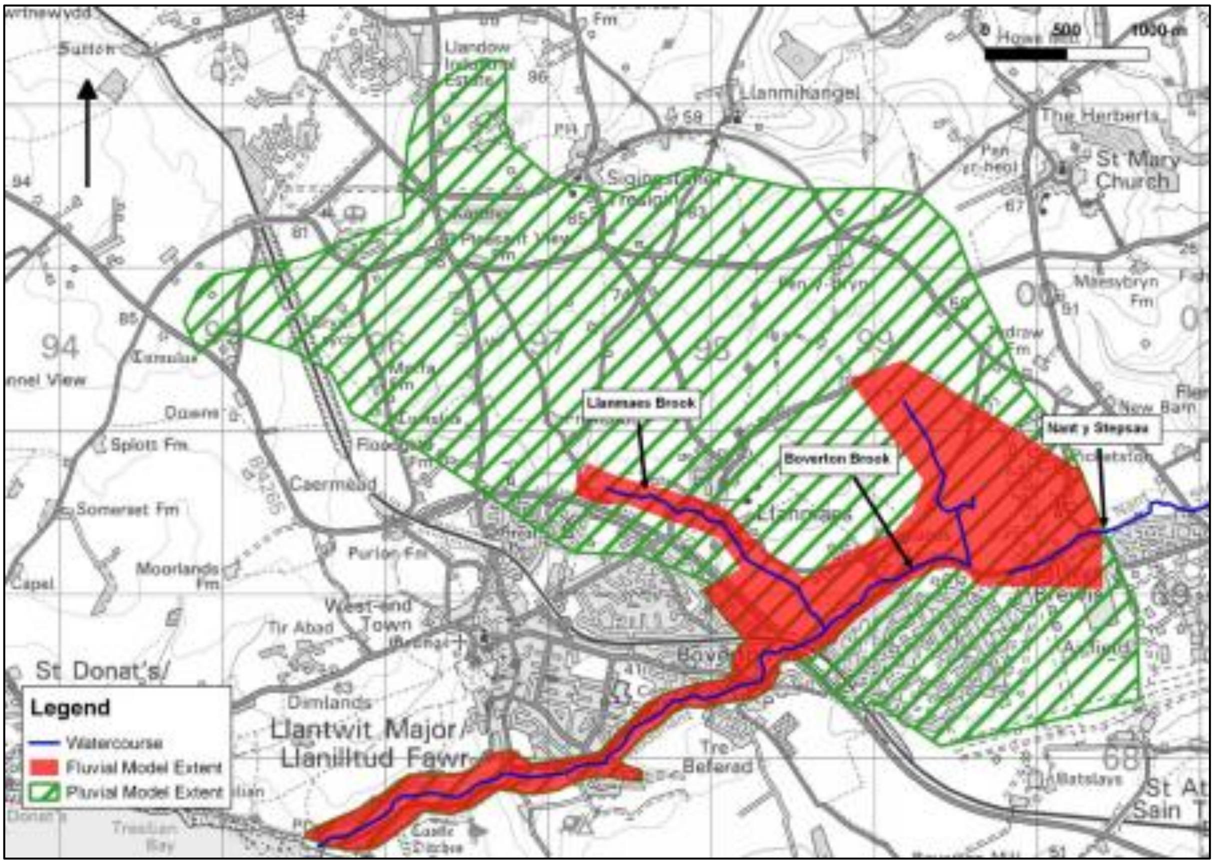


Figure 6-1- Pluvial 2D Model Domain.

6.2.2 Hydrological Inflows

Hydrological analysis was completed to form rainfall hyetographs 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 and an assessment of the critical storm duration undertaken. Examination of flood depths and extents 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 (Appendix D, Section 3.5).

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 impermeable surfaces. Therefore the approach adopted assumed that all losses within the model domain were attributable to infiltration. Due to the predominately rural nature of the modelled catchment, losses due to surface water drainage network were not represented. Following the analysis described in Appendix D, Section 2.3 a runoff coefficient of 0.3 was selected and applied to all rainfall hyetographs to represent infiltration loses.

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.

6.2.3 Climate Change Allowance

The climate change allowances used within this report were taken from the Welsh Government 2016[12] 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, prior to the commencement of this FCA, that the central estimate should be used.

6.2.4 Design Runs

Once the NRW fluvial model had been combined with the pluvial model and updated with the changes described in Appendix D, 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 Appendix D, Section 2.

6.3 Baseline (Bare Earth) Model Results

Baseline model results are detailed in Appendix D and are summarised below. The 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 6-2 shows the location of these key overland flow routes identified during the 1% + 30% Climate Change Flood Event.

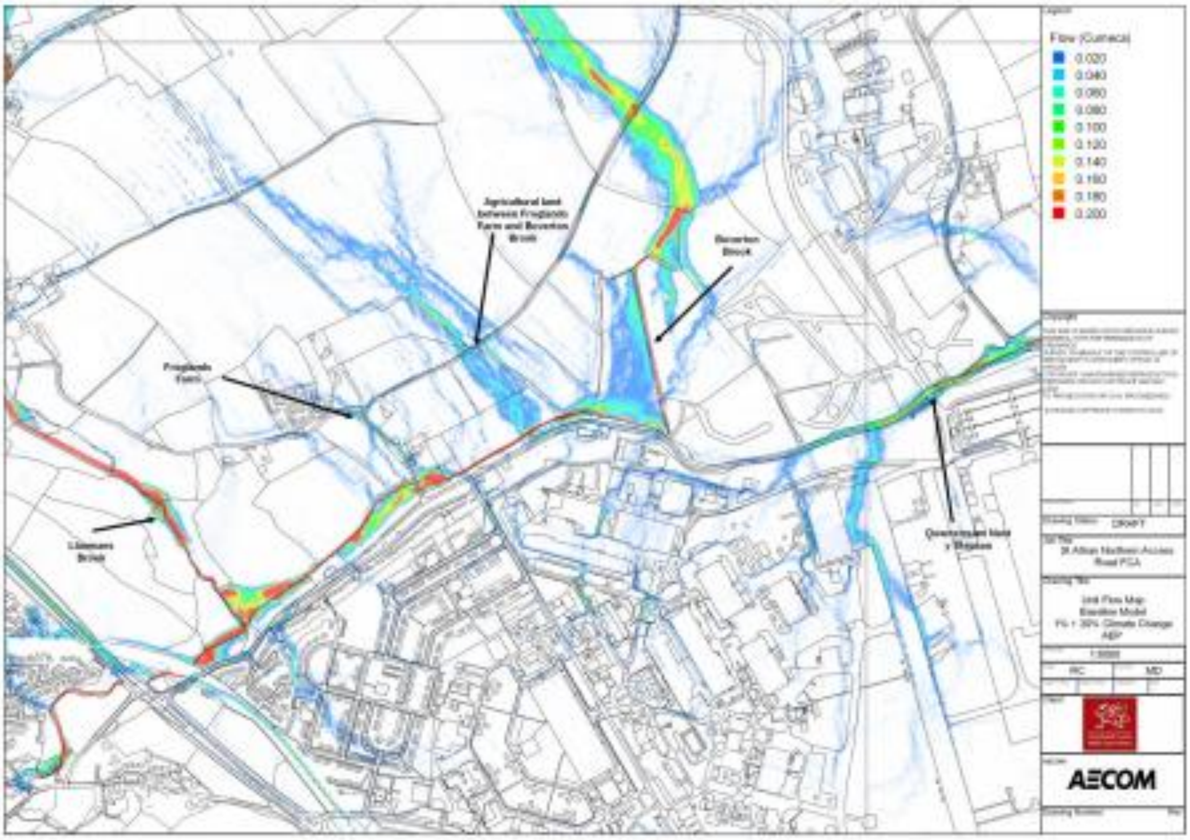


Figure 6-2- Baseline overland flow for the 1% + 30% Climate Change AEP event

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. Table 6-1 shows the maximum flow across these flow paths during the 1% + 30% Climate Change AEP event.

[12] 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

Table 6-1-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.

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 6-3 shows the flood depths for the 1% + 30% Climate Change event.

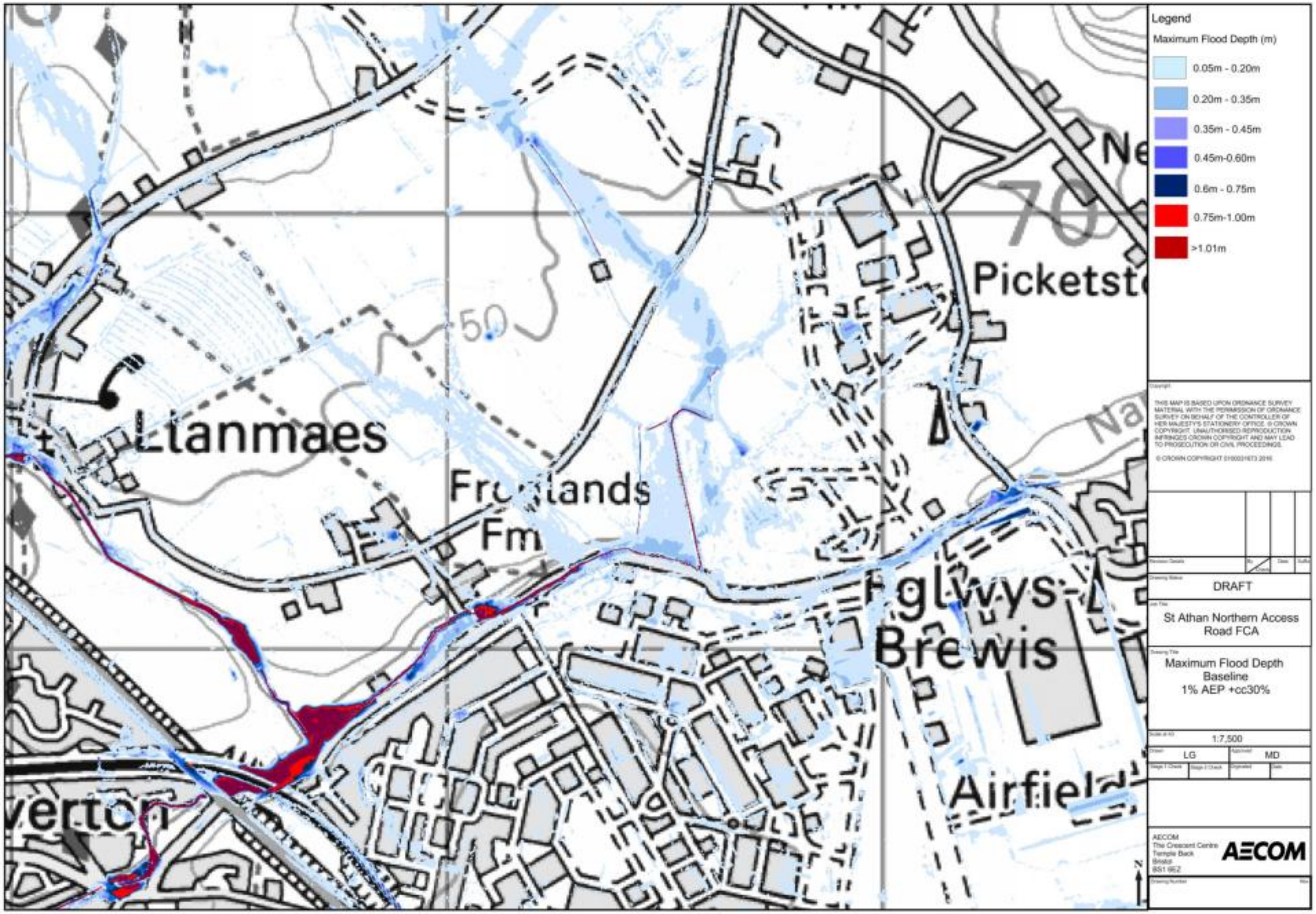


Figure 6-3- Maximum Flood Depth, Baseline Scenario, 1% + 30% Climate Change AEP

6.4 Proposed Scenario

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 6-4 shows the location of the proposed NAR and the location of the surrounding watercourses.

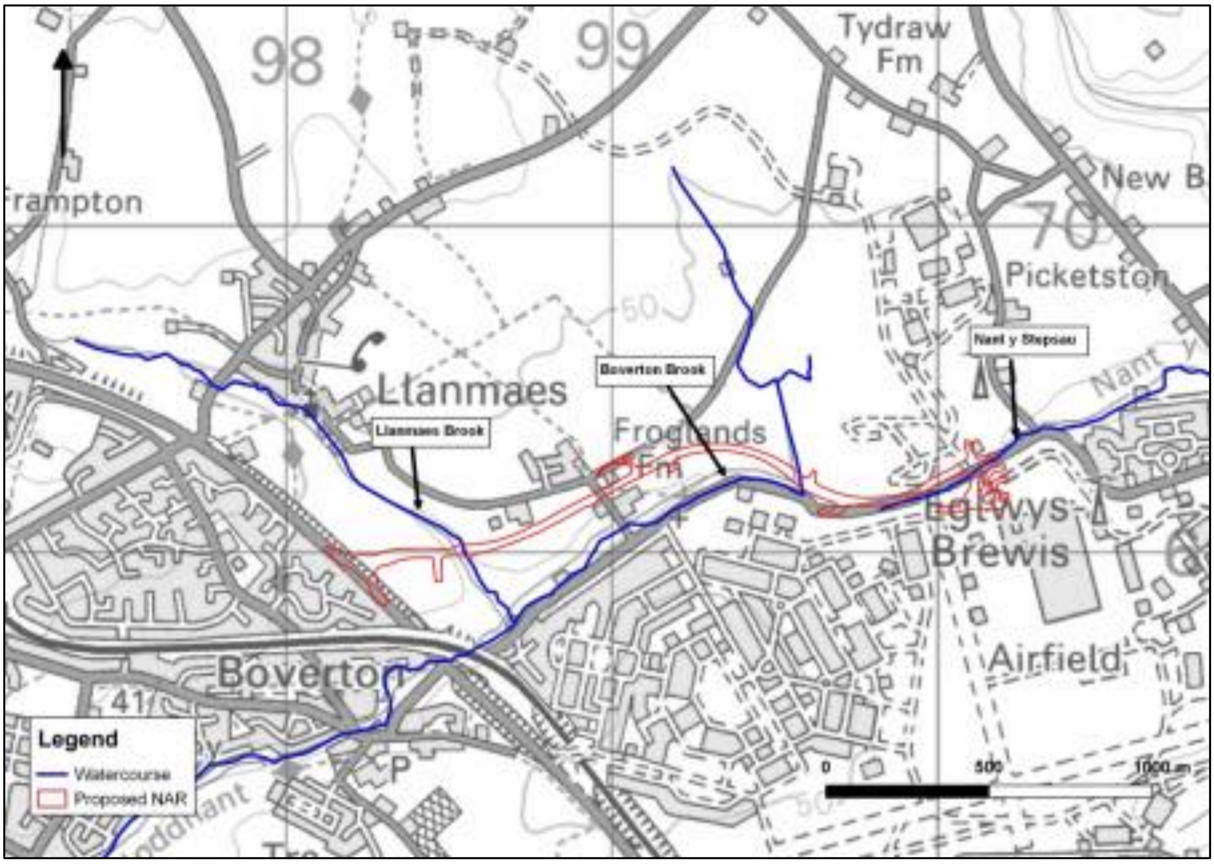


Figure 6-4-Location of the Proposed NAR.

6.5 Proposed Scenario Model Results

The model results show that the Proposed Scheme intersects a number of primary flow paths identified in Section 6.3. Figure 6-5 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, 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 0.60 - 0.80m with no mitigation measures during the 1% + 30% Climate Change AEP event.

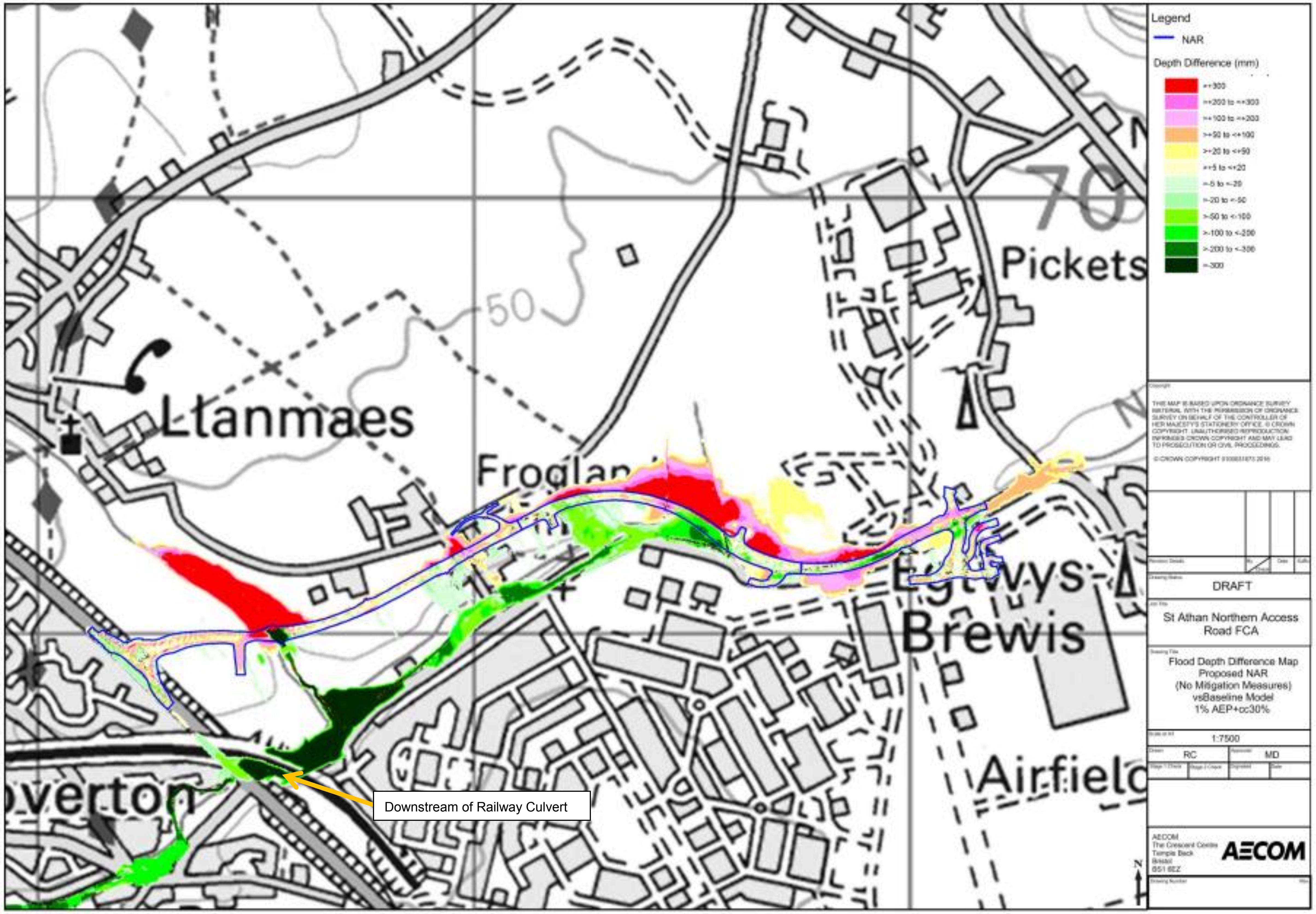


Figure 6-5-Flood Depth Difference Map, 1% + 30% Climate Change ,Proposed NAR (No Mitigation Measures) vs Baseline

Figure 6-5 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 Section 7.

6.6 Proposed Mitigation Measures

It has been demonstrated 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 6-5 shows that at Llanmaes Brook, Froglands Farm, Boverton Brook and Nant y Stepsau there is an increase in flood depths on the north and south side of the NAR and also inundation of the highway. The volume of water stored upstream of the NAR on Llanmaes Brook, Boverton Brook and Nant y Stepsau was found to exceed 10,000m^3.

Discussions with NRW highlighted the need to avoid the formation of reservoirs in the design of mitigation options. If the volume of water stored upstream of the NAR exceeds 10,000m^3 these detention areas would be classified as reservoirs. The Flood and Water Management Act 2010[13] stipulates that a large raised reservoir is classified as:

(a) a large, raised structure designed or used for collecting and storing water, and
(b) a large, raised lake or other area capable of storing water which was created or enlarged by artificial means.
(2) a structure or area is “raised” if it is capable of holding water above the natural level of any part of the surrounding land.
(3) a raised structure or area is “large” if it is capable of holding 10,000 cubic metres of water above the natural level of any part of the surrounding land.

To address this, a series of flood mitigation options were developed in tandem with the fluvial model described in Section 7 and the Drainage Strategy Report. 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 1%AEP+ 30% climate change 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.

6.7 Mitigation Measures

A series of mitigation options were developed to address the criteria set out above. Figure 6-6 shows an overview of the proposed flood mitigation methods

The development of the flood storage areas and culvert optimisation on Llanmaes Brook and Boverton Brook is discussed in Section 7 and is described in detail within Appendix E (Section 4.3.6).

[13] http://www.legislation.gov.uk/ukpga/2010/29/contents

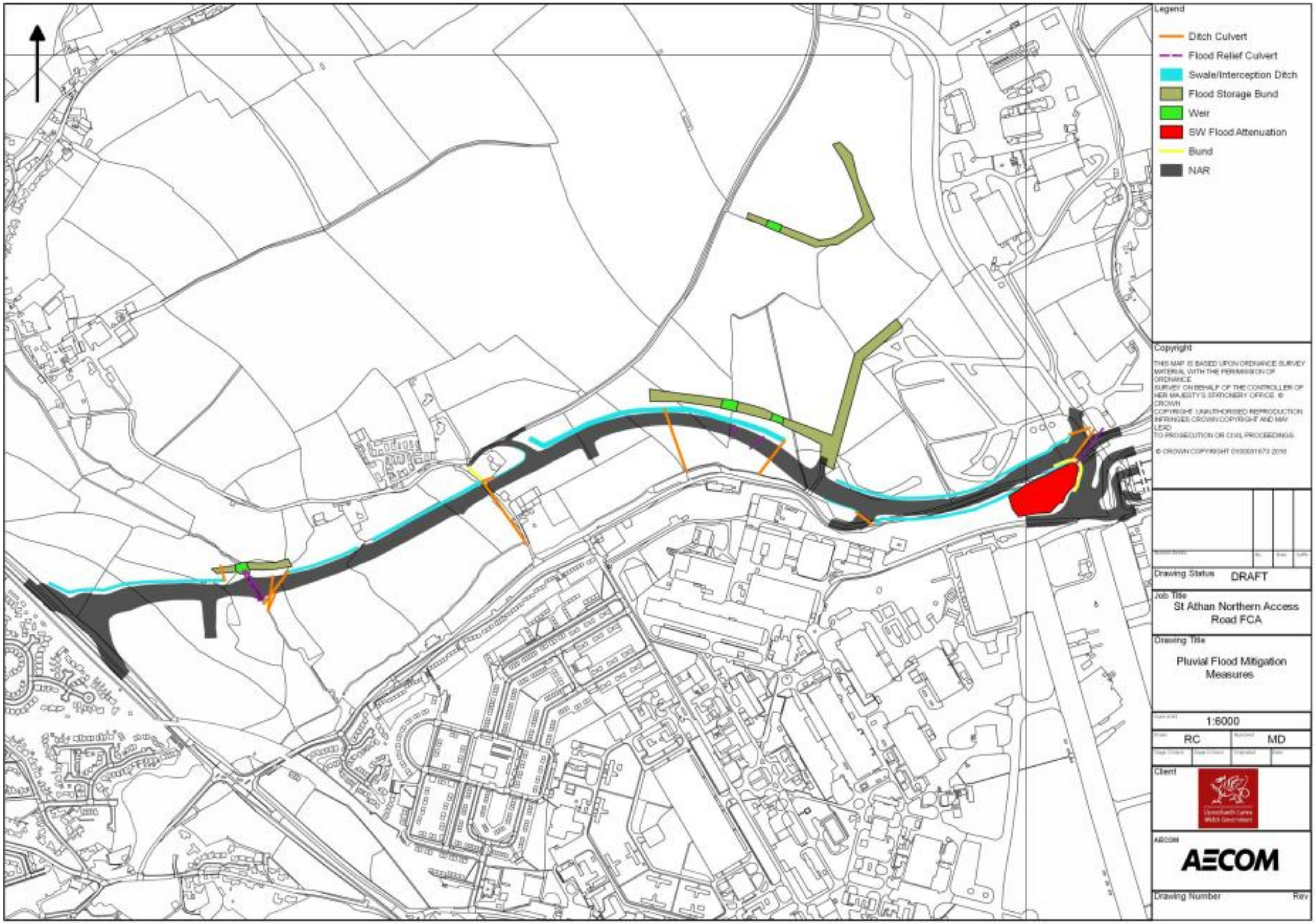


Figure 6-6-Overview of Flood Mitigation Measures

6.7.1 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. Figure 6-7 shows the location of the surface water swales and interception ditches and Table 6-2 shows the dimensions of these the ditches and swales.

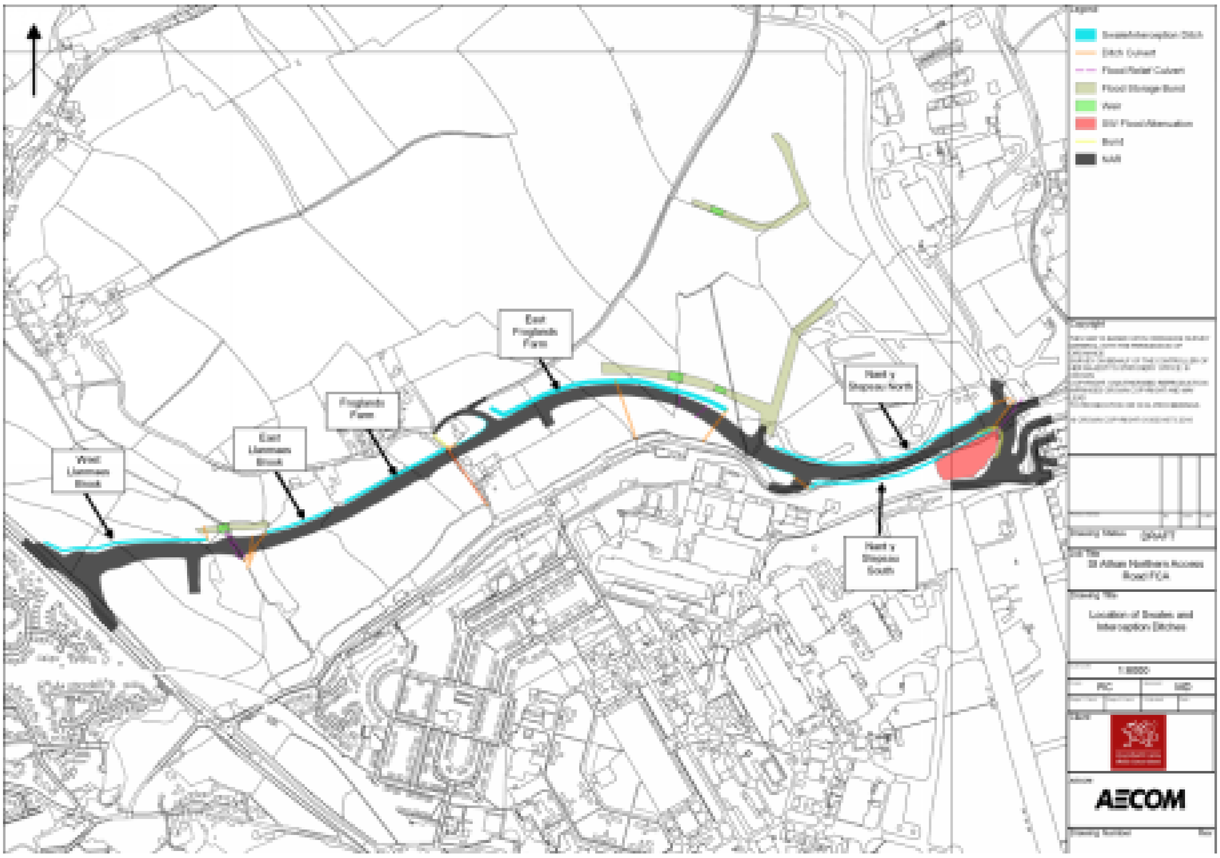


Figure 6-7-Location of surface water swales and interception ditches

Table 6-2-Specification of swales and interception ditches

Location	Catchment[14]	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

[14] See Figure 5-3 Appendix D for local drainage catchments

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.

6.7.2 Ditch Culverts

To ensure the continued conveyance of water along the swales and interception ditches a series of culverts were schematised. Figure 6-8 shows the location and capacity of these culverts.

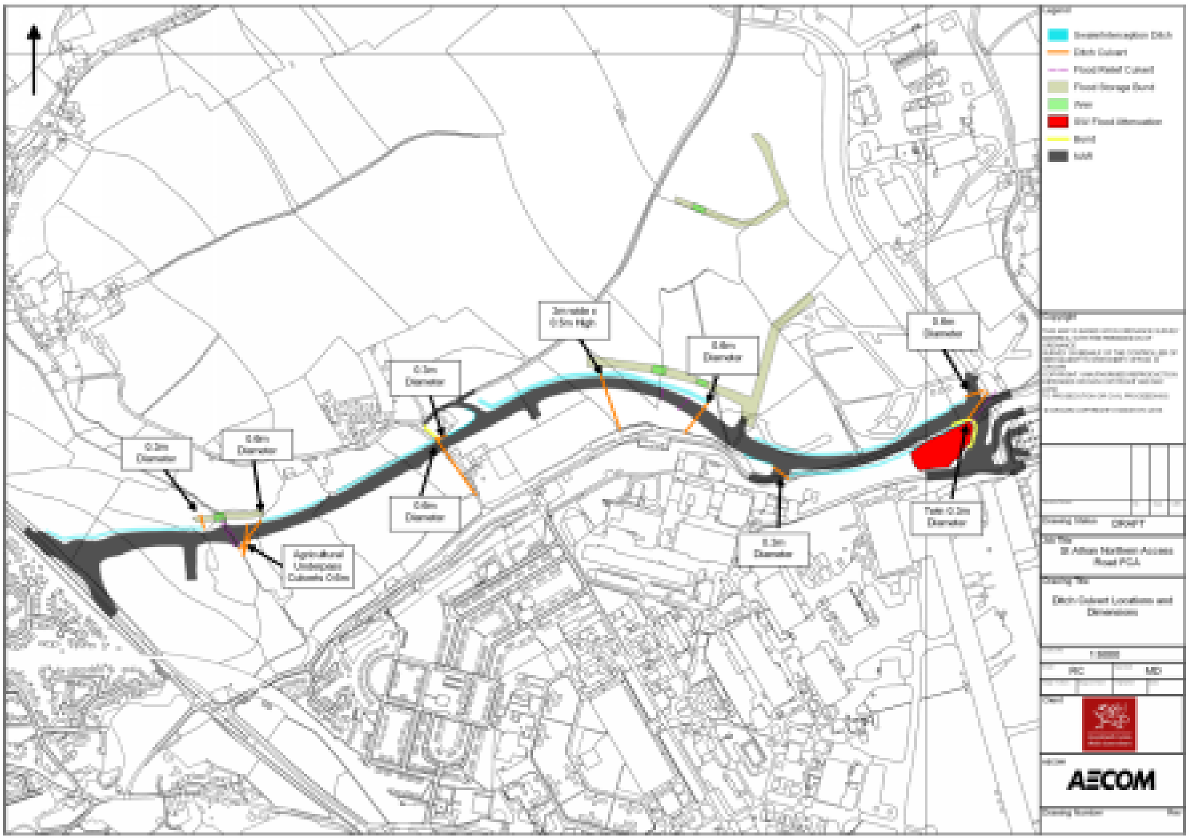


Figure 6-8-Ditch Culvert Location and Dimensions

It is noted that there are two culverts located within the East Froglands Drainage Ditch. The overland flow path identified in Section 6.3 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 3.00m wide by 0.50m 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).

6.7.3 Flood Storage Areas

In addition to the three flood storage areas at Boverton Brook (two areas) and Llanmaes Brook (one area) described in Section 7.4.3 and Appendix E, initial pluvial results showed that a further flood storage area was required at Nant y Stepsau to accommodate overland flow routes. Figure 6-9 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 0.30m during the 1% + 30% Climate Change AEP event (Figure 6-9). To prevent the inundation of the proposed NAR and control the flows entering Nant y Stepsau downstream of the NAR, the attenuation basin was set to a base level of 40.20m 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 6.7.4).

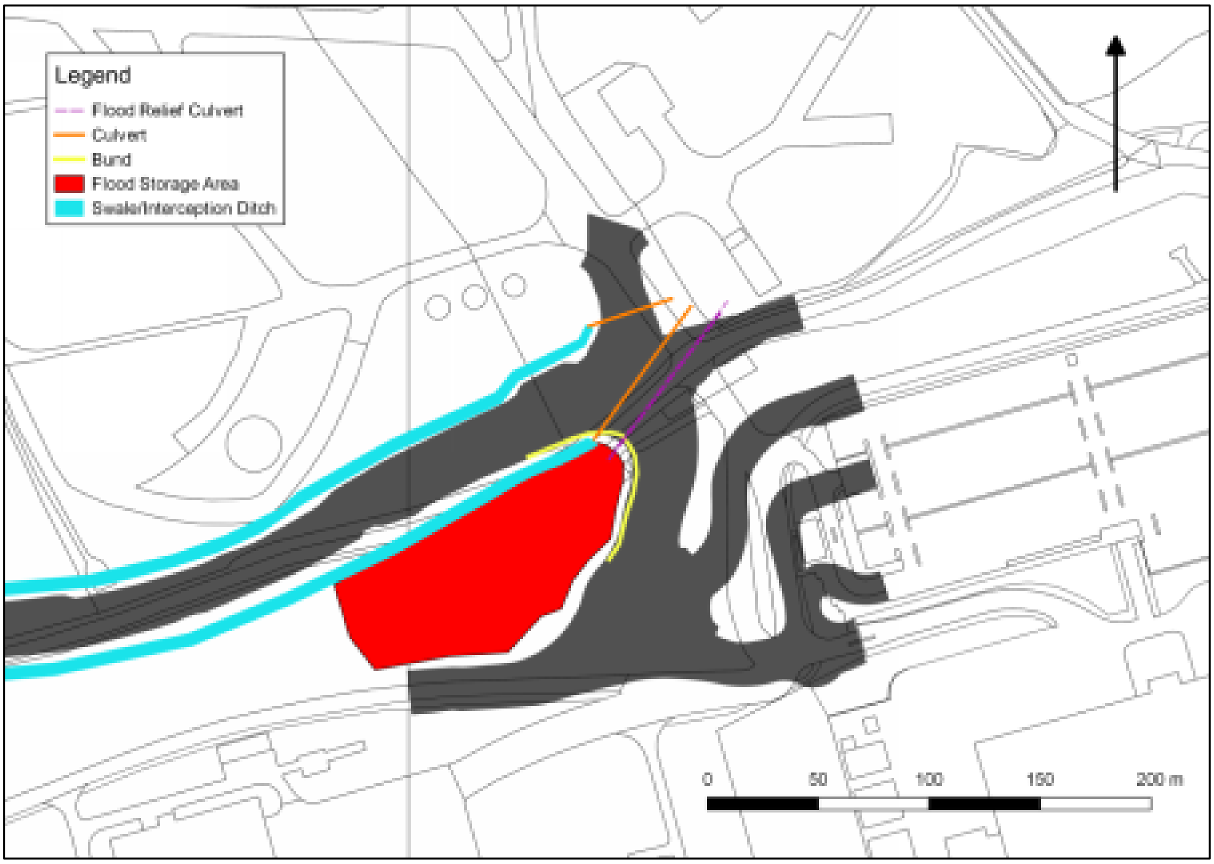


Figure 6-9 - Nant y Stepsau Flood Storage Area.

6.7.4 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. Table 6-3 details the specification of the flood relief culverts.

Table 6-3-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	0.60	41.60
Nant y Stepsau	Rectangular	3	1 x 0.30	40.40

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

6.7.5 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. This bund would form the highway boundary and not encroach on private land.

6.8 Proposed Mitigation Measure 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 6.2.2. 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 6-10 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 6-10). 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. Table 6-4 shows the flood storage volumes during all modelled AEP events remain below 10,000m^3 and that downstream flows are reduced on both Boverton Brook and Nant y Stepsau.

Table 6-4-Pluvial Flood Storage Volumes and Downstream flows for various AEPs with Proposed Mitigation Measures

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 2.00m 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.

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 6.8.1.

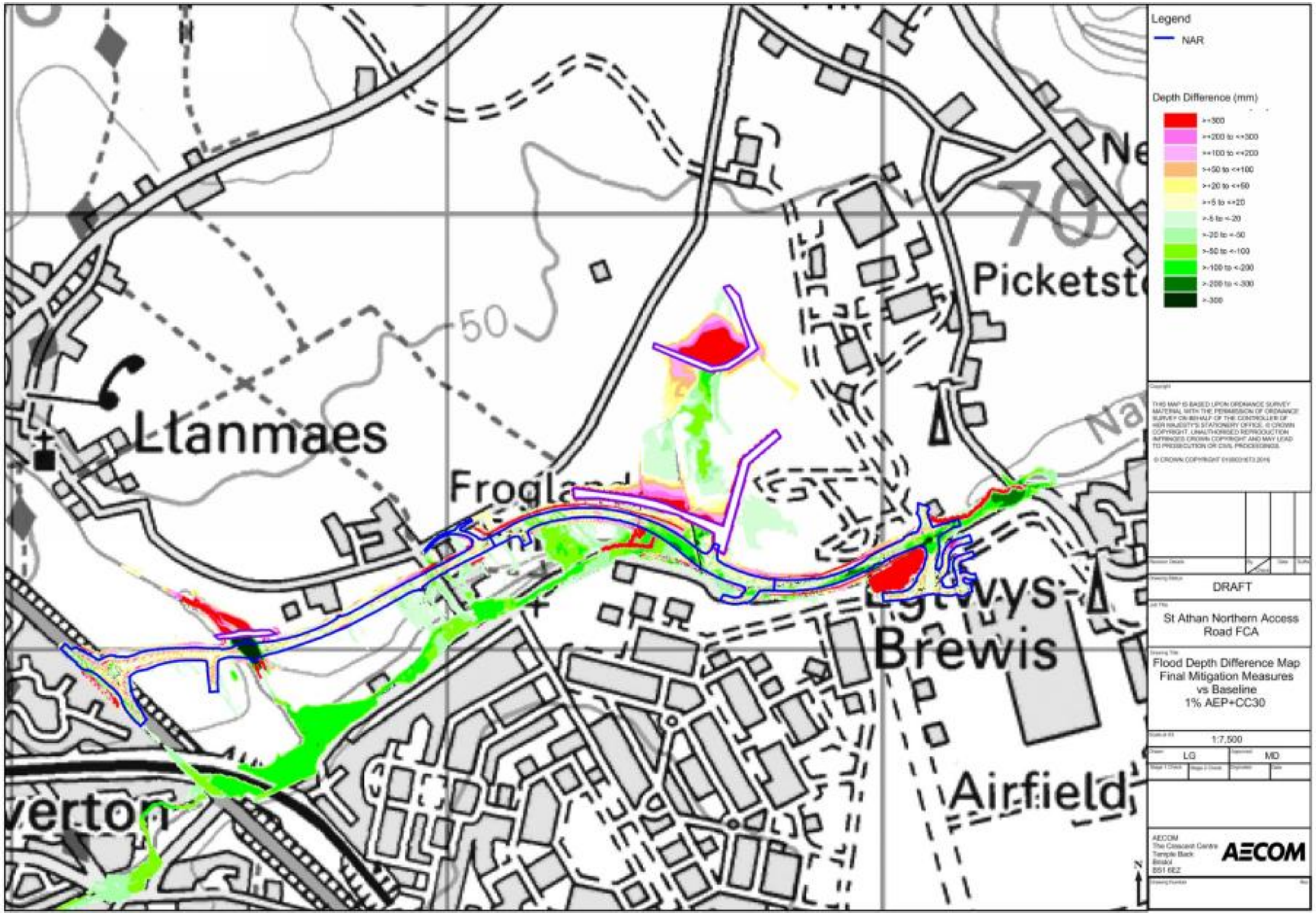


Figure 6-10 - Flood Depth Difference Map, 1% + 30% Climate Change, Final Mitigation Measures vs. Baseline

6.8.1 Blockage Scenarios

To ensure that the flood mitigation measures meet the design criteria outlined in Section 6.7, 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[15]

The following combinations of blocked culverts were 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 6-10 shows the location of the blocked culverts.

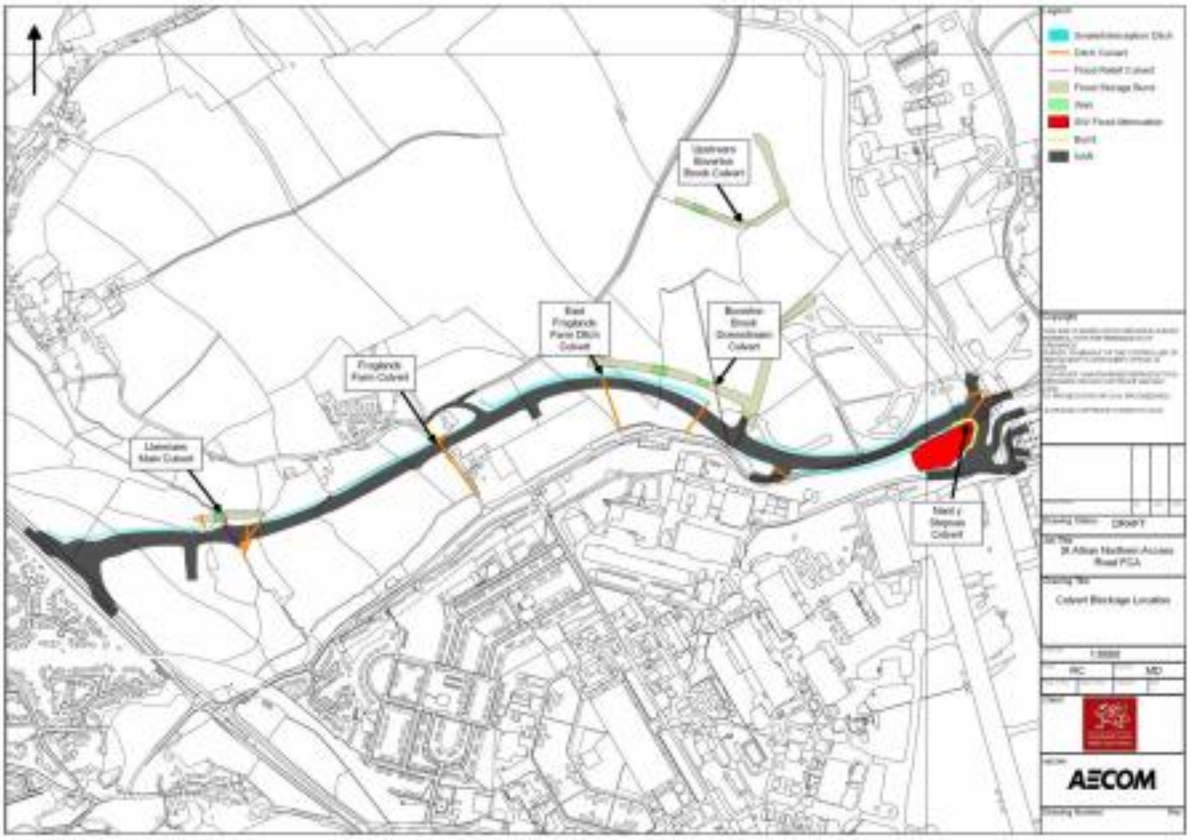


Figure 6-11 - Culvert Blockage Locations

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

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% AEP + 100% blockage. Figure 6-12 shows the depth difference for the 0.1% AEP event with 100% blockage of the Llanmaes and Nant y Stepsau culvert compared to 0% blockage. During this 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 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.

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

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 6-5 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 6-5-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 6-13). 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.

Figure 6-13 also shows there is an increase in flood depths of 0.20m 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 (Appendix D3). 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 6-12 - Flood Depth Difference, 0.1% AEP + 100% Blockage of Llanmaes and Nant y Stepsau

Figure 6-13: Flood Depth Difference, 0.1% AEP + 100% Blockage of Froglands Ditch and East Froglands Ditch Culverts

6.9 Summary

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 and intersects overland flow routes, including that to the Nant Y Stepsau. 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 Section 7 and 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.

7. Hydraulic Modelling and Conceptual Assessment of Fluvial Mitigation Measures

7.1 Overview

Hydraulic modelling has been used to assess the fluvial flood risk to the existing site, the effects of the proposed scheme, and the determination of mitigation measures required to manage fluvial flood risk appropriately.

The hydraulic model of the Boverton Brook has been developed sequentially as follows:

- The model received from NRW (Boverton Brook) was internally reviewed by AECOM to check that all modelling files and outputs had been received correctly;
- The model was updated to include the latest (2014) LiDAR data;
- The model was extended approximately 1km upstream to include land to the north of the proposed scheme that may be impacted by the Northern Access Road;
- Once the model had been updated and extended, baseline model simulations were run;
- 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 flood risks to the NAR and surrounding area; and
- The flood 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.

7.2 Received Fluvial Model

NRW provided AECOM with the latest hydraulic model of Boverton Brook, inclusive of Llanmaes Brook. The hydraulic model was constructed using ESTRY-TUFLOW (1D-2D) in 2014.

The NRW model is explicitly confined to the maximum flood extents in order to maximise runtime efficiencies. As a result, the upstream boundary of the Boverton Brook required extension north and east by approximately 1km to fully represent the Northern Access Road appropriately. A technical note explaining these updates, is available within Appendix E, and is summarised herein.

A channel survey for the NRW model was undertaken in 2013 (for the modelled region only) and it was therefore assumed that this is current and could be taken forward. However, as the existing NRW model did not include for the stretch of watercourse between the existing upstream boundary and the proposed upstream boundary (north of the proposed Northern Access Road), the model was updated to represent the channel between these two locations, utilising new channel cross sectional survey and introduced to the model accordingly.

The LiDAR data within the received NRW model originates from 2006. The hydraulic model was updated using the most current NRW LiDAR (2014) as this should be more accurate and represent any recent developments or improved land object filtering algorithms.

Upon receipt of the model, the NRW data 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 received model were applied. These are considered conservative because at a location 1km upstream of the existing inflow location the receiving catchment will be slightly smaller and so flows will be less.

AECOM are aware that VoGC are undertaking a hydraulic model study of Llanmaes Brook which includes for a flood relief culvert and flood storage area (to be confirmed). Whilst much of the proposed study focusing on the proposed Northern Access Road and Boverton Brook can be undertaken separately from the VoGC study, this aspect is able to be progressed simultaneously in order to progress the assessment and produce supplementary design outputs as efficiently as possible.

To assist in providing assurance in the proposed scheme, in lieu of further details from the VoGC design which is to be finalised, the NAR highway crossing on Llanmaes Brook has been designed to a higher climate change specification as a sensitivity. Results of this FCA will be supplied to VoGC, the VoGC scheme will need to be designed to this maximum design flow downstream of Llanmaes in lieu of further studies.

7.3 Proposed Scheme

As discussed in Section 5.3, with the proposed embankment based scheme crossing two watercourses and being within the existing floodplain, there is a risk posed to the proposed scheme and a potential loss of floodplain storage. Figure 7-1 shows the location of the proposed scheme. The new extended baseline model was used to assess the impact of the proposed scheme.

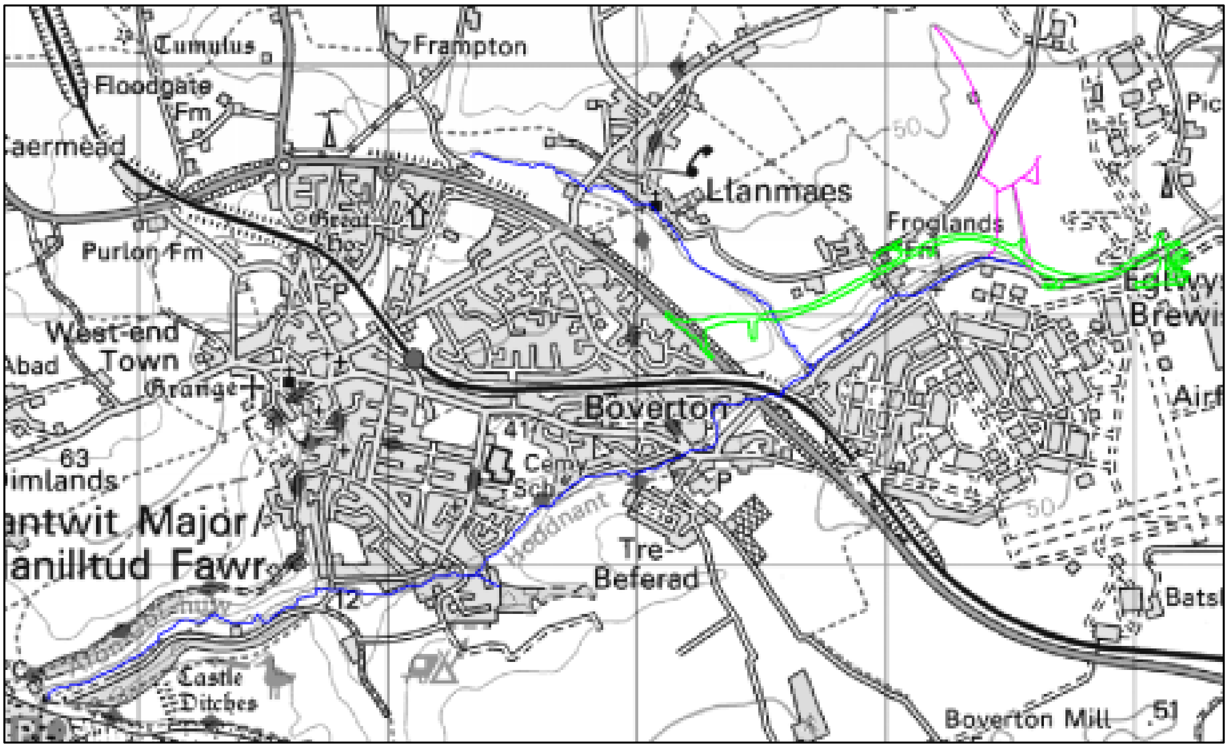


Figure 7-1- Map showing proposed scheme in Green, Received modelled Watercourse extents in Blue, and extended model in Pink.

The proposed scenario was created through modifications of the finalised baseline scenario model. The NAR design was provided by the AECOM design team in CAD format. The proposed layout of the NAR (Figure 7-1) was represented in the model through changes to topographical geometry where the highway extends from the B4265 to Eglwys Brewis Road, adjacent to MoD St. Athan. The proposed highway also bisects two watercourses, namely the Llanmaes Brook and Boverton Brook, at these locations culverts were added to the network.

7.4 Modelling Results

Flood risk modelling results are presented in Appendix E for the new (extended) model for both the existing scenario and proposed scheme. A summary of results is contained within this section.

7.4.1 Extended Baseline Model Results

As shown in Figure7-2, the flood depths in the extended model are as a result of the model extension, update to the most current and available LiDAR data and update to the most current software version. The difference noted is also a function of the change in location of the Boverton Brook flow inflow hydrograph, where water now has the ability to spill out over the floodplain further upstream. The greatest increase in flood depths are seen where the ditch network has been added to the model. These depth increases are a result of the improved accuracy of the topography by the addition of channel cross sections compared to the representation of the ditches by LiDAR.

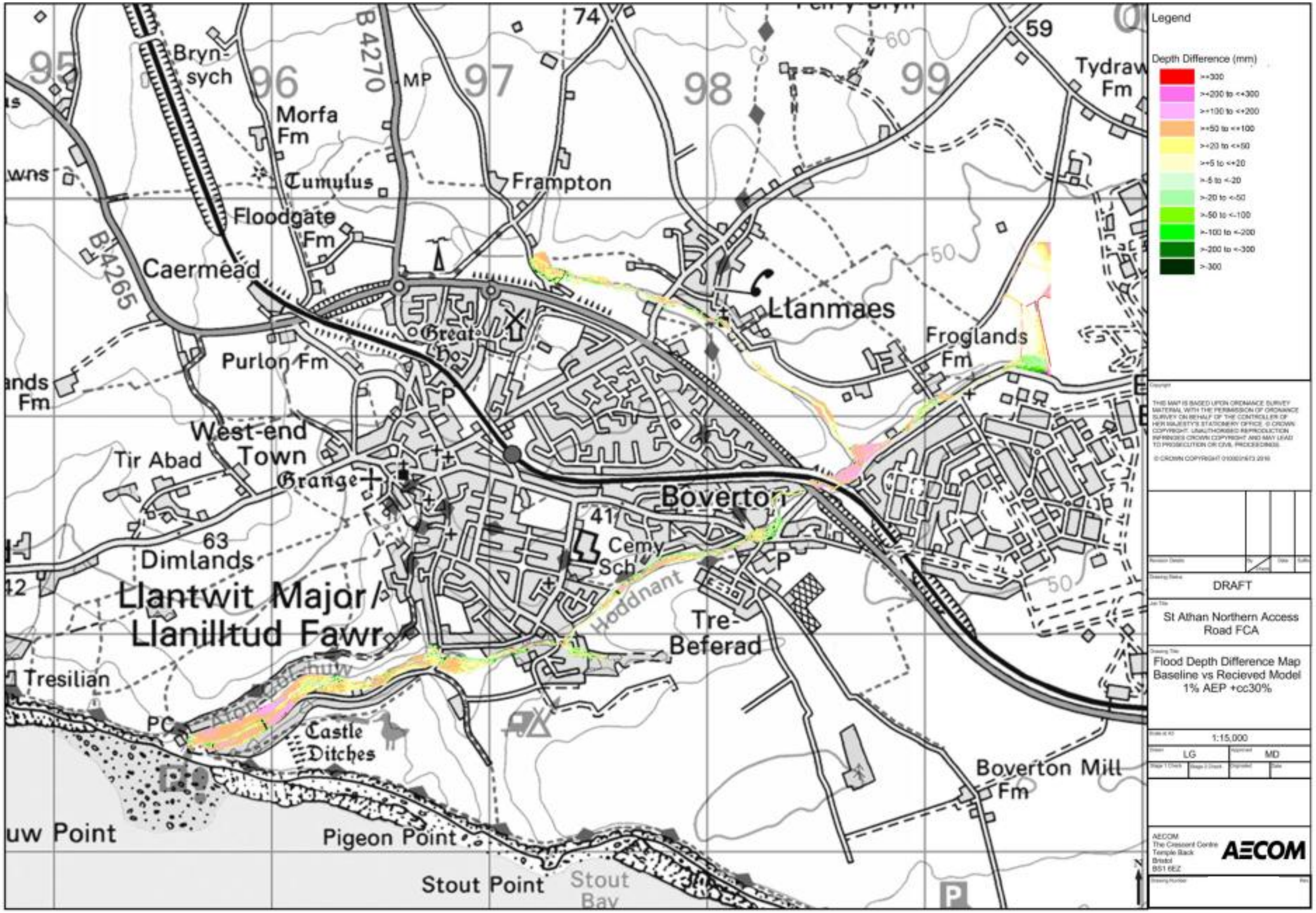


Figure7-2-Flood Depth Difference Map, Existing vs Extended Model, 1% AEP +Climate Change 30% Allowance

7.4.2 Proposed Scenario

Initial culvert dimensions inputted to the proposed scenario were for 600mm diameter culverts at the two locations where the NAR crosses the Boverton Brook and a 1.5m diameter culvert where the NAR crosses the Llanmaes Brook. Analysis of results showed that this proposed scenario reduced maximum flows immediately to the north of the railway line by 40% compared to the new baseline scenario.

As can be seen in Figure 7-3, significant ponding occurs as a result of the road, with large areas of storage on both the Llanmaes and Boverton Brook upstream of the NAR. Inspection of results showed that the volume of water stored upstream of the NAR on Llanmaes Brook was found to be in excess of 30,000m^3. Mitigation measures were required to reduce this volume below 10,000m^3 for the 1% AEP plus Climate Change 30% event.

Climate change allowances were taken from the Welsh Government's 2016[16] 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.

NRW highlighted the requirement for the effects of blockage on flows and storage volumes to be examined. 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[17].
Therefore, the key considerations in the design of mitigation measures were to ensure:

- that the storage areas on Boverton Brook and Llanmaes Brook hold less than 10,000m^3 in a 1% AEP +CC30% event;
- that no additional water is discharged into the Nant-y-Stepsau as a result of construction of the proposed scheme;
- to ensure that no increase in flood risk results downstream of the NAR;
- to ensure that no overtopping of the road occurs during the 1% AEP+ CC30% event; and
- to ensure that blockage of culverts does not result in an increase in flood depth.

A series of mitigation measures to meet these key considerations were explored, and are detailed in the next section of this report.

[16] http://gov.wales/topics/planning/policy/policyclarificationletters/2016/cl-03-16-climate-change-allowances-for-planning-purposes/?lang=en.
[17] NRW, Unpublished Guidance, 2015. Flood Risk Management: Modelling blockage and breach scenarios.

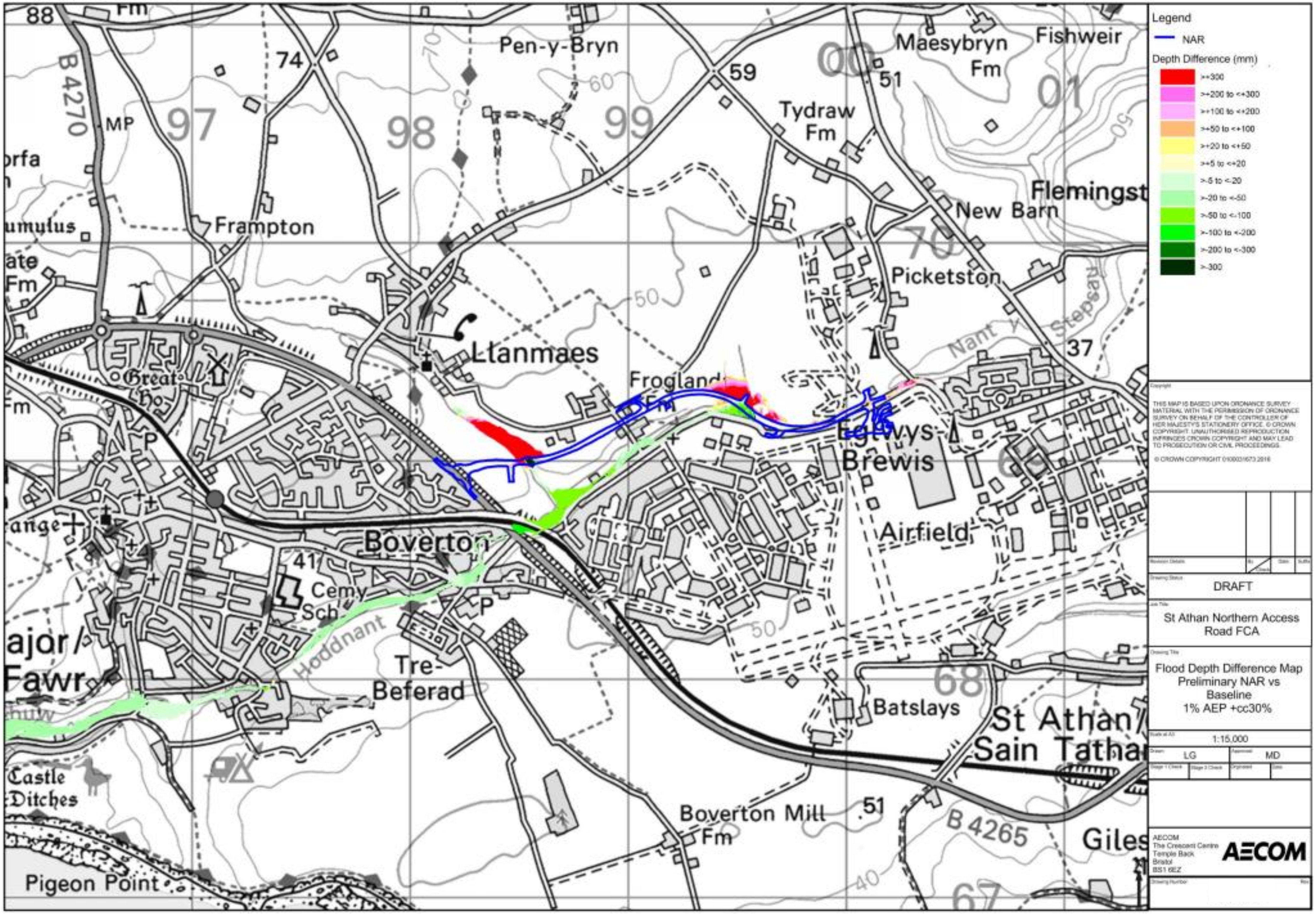


Figure 7-3-Flood Depth Difference Map Preliminary Proposed Scenario vs Baseline, 1% AEP +cc30%

7.4.3 Mitigation Measures

To meet the key considerations detailed in Section 7.4.2, a series of mitigation measures were tested. These included:

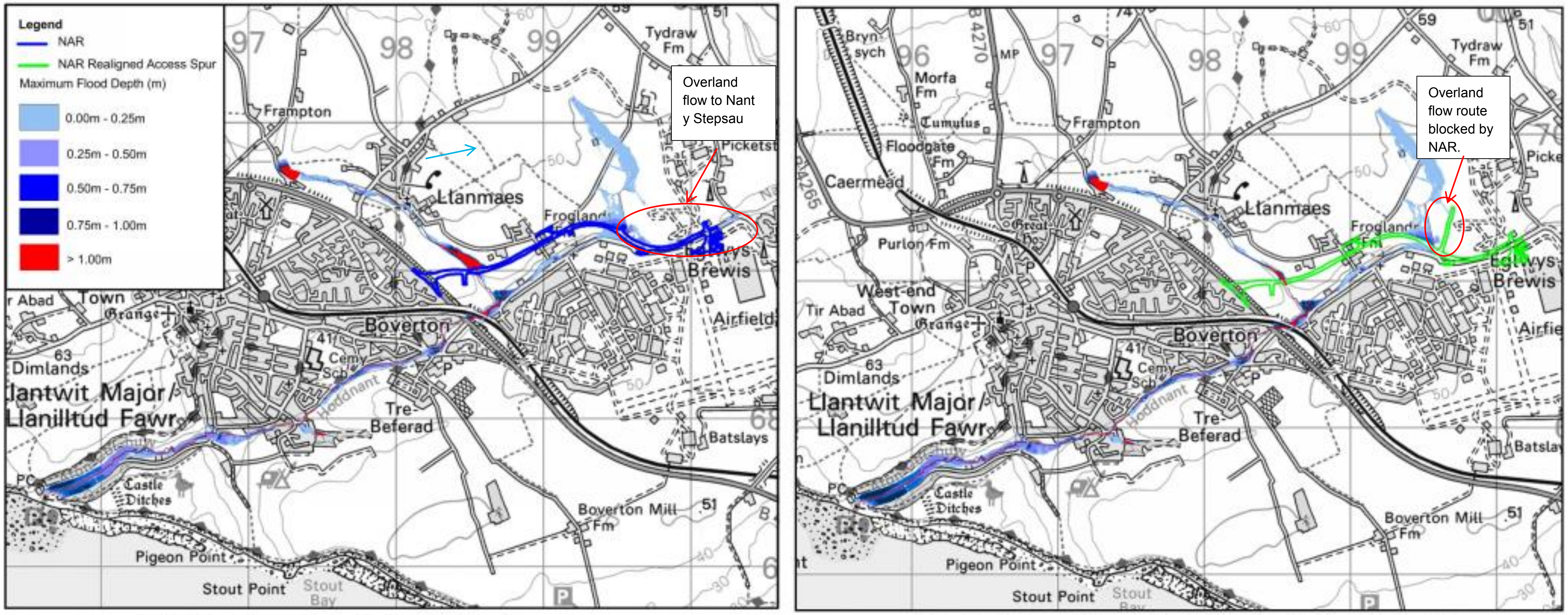
- Increasing the NAR highway elevation in key areas where overtopping had been observed in the proposed scenario;
- Re-alignment of the access spur further eastwards off of the NAR to form a bund. This bund is designed to prevent water from flowing to the east of the Boverton Brook into the Nant-y-Stepsau;
- Decreasing the number of culverts at the Boverton Brook, and optimising the size of culvert;
- Flood relief culverts to ensure that storage areas do not exceed 10,000m^3, for the 1% AEP plus 30% climate change event, when blockage of the main culverts occurs; and
- Separate flood relief bunds.

Detailed discussion of these mitigation measures and results are contained within Appendix E.

Road Raising and Re-alignment of the Access Spur

The access spur on the left bank of the Boverton Brook upstream of the NAR, was moved 115m east, and extended 225m in length. It can be seen in Figure 7-4, that after these alterations, the overland flow path to the Nant-y-Stepsau was blocked by the Access Spur. Model results show that no additional overland flow is reaching the Nant-y-Stepsau as a result of the proposed scheme.

The road elevation was raised by 500mm in key locations where overtopping had been observed in model simulations of the proposed scenario for the 1% AEP plus 30% climate change event.



Depth of Flooding, Proposed Scheme, 1% AEP pus 30% Climate Change

Depth of Flooding, Proposed Scheme with Realigned Access Spur, 1% AEP pus 30% Climate Change

Figure 7-4- Maximum Flood Depth before and after Realignment of the Access Spur

Culvert Optimisation

Following discussions with NRW, a series of different culvert dimensions were modelled to determine the optimum culvert size which ensures that flow was reduced downstream of the proposed scheme and that the storage areas upstream of the NAR did not exceed 10,000m^3 for the 1% AEP +30% climate change. The culvert dimensions that were modelled included; 0.6m, 1m, 1.2m, 1.5m, 1.6m and 2m diameter circular culverts. Results for these culvert dimensions are detailed in Appendix E, Section 4.4.3.

Analysis of results found that culverts within the following dimension ranges met the design criteria:

- for the Boverton Brook the culvert diameter required is within the range of 1.20-2.00m; and
- for Llanmaes the culvert diameter required is within the range of 1.60-2.00m.

In order to examine the effects of blockage on the designed culverts, all further model simulations were conducted with culverts in the middle of these ranges; i.e. one 1.50m by 1.50m rectangular box culvert at Llanmaes Brook and one 1.375m diameter circular culvert at Boverton Brook.

Figure 7-5 shows the depth difference map for the proposed scheme with mitigation measures vs the extended baseline scenario. It can be seen that the depth of flood water downstream of the NAR is decreased by 5-50mm for the 1%AEP plus 30% climate change event.

It can be seen in Figure 7-5 that there is a reduction in flood depth upstream of the NAR on Llanmaes Brook. This is a result of removing the storage area and control structure (0.5m diameter culvert) on Llanmaes immediately downstream of the road. This has been replaced by a much larger 1.5m by 1.5m diameter box culvert on Llanmaes Brook through the NAR.

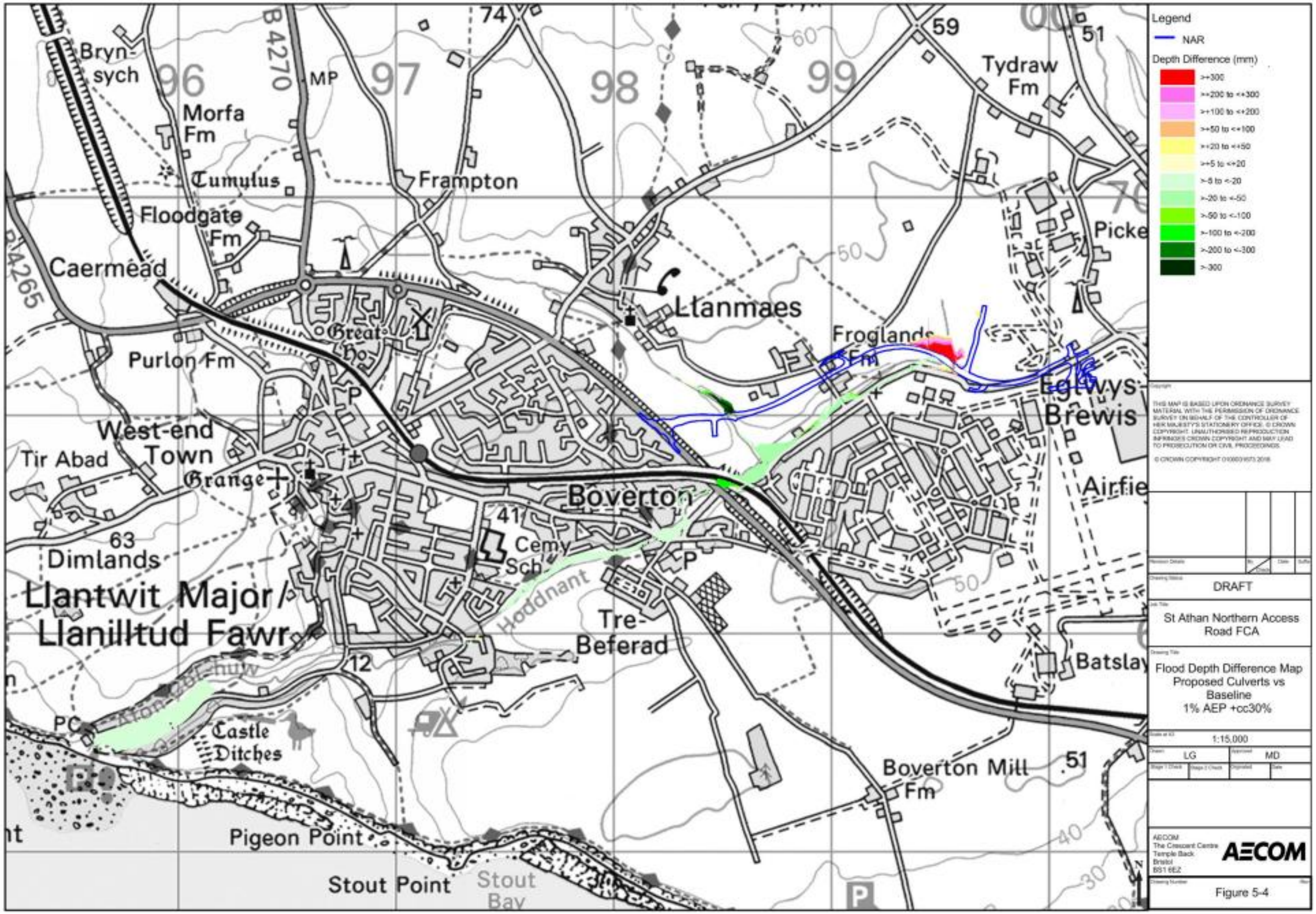


Figure 7-5 - Depth Difference Map of Proposed Scenario with Mitigation Measures vs Baseline, 1% AEP plus 30% Climate Change Event

Table 7-1 shows that the proposed scheme results in a decrease of flow downstream of the NAR for all modelled events. The storage volumes contained upstream of the NAR on the Llanmaes Brook and on Boverton Brook are shown in Table 7-2. It can be seen that the proposed scheme now provides an overall benefit to Boverton and that the two storage areas contain less than 10,000m^3 for all events.

Table 7-1- Maximum Downstream Flows of NAR with Proposed Culverts

Event	Downstream Flow (m^3s^{-1})		
	Baseline	Proposed	Difference
20% AEP	0.88	0.75	-0.12
2%AEP	1.03	0.97	-0.06
1%AEP	1.06	1.04	-0.02
1%AEP + Climate Change 30%	1.22	1.19	-0.03

Table 7-2-Upstream Storage Volumes at Boverton Brook and Llanmaes Brook with Proposed Culverts

Event	Storage Area (m^3)	
	Llanmaes	Boverton
20% AEP	1371	841
2%AEP	2304	8163
1%AEP	2898	1892
1%AEP + Climate Change 30%	6059	5513

Culvert Blockage Simulations

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.

The upstream storage volumes resulting from these events are shown in Table 7-3. Depth difference maps are shown within Appendix E figures E13-E16.

Table 7-3- Storage Areas on Llanmaes and Boverton Brook with Culvert Blockage Scenarios

% Blockage	67%		100%	
Event	1%AEP+30%	0.1%AEP	1%AEP+30%	0.1%AEP
Llanmaes Storage Area (m^3)	36872	38667	38614	39994
Boverton Storage Area (m^3)	14437	15858	15875	16414

It can be seen in Table 7-3 that with blockages the storage volumes exceed 10,000m^3. Therefore, in order to ensure that storage volumes do not exceed the 10,000m^3 flood relief culverts were designed on both Llanmaes and Boverton Brook.

Culvert Blockage Mitigation

Various arrangements of the flood relief culverts were modelled in order to meet the design criteria; these are detailed in Appendix E. The invert levels of the flood relief culverts on Llanmaes Brook are set to the approximate maximum water elevations for the 1%AEP plus 30% climate change event, and just below this elevation on Boverton Brook. This is in order to ensure that during times of no blockage on the main culverts, the proposed scheme still provides downstream benefit.

The proposed minimum culvert dimensions are shown in Table 7-.

Table 7-4 - Flood Relief Culvert Specification

Culvert Parameter	Llanmaes Brook	Boverton Brook
Invert Level (mAOD)	Two at 39.69 and two at 39.89	42.5
Height (m)	1.00	0.40
Width (m)	2.10	3.00
Number of	4	4

Figure 7-6 shows that as a result of including these flood relief culverts, the depths of flooding upstream of the NAR do not increase even for the 100% blockage 0.1% AEP event. The maximum storage volumes upstream on the Llanmaes Brook and Llanmaes Brook are below 10,000m^3. Flood depth difference maps and storage volumes for the other blockage scenarios and AEPs are shown in Appendix E, Section 4.4.6.

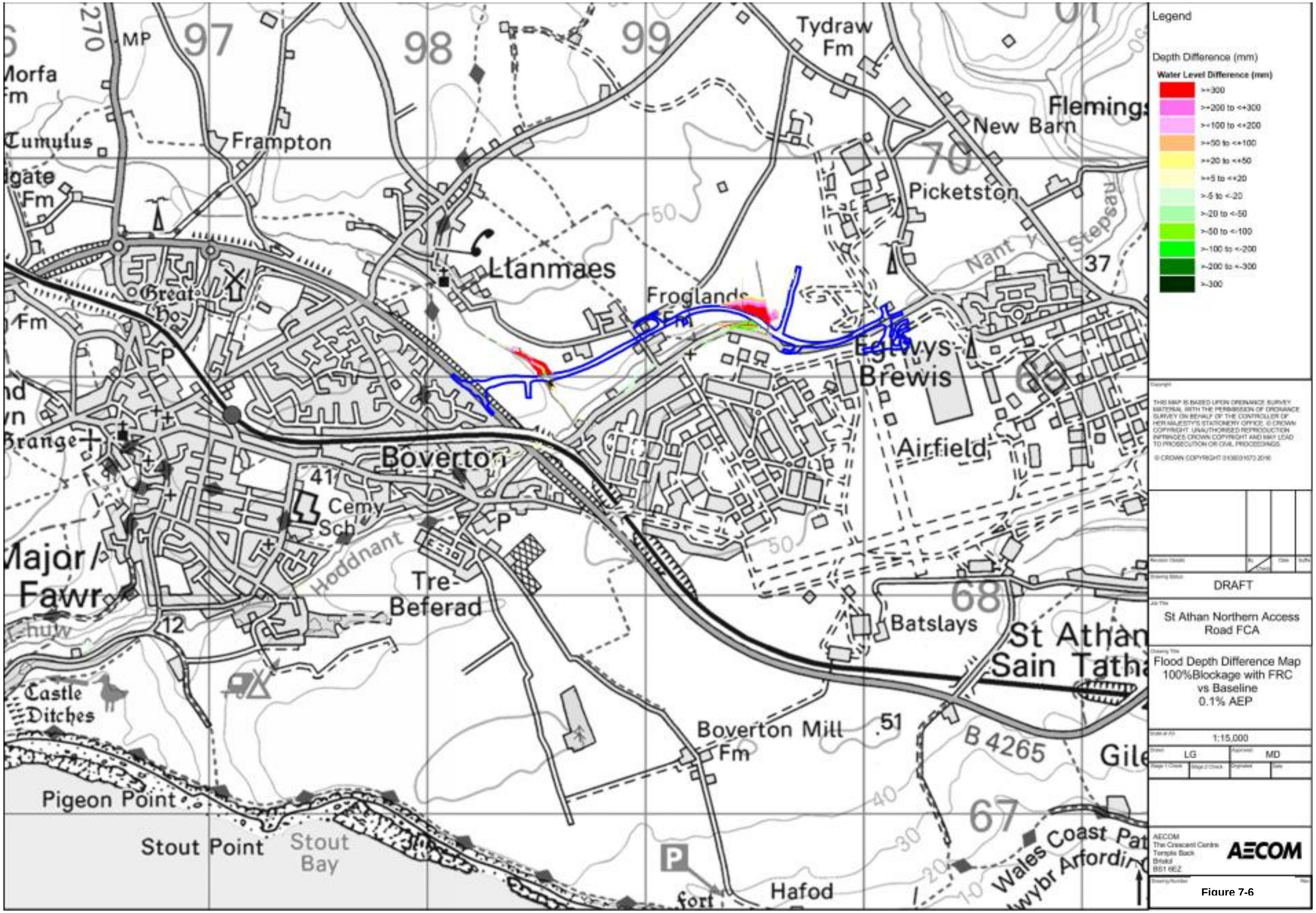


Figure 7-6 - Flood Depth Difference Map - 100% blockage scenario with Flood Relief Culverts vs Baseline 0.1% AEP

Flood Bunds Pluvial Mitigation Measures and Highways Drainage

It was decided that separate flood bunds are to be constructed to prevent long term hydrostatic pressure and softening of the NAR highway embankment. Modelling was completed to assess the impact of the flood bunds on storage volumes and downstream flows. The modelled flood bund locations are shown in green in Figure 7-7 . 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 start of the NAR.

Highways drainage storage areas and pluvial mitigation measures were also incorporated within the model at this stage. The location of these measures is shown in Figure 7-7. It should be noted that the drainage ditches shown in blue are pluvial mitigation measures.

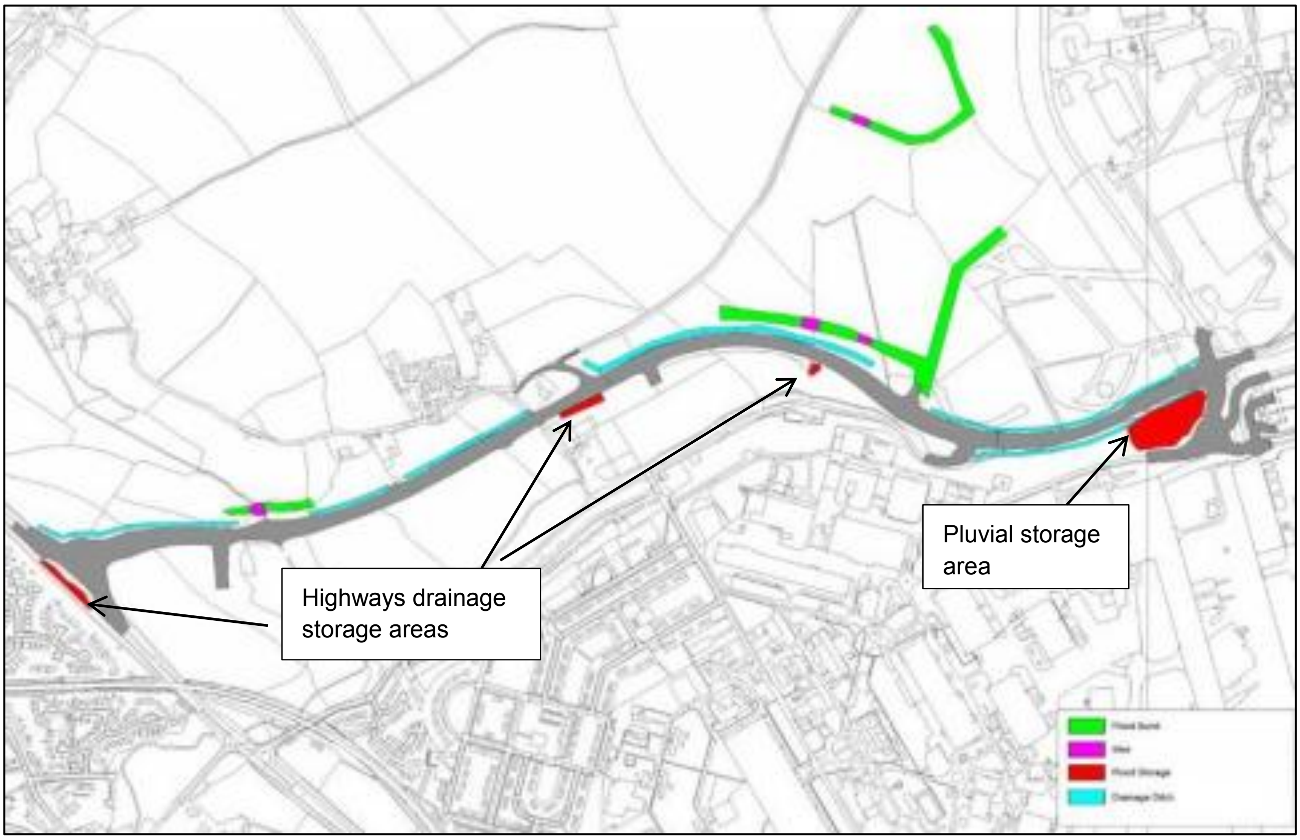


Figure 7-7- Modelled Flood Bund Locations

Flows and storage volumes in the pluvial model were found to be greater than those in the fluvial model, therefore these more conservative values were used in design of the flood bunds and overspill weirs. A second upstream storage area was found to be required at Boverton Brook as hydraulically, no solution could be reached where the storage bund is to be positioned further upstream of the NAR which maintains storage below 10,000m^3 during the 1000yr event (0.1%). This second storage area acts to slow the passage of overland flows and reduce downstream storage volumes.

The elevation of the flood bunds was set to the 1% AEP plus 30% climate change pluvial flood water elevations immediately upstream of the flood bunds plus 0.5m to allow for a freeboard. The culverts on both Llanmaes Brook and Boverton Brook were extended to the upstream face of the flood bunds to allow flow through the bunds and the NAR. An additional 1.25m diameter culvert was located in the upstream storage area at Boverton, this culvert outfalls to the existing ditch network.

The design of the flood bunds incorporates overspill weirs to allow overflow if the main culverts block. Details of the weir design process are included within Appendix E, Section 4.3.6.The flood relief culverts at Boverton are designed to also take surface water away from the area in between the bund and NAR in extreme pluvial events. Pluvial flood storage volumes for the 1% AEP plus climate change event dictated that the culvert on Boverton Brook was increased to 2m in diameter. The culvert on Llanmaes Brook was reduced to 1.40m by 1.40m.

The dimensions of the flood bunds modelled are shown in Table 7-4.

Table 7-4- Dimensions of Modelled 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	40.52	20.00
Boverton	44.15	2	42.65 and 42.78	22.00 and 30.00
Boverton Upstream	46.39	2	45.49	28.00

It can be seen in Figure 7-8 that the final proposed solution with flood bunds and smaller culverts decreases flood depths downstream in the 1% AEP plus 30% climate change event.

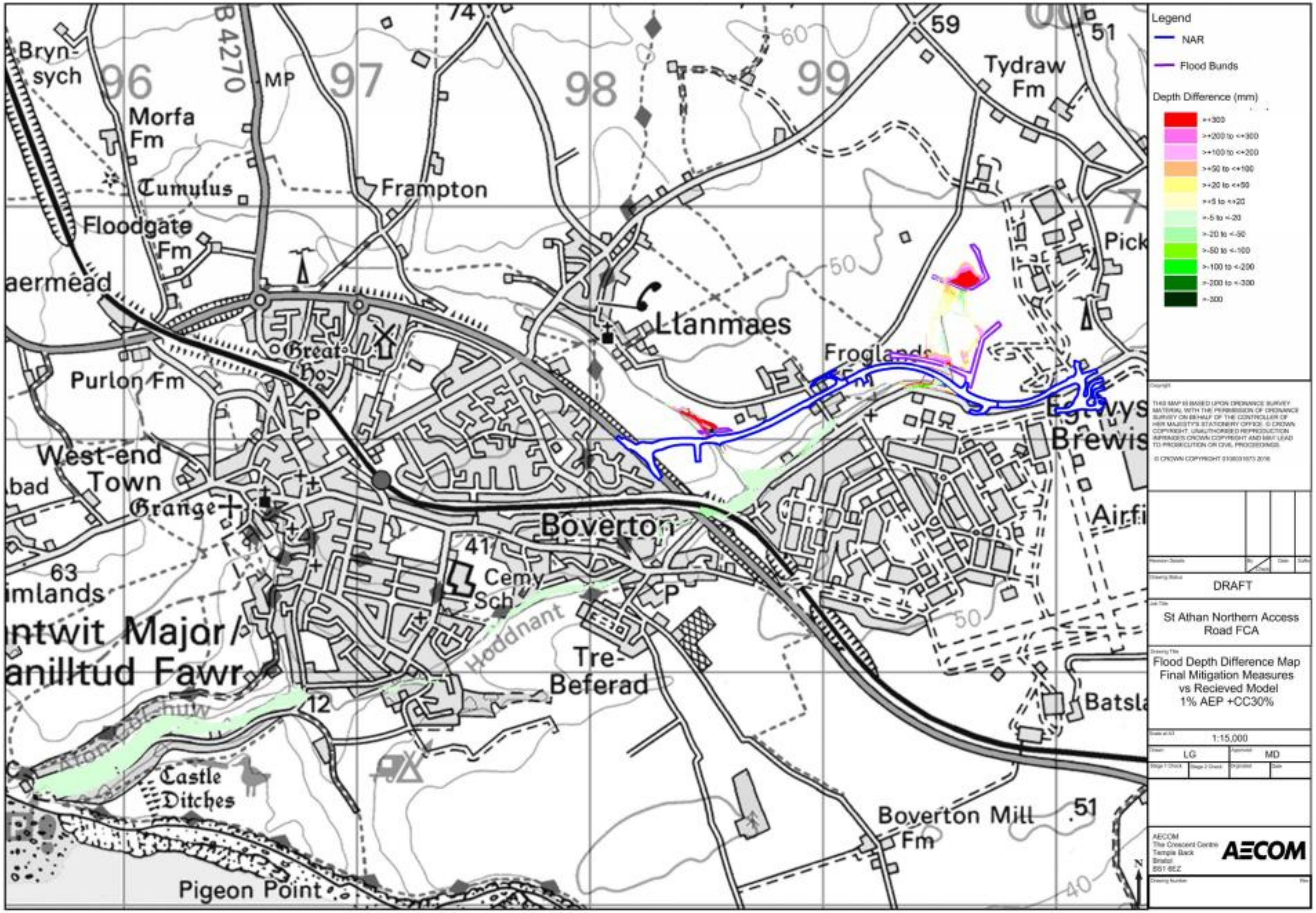


Figure 7-8- Flood Depth Difference Map Proposed Mitigation Measures with Flood Bunds, 1% AEP plus 30% climate change

Table 7-7-5 shows that downstream peak flows are reduced in all modelled scenarios, including blockage, and upstream storage volumes are less than 10,000m^3 in all events. The depth difference map for the 0.1% AEP event with 100% blockage of the upstream storage area culvert is shown in Figure 7-9. Depth difference maps for other scenarios are shown within Appendix E and F.

Table 7-7-5-Mitigation Measures with Flood Bunds, Upstream Storage Volumes and Downstream Flow

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

Figure 7-9 shows that 0.01m of detriment is observed around Froglands Farm, this detriment is away from buildings and is only observed for this event and blockage scenario. Iterations of higher flood weir elevations were modelled to try to remove this detriment, however, no solution could be found that kept the storage areas below 10,000m^3 in the pluvial model.

It should be noted that the required elevations of flood bunds and the overspill weirs are very sensitive to change in position of the bund. If the bund position requires moving at a later design stage, further modelling will be required to determine the overspill weir elevations.

Table 7-6 and Figure 10 in Appendix F show that even for lower flows the mitigation measures do not result in either the Llanmaes or Boverton Brook running dry more frequently. The invert level of the main culvert on Llanmaes Brook was raised from the upstream bed elevation to ensure that water pools upstream in all flow events. This is consistent with the current day scenario where there is a flow constriction at this point.

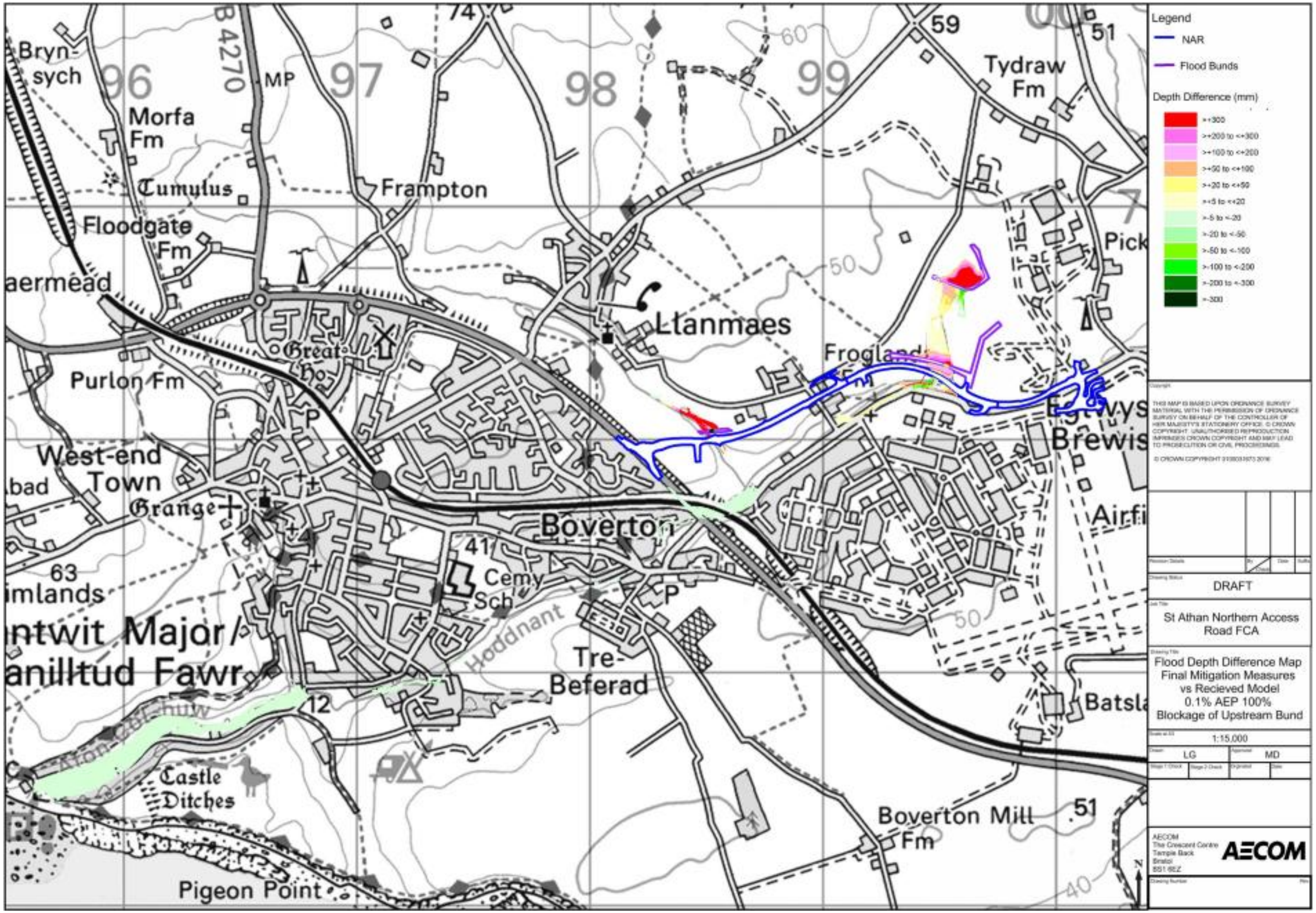


Figure 7-9- Flood Depth Difference Map, Flood Bunds vs Baseline, 0.1% AEP, 100% Blockage of Boverton Upstream Storage Area Culvert

7.5 Otter Passes

The presence of otters has been noted on both the Llanmaes and Boverton Brook. Otters are protected under UK and European law, in order to ensure the effects on otters are mitigated in the NAR design a series of otter ledges and underpasses are required.

The DMRB provides guidance in relation to nature conservation and otters[18]. Mitigation measures are needed to ensure the safe overland passage of otters during flood events. Key requirements are:

- Otter ledges should be provided within culverts, these should be at least 500mm wide, situated 150mm above the highest water level and allow for 600mm headroom;
- Underpasses should be constructed using a 600mm diameter cylindrical pipe up to a length of 20m, and in crossings that exceed 20m in length underpasses should be 900mm in diameter; and
- Underpasses should be located within 50m of the riverbank and above possible flood levels.

It is recommended that steps and hedges are used to encourage the passage of otters over the flood bunds in high flow incidences. Separate animal underpasses should be provided on both Llanmaes Brook and Boverton Brook, these should be positioned outside of the flood extents. This is a result of a lack of 0.75m of clearance and headroom in any of the culverts. The location of these underpasses is shown within Figure 7-10, where it can be seen that it they are located outside of the flood extents but less than 50m from the riverbank.

[18] Design Manual for Roads and Bridges, 1999. Volume 10 Environmental Design and Management, Section 4 Nature Conservation, Part 4 Nature Conservation Advice in Relation to Otters.
http://www.standardsforhighways.co.uk/ha/standards/dmrb/vol10/section4/ha8199.pdf

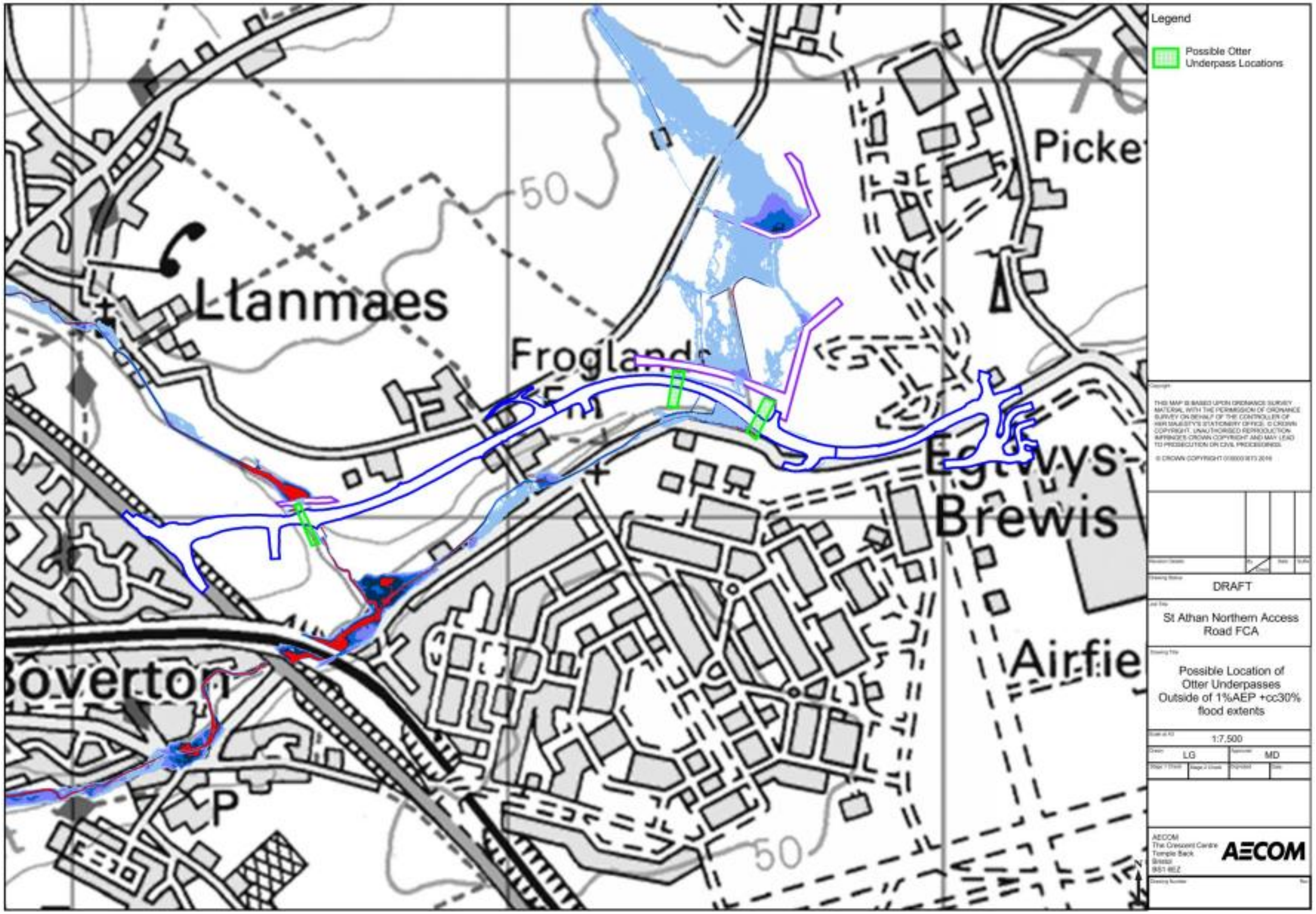


Figure 7-10-Possible Otter Underpass Locations

7.6 Fish Passage

Consultation with NRW has indicated that there has not been any monitoring of fish populations on the modelled watercourses. But based on habitat and location, there is a potential that the streams could be important for Elvers, Brown Trout, and potentially Salmon. Based on this it is proposed that the culvert designs will include provision for fish, with potential suggestions detailed below:

- Ensuring the invert level of the culverts are set so that they are not perched;
- baffles through the culverts to create deep water; and
- bristle substrate to allow the passage of elvers.

Where invert levels are set higher than upstream bed levels on Llanmaes Brook fish passes will be provided.

7.7 Fluvial Mitigation Measures Summary

Mitigation measures were designed to ensure:

- that the storage areas on Boverton Brook and Llanmaes Brook hold less than 10,000m^3 in a 1% AEP +CC30% event;
- that no additional water is discharged into the Nant-y-Stepsau as a result of construction of the proposed scheme;
- to ensure that the hydrograph downstream of the NAR scheme does not increase as a result of the development under the design events;
- to ensure that no overtopping of the road occurs during the 1% AEP+CC30% event; and
- to ensure that blockage of culverts does not result in an increase in flood depth.

In order to meet these criteria the following mitigation measures have been incorporated into the NAR design:

- 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 rook;
- 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 1; 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.

Figure 7-11 shows that with the proposed mitigation measures, the proposed scheme still provides downstream benefit for the 1%AEP plus 30% climate change event.

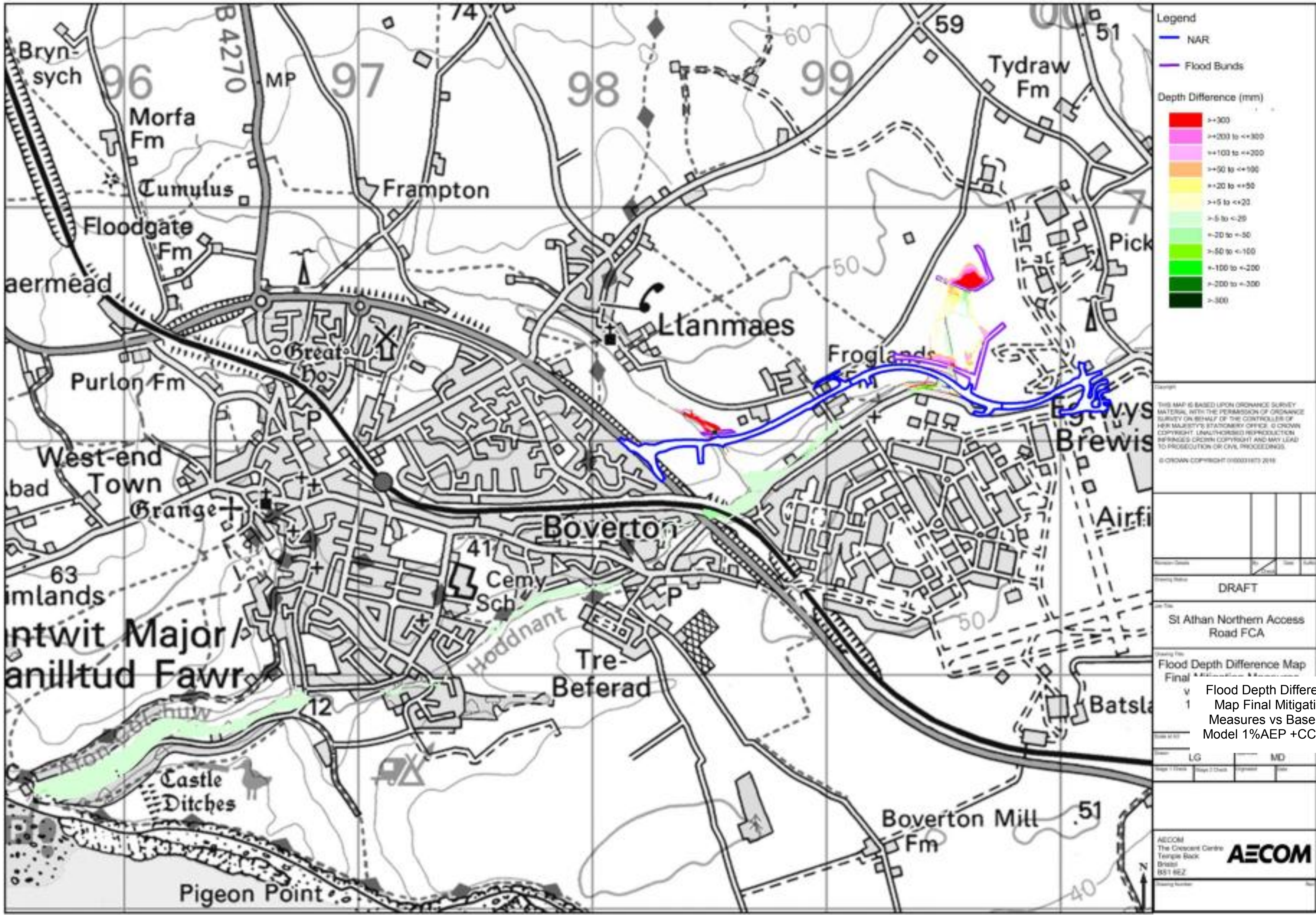


Figure 7-11 - Difference Map Final Mitigation Measures vs Baseline Model, 1% AEP plus 30% Climate Change

8. Conclusions

In flood risk terms, without appropriate mitigation measures in place the proposed scheme has the potential to increase impermeable surfacing (highway), present a constriction to existing watercourse flows (Llanmaes Brook and Boverton Brook crossings) and also compartmentalise existing surface water runoff conveyance routes throughout the catchment. Therefore pluvial and fluvial hydraulic modelling has been undertaken to assess the effects of the scheme on flood risk and possible mitigation measures to, and from, the proposed NAR scheme were assessed as follows:

- There is no risk of tidal flooding;
- The risk of fluvial flooding is considered to be medium to low. Hydraulic modelling including conceptual mitigation measures has been undertaken to investigate the impact of the NAR crossings at Boverton Brook and Llanmaes Brook, the loss of floodplain storage and potential impacts to third parties as a result of the proposed scheme;
- The risk of surface water flooding is considered to be medium. Hydraulic modelling including conceptual mitigation measures has been undertaken to investigate the impact of the NAR on overland flow routes, the loss of floodplain storage, and potential impacts to third parties as result of the proposed scheme;
- The risk of sewer flooding is considered to be negligible;
- The risk of groundwater flooding is considered to be low; and
- The risk of flooding from artificial sources is considered to be negligible.

Hydraulic modelling has been undertaken to assess the pluvial and fluvial flood risk posed to, and as a result of, the proposed scheme. The formation of a new baseline model was achieved by: extension of the received NRW ESTRY-TUFLOW model, by approximately 1km north and east; and updating the model to include the latest LiDAR (2014). Alterations to the DTM and networks were then made to incorporate the proposed scheme and mitigation measures.

Following the combination of the fluvial and pluvial models to analyse the impact of the proposed NAR on fluvial and surface water flood risk, the preliminary design of the NAR has been concluded. The proposed NAR crosses Boverton Brook, Llanmaes Brook and and intersects overland flow routes, including that to the Nant Y Stepsau. Flood modelling has demonstrated that without mitigation measures the NAR results in an increase in flood depth upstream of the proposed scheme resulting in large volumes of water stored on all three watercourses.

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 during 100% blockage scenarios, flood levels downstream of the proposed scheme are decreased 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, an area which has experienced flooding in the past, 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.

By incorporating the proposed flood mitigation measures, it has been shown through hydraulic modelling that:

- the proposed scheme is not at risk of flooding up to and including the 1% AEP + 75% Climate Change event. This is in excess of the 1% + 30% Climate Change event that NRW require the proposed scheme to be designed to demonstrating future resilience to large climate changes;
- the proposed scheme provides betterment downstream of the NAR and reduces flood depths and peak flows at Boverton and the properties at Froglands Farm. This demonstrates that the scheme provides overall benefit to flood risk in the area;

- there are no additional flows into the Nant y Stepsau watercourse as a result of the proposed scheme;
- all proposed flood storage areas have a volume less than 10,000m3 and therefore will not be classified as reservoirs under the requirements of the Flood and Water Management Act (2010); and
- the proposed scheme does not increase flood risk downstream during extreme blockage scenarios demonstrating that the scheme design is robust against failure of primary culverts.

As a result of a lack of data, the impact of the proposed VoGC flood relief scheme at Llanmaes on the NAR is unknown. The NAR has been designed to 1% AEP plus 30% climate change event flows, and the mitigation measures have been shown to meet the design criteria for the 1%AEP plus 75% climate change event. This is in excess of required 1% AEP plus 30% climate change event that NRW require the NAR scheme to be designed to. To assist the VoGC surface water flood alleviation scheme in Llanmaes and ensure that the proposed NAR mitigation measures operate effectively, it is recommended that the flows in Llanmaes Brook immediately downstream of Llanmaes Village should not exceed 8.5m^3/s during the 1% + 30% Climate Change allowance Annual Exceedance Probability Event (AEP). This is the maximum flow that the mitigation measures for the proposed NAR scheme have been designed for. It is also a recommendation that for consistency and continuity, that VoGC should look to update this version of the model once approved by NRW as part of this planning application.

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.

9. References

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Appendix A – Concept masterplan

Appendix B – Natural Resources Wales Correspondence

Appendix C – Site Walkover Photographs

Appendix D – Pluvial Modelling Technical Note

Appendix E – Fluvial Modelling Technical Note

Appendix F– Fluvial Modelling Flood Depth Maps

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