# Appendix C – Hydraulic Modelling Report

# Llanmaes
# Flood Alleviation Scheme
# Hydraulic Modelling Report

Vale of Glamorgan Council

Project Number: 60509148

April 2021

## Quality information

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## Revision History

| Revision | Revision date | Details | Authorized | Name | Position |
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| 1 | March 2018 | Hydraulic Modelling Report | For distribution to NRW and VoGC | Steve Cook | Associate Director |
| 2 | August 2018 | Draft Hydraulic Modelling Report | For distribution to NRW and VoGC | Mark Davin | Associate Director |
| 3 | November 2018 | Hydraulic Modelling Report | For distribution to NRW and VoGC | Mark Davin | Associate Director |
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| 5 | October 2019 | Hydraulic Modelling Report | For distribution to NRW and VoGC | Steve Cook | Associate Director |
| 6 | April 2021 | Hydraulic Modelling Report | For distribution to NRW and VoGC | Rob Sweet | Principal Consultant |

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# Table of Contents

## Figures

# Tables

# 1. Introduction

The village of Llanmaes is situated on the eastern bank of Llanmaes Brook, approximately 1km north-east of Boverton, Vale of Glamorgan, South Wales. A small, heavily modified unnamed watercourse, a tributary of Llanmaes Brook, flows from north east to south west through Llanmaes and forms the main drainage conveyance route for the residential area and surrounding agricultural land.

Historically, Llanmaes has regularly suffered from a series flood events caused by surface water runoff from the surrounding fields and becomes focused along highways and footpaths within Llanmaes. Once surface runoff reaches the village the unnamed watercourse does not have capacity to convey the water away resulting in flooding to highways and properties (Appendix A).

This report details the information relating to the Direct Rainfall Assessment (DRA) flood hydraulic modelling undertaken to confirm the effectiveness and suitability of a Flood Alleviation Scheme (FAS) at Llanmaes. By definition, any proposed FAS would aim to reduce flood risk within the village of Llanmaes whilst providing benefits to the wider catchment including the town of Boverton and the St Athan Northern Access Road (NAR) downstream, constructed in 2019 (Figure 1-1).

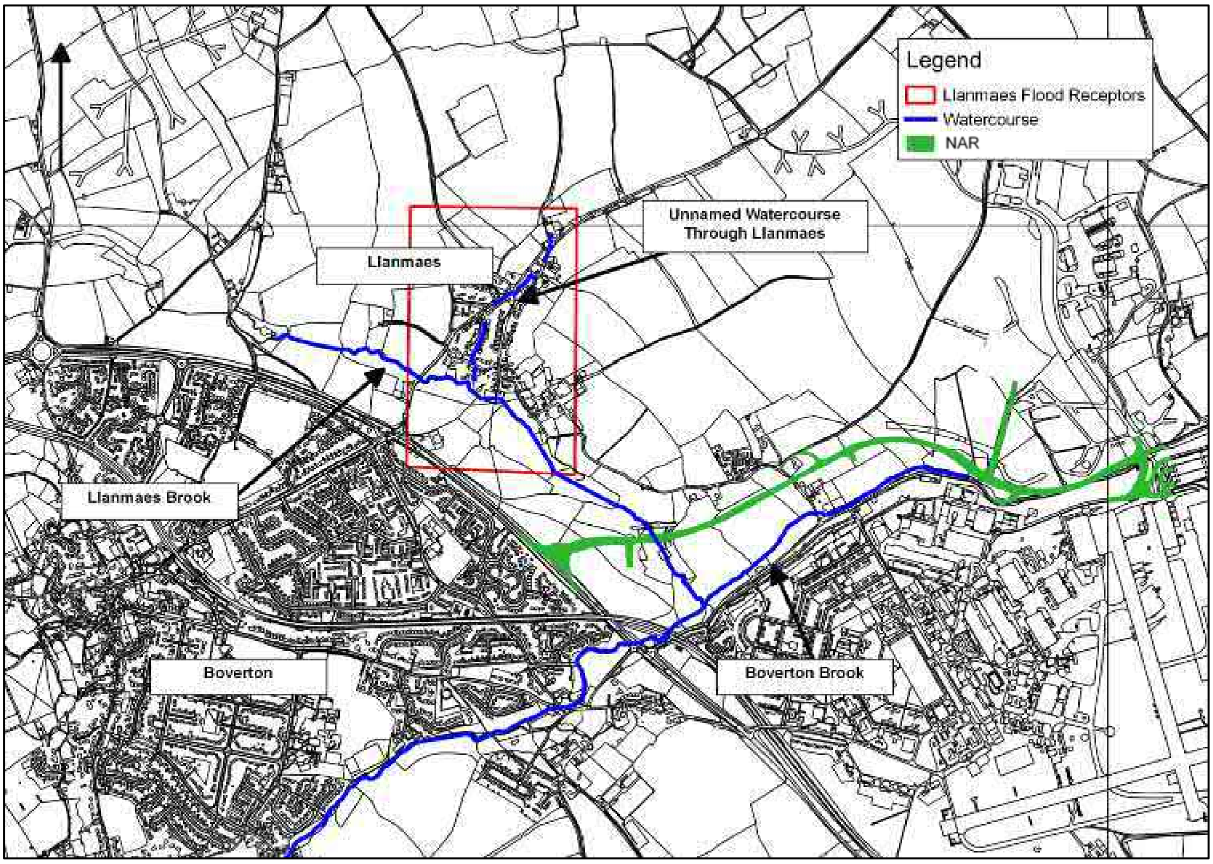

**Figure 1-1: Overview Map**

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## 1.1 Commission

Since 2004, Vale of Glamorgan Council (VoGC) has explored a number of options for the Llanmaes FAS through the production of a Pre-feasibility Study[1], Project Appraisal Report[2] (PAR) and Options Appraisal Report[3] (OAR). The aim of the process between the three studies was to develop a feasible and technically suitable option to take forward for construction which reduces flood risk to properties in Llanmaes, whilst providing no detriment to flooding downstream in Boverton via the Llanmaes Brook and Boverton Brook. Since production of the OAR, a preferred solution was highlighted but had not been proven through appraising any positive and negative impacts using a hydraulic model.

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[1] Vale of Glamorgan (2004) Pre-Feasibility Study – Llanmaes
[2] Martin Wright Associates (2009) Project Appraisal Report – Llanmaes Flood Alleviation Scheme
[3] Mott MacDonald (2014) Option Appraisal report – Llanmaes Flood Management Scheme

In order to progress the work completed during 2004-2014 by VoGC, AECOM were appointed by Welsh Government (WG) in May 2017 to appraise the solution determined in 2014 by the OAR, taking forward the most appropriate elements of this scheme and to develop a Proposed Option for the Llanmaes FAS.

This technical report appraises the OAR solution and also establishes the methodology for hydraulic modelling, inclusive of assumptions and results for the Proposed Option to support the planning application for the scheme.

## 1.2 Model Development

Following a meeting with NRW in July 2017[4] it was agreed that AECOM would adopt a revised Baseline hydraulic model representation under the assumption that the construction of the NAR and all associated flood mitigation measures has taken place. NRW were accepting of this approach. The NAR has now been constructed and therefore this approach remains consistent with current conditions.

AECOM have updated the NRW approved 2017 NAR ESTRY-TUFLOW hydraulic models (the NAR model) with additional site specific survey and topographic data supplied by VoGC to include the unnamed ordinary watercourse that flows through Llanmaes to create an updated Baseline model (Figure 1-1).

From a review of flood history at Llanmaes, it was clear that the primary mechanism for flooding throughout the village is from widely distributed overland flow in conjunction with the limited capacity of the unnamed watercourse through the village. The Proposed Option presented in this document relies heavily on the interception of flow within the upper catchment and re-routing of overland flow within Llanmaes village.

AECOM have applied professional judgment of experience within similar case studies, adopting a methodology inclusive of a direct rainfall (pluvial) model of the catchment contributing to Llanmaes village. It was determined that using more conventional fluvial based ‘point inflow’ hydraulic modelling through Llanmaes village, would not be representative of the real issues posed to the region and could therefore produce an unreliable estimation of flooding and resultant scheme taken forward.

Figure 1-2 demonstrates the up-catchment overland flow routes contributing to the routing of flow towards Llanmaes village. Based on the assessment of catchment flow paths which would not be suitably captured through point inflow fluvial modelling, the approach detailed above with respect to a DRA is considered representative of the flood mechanisms at Llanmaes, forming the basis of this study (Figure 1-3).

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[4] AECOM (2017) Llanmaes FAS – NRW revised Minutes 170707

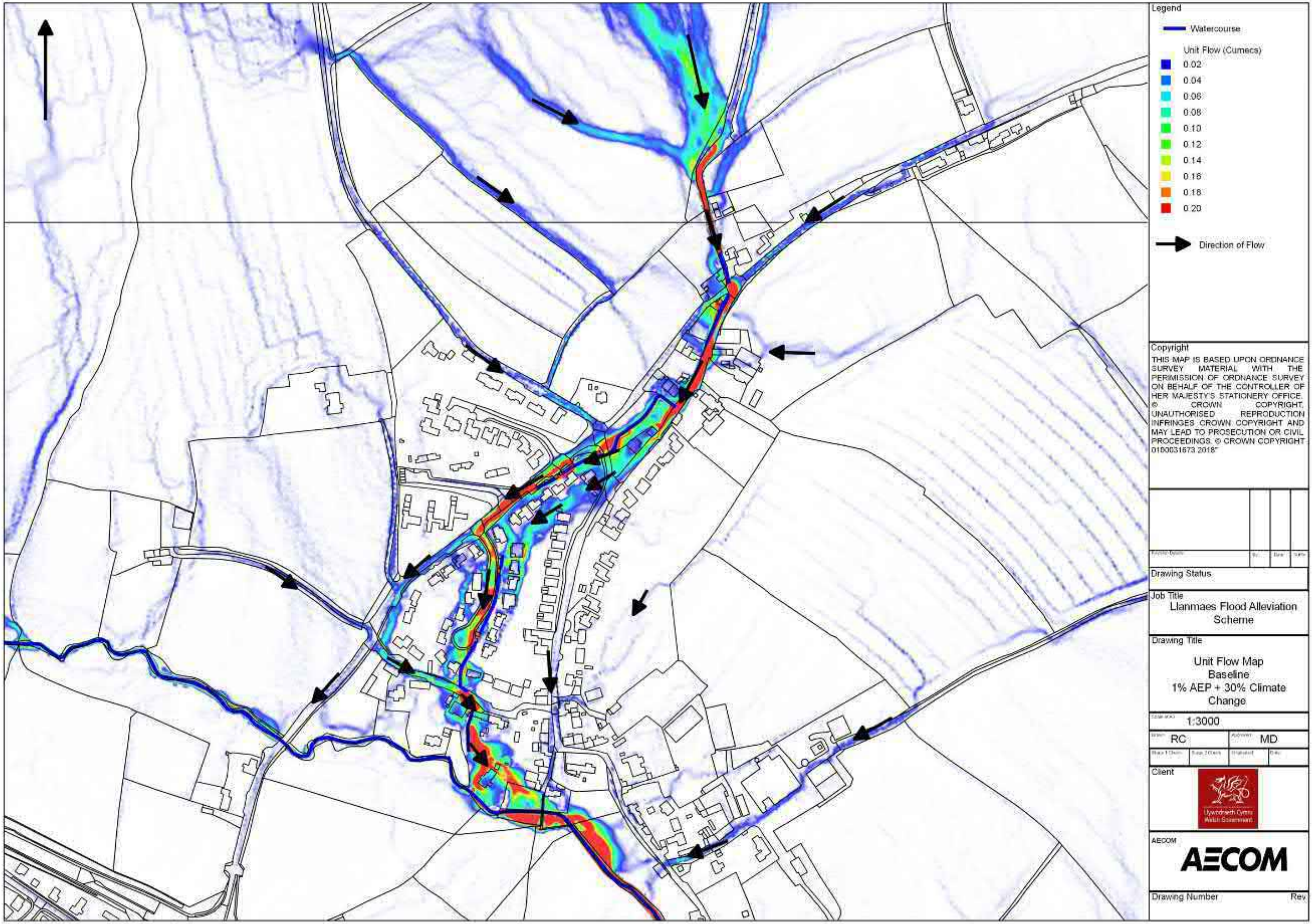

Figure 1-2: Baseline Flow Paths 1% AEP + 30%CC

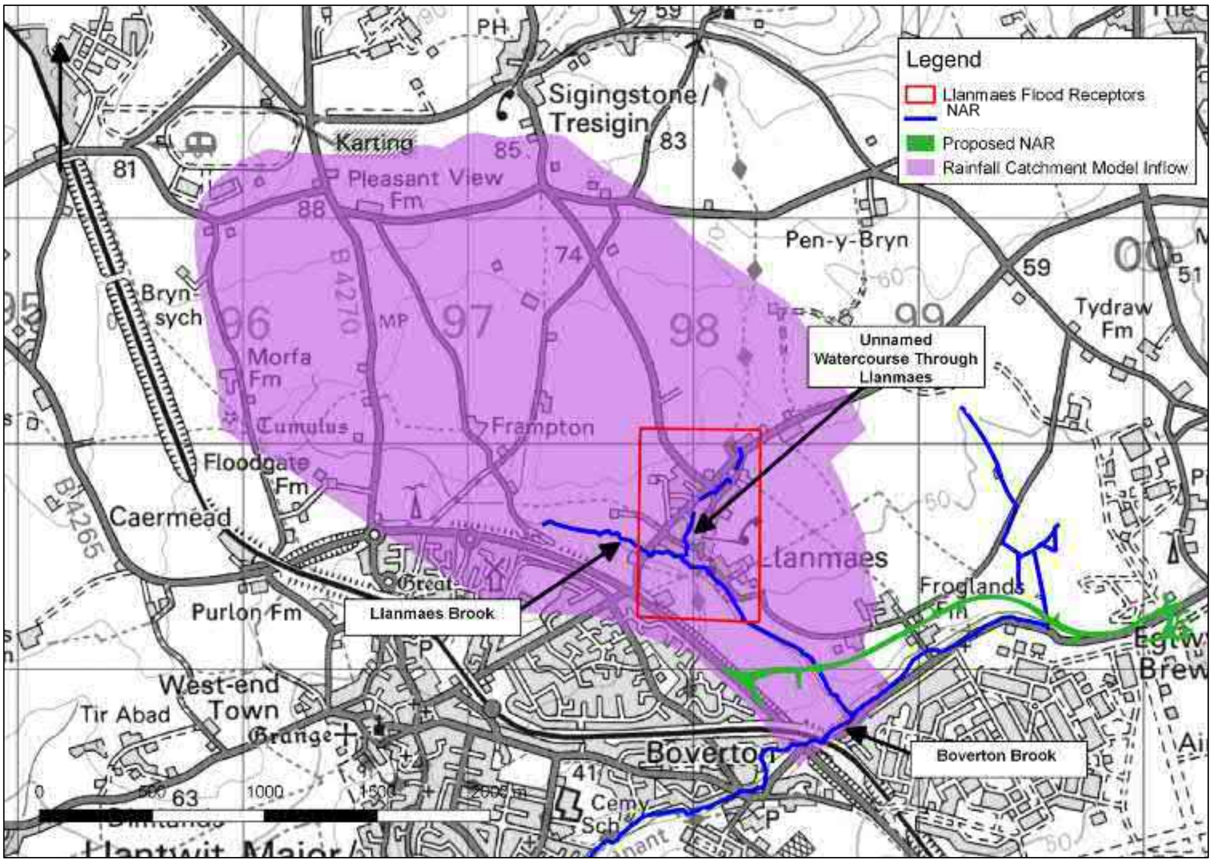

**Figure 1-3: Llanmaes FAS Model Extent**

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The pluvial representation of the Llanmaes village catchment has been developed sequentially as follows:

**1 - Baseline Model Update** – As outlined earlier in this section, appropriately set up the hydraulic model to represent the flood mechanisms in Llanmaes village. The Baseline model of the Llanmaes Brook pluvial catchment, at a grid resolution of 2m, was undertaken;

**2 - Baseline Scenario Modelling** - 20% Annual Exceedance Probability (AEP), 10% AEP, 5% AEP, 2% AEP, 1% AEP + 30% climate change, 1% AEP + 75% climate change and 0.1% AEP design events;

**3 - OAR Preferred Solution Appraisal** - The Baseline model was updated with the solution determined by the OAR (2014) to appraise its technical suitability, identifying where improvements could be made;

**4 - Llanmaes FAS Proposed Option** – Following appraisal of the OAR Preferred Solution (3), the Llanmaes FAS Proposed Option was developed in order to find scheme improvements, and to assess the impact on the flood risk in Llanmaes and further downstream at the NAR and Boverton. The results of this have been presented in the Llanmaes FAS Proposed Option report and reviewed by NRW for comments in July 2017 and December 2018. These comments have been taken forward into the detailed design stage; and

**5 – Llanmaes FAS Detailed Design Proposed Option** (Herein the Proposed Option) – Following development of the Llanmaes FAS Proposed Option with consultation with VoGC and NRW, AECOM were commissioned to carry out the detailed design of the Llanmaes FAS Proposed Option in 2019-2021. The model construction and model results from this stage are presented in this report.

## 1.3 Key Locations in Llanmaes

As the properties are not specifically numbered throughout Llanmaes, utilising road naming conventions, Figure 1-4 identifies key locations and house names throughout Llanmaes that are described further within this report.

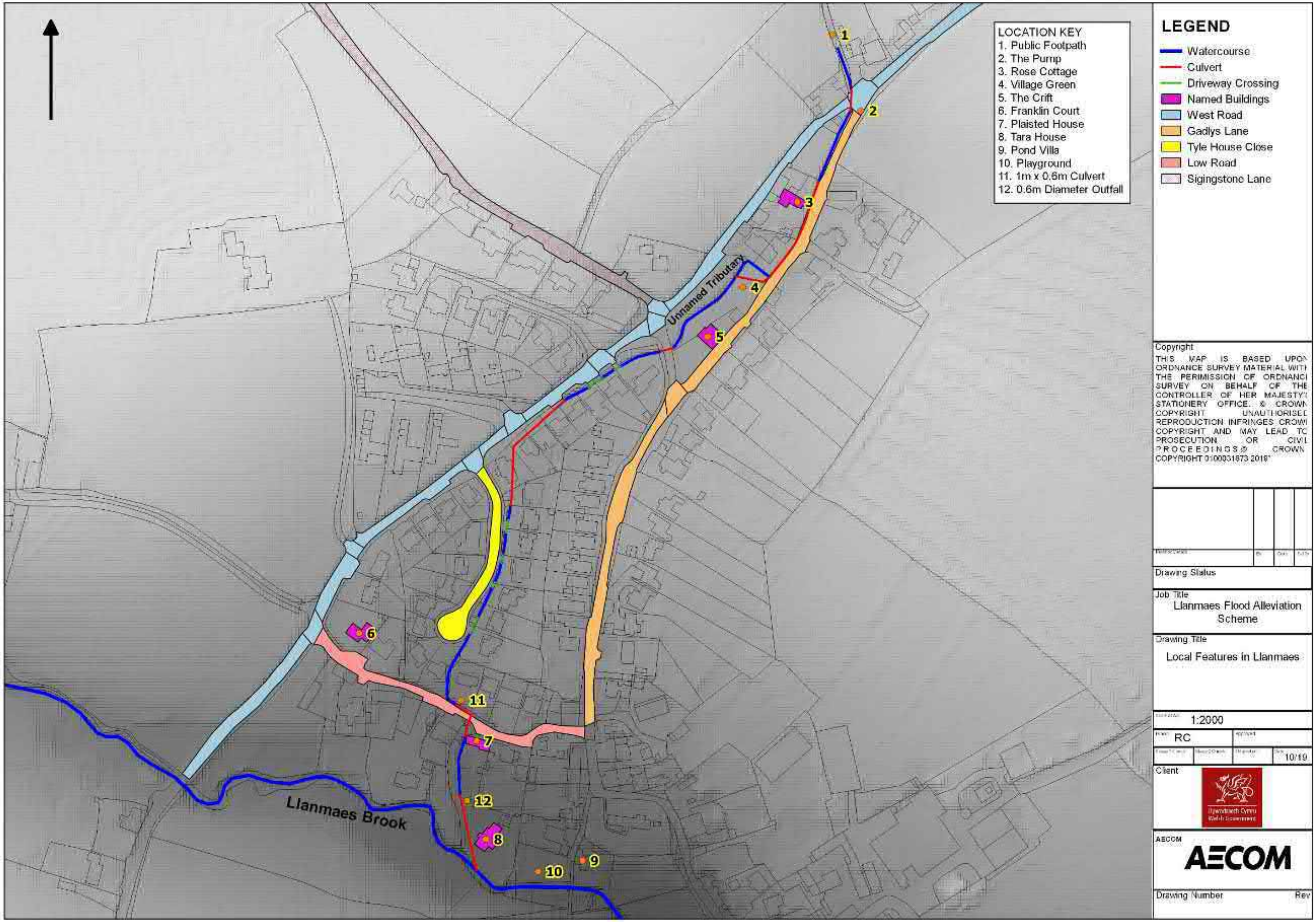

Figure 1-4: Key Locations in Llanmaes

# 2. Hydrological Analysis

## 2.1 Overview

It was agreed with NRW at the outset of this project that to maintain consistency with the existing NAR hydraulic model, the pluvial inflows to the model would remain unchanged. The methodology for the development is outlined in Section 2.2 to Section 2.4. The key characteristics of this contributing catchment are:

- The rural catchment has a surface percentage runoff of 30% and as such all rainfall hydrographs have been reduced by 70% to account for infiltration within the catchment. A sensitivity analysis has been carried out on the percentage runoff and is described in Section 7.3;
- The rainfall catchment is defined as the area contributing to flows within Llanmaes Brook to the confluence with Boverton Brook (Figure 1-3); and,
- Climate Change Allowances for the Central Estimate (30%) and Upper Estimate (75%) scenarios have been applied to the 1% AEP rainfall hydrograph. This is to maintain consistency with the NAR model and provide an appropriate and comparative estimate of flows within the catchment.

## 2.2 Rainfall Analysis

To provide rainfall inputs into the pluvial model, a hydrological analysis was undertaken for the Boverton Brook catchment in line with the St Athan NAR Flood Consequence Assessment (FCA)[5]. Flood Estimation Handbook (FEH) catchment descriptors were downloaded for the Boverton Brook catchment from the FEH Service website. In line with the scope of works, design rainfall profiles were generated for events with an Annual Exceedance Probability (AEP) of 20%, 10%, 5%, 2%, 1%, 1% + 30% climate change, 1% + 75% climate change and 0.1% using the Microdrainage software package. For each AEP, hyetographs were created for storms with durations of 60, 180 and 360 minutes with a winter profile.

Climate change allowances were taken from the Welsh Government 2016[6] guidance for FCAs. Boverton Brook and Llanmaes Brook are located within the Western Wales river basin district, the central estimate of potential change to peak river flows is 30% for this region, and the upper end estimate is 75%. It was agreed with NRW that the central estimate should be used.

## 2.3 Critical Storm Duration

An assessment of Critical Storm Duration was performed during the October 2016 preliminary DRA[7]. The critical duration is defined as the duration that gives the largest flow at the site of interest. Accordingly, the preliminary DRA was used to simulate the 60, 180 and 360 minute duration storms for the 1% AEP design rainfall event, including +30% for climate change. This model also included for no representation of infiltration or runoff coefficients to provide a worse case, fully saturated ground conditions throughout the catchment. A comparison of flood extent outlines demonstrated that the 60 minute storm duration was associated with the largest extent/depth of inundation and should be considered as the critical storm duration for this study.

## 2.4 Infiltration Losses

In order to calculate effective rainfall for application within a pluvial hydraulic model, it is necessary to account for losses attributable to infiltration and the capacity of the surface water drainage network within the catchment. Analysis of satellite imagery and land cover information within GIS demonstrated that the Boverton Brook catchment comprised of 95% undeveloped land, with less than 5% of the modelled area being characterised by impermeable surfaces. Therefore the approach adopted assumed that all losses within the model domain were attributable to infiltration. Due to the rural nature of the modelled catchment, losses due to surface water drainage network were not represented.

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[5] AECOM 2017 St.Athan Northern Access Road Flood Consequence Assessment

[6] 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.

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

Following the preliminary investigation in October 2016 by AECOM, a runoff coefficient of 0.3 was selected based upon comparison of total rainfall volume and total runoff volume for the Boverton Brook catchment, calculated using the Revitalised Flood Hydrograph 2 (ReFH2) rainfall-runoff model. This analysis showed that approximately 30% of total rainfall contributed to surface runoff over the full storm duration. An example of the application of this runoff coefficient is shown within Figure 2-1, which shows total rainfall depth for the 1 % AEP plus 30% climate change design event (60 minute storm duration), the depth of water lost to infiltration, and the resulting surface water runoff applied to the model domain. This same method was used to assess the runoff coefficient for the extended Boverton Brook catchment and confirmed to be consistent with the wider catchment.

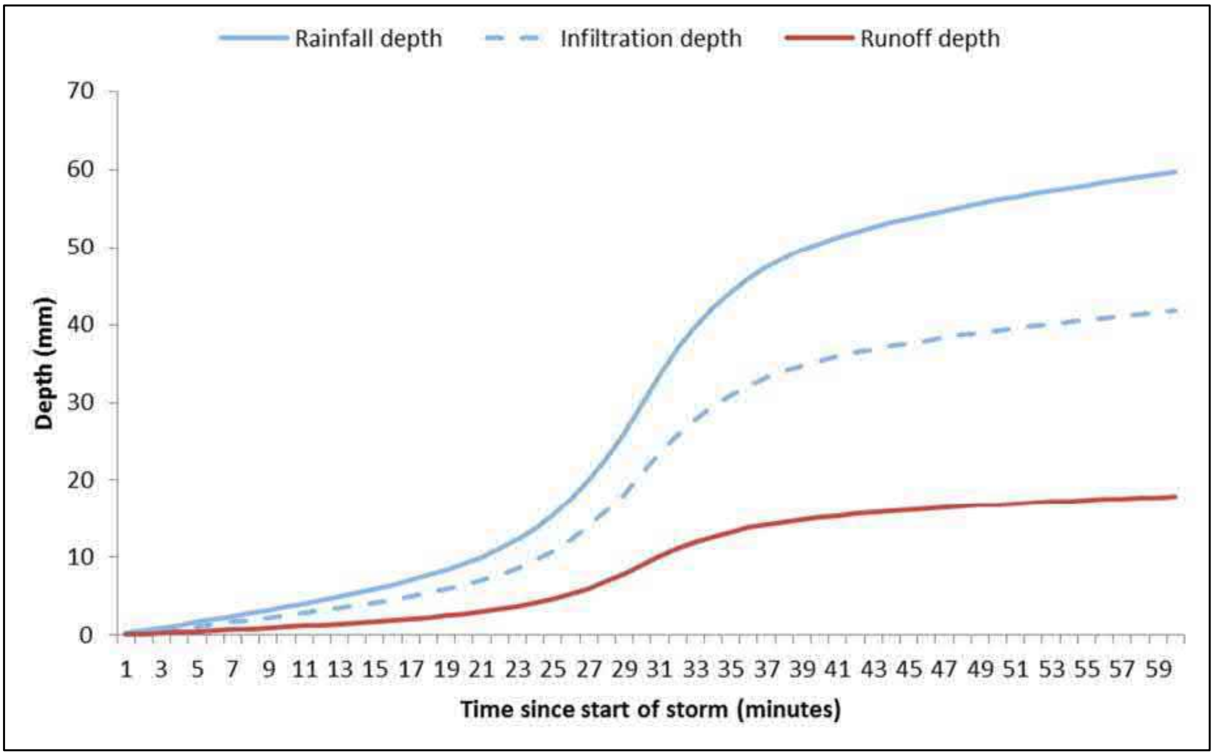

**Figure 2-1: Calculation of the depth of surface runoff applied to TUFLOW domain through application of a runoff coefficient of 0.3 in order to account for infiltration (1% AEP plus 30%CC, 60min storm duration)**

The Entec 2009 FCA[8] report indicates that the SPRHOST was adjusted from 11.7% (FEH CD value) to an SPR of 31.7%, based on the investigations into percentage runoff undertaken, which indicated a higher level of percentage runoff. This higher rate agrees with coefficients calculated as part of this investigation.

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

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[8] ENTEC 2009 St Athan Flood Consequence Assessment

# 3. Baseline Scenario

A direct rainfall hydraulic model was developed by updating the NAR model with a representation of the unnamed watercourse through Llanmaes and associated topography within the village. This section describes the existing NAR model and the updates made during this study.

## 3.1 Available Model at Outset of Study - NAR Model

Between September 2016 and May 2017, AECOM updated and extended the NRW Boverton Brook ESTRY-TUFLOW model to include the St. Athan NAR scheme. The purpose of this model was to extend the hydraulic representation of the Boverton Brook, include the NAR scheme and develop flood mitigation measures to support the FCA for planning. The final flood mitigation measures included flood storage areas on Llanmaes Brook and Boverton Brook and a series of overland flood storage areas, ditches and flood relief culverts. A detailed appraisal of the pluvial and fluvial model development can be found in the 2017 St Athan FCA[9].

Figure 3-1 shows the model extents of the AECOM pluvial and fluvial NAR model. It was agreed with NRW in 2017, that for the purposes of determining the effectiveness of a FAS at Llanmaes, the proposed NAR scheme and associated flood mitigations measures downstream of Llanmaes should be assumed as having been constructed. The NAR scheme was constructed as per the design in 2019 and therefore the representation in the hydraulic model is valid.

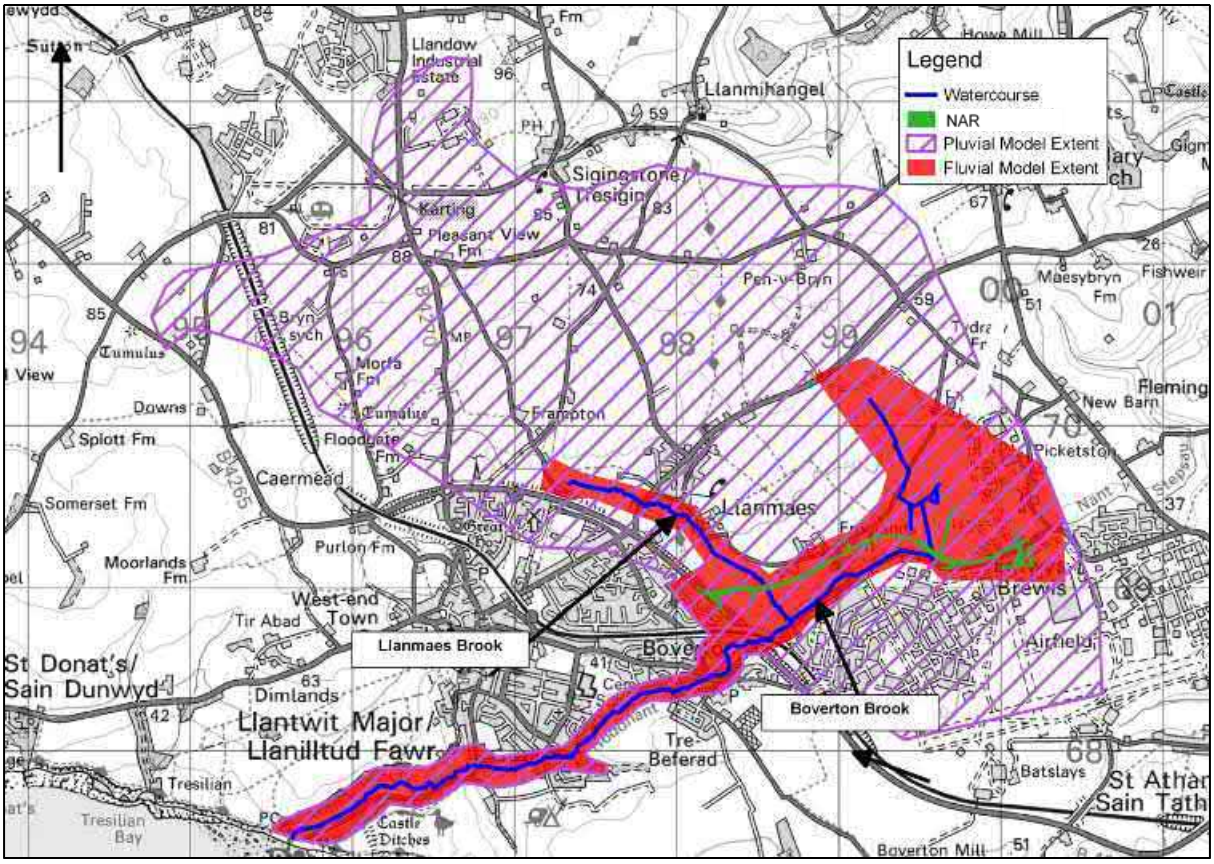

**Figure 3-1: NAR Model Extents (Fluvial and Pluvial)**

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## 3.2 Updated Baseline Model - Llanmaes Model Extents

Within the NAR model, the unnamed watercourse within Llanmaes was not explicitly represented and as such, this was surveyed and added to the NAR model to improve the Baseline model representation of water conveyance within the village (Figure 1-3).

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[9] AECOM 2017 – St. Athan Northern Access Road Flood Consequence Assessment

This included the representation of approximately 600m of small heavily modified channels and culverts upstream of the confluence with Llanmaes Brook.

The improved representation of the unnamed watercourse included the addition of:

- 35 cross-sections;
- 13 culverted reaches; and,
- 6 bridge structures.

The rainfall catchment (2d_rf layer) was reduced from the NAR model to include only the Llanmaes Brook catchment which covers an area of approximately 5.2km$^2$. The rainfall catchment is shown within Figure 1-3 and is considered to be hydrologically representative of the total contributing area for overland flow entering Llanmaes Brook. This rainfall catchment defines the Llanmaes FAS study area and has allowed for an assessment of pluvial flows within the Llanmaes Brook catchment.

The existing surface water sewer network has not been included within the Baseline model and it is assumed that there is no capacity within the surface water network during any model simulation or design event. This approach is considered to be conservative as the design capacity of the surface water sewer network is unknown at the time of this study.

## 3.3 Manning's Roughness Coefficients

The NAR model is considered by NRW to have acceptable Manning's Roughness Coefficient throughout the 1D and 2D domains. As such, to maintain consistency between the Llanmaes FAS model and existing NAR model, the specified roughness coefficients have been retained (Table 3-1).

**Table 3-1: Manning's Roughness Coefficients**

| 1D or 2D Representation | Surface Type | Manning's Roughness Coefficient |
|---|---|---|
| 2D | Roadside/ Pavement | 0.02 |
| 2D | Road | 0.02 |
| 2D | Mixed Vegetation (Dense) | 0.08 |
| 2D | Building | 0.3 |
| 2D | Natural Surface (Urban) | 0.04 |
| 2D | Manmade Surface | 0.017 |
| 2D | Stability Patches | 0.1 |
| 1D | Channel cross-sections (Stonework) | 0.018 |
| 1D | Channel Cross Sections (Grass) | 0.041 |

A site visit was undertaken in June 2017 to validate available survey information and to explore flood mitigation options in Llanmaes. During the site visit it was observed that the unnamed watercourse that flows through Llanmaes is predominantly a heavily modified rectangular stonework channel (Figure 3-2). As such, a Manning's Roughness Coefficient of 0.018 was used for the channel which is consistent with values used in the existing NAR model. Small sections of the unnamed watercourse have a natural grassed channel, like at the Village Green (Figure 3-3), where a Manning's Roughness Coefficient of 0.041 was used for the channel.

Figure 3-2: Indicative Rectangular Stonework Channel

(Manning's Roughness Coefficient of 0.018)

Figure 3-3: Channel Cross Section Through the Village Green at Llanmaes

(Manning's Roughness Coefficient of 0.041)

Due to model instability within the Baseline and Proposed Options model in the 1D domain, the roughness coefficient of the channel had to be increased to from 0.018 to 0.03 at seven cross sections from L_FAS_033 to L_FAS_047. These seven cross sections represent an approximate chainage of 69m with the location of the adjusted cross sections shown in Figure 3-4. At this location the watercourse channel elevation drops from 49.4m AOD to 48.49m AOD before entering a culvert beneath Low Road. This causes an increase and then a fast decrease in conveyance within the 1D channel due to the constriction at the culvert. Through the modelling process it was found that this caused the model to become unstable. A series of attempts were made to resolve the stability issues including 2D stability patches, narrowing the 1D cross sections and raising the culvert invert level.

It was found however that increasing the roughness within the channel was the only method that would allow the model to simulate for all design events. The attempts made to improve the instability within the hydraulic model are fully documented within the supplied Model Log.

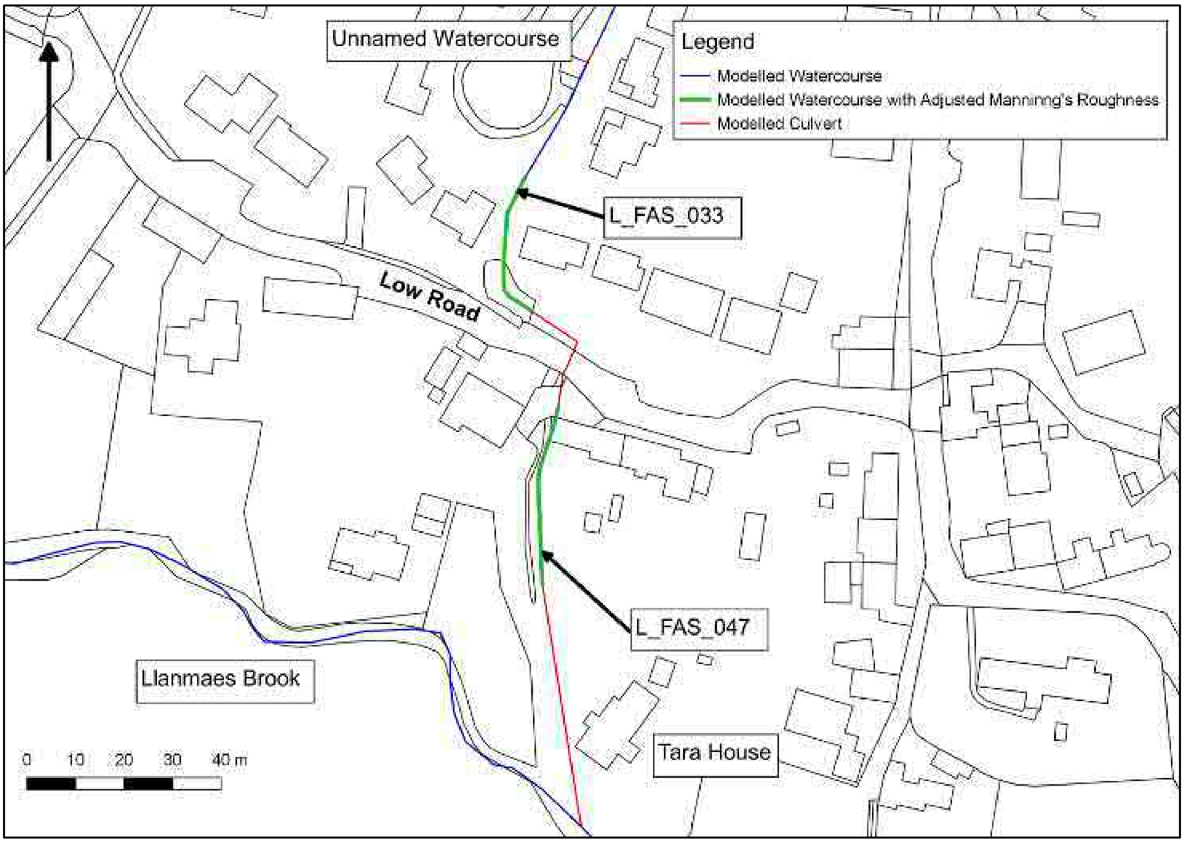

**Figure 3-4: Location of cross sections with adjusted Manning's Roughness Coefficient values**

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Buildings have been represented using a combination of a high Manning's Roughness Coefficient of 0.3 and adjustment of the LiDAR DTM using a threshold survey carried out by VoGC in February 2018 (Section 3.4). The Manning's Roughness Coefficient has been used to maintain consistency with the NAR model building representation. A sensitivity analysis has also been carried out to represent the buildings using only a Manning's Roughness Coefficient of 0.3, excluding the DTM adjustment, to assess the impact on the number of properties classified as being at risk of flooding.

## 3.4 Topography

The NAR model utilises 2m resolution LiDAR data from 2014 and following a review of online sources it was confirmed that no more recent LiDAR data is available for this study. Therefore, the 2014 2m LiDAR is considered to be the most up to date data and as such has been taken forward for the Llanmaes FAS study where no other site specific topographic survey has been provided.

A gap in the LiDAR data was identified in the upper Boverton Brook catchment during the NAR model[10] build and was rectified using an approximation to Ordnance Survey 50k contour mapping. To try and improve this representation in the Llanmaes FAS study in this area, 5m resolution Photogrammetry data was acquired and applied to the missing LiDAR DTM area. However, due to the low degree of vertical accuracy associated with the photogrammetry data when compared to the LIDAR DTM (up to +/-1.50m for Photogrammetry compared to up to +/-0.15m for LiDAR) it was found that an unacceptable topographic 'step' was created where the datasets intersected. This resulted in ponding in the upper catchment and a potential reduction in volume of water entering the Llanmaes Brook catchment. To resolve this, a conservative approach has been taken by creating a 2D topographic patch that directs all water from the area of missing LiDAR into the Llanmaes Brook catchment (Figure 3-5).

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[10] AECOM 2017 – St. Athan Northern Access Road Flood Consequence Assessment – Appendix D

It is noted that the contributing catchment has been extended beyond the expected Llanmaes Brook watershed and does not include a raised highway that could potentially hold back water. Given the small area of the Llanmaes Brook catchment that is affected by the missing LiDAR DTM data (approximately 0.025km$^2$) it is considered that this conservative approach provides a suitable representation of the upper Llanmaes Brook catchment.

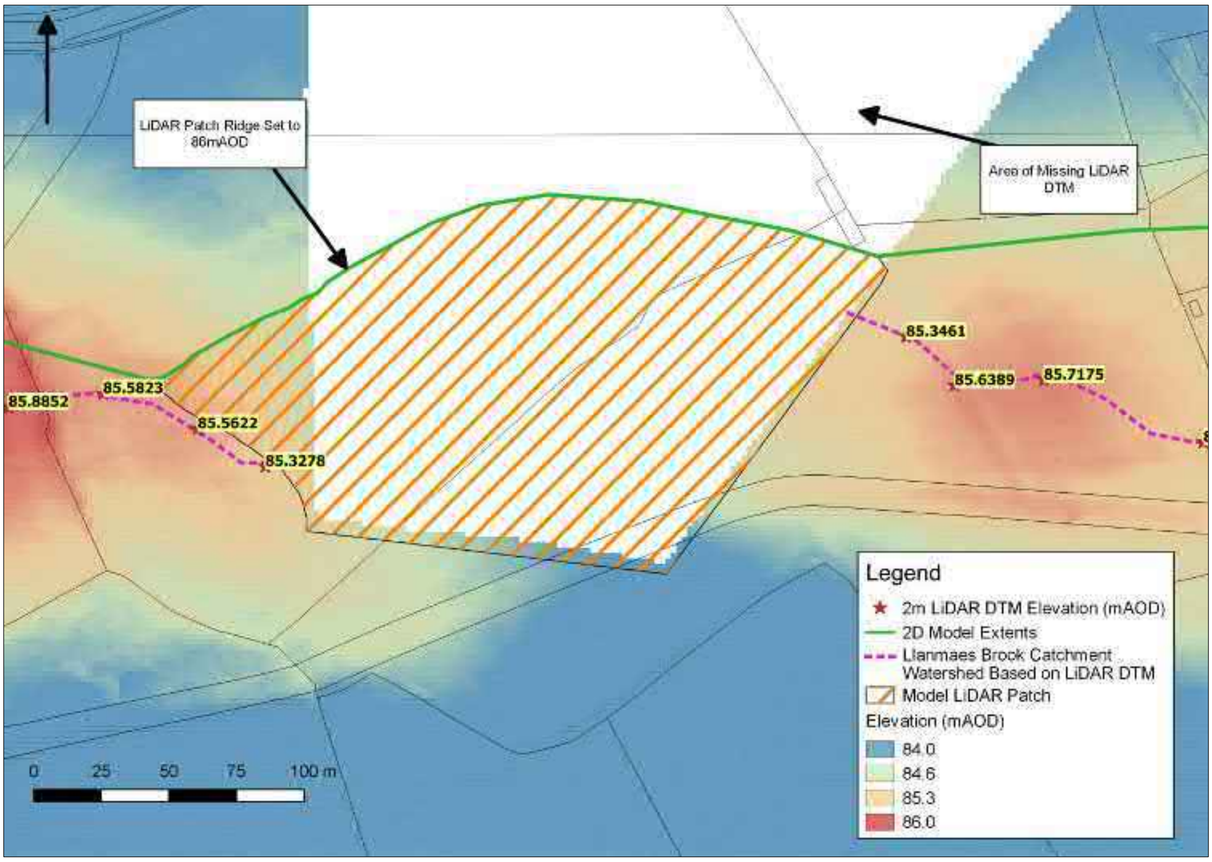

Figure 3-5: Location of Missing LiDAR DTM

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Prior to this study, Alzimuth Land Surveys Limited were commissioned in February 2013 by VoGC to undertake a topographic survey of the unnamed watercourse through Llanmaes. This survey was made available to AECOM by VoGC and ground truthing of this survey was also carried out in June 2017. It was determined that the unnamed watercourse is unlikely to have changed since 2013 and that the existing survey was suitable for use once the levels were compared and verified.

It is noted that the channel width of the unnamed watercourse is generally small (approximately 1m wide) throughout the village. This is less than the 2m grid cell size used within the model (Section 3.6) and therefore the 1D channel cross sections have been extended to provide a minimum of 2 grid cells width (4m) to prevent stability issues within the model. Figure 3-6 shows a typical cross section of the narrow unnamed watercourse through Llanmaes, demonstrating the requirement to extend the cross sections to beyond the channel banks to support best practice model build channel width assumptions allowing for more accurate transference of flood water between the 1D and 2D domains.

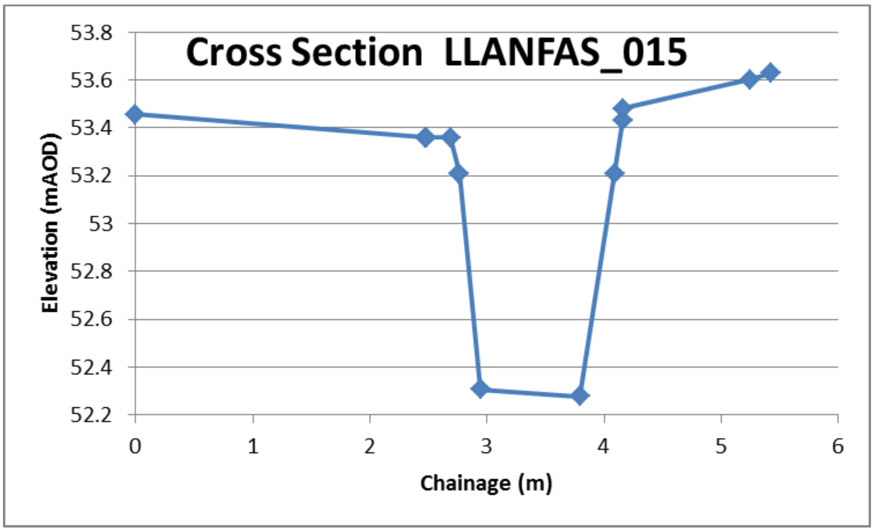


**Figure 3-6: Typical Channel Cross Section Through Llanmaes**

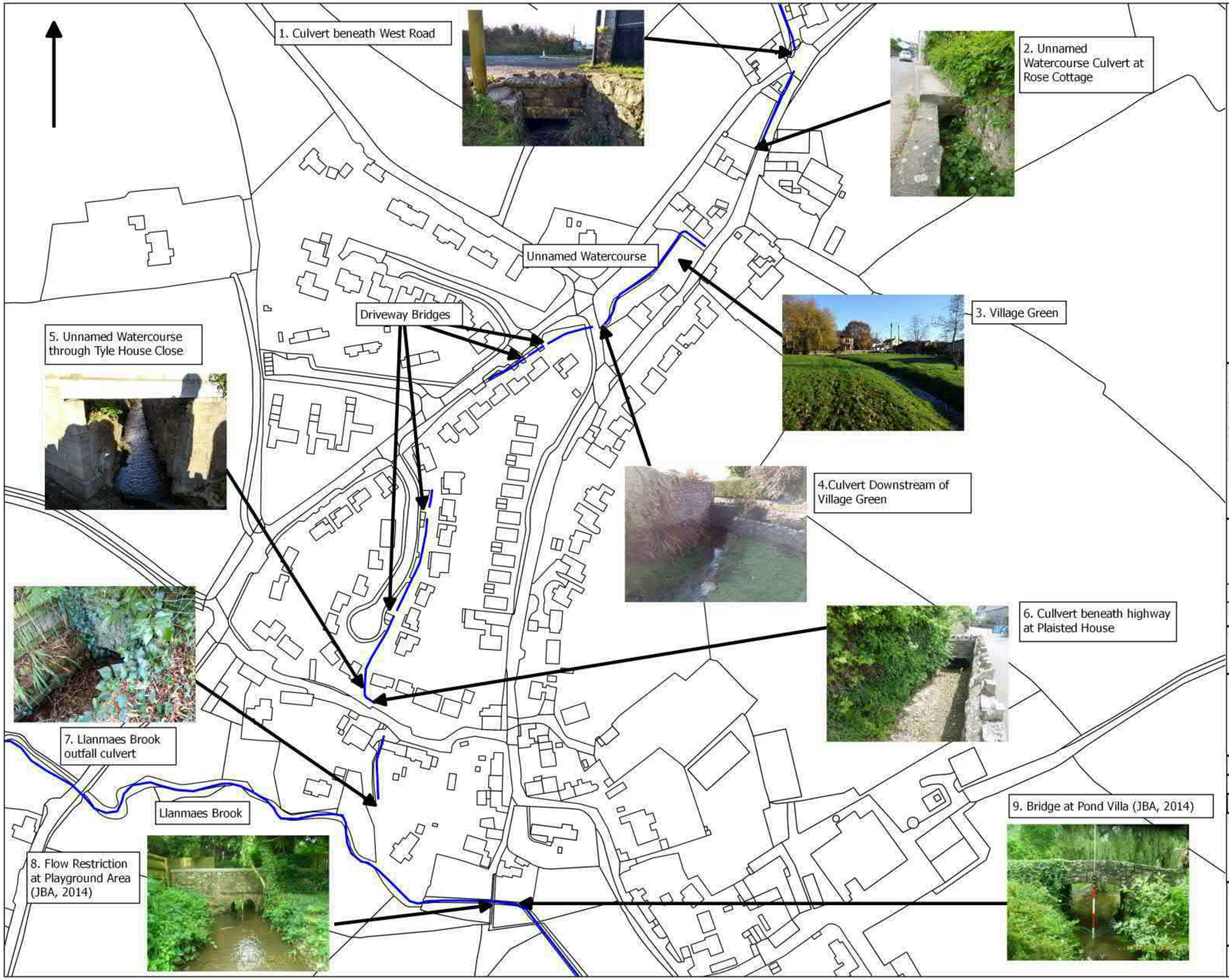
Immediately upstream of The Croft within the Village Green, VoGC installed improved highways drainage and a swale in 2015. Design drawings for the swale and associated drainage were incorporated into the Llanmaes FAS Baseline model (VoGC Project Number 1984, Drawing Number 1) and are provided with this modelling report.

A full topographic survey of highways within Llanmaes was undertaken in conjunction with the threshold survey highlighted in Section 3.3 in February 2018. This information has been used to improve the representation of the highways through the village and public footpath upstream of Llanmaes. It is noted that a threshold survey was not carried out for all properties in Llanmaes and only those identified to be at risk during this study were surveyed to expedite the process of this study.

Following the commission of detailed design for the scheme in 2019 further site specific topographic survey was acquired along Sigingstone Road, West Road and within agricultural fields to the north of the village. Topographic survey was used to improve the representation along key areas of the scheme and included as raster layers within the hydraulic model. It is noted that the 2018 topographic survey was maintained for the representation of West Road and the public footpath upstream of Llanmaes in the Baseline model as it was considered more complete and no significant topographic changes had occurred within the area between the two surveys.

## 3.5 Modelling of Structures

A number of structures were identified during the cross-sectional survey of the unnamed watercourse through Llanmaes in February 2013. Further to this, VoGC also carried out CCTV surveys of all culverts and drainage throughout Llanmaes in November 2015. This was used to inform culvert sizes and inverts as part of this study. Figure 3-7 shows the location of the key existing hydraulic structures within Llanmaes. It is noted that the unnamed watercourse through Llanmaes passes beneath a number of driveways and footbridges for very small distances along West Road and Tyle House Close. Due to the small length of the structures (typically between 2-3m) and/or double driveways with short reaches of open channel between them, only the most hydraulically significant constrictions were chosen to be represented so as to improve model stability. Table 3-2 reports the structures that were omitted from the model and reasons for why they were not included. A full list of structures included in the model is supplied with the Model Log.



Legend

— Watercourse

Structures Photo 8 and 9 are from JBA 2014, Boverton Brook Flood Study, Model User Report

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| Revision Details | By | Date | Suffix |
|---|---|---|---|

Drawing Status

Job Title
Llanmaes Flood Alleviation Scheme

Drawing Title
Key Structures on Modelled Watercourse

Scale at A3 1:2000

Drawn RH
Approved RC

Stage 1 Check
Stage 2 Check
Originated
Date 02/18

Client
Llywodraeth Cymru
Welsh Government

AECOM
AECOM

Drawing Number
Rev

Figure 3-7: Key Hydraulic Features and Structures within Llanmaes

**Table 3-2: Structures Omitted from the Model**

| Survey Section Reference | Location | Reason for Omission |
|---|---|---|
| Survey Ref: Section 17/16 | Footbridge 2 | Very short width of footbridge. Section immediately upstream of this location is considered to provide the upstream limiting conveyance capacity of the channel in this location. |
| Survey Ref: Sections 12/13 | Village Green Bridge | Bridge is a very short width and small deck and considered a negligible restriction to flow |
| Survey Ref: Section 5/4 | No.23 West Road Driveway | Upstream Section is limiting conveyance capacity at this location as No.24 driveway has smaller opening size. |
| Survey Ref: Section 22 | No.18 Tyle House Close Driveway | Unknown upstream extent as on private land and not available within provided survey. Visual estimations and review of model outputs were such that this structure would provide a negligible impact on model results. |
| Survey Ref: Section 24/25 | No.17 Tyle House Close Footbridge | Structure less than 1m in deck width and deck is at the level of the bank. This is not considered to affect the conveyance of the channel. |
| Survey Ref: Section 35/36 | Footbridge 3 - No.11 Tyle House Close | Timber bridge soffit at level of bank with small 100mm bridge deck. This is not considered to affect conveyance in the channel. |
| Survey Ref: Section 37/38 | Garden Wall 1 - No.11 Tyle House Close | Garden wall crosses the watercourse channel. Out of bank flow would pass around the wall on the RB and is not a flood defence structure. In addition it was viewed that this structure has holes to allow water to pass through. Therefore this wall has not been considered in the model. |
| Survey Ref: Section 39/40 | Footbridge 4 - No.11 Tyle House Close | Timber bridge soffit at level of bank with small 100mm bridge deck. This is not considered to affect conveyance in the channel. |
| Survey Ref: Section 41/42 | Garden Wall 2 - No.11 Tyle House Close | Garden wall crosses the watercourse channel. Out of bank flow would pass around the wall on the RB and is not a flood defence structure. In addition it was viewed that this structure has holes to allow water to pass through. Therefore this wall has not been considered in the model. |

### 3.5.1 Bridges

The Baseline model has 6 bridge units representing structures in the unnamed watercourse through Llanmaes. All bridge units have been specified as “BB” bridges as outlined within the TUFLOW Manual to represent losses. It is noted that all bridge units upstream of the B4265 culvert within the NAR model have also been reviewed and updated to “BB” bridges.

Structures on the unnamed watercourse through Llanmaes have been represented as bridge units in 1D where either the deck width is below or close to the 2D grid cell size (i.e. less than 2m) or where the upstream section of a double driveway is considered to provide the limiting conveyance capacity in the watercourse. Double driveways have been represented in this way at No.12 and No.13 Tyle House Close and No.23 and No.24 West Road. This is considered to provide a suitable representation of the smallest structures within the watercourse.

### 3.5.2 Culverts

The Baseline model contains 7 culvert units on the unnamed watercourse through Llanmaes. Junction loss units were included on the culvert from Rose Cottage to the Village Green, No.22 West Road to Tyle house Close and the culvert beneath Low Road to represent energy loss in the culverts. The Engelund loss approach as recommended by the TUFLOW Manual is used to calculate losses at these junctions.

### 3.5.3 Walls

The unnamed watercourse through Llanmaes is bound along much of its length by stone-built garden walls. During the site visit in 2017 it was determined that these walls are of varying build quality and size. None of these structures are designated specifically as flood walls and therefore their ability to retain flood waters is unknown. Furthermore, the 2m grid cell size (Section 3.6) used within this model limits the ability to accurately represent the thickness of the walls. For this reason, a conservative approach has been taken to not include any walls along the banks of the unnamed watercourse through Llanmaes within the 1D or 2D domain.

## 3.6 Model Parameters

The grid cell size was reduced from 4m within the NAR model to 2m within the updated Llanmaes FAS study to provide a greater resolution of results within Llanmaes. This increased the total simulation time from 7.5 hours to 18.0 hours. A check was carried out on the 1m grid cell size, however the total simulation time was estimated to be approximately 96 hours (4 days). It was determined by AECOM that in order to make efficient progress with the hydraulic modelling, and in light of the available LiDAR DTM resolution being limited to 2m (a 1m grid cell representation would be restrained by this) for much of the catchment, all simulations would be maintained at a 2m grid cell size. It is appreciated that this diverges from the methodology previously discussed with NRW[11] (07/07/2017). This issue has been raised by NRW during the model build process and it was recommended that using the TUFLOW HPC/GPU modelling version to improve simulation times and should be explored. The Baseline model was simulated using the HPC solver but it was found that the model simulation was commensurate with the TUFLOW Classic Licence (c.18hrs). Therefore it was not felt that the HPC solver alone would significantly improve simulation times if the grid was reduced to 1m. Combined with the availability of suitable topographic data and increased simulation times it was considered appropriate to maintain a 2m grid within the hydraulic model.

## 3.7 Hydrological Inflows/Model Runs

The hydrological inflows for the pluvial Llanmaes model are all applied using a TUFLOW rainfall boundary across the whole Llanmaes Brook catchment (Figure 1-3). Rainfall hyetographs were generated using catchment descriptors and MicroDrainage software and are shown in Figure 3-8.

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[11] AECOM (2017) Llanmaes FAS – NRW revised Minutes 170707

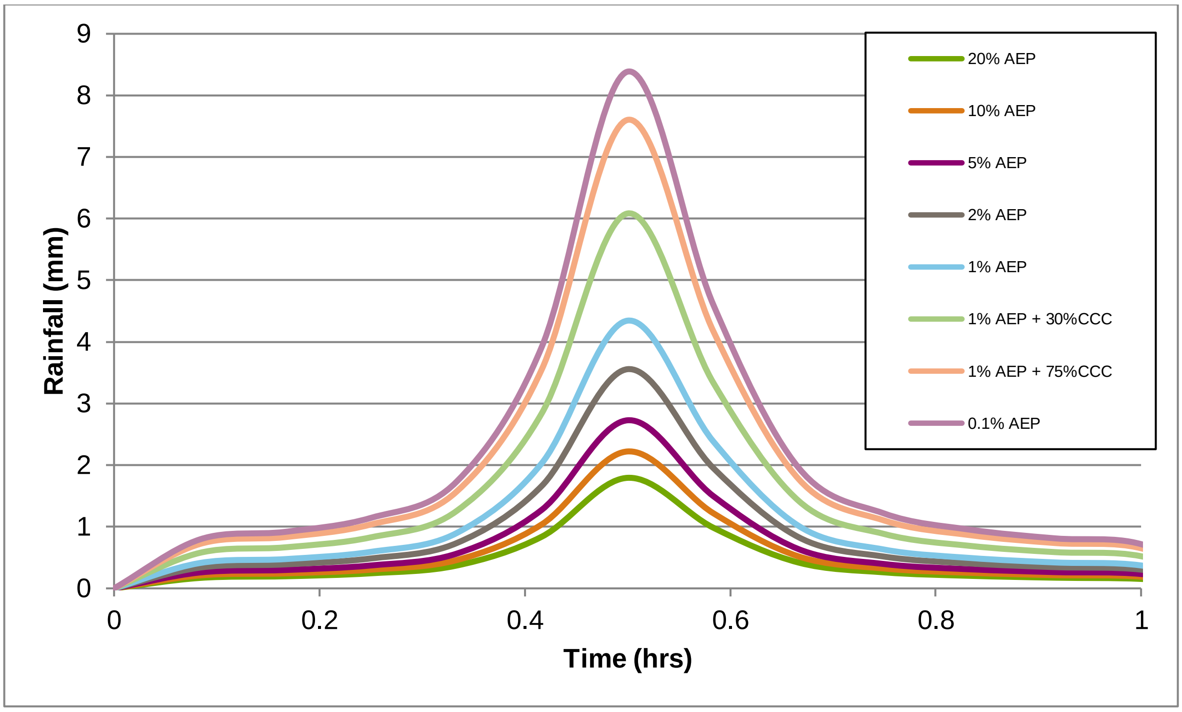


**Figure 3-8: Design Rainfall Hyetographs**

Pluvial inflows for the 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 1% AEP plus 30% climate change, 1% AEP plus 75% climate change, and 0.1% AEP were simulated. Climate change allowances were taken from the Welsh Government's 2016 guidance for FCAs. Llanmaes Brook is located within the Western Wales river basin district, whereby 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%. These climate change allowances have been applied to the pluvial model to maintain consistency with the existing NAR model and allow direct comparison of results. This is also recommended due to the strong inter-dependency between pluvial and fluvial sources as a result of the assessment of flood history in the village.

The TUFLOW rainfall boundary in the hydraulic model extends partially into the Boverton Brook catchment (Figure 1-3) south of Boverton Brook and west to the B4265 road crossing downstream of the Llanmaes Brook confluence to ensure all rainfall into the Llanmaes Brook catchment has been captured. It is noted that in this study, no 1D inflow has been included to represent flows on Boverton Brook upstream of the confluence with Llanmaes Brook meaning that flows on Boverton Brook are effectively incomplete. This approach has been taken because Boverton Brook is sufficiently downstream of Llanmaes to not impact the conclusions of this study and any pass on detriment/benefit to Boverton downstream of the Llanmaes Brook is indicated by the flows hydrographs on Llanmaes Brook downstream of the NAR. It is recognised that maintaining or bettering the current flood risk to Boverton is a key requirement for Welsh Government given the flooding experienced within the town in the past. Therefore to provide reassurance that this approach is robust and the Proposed Option does not increase flood risk downstream of Llanmaes a sensitivity analysis, agreed with NRW (correspondence 09/01/19), has been carried out with the estimated flows on Boverton Brook included within the hydraulic model (Section 7.4).

## 3.8 Model Software

The Llanmaes FAS model was constructed and simulated using the hydraulically coupled 1D-2D ESTRY- TUFLOW platform (TUFLOW version 2020-10-AA-iDP-w64). The version used to inform this study is a more recent software version than the existing NAR model (TUFLOW version 2016-03-AC-IDP-w64) and throughout the model development model versions have been updated as they have been released. A comparison of the flows at key locations on Llanmaes Brook using the earlier 2018-03-AB-iDP-w64 and 2016-03-AC-IDP-w64 versions of the software was carried out for the submission of Revision 4 of this report.

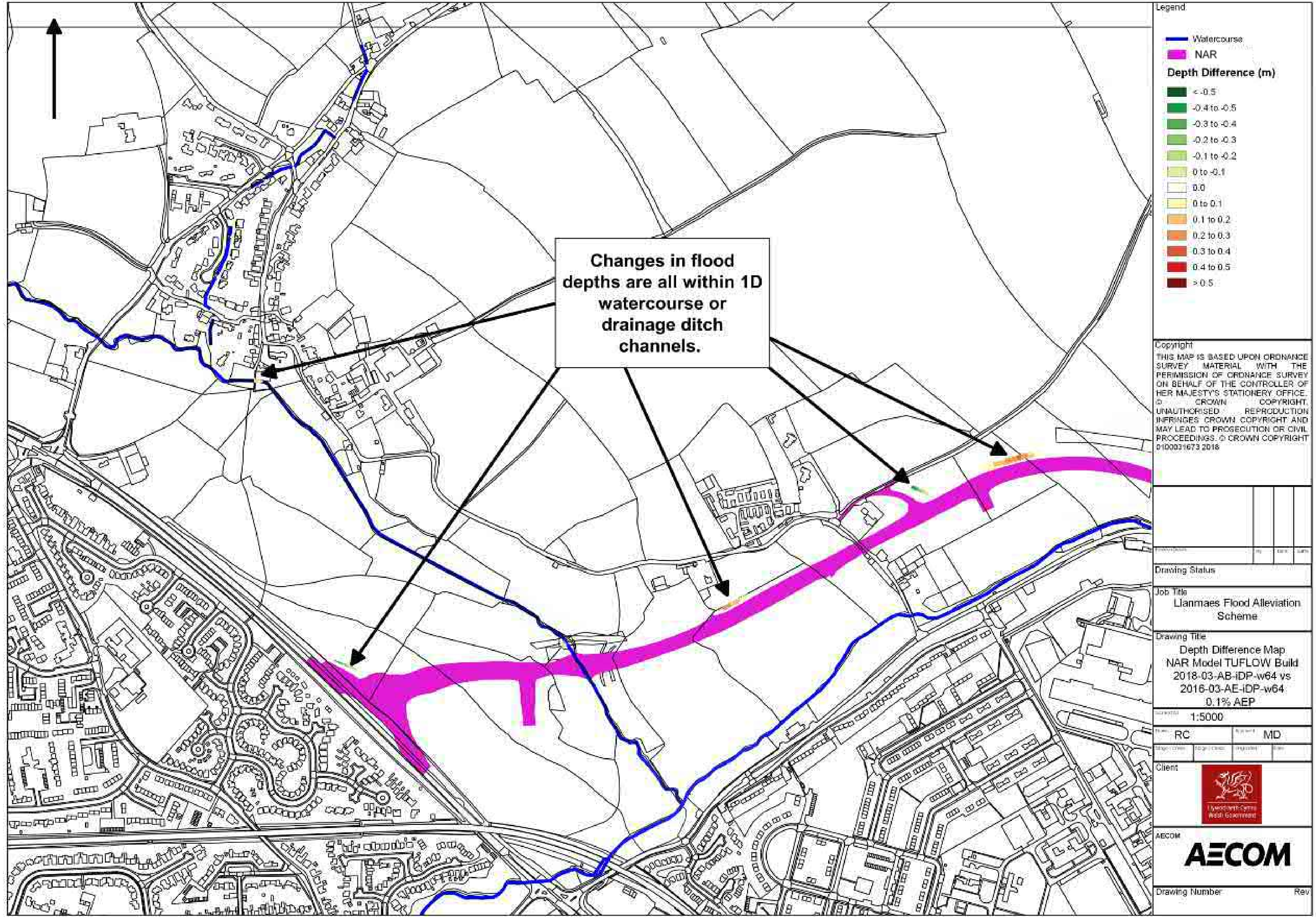
Figure 3-9 shows the maximum depth difference plot between the NAR model for TUFLOW model builds 2018-03-AB-iDP-w64 and 2016-03-AC-IDP-w64. Small areas of the Llanmaes Brook channel and NAR drainage ditches show changes in flood depths. These areas are all within the coded out areas of the 1D channel and downstream of the main area of interest. The 1D channel flow was investigated further and it was found there was no change in the 1D channel flow between TUFLOW version 2018-03-AB-iDP-w64 and 2016-03-AC-IDP-w64 at the locations of increased or decreased flood depths. It is therefore concluded that as there is no change in flood depths outside of the 1D channel and no change in flow within the 1D channel that the TUFLOW model build does not have a significant impact on the model results.

It is noted that the 2014 Options Appraisal Report was simulated using TUFLOW model builds 2016-03-AE-IDP-w64. This is because the OAR model was built at an earlier stage in the modelling study when the current version of TUFLOW was unavailable. It has been shown that the model build has minimal impact upon the results and it is considered that the conclusions drawn in Section 5.1.1 would not change as a consequence of changing the model build.

## 3.9 Model Limitations

The following hydraulic model limitations have been identified within this study:

- There is currently no defined best practice guidance for the estimation of rainfall hydrology and losses, and subsequent inclusion within surface water hydraulic modelling. Therefore, the approach developed and adopted represents an appropriately conservative representation of surface water flood risk within the catchment, based upon both hydrological and engineering judgement. The methodology was agreed with NRW at the outset of this study;
- The Llanmaes Brook catchment is ungauged and therefore there are no quantitative data available for calibration or verification of the hydraulic model. Verification is therefore limited to anecdotal evidence provided by VoGC;
- Antecedent conditions within the catchment may vary across the year and therefore may impact surface water runoff rates. Sensitivity analysis has been carried out on the percentage runoff within the catchment to assess the hydraulic model against a range of conditions (Section 7);
- The basic hydrological component present within the TUFLOW software also precludes a representation of interactions between groundwater and surface water within the hydraulic model. The results presented therefore do not account for groundwater interactions;
- A large source of uncertainty commonly associated with hydraulic modelling is associated with the data utilised to define catchment topography. The composite DTM utilised within this study comprises of 2m resolution NRW LiDAR which has a typical vertical accuracy of +/- 0.15m;
- LiDAR DTM data does not exist for the upper Llanmaes Brook catchment and therefore a conservative representation of the topography has been adopted (Section 3.4);
- Walls have not been represented within the hydraulic model unless they are designated flood defences. This is because the ability of the structure to retain water could not be verified and therefore it is not known whether they would be resilient enough to withstand large overland flows. Walls may impact overland flow paths throughout the catchment and as such, inclusion for specifically designed flood walls have been included within the Proposed Option;
- A grid cell size of 2m was utilised within the hydraulic model to allow practical simulation times (Section 3.6). Small topographic features that may impact on overland flow paths may not be represented within the hydraulic model, although this has been minimised as far as is practicable;
- Manning's Roughness Coefficients have been specified across the catchment using OS MasterMap data. This does not account for heterogeneity of roughness within large areas of the catchment which may impact overland flow routes. Sensitivity analysis has been carried out to improve confidence in the representation of the catchment (Section 7); and
- The Baseline and Proposed Option hydraulic model represents Llanmaes Brook catchment and does not include inflows from Boverton Brook. Sensitivity analysis has been undertaken to assess the Proposed Option model including Boverton Brook catchment (Section 7).



Changes in flood depths are all within 1D watercourse or drainage ditch channels.

Figure 3-9: Depth Difference TUFLOW version 2018-03-AB-IDP-w64 vs TUFLOW 2016-03-AC-IDP-w64 (0.1% AEP)

# 4. Baseline Scenario Model Results

All updates to the existing NAR model described in Section 3 were incorporated into the new pluvial Baseline model (Figure 1-3) and simulated for the design events stated in Section 3.7.

Within a direct rainfall model, every cell within the desired rainfall catchment area becomes wet (2d_rf). This may cause some confusion with the extent of inundation throughout the catchment due to the wide ranging 'shallow depths' experienced throughout. As a result, and in order to assist in focusing on the areas of greatest flooding, it is common practice to produce flood depth visualisations which exclude lower bandwidth of depth, starting at a depth of +0.05m, whereby lower depths are removed from the visualisation mapping. This is continued throughout the representation and discussion of pluvial results within this report.

The full suite of baseline scenario results can be found in Appendix B

## 4.1 Pluvial

### 4.1.1 Primary Flow Paths

The direct rainfall model was first simulated to identify the primary flow paths contributing to Llanmaes Brook and also the urbanised area of Llanmaes village, in order to understand the key mechanisms and flow paths contributing to flooding in the village, validating them against available flood history information.

Figure 4-1 demonstrates that during the 1% AEP + 30% climate change scenario, the unnamed watercourse through Llanmaes directs flow from the fields at the north end of the village through the Village Green, along West Road and down Tyle House Close before passing beneath Low Road, reaching a confluence with Llanmaes Brook south west of Tara House. The capacity of the modified channel has been observed through assessment of flood history (and also verified by this study) to be of insufficient capacity for low order events, let alone the 1% AEP +_ 30% climate change design event. As a result, overland flow has been observed within the model to be passing through properties and gardens along Tyle House Close, Low Road and towards Tara House. Figure B1 in Appendix B demonstrates that the channel capacity is exceeded during the lowest magnitude event simulated (20% AEP).

A significant overland flow path propagates south from the agricultural fields to the north of the village and is the primary contributor of flows entering Llanmaes. During the 1% AEP + 30% climate change scenario, this reaches a peak of approximately 4.7$m^3$/s which cannot be contained in-channel by the low capacity of the unnamed watercourse (Figure 4-1). Figure 4-1 shows a number of other smaller flow paths entering Llanmaes from the surrounding fields where they are concentrated by the graded road network towards the Village Green. In particular West Road, Gadlys Lane and Sigingstone Lane act as primary conduits for overland flow to the north of Llanmaes where collection of overland floodwater is evident.

At the southern end of Llanmaes, properties on Tyle House Close, Low Road and surrounding Tara House are impacted by overland flows from West Road and the surrounding fields. Overland flow is directed towards a low spot on Low Road then ultimately south towards Llanmaes Brook. Model results show that during the events greater than the 20% AEP (Appendix B Figures B1-B8) flooding is exacerbated by overtopping of the right bank of the unnamed watercourse at Low Road and left bank immediately upstream of the Llanmaes Brook outfall culvert. The left bank of Llanmaes Brook also overtops in events larger than 5% AEP causing additional flooding to properties close to the watercourse.

The mechanism of flooding described for the 1% AEP + 30% climate change scenario is evident during all the AEP's simulated within Appendix B and is supported by anecdotal evidence of flooding between 2012 and 2020 (Appendix A1).

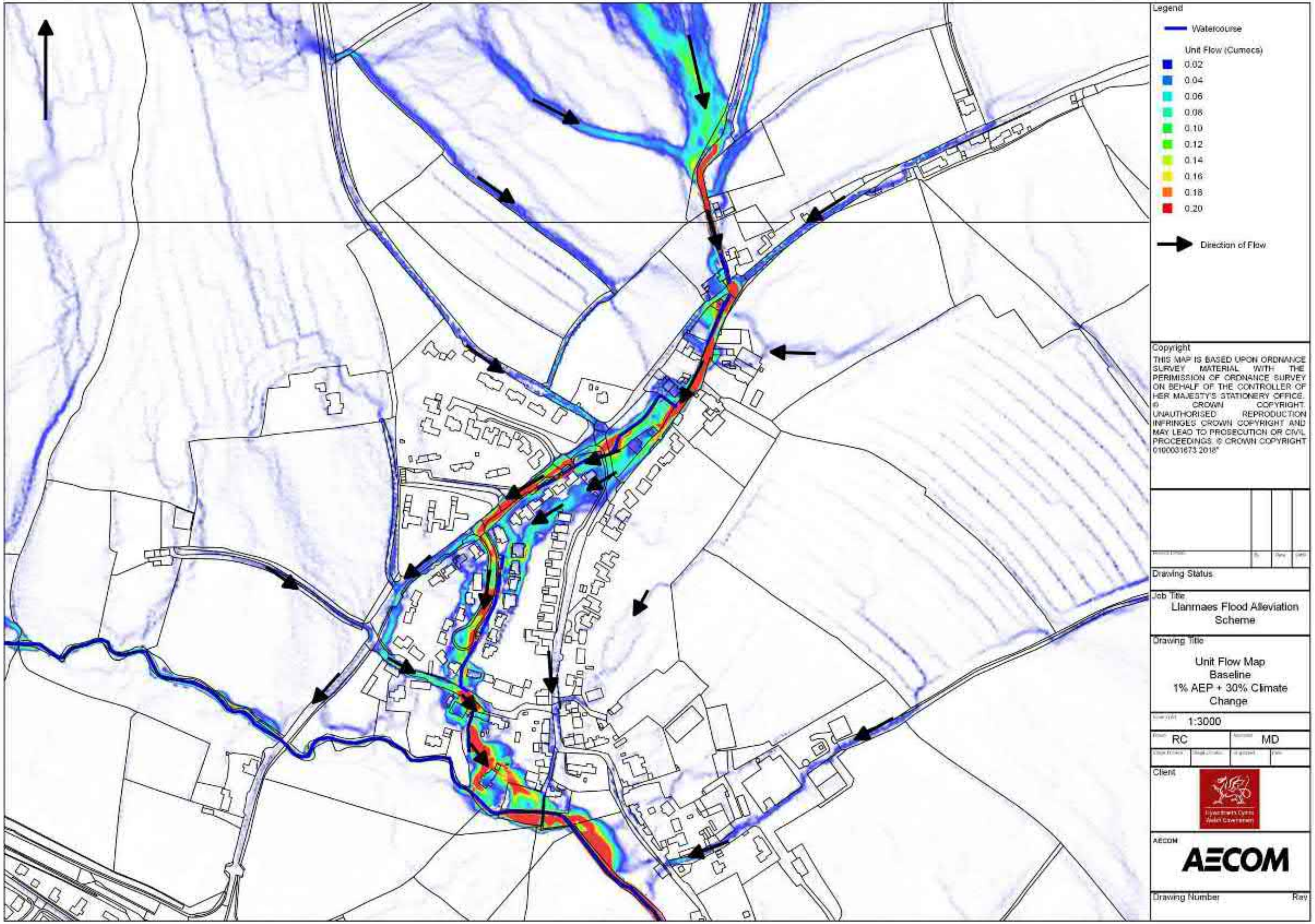


Figure 4-1: Baseline Flow Paths 1% AEP + 30% Climate Change

### 4.1.2 Flood Depths

The maximum flood depths for each design event have been mapped to demonstrate the level of flooding within Llanmaes. Figure 4-2 shows that during the baseline 20% AEP event there is flooding around the Village Green to a depth of approximately 0.1-0.3m. This is consistent with reported flood events whereby this area of the village is inundated approximately every five years[12] (Appendix A1). At the southern end of the village, flood depths are approximately 0.1-0.3m on Low Road and the area around Tara House reaches depths of 0.1-0.5m during the 20% AEP event. The model results estimate that 19 properties are affected by flooding during the 20% AEP event.

The 1% AEP + 30% climate change scenario baseline results show that a significant amount of flooding in Llanmaes particularly around The Pump, The Croft, The Village Green, Tyle House Close and Tara House where flood depths reach between 0.4-0.5m (Figure 4-3). The largest extent of flooding is at the junction of Sigingstone Lane and West Road where there is a combination of out of bank flow and overland flow from the surrounding highways that are attributable to flood depths. At the southern end of the village, flooding at Tyle House Close and Low Road reach between 0.2-0.4m during the 1% AEP + 30% climate change scenario. The largest flood depths in this part of the village are recorded on Low Road where both the highway and properties are inundated. The model estimates that 61 properties are affected by flooding during the 1% AEP + 30% climate change scenario.

### 4.1.3 Culvert Capacity

The model results demonstrate that the open channel and culvert network through Llanmaes creates a series of constrictions within the network which result in backing up of flow, resulting in overtopping of the watercourse banks. During the 20% AEP event, the culverts beneath West Road near the Pump, at Rose Cottage towards the Village Green, beneath Low Road and the Llanmaes Brook Outfall (Figure 3-7) all reach full capacity contributing to out of bank flow. This is supported by anecdotal evidence where the undersized 0.375m diameter culvert at Rose Cottage has been seen to overtop regularly contributing to highway and property flooding. The model results show that during the 10% AEP event, all culverts within Llanmaes have effectively reached full capacity.

### 4.1.4 Number of Flooded Properties

To quantify the number of properties that flood within the village it is proposed that a property at risk of flooding is defined as one that shows flooding to a depth greater than 0.05m, due to the shallow depth nature of a catchment wide direct rainfall assessment, or if there is a large access restriction from floodwater surrounding the property. The threshold survey data supplied by VoGC builds confidence in the identification of inundated properties. Using these parameters there are 61 properties shown to be affected by flooding during the 1% AEP + 30% climate change scenario. Table 4-1 shows the number of properties that are considered to be affected by flooding during each design flood event in the Baseline model.

**Table 4-1: Properties Affected by Flooding - Baseline Scenario**

| Annual Exceedance Probability (AEP) | Number of Flooded Properties |
|---|---|
| 20% | 19 |
| 10% | 27 |
| 5% | 31 |
| 2% | 45 |
| 1% + 30% CC | 61 |

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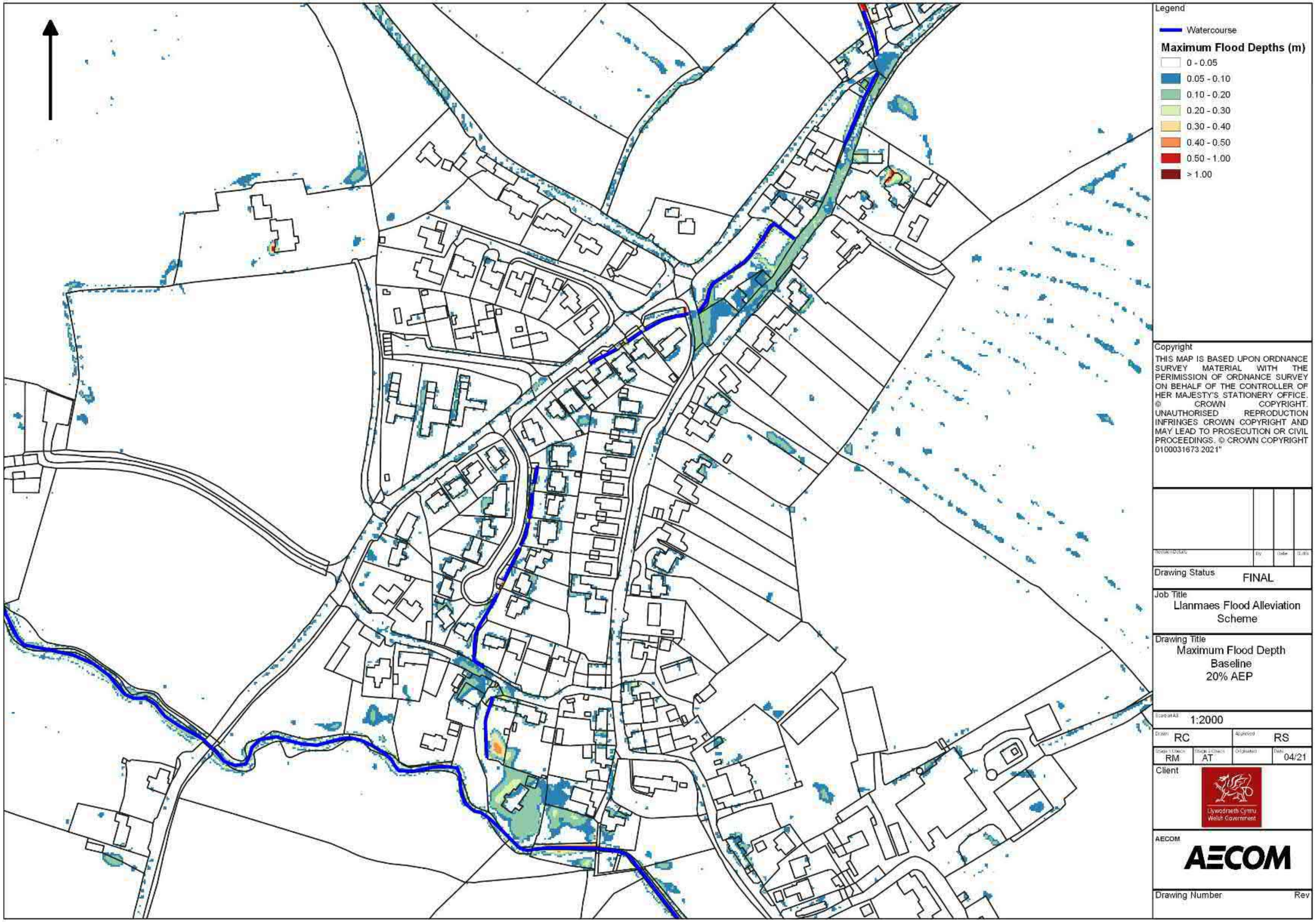
[12] Martin Wright Associates, 2009 Project Appraisal Report



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Revision Details By Date Suffix

Drawing Status FINAL

Job Title
Llanmaes Flood Alleviation Scheme

Drawing Title
Maximum Flood Depth
Baseline
20% AEP

Scale at A3 1:2000

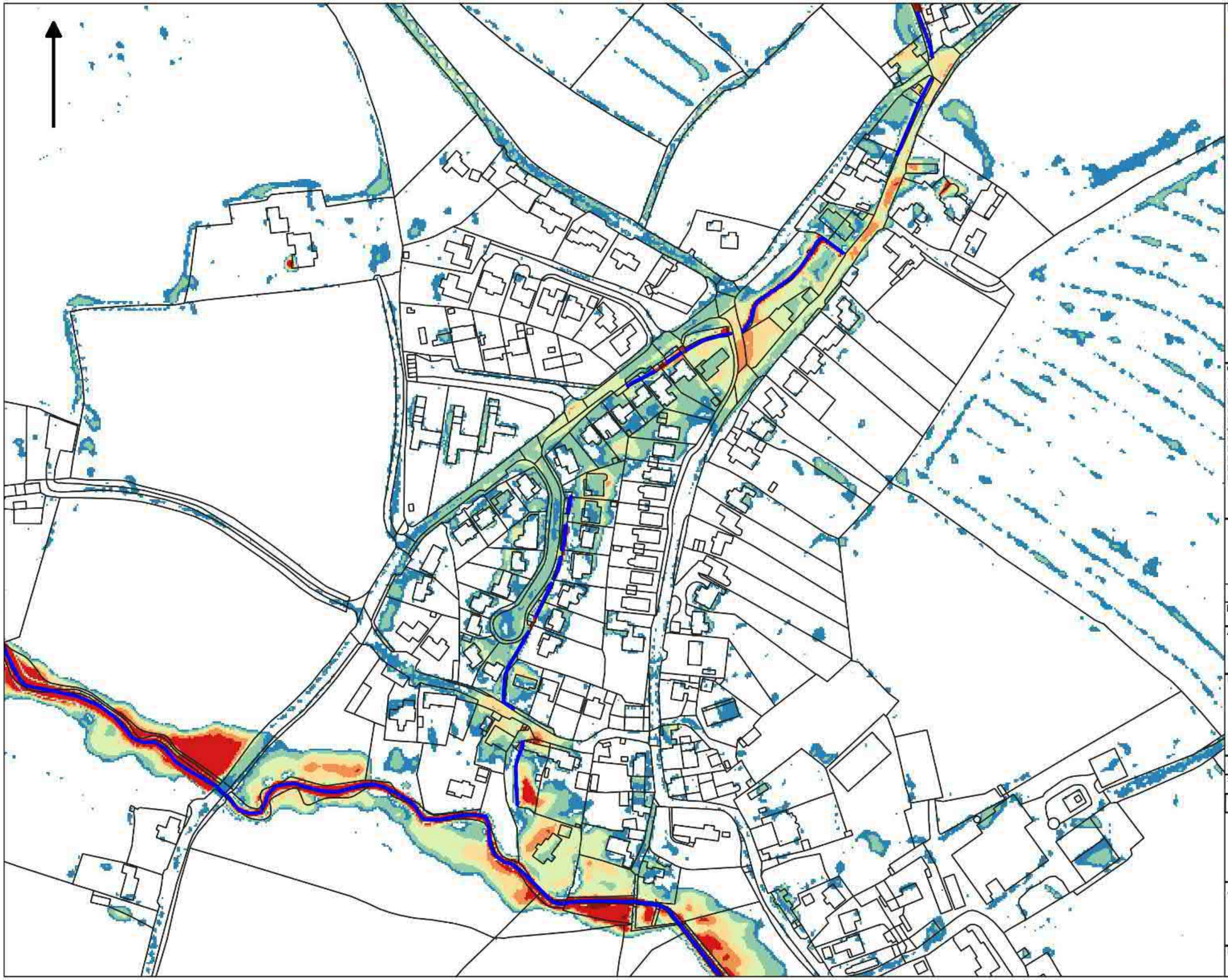
Drawn RC
Approved RS

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

Client

Drawing Number
Rev

Figure 4-2: Maximum Flood Depths - 20% AEP Baseline Results



Legend

▬ Watercourse

**Maximum Flood Depths (m)**

| | |
|---|---|
| ☐ | 0 - 0.05 |
| 🟦 | 0.05 - 0.10 |
| 🟩 | 0.10 - 0.20 |
| 🟩 | 0.20 - 0.30 |
| 🟨 | 0.30 - 0.40 |
| 🟧 | 0.40 - 0.50 |
| 🟥 | 0.50 - 1.00 |
| 🟫 | > 1.00 |

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Revision Details | By | Date | Chk

Drawing Status FINAL

Job Title
Llanmaes Flood Alleviation Scheme

Drawing Title
Maximum Flood Depth
Baseline
1% AEP + 30% Climate Change

Scale at A3 1:2000

Drawn RC | Approved RS

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

Client

Llywodraeth Cymru
Welsh Government

AECOM

AECOM

Drawing Number | Rev

Figure 4-3: Maximum Flood Depths 1% AEP + 30%CC Baseline Results

## 4.2 Summary

The modelled results in Appendix B show that flooding of properties and highways is prevalent across all simulated AEP's, from the 20% AEP to the 0.1% AEP event. This is primarily caused by a lack of capacity within the channel of the unnamed watercourse through Llanmaes and at a number of culverts throughout the village. Flooding is further exacerbated by Llanmaes Brook, where overtopping occurs on the left bank near Tara House. This is partially due to the restriction caused by the existing footbridge across Llanmaes Brook downstream of the Playground Area.

To summarise, a baseline representation of flooding has been created and improved from using best practice techniques and available data. The intended purpose of the hydraulic model is to appropriately represent the contribution of pluvial flood sources within the Llanmaes catchment. The mechanism of flooding shown within the baseline model results are demonstrated to be congruent with observed historical flood events between 2012 and 2020. As a result, it is viewed that this representation of baseline flood mechanisms of Llanmaes is therefore considered suitable to take forward to determine the effectiveness of proposed flood mitigation options.