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WYLFA NEWYDD

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1 Introduction

1.1 Overview

1.1.1 This Flood Consequence Assessment (FCA) describes the assessment of potential flood risk from all sources resulting from the operation of the A5025 Off-line Highway Improvements. The FCA assesses the flood risk posed to the A5025 Off-line Highway Improvements as well as any changes to flood risk arising from the highway.

1.1.2 The hydrological baseline is outlined in chapter G8 (surface water and groundwater) (Application Reference Number: 6.7.8) of the Environmental Statement, information from which is used in this FCA. This FCA should be read in conjunction with chapter G8 (Application Reference Number: 6.7.8).

1.1.3 Consultation with relevant statutory bodies has taken place during the production of this FCA. A record of consultation can be found in section 8.3 of chapter B8 (surface water and groundwater) (Application Reference Number: 6.2.8).

1.2 Site locations and study areas

1.2.1 The A5025 Off-line Highway Improvements sections are shown in figure G8-1.1. The road crosses a number of watercourses that have the potential to affect or be affected by the Proposals.

1.2.2 The A5025 from Valley to the Wylfa Newydd Development Area is approximately 16.5km in length. It is a rural A-classification road with variable speed limits and it varies significantly in width and elevation. It is a winding road with a number of sharp bends. In some places, the road passes through communities and is closely flanked on one or both sides by residential properties.

1.2.3 The proposed A5025 Off-line Highway Improvements consist of five sections of improvements:

- Section 1 – Valley

  The A5/A5025 Valley junction. A roundabout is proposed for a section of the A5025, which would provide a new link between the A5 and A5025, east of Valley.

- Section 3 – Llanfachraeth

  This section extends from north of Llanynghenedl to north of Llanfachraeth. Llanfachraeth is a large village accommodating a high density of residential properties, small businesses and a school. It is proposed that the A5025 would bypass Llanfachraeth to the east of the village.

- Section 5 – Llanfaethlu

  This 2.5km section passes through the settlement of Llanfaethlu. Proposals have been developed to improve two existing bends on the A5025 within the village.

- Section 7 – Cefn Coch

  The proposal comprises a bypass for the A5025, which would provide realignment of the carriageway west of Cefn Coch.

- Power Station Access Road junction

  The proposal includes a new road junction to allow access to the Power Station from the A5025.

1.2.4 The surface water study area is 500m in all directions around the Off-line Highway Improvements as shown in figures G8-2 to G8-6 (Application Reference Number: 6.7.48). Within this study area an assessment has been completed to determine if there were any surface watercourses or features that could be relevant for flooding, and an assessment was completed to identify any areas currently at risk of flooding. If watercourses were identified where there was potential for flood risk to be increased downstream then the study area was extended along that watercourse. The whole downstream watercourse was then assessed as far as a point where it enters the sea. The surface water study area with respect to flood risk was therefore based on the stream catchments in and around the Off-line Highway Improvements, which in some cases extend beyond 500m.

1.3 Technical Advice Note (TAN) 15 Development Advice Map

1.3.1 There are two initial reference maps for assessing the level of fluvial and tidal flood risk associated with land: the TAN 15 Development Advice Map [RD1] and the Natural Resources Wales (NRW) flood map of fluvial flood risk [RD2]. These are broadly similar, although the NRW flood map provides additional detail in relation to flood probability. The TAN 15 Development Advice Map, which shows the fluvial and coastal flood zones as issued by the Welsh Government, is primarily used in this assessment as the TAN 15 Development Advice Map forms the basis of assessment of flood risk in accordance with planning policy.

1.3.2 The TAN 15 flood zones are defined as follows:

- Zone A: Considered to be at little or no risk of fluvial or coastal/tidal flooding;
- Zone B: An area known to have been flooded in the past;
- Zone C1: An area with an annual probability of flooding from river, tidal or coastal sources equal to, or greater than, 0.1%, but which has significant infrastructure including flood defences; and
- Zone C2: An area with an annual probability of flooding from river, tidal or coastal sources equal to, or greater than, 0.1% and without significant flood defence infrastructure.

1.4 Planning guidance for a FCA

1.4.1 In Wales, Planning Policy Wales (PPW) [RD3] and Technical Advice Note (TAN) 15: Development and Flood Risk [RD4] provide the national policy framework for the assessment and management of flood risk for new developments. Taken together, they establish a presumption against development in areas at the highest risk of flooding, setting a framework for the sequential assessment of the suitability of sites for development. They also set out an assessment methodology (the FCA methodology) for the systematic evaluation of flood risk and the need to integrate mitigation and flood resilience in the design of new development.

1.4.2 This FCA has been written to address the planning policy requirements for the A5025 Off-line Highway Improvements proposals, in association with TAN 15 guidance.

1.5 Report objectives

1.5.1 The objectives of this FCA are set out below:

- identify possible mechanisms by which the proposed A5025 Off-line Highway Improvements site could flood;
- identify any aspects of the design that could exacerbate flooding elsewhere;
- undertake a formal assessment of the risks posed to the proposed A5025 Off-line Highway Improvements from all identified flood risk sources and mechanisms;
- confirm that the proposed A5025 Off-line Highway Improvements would not exacerbate flooding elsewhere;
- consider the level and acceptability of any residual flood risk; and
- produce an FCA compliant with Planning Policy Wales (PPW) [RD3] and TAN 15 [RD4].

2 Policy and planning

2.1 Planning Context

2.1.1 The context for planning policy in Wales is set out within PPW Edition 9 [RD3]. This provides the national policy framework for the assessment and management of flood risk for new developments and references a range of European and national legislation that relates to the flood risk. This is supplemented by TAN 15 [RD4] and local planning policy. Although there is other legislation and guidance relevant to flood risk (including National Policy Statement for Energy (EN-1) (NPS EN-1) and National Policy Statement for Nuclear Power Generation (EN-6) (NPS EN-6)), this is discussed in section 8.2 of chapter B8 (Application Reference Number: 6.2.8) and is not repeated in this FCA.

2.2 PPW

2.2.1 The objective of PPW [RD3] is to avoid the construction of new development within areas defined as being at flood risk, with planning authorities adopting a precautionary approach when formulating development plan policies, including the principle that climate change will likely increase the risk of coastal and river flooding. A strategic approach to flood risk that considers the catchment as a whole is encouraged.

2.2.2 PPW states that new development should not be at risk of flooding itself and should not increase the risk of flooding elsewhere. Additionally, hard-engineered flood defences should be considered likely to be unsustainable in the long term, and new development should avoid development in flood hazard zones.

2.2.3 Only essential transport and utilities infrastructure is considered acceptable within unobstructed floodplains, and then only when such infrastructure is designed to remain operational during times of flooding and with no net loss of floodplain storage or increase in flood risk elsewhere.

2.3 TAN 15

2.3.1 TAN 15 [RD4] provides technical guidance that supplements the policy set out in PPW in relation to development and flooding. It advises on development and flood risk relating to sustainability principles and provides a framework within which risks arising from all sources including river and coastal flooding, and from additional runoff from development in any location, can be assessed. This incorporates climate change scenarios.

2.3.2 TAN 15 provides guidance on flood consequences that may not be acceptable for particular types of development. The location of the development needs to be justified in line with TAN 15 and flood risk areas, and the consequence needs to be acceptable given the vulnerability and use of the receptor.

2.3.3 Development should be directed towards Flood Zones A and B and will only be acceptable in Flood Zones C1 and C2 if it is necessary as part of a local

regeneration scheme or to sustain an existing settlement or if key to support employment objectives.

2.3.4 The guidance defines a threshold for the frequency of flooding below which development should not be allowed. This threshold for general infrastructure is equivalent to the 1% Annual Exceedance Probability (AEP) event, or an event with a 1 in 100 chance of occurring in any given year, for fluvial flooding and it is equivalent to the 0.5% AEP event, or an event with a 1 in 200 chance of occurring in any given year, for tidal flooding. Additionally, the depth of flooding, regardless of development type, should not be greater than 0.6m for any storm event. These thresholds automatically apply to all developments in Flood Zone A and B and to those in Flood Zone C once the justification test has been passed. A justification test is a set of criteria only applicable to developments located in Flood Zone C, which must be considered for the development to take place.

2.3.5 It is also a requirement of TAN 15 that future users and occupiers of all types of development are adequately aware of the flood risk and consequences, that effective flood warning is provided, that emergency flood plans are available and that safe access and egress are available. There is also a requirement that the site is designed to facilitate movement of goods/possessions away from flooding, to minimise structural damage and to facilitate recovery.

2.3.6 TAN 15 also states that new development should not increase flooding elsewhere; however, it acknowledges that there may be practical difficulties in achieving this aim.

2.3.7 TAN 15 states that consideration must be given to the effects climate change may have on the risk of flooding over the lifetime of a development; to ensure that development does not take place where flooding would be unacceptable either now or in the future. The Welsh Government has provided guidance (CL-03-16) [RD5] on how the UK climate change projections (UKCP09) [RD6] should be used to determine the future flood consequences for developments in Wales and must be incorporated in all FCAs produced after December 2016.

2.4 Local planning policy

2.4.1 The Anglesey and Gwynedd Joint Local Development Plan forms the basis for land use planning in the Anglesey and Gwynedd areas. The Written Statement was published in 2017 [RD7] and is the main source of local planning policy. Within the Plan, the strategic objectives in relation to flood risk are as follows.

2.4.2 Strategic Objective 6 (SO6): "*Minimise, adapt and mitigate the impacts of climate change. This will be achieved by: ensuring that highly vulnerable development is directed away from areas of flood risk wherever possible;……*".

2.4.3 Strategic Objective 8 (SO8): "*Ensure that settlements are sustainable, accessible and meet all the needs of their communities in accordance with*

their role in the settlement hierarchy: .....new developments that are vulnerable to harm will not be located in areas at risk from flooding".

2.4.4 In order to adapt to the effects of climate change Policy PS 6 (Alleviating and adapting to the effects of climate change) requires proposals to take account and respond to a number of concerns, including: "*Locating* (developments) *away from flood risk areas, and aim to reduce the overall risk of flooding within the Plan area and areas outside it, taking account of a 100 years and 75 years of flood risk in terms of the lifetime of residential and non-residential development, respectively, unless it can be clearly demonstrated that there is no risk or that the risk can be managed"* and to: *"Aim for the highest possible standard in terms of water efficiency and implement other measures to withstand drought, maintain the flow of water and maintain or improve the quality of water, including using sustainable drainage systems (in line with Policy PCYFF 6)*".

2.4.5 The Anglesey and Gwynedd Joint Local Development Plan Stage 1 Strategic Flood Consequence Assessment [RD8] forms a key part of the evidence base for planning with respect to FCAs. The document helps to determine appropriate development policies and land allocations that avoid or minimise flood risk from all sources, and helps to assess any future development proposals in line with the precautionary framework in PPW and TAN 15. This document and the IACC's Preliminary Flood Risk Assessment [RD9] include information on surface water, groundwater, ordinary watercourses and small reservoir flooding. Information on the IACC's flood strategy and the council's objectives in managing flood risk is provided in the Anglesey Local Flood Risk Management Strategy [RD10].

2.5 River Basin Management Plan

2.5.1 The proposed A5025 Off-line Highway Improvements are wholly located within the Western Wales River Basin District, an area encompassing river basins from Anglesey in the north of Wales to the Bristol Channel in the south. The *Western Wales River Basin Management Plan 2015 – 2021 Summary* [RD11] provides an overview of NRW's approach to managing flood risk within the Western Wales River Basin and details measures designed to reduce the potential flooding, such as use of sustainable drainage systems and improvements and maintenance of flood defence schemes. In addition, the plan proposes improving the understanding of flood risk through the application of mapping and modelling.

3 Baseline site context

3.1 Climate

3.1.1 The RAF Valley rain gauge (3km to the southeast of the A5025/A5 junction) comprises more than 50 years of digitised hourly data (1960–2014). Data from before this date are only available in analogue form.

3.1.2 Meteorological Office average annual rainfall data available online, for the period 1981 to 2010, show an average annual rainfall at RAF Valley of 841mm/yr. This is below the UK average of 1154mm/yr. The long-term data indicate that rainfall is typically higher in the late autumn/early winter and lowest in late spring/early summer.

3.2 Landscape

3.2.1 The key feature of the landscape along the A5025 is a drumlin field: a series of low rolling hillocks formed by glaciation. The hillocks run south-west to north-east and the majority are covered by improved grassland. There are also small areas of marsh, scrub and rocky outcrops in some areas.

3.2.2 The vegetation pattern along the A5025 includes hedgerows formed by dense linear belts of planting, enclosing dominantly agricultural fields.

3.3 Topography

3.3.1 The study area is largely undulating pastoral land. There are several small villages along the route of the A5025 and a number of isolated farmsteads. Within section 1 the highway is around 5m above Ordnance Datum (AOD) along its short stretch, although the roundabout in this section is at approximately 2mAOD.. Through section 3, to the east of Llanfachraeth, the road is elevated to cross watercourses and dry valleys that drop from east to west. At Llanfaethlu the road remains at approximately 60mAOD through its short length. Section 7 starts at 65mAOD and drops down to 30mAOD at the northern end at Cefn Coch. The Power Station Access Road junction is at an elevation of approximately 40mAOD on a slight topographic high point.

3.4 Off-site receptors

Section 1 - Valley

3.4.2 Section 1 of the proposed A5025 Off-line Highway Improvements is intended to link the A5025 and the A5 to the south-east of Valley. The A5025 Off-line Highway Improvements are considered to have a medium importance as determined by the Design Manual for Roads and Bridges (DMRB) categories in appendix G8-01.2.

3.4.3 The town of Valley is located northwest of the proposed bypass. The town has been considered in this assessment to ensure that there is no increase in the risk to residential or commercial properties or to local rail and road

infrastructure from any source of flooding due to the planned A5025 Off-line Highway Improvements. By virtue of the number of properties within Valley, the town is considered to have a high importance.

3.4.4 It should be noted that Valley is afforded protection from tidal flooding by defences located approximately 1km to the southwest. There have however been cases of flooding from surface water, noticeably October 2014, which are believed to have been influenced by fluvial flooding. Increases in flood risk from tidal or fluvial sources could therefore have a detrimental effect on surface water flooding within Valley.

3.4.5 Immediately downstream of Valley is the Beddmanarch-Cymyran Site of Special Scientific Interest (SSSI). The shallow waters between Holy Island and the Anglesey mainland include the tidal estuary of the Afon Alaw. The wide range of coastal habitats support a range of ornithological and botanical species. The current water level regime is important to conserve the habitats of the SSSI. This is an important receptor to consider in this assessment, however, its importance from a flood risk perspective, as defined in appendix G8-01.2, is low.

3.4.6 The existing highways of the A5025 and the A55 and A5 are receptors and flooding to this important road infrastructure was considered in the assessment. There is a cemetery adjacent to the proposed roundabout junction on the A5 to the east. Directly south of the A5 there is a freight yard. These receptors are all considered to have a medium importance, as are the proposed A5025 Off-line Highway Improvements.

Section 3 – Llanfachraeth

3.4.7 The proposed route of section 3 of the A5025 Off-line Highway Improvements would cross the Afon Alaw at Llanfachraeth. The crossing is a short distance upstream of the existing A5025 crossing at the south of the village. The existing road bridge is therefore a receptor of medium importance. Adjacent to the watercourse within the village are residential properties on the right bank on Pont Yr Arw, which would be sensitive to changes in flood risk and of high importance. On the west of the existing A5025, downstream on the right bank there is also a church which has a high importance.

3.4.8 Approximately 1km upstream at Pont Llanfigael there are residential properties on both banks of the Afon Alaw. These are expected to be sufficiently far upstream of any backwater reach, which is the length of watercourse within which any restriction to flow at Llanfachraeth could cause increased water levels. However, for certainty these off-site receptors of high importance have been considered in this assessment. A property approximately 250m upstream of the proposed elevated viaduct is also considered for this reason.

3.4.9 Towards the northern end of Llanfachraeth there is a school, past which flows a field drain in an east to west direction on its way to its confluence with the Tan R'Allt. The school is considered to have a high importance.

3.4.10 Immediately downstream of the existing A5025 road crossing is the Beddmanarch-Cymyran SSSI. This is an important receptor, as detailed above, to consider in this assessment but from a flood risk perspective it is considered to have a low importance.

3.4.11 Agricultural land is considered to be an off-site, undeveloped receptor and is classed as having a low importance.

Section 5 – Llanfaethlu

3.4.12 The proposed Off-line Highway Improvements section 5 is located to the west of the village of Llanfaethlu. In addition to the main village, there are other residential properties close to the proposed route including Tan-y-bryn to the west of the highway and Cae'r-brynlau, Fadog Frech, Awel y Rhyd and Ty'n-llech to the east. All of these property receptors are considered to have a high importance.

3.4.13 The village has a church and post office, and a new school is due to open in autumn 2017. These are not currently considered at risk as they are at a higher level than the proposed A5025 Off-line Highway Improvements. However, alteration of the river regime may increase flood risk to these receptors, and so they are included within this assessment and have been given a high importance.

3.4.14 The land drains generally to the east in this area towards the Afon Llanrhuddlad and its tributary. Downstream is the Beddmanarch-Cymyran SSSI. This is an important receptor to consider but it has a low importance in terms of sensitivity to flood risk.

3.4.15 Runoff from the site enters an unnamed watercourse which passes under the existing highwayand the proposed A5025 Off-line Highway Improvements at Tan-yr-allt, north of Llanfachraeth. Increases in water level in the river may increase the flood risk to these receptor, and so it is included within this assessment. Both receptors are considered to have a medium importance.

Section 7 - Cefn Coch

3.4.16 The proposed location of section 7 of the A5025 Off-line Highway Improvements is between the existing A5025 and the Afon Cafnan to the south of the village of Cefn Coch. The existing A5025 is a receptor of medium importance but after the amendments are made to the road network, this stretch of the road would be of lesser importance since it would no longer be part of the main highway. A minor road crosses the existing A5025 in this section in an east-west orientation. This road is also considered to be a receptor of medium importance.

3.4.17 In addition to the residential properties in the main village of Cefn Coch, there are properties on the A5025 to the north. These properties are very close to the watercourse and the furthest west is within the floodplain of the Afon Cafnan, Flood Zone C2, as shown on the TAN 15 flood maps. These receptors are considered to have a high importance.

3.4.18 Further downstream (outside of the study area) are the settlements of Caerdegog Uchaf and Cafnan before the Afon Cafnan and Felin Gafnan reach the coast at Porth-y-pistyll, 3km to the north. These receptors are also considered to have a high importance.

3.4.19 The river passes to the west of the Cae Gwyn SSSI. At the closest point the watercourse is approximately 250m from the Cae Gwyn SSSI but does not encroach onto it nor flow into the site. The Cae Gwyn SSSI has been discounted as a receptor in this FCA.

3.4.20 Upstream of the proposed A5025 Off-line Highway Improvements on the Afon Llygeirian is the Llyn Llygeirian SSSI. It is a moderately base-rich lake supporting a range of uncommon aquatic plants. The diversity of the lake is dependent on the water level regime; however, as it is approximately 500m upstream the Llyn Llygeirian has been discounted as a receptor in this FCA.

Power Station Access Road junction

3.4.21 The Power Station Access Road junction is on the A5025 immediately north of Groes-fechan. The existing A5025 is a receptor of medium importance. The Power Station Access Road itself is considered a minor road but is also considered to be a receptor of medium importance as it would provide access to the Power Station.

3.4.22 Properties adjacent to the access road roundabout at Groes-fechan are considered receptors of high importance. Further downstream (outside of the study area) are the settlements of Caerdegog Isaf and Cafnan. These receptors are also considered to have a high importance and are included for completeness but are not expected to be affected.

3.5 Surface water features

3.5.1 Design of the final A5025 Off-line Highway Improvements layout has been an iterative process and has been significantly altered during the design process, to ensure the footprint of the development has been kept as far as practicable from wetland habitats, which may have groundwater dependency, to avoid direct effects.

3.5.2 The study area includes four Water Framework Directive (WFD) water bodies (Afon Cleifiog, Afon Alaw, Tan R'Allt and Afon Cafnan). The western extent of the Afon Alaw is a transitional water feature. There are also several non-WFD watercourses, drainage ditches and a lake (Llyn Llygeirian). The smaller watercourses and drains are typically tributaries to the WFD water bodies and as a result form part of the WFD catchments. The main water features, as illustrated in figure G8.1.1, are described below (from south to north).

- **Afon Cleifiog**: located to the south-east of the A5025 (section 1), which has two tributaries: Cleifiog Fawr, which originates to the south of Llanynghenedl; and Cleifiog Isaf, which rises south of Bodedern. Both flow in a south-westerly direction parallel to the A5025 towards Valley.

The two streams join and the resulting river is crossed by the A5 and the A55.

- **Afon Alaw (fluvial)**: a watercourse that is fed by a series of tributaries. The main tributary, the Tan R'Allt joins the Afon Alaw within section 3. Most of the tributaries rise to east of the A5025, with the main watercourse flowing from Llyn Alaw approximately 6km to the north-east of Llanfachraeth.
- **Afon Alaw (transitional)**: a transitional water body that continues from the Afon Alaw and flows into Holyhead Bay at Traeth y Gribin.
- **Tan R'Allt**: a watercourse crossed by the A5025 north of Llanfachraeth (a short distance upstream of section 3). The Tan R'Allt flows in a southerly direction parallel to the A5025 and is joined by a number of minor tributaries and discharges to the Alaw estuary downstream of the A5025. This includes a relatively significant channel that flows in a southerly direction parallel to, and to the east of, the A5025 for around 6km between the village of Llanrhuddlad and its confluence with the Tan R'Allt.
- **Afon Cafnan**: a watercourse which is crossed by the A5025 in the vicinity of Cefn Coch (section 7 and Power Station Access Road junction) and into which several smaller watercourses flow in the vicinity of section 7.
- **Small watercourses and ditches**: There are a significant number of small watercourses and ditches across the area in the vicinity of the A5025 corridor.
- **Llyn Llygeirian**: is a water body located to the east of the A5025 within section 7. It is designated as a Site of Special Scientific Interest (SSSI) for its biological interest.

3.5.3 The most significant of these watercourses in terms of upstream catchment areas are the Afon Alaw (57km^2) and Tan R'Allt (20km^2).

3.6 Geology and hydrogeology

3.6.1 The two most important elements of the underlying bedrock are the New Harbour Group and Gwna Group, which both comprise psammite and mica schist, and are both Secondary B Aquifers with similar hydrogeological characteristics, in which fracture flow dominates. These strata generally store and yield limited amounts of groundwater although this may differ slightly depending on the lithology. For a more detailed assessment of the geology see chapter G7 (soils and geology) (Application Reference Number: 6.7.7).

3.6.2 The majority of the scheme is underlain by glacial till, which is classed as a Secondary (undifferentiated) aquifer by NRW. The deposits can be very variable in makeup but often have a clay matrix, in which case they have low permeability with limited significance for water supply or river base flow. Where they are more granular they can be more important. The deposits are important in terms of pluvial and fluvial flood risk response.

3.6.3 Section 1 is an exception to the above as the majority of this section is underlain by tidal flat deposits which are classed as an unproductive stratum with low permeability. It should be noted that there are no superficial deposits present in the majority of section 5 and to the southern extent of section 7.

3.6.4 Beneath and adjacent to watercourses across the study area, alluvium is present in the form of a mixture of clay, silt, sand and gravel, and this is classed as a Secondary A Aquifer. Alluvium includes permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. The areas of superficial Secondary A Aquifer are generally classified as being of high vulnerability.

3.7 Water services

3.7.1 Water main supplies and foul sewers follow the route of the existing A5025.

3.8 Reservoirs

3.8.1 Sections 1 and 3 of the A5025 Off-line Highway Improvements are downstream of the Llyn Alaw and are at risk of flooding from the reservoir in event of reservoir failure.

4 A5025 Off-line Highway Improvements proposals

4.1 Limits of deviation

4.1.1 As described in chapter G1 (proposed development) (Application Reference Number: 6.7.1) and chapter G8 (Application Reference Number: 6.7.8), the application for development consent for the A5025 Off-line Highway Improvements is based on a Works Plan and limits of deviation approach. This FCA has assessed a worst-case scenario from a surface water and groundwater perspective based on an indicative design and it has been concluded that changes within the confines of the Works Plans and limits of deviation would not affect the assessment outcomes. This is because the limits of deviation are quite small in lateral extent and any changes within these limits would not have any significantly different effects to those detailed in this chapter for the indicative design. The flood consequence assessment reported in this document is therefore representative of a worst-case in this respect.

4.2 Section 1 – Valley

4.2.1 A roundabout and a bypass are proposed to the east of Valley to connect the A5 to the A5025. The design also incorporates a floodplain compensatory storage area at the western edge of the proposed bypass. Drainage features intended to collect runoff generated by the proposed road and adjacent land include a storage swale to the west and two pipes culverting two minor drains encroached by the proposed road. Close to the tie-in with the A5025, an existing access road is proposed as a turning-head and a new culvert crossing at the unnamed tributary of the Cleifiog Fawr is also proposed. This compensatory storage area would be selected so as not to impact on the highway drainage scheme. The appropriate design of the compensation flood storage area would be undertaken and agreements with landowners implemented.

4.3 Section 3 – Llanfachraeth

4.3.1 It is proposed to provide a new 2.2km highway to provide a bypass to the east of Llanfachraeth village. The bypass is proposed to avoid an increase in vehicles passing through the village, and to provide increased safe overtaking opportunities by creating improved visibility along the A5025.

4.3.2 The design includes an elevated viaduct allowing traffic to cross the Afon Alaw and Afon Llywenan immediately upstream of their confluence. The alignment is shown in figure G8-1-3 with the surface water features.

4.4 Section 5 – Llanfaethlu

4.4.1 At Llanfaethlu, a bypass is proposed to provide a straighter section of road, where there are two existing substandard bends near the Black Lion pub and

through Llanfaethlu village. The alignment is shown in figure G8-1-4 with the surface water features.

4.5 Section 7 – Cefn Coch

4.5.1 The Cefn Coch bypass is proposed to provide a straighter section of road, where there are two existing substandard bends. The alignment is shown in figure G8-1-5 with the surface water features.

4.6 Power Station Access Road junction

4.6.1 A new roundabout is proposed on the A5025 to the south of Tregele to allow access to the new Power Station road to the north-west. The general layout of the roundabout is shown in figure G8-1-6.

4.7 Drainage

4.7.1 Formal drainage assets are limited along the A5025. The current system relies on runoff from the road discharging 'over-the-edge' into adjoining land, ditches or watercourses and in some cases into gullies installed at low points. In some cases the gullies are directly connected to ditches and watercourses. However, the connectivity of some of the gullies is unclear and it is possible that some gullies may be connected to soakaways.

4.7.2 There are no reports of significant carriageway flooding in the past. Where localised flooding has repeatedly occurred, reactive measures have been put in place by the IACC to reduce the risk of localised flooding. This is mainly achieved by installing additional gullies at low points, where runoff from the road tends to accumulate.

4.7.3 The IACC will adopt the proposed drainage assets on completion of the A5025 Off-line Highway Improvements. Consultation with the IACC ensured that its requirements were incorporated into the design. The IACC's requirements are given below.

- The proposed drainage and maintenance regime should be similar to the existing system.
- Minimised use of piped drainage systems. This implies that runoff will not be concentrated at one discharge point, but will instead be distributed, attenuated and slowed down before being discharged.
- Minimised asset maintenance requirements.
- Reduced risk of flooding to the road and third parties, focusing in particular on areas with flooding history or known drainage problems.
- Reduced effect of the road improvement works on flooding and the water environment.

4.7.4 The increased areas of hardstanding associated with the introduction of bypasses would provide increased volumes of runoff and a change in flow paths associated with changes in road contouring. Although the increase in

hard surfaces is small compared to the size of the catchment of any receiving watercourses, the increased runoff may have localised effects. The highway drainage would be designed to mitigate these effects locally following these general principles:

Section 1 - Valley

4.7.5 The runoff from the most northern wedge of the bypass would be collected by an over-the-edge drain into a new ditch discharging into the Cleifiog Isaf via an existing culvert. More southerly, runoff from the bypass would be collected by over-the-edge/filter/kerb drains and would ultimately be discharged into the Cleifiog Fawr. Drainage features include two culverts beneath the highway and a storage swale provided with weir wall and opening to control the discharge into the Cleifiog Fawr.

4.7.6 The drains would be designed to have the capacity to carry flows for a 1 in 1 year rainfall event and cause no flooding in a 1 in 5 year event as per the Design Manual for Roads and Bridges (DMRB) standards [RD12] and in line with the IACC requirements.

4.7.7 Due to the high topography of the area to the east of the proposed bypass, it was deemed impractical to provide attenuation ponds outside of the floodplain for this section of the highway.

Section 3 - Llanfachraeth

4.7.8 The runoff from the most northern end the bypass would be collected by filter drain and discharged into a small pond providing 400m^3 of attenuation on the western side of the bypass at grid reference 231567 383103. This pond would be designed to discharge at a rate of 3.4l/s to a small field drain that discharges westwards to the Tan R'Allt.

4.7.9 Centrally, the road would be drained to filter drains that carry runoff to discharge to a 980m^3 attenuation pond on the eastern side of the bypass at grid reference 231794 382319. The outlet of this pond would run southwards via a 300mm pipe in parallel to the bypass to discharge into the Afon Alaw at grid reference 231808 382243 at a rate of 13l/s.

4.7.10 In the south of the bypass, drainage would be captured by a combination of filter drains and, where the road crosses the Afon Alaw on a viaduct, via kerb drainage. Runoff would be directed towards an attenuation pond on the western side of the bypass at grid reference 231780 381714. The pond would have a volume of 400m^3 and discharge to field drains at a rate of 3.5l/s.

4.7.11 The drains would be designed to have the capacity to carry flows for a 1 in 1 year rainfall event and cause no flooding in a 1 in 5 year event as per the DMRB standards [RD12] and in line with the IACC requirements. Runoff intercepted from surrounding land would be captured in land drainage ditches that are appropriately sized and which would all discharge to the Afon Alaw.

4.7.12 Ponds would be sized to accommodate runoff from a 1 in 100 year return period storm event plus a 30% allowance for the effects of climate change.

Section 5 - Llanfaethlu

4.7.13 Runoff from the surface of the highway would drain to filter drains in the verge either side of the carriageway. The filter drains would be designed to have the capacity to carry flows for a 1 in 1 year rainfall event and cause no flooding in a 1 in 5 year event as per the DMRB standards [RD12] and in line with the IACC requirements.

4.7.14 The filter drains would discharge to three attenuation ponds. The southernmost pond provides 175m^3 of attenuation and is located east of the bypass at grid references 231906, 386480. The discharge from this pond is via pipe to the north-east where it discharges directly into the Afon Llanrhuddlad at a rate of 1.7l/s. The central pond is located 150m to the north-west, on the western side of the bypass at grid reference 231809 386589. The pond would provide 400m^3 of attenuation and it discharges in a south-westerly direction via pipe to a field drain at a rate of 4.8l/s. The northern pond is located east of the northern end of the bypass at grid reference 231805 387156. The pond would provide 390m^3 of attenuation and would discharge at a rate of 5.6l/s into East Drain, just upstream of its confluence with the Afon Llanrhuddlad.

4.7.15 Ponds have been sized to accommodate runoff from a 1 in 100 year return period storm event plus a 30% allowance for the effects of climate change.

Section 7 – Cefn Coch

4.7.16 Runoff from the surface of the highway would drain to filter drains situated in the verge either side of the carriageway. The filter drains would be designed to have the capacity to carry flows for a 1 in 1 year rainfall event and cause no flooding in a 1 in 5 year event as per the DMRB standards [RD12] and in line with the IACC requirements.

4.7.17 The filter drains would discharge to three attenuation ponds. The southernmost pond provides 451m^3 of attenuation and is located east of the bypass at grid references 233947, 389997. The discharge from this pond is via pipe to the north where it discharges directly into the confluence of Afon Llygeirian and Afon Cafnan at a rate of 2.7l/s. The central pond is located 436m to the north-east, on the eastern side of the bypass at grid reference 234142, 390387. The pond would provide 1,123m^3 of attenuation and it discharges in an easterly direction via pipe to Afon Cafnan at a rate of 7.6/s. The northern pond is located 270m further north and it lies to the east of the bypass at grid reference 234139, 390666. The pond would provide 373m^3 of attenuation and would discharge at a rate of 2.1l/s into Afon Cafnan.

4.7.18 Ponds have been sized to accommodate runoff from a 1 in 100 year return period storm event plus a 30% allowance for the effects of climate change.

Power Station Access Road junction

4.7.19 Runoff from the surface of the highway would be captured by filter drains and kerb drains and discharged to an earth ditch on the western side of the road,

with a small area of existing highway at the north of the junction discharging eastwards onto adjacent land. The earth ditches would transport runoff westwards where it would connect into the Power Station Access Road drainage.

4.7.20 There is no provision for attenuation and the drains would be designed to have the capacity to carry flows for a 1 in 1 year rainfall event and cause no flooding in a 1 in 5 year event as per the DMRB standards [RD12] and in line with the IACC requirements.

5 Flood modelling

5.1 Sources of modelling data

5.1.1 The sources of flood modelling data and flood mapping described below have been considered within the preparation of this FCA.

- **NRW river and tidal flood mapping [RD2]:** This mapping, delivered as part of a national programme, delineates indicative areas of elevated flood risk into four flood zones and includes both major fluvial (catchment area >3km^2) and tidal sources.
- **TAN 15 Development Advice Map [RD1]:** This mapping, which is primarily based on the NRW flood map, defines indicative areas where the annual probability of inundation from fluvial and tidal sources is greater than 0.1% (Zone C). It also identifies areas where there are geological indicators of elevated flood risk (Zone B) with low risk areas classified as Flood Zone A.
- **Pluvial Flood Risk Hydraulic Modelling (Amec Foster Wheeler, 2017):** Hydraulic modelling (see appendix G8-01.3 - G8-01.6 for full details) was undertaken to better understand the baseline pluvial flood risk for a range of events and to inform the development of measures to mitigate and manage the pluvial risk, as well as to inform an understanding of the need for adaptation for more extreme events.

5.2 NRW and TAN 15 flood maps

5.2.1 While the NRW fluvial and tidal flood map [RD2] does provide some additional detail in relation to flood probabilities over and above the TAN 15 Development Advice Map, the two are broadly comparable. Only the TAN 15 Development Advice Map, which shows the fluvial and coastal flood zones, as issued by the Welsh Government, is therefore discussed here as the classifications from this better relate to planning policy.

5.2.2 The TAN 15 Development Advice Map [RD1] categorises locations from A to C based on their perceived flood risk as detailed in section 1.3. The maps are based on the best currently available data. They use the Environment Agency's extreme flood outlines to inform Zone C and the British Geological Society's drift data to inform Zone B.

5.2.3 NRW's surface water flood maps have been used as the basis for the surface water flood risk assessment where detailed modelling was not available.

5.3 Fluvial and pluvial flood modelling

5.3.1 Fluvial and pluvial modelling has been undertaken by Amec Foster Wheeler for sections 1 and 3 and the Power Station Main Site, as these sources are relevant at those locations. Fluvial modelling only was undertaken for section 7, as there is no significant pluvial flood risk to section 7. Pluvial modelling

only was undertaken for the Off-Site Power Station Facilities, which is located at the northern end of section 5, as there is no significant fluvial flood risk to section 5. Tidal, fluvial and pluvial flooding has been modelled where relevant using Flood Modeller Pro [RD13] and TUFLOW software [RD14], as well as, for section 5 and the Wylfa Newydd Development Area, InfoWorks ICM software [RD15].

5.3.2 Hydraulic modelling was undertaken for a variety of scenarios, as indicated below.

- Section 1 (appendix G8-01.3):

  fluvial (AEP): 20%, 5%, 1%, 0.1%, 1% + climate change (CC) (30% as per current guidance on fluvial flow increases due to climate change allowances [RD5]);

  tidal (AEP): 0.5%, 0.1%, 0.1% + CC (2115, as per current guidance on sea level rise due to climate change allowances [RD5]); and

  joint (AEP): Fluvial 20%, Tidal 0.5%, Fluvial 1% + CC, Tidal 0.5% + CC.
- Section 3 (appendix G8-01.4):

  fluvial (AEP): 20%, 5%, 1%, 0.1%, 1% + CC (30%);

  tidal (AEP): 0.5%, 0.1%, 0.1% + CC (2115); and

  joint (AEP): Fluvial 20% Tidal 0.5%, Fluvial 1% + CC Tidal 0.5% + CC.
- Section 5 (appendix G8-01.5):

  pluvial (AEP): 3.3%, 1%, 0.1%, 1% + CC (20%), 1% + CC (40%).
- Section 7 (appendix G8-01.6):

  fluvial (AEP): 20%, 1%, 0.1%, 1% + CC (30%).
- Power Station Access Road junction (as part of Wylfa Newydd Development Area FCA and detailed in appendix D8-4 (Appendix Reference Number: 6.4.29)):

  fluvial (AEP): Summer profile - 50%, 3.3%, 1%, 0.1% - 2020s, 2080s (reasonably foreseeable and credible maximum) and 2180s (reasonably foreseeable) climate change allowances; and

  pluvial (AEP): 30min and 60min duration - 50%, 3.3%, 1%, 0.1% - 2020s, 2080s (reasonably foreseeable and credible maximum) and 2180s (reasonably foreseeable) climate change allowances.

5.3.3 The modelling uses more detailed topography and modelling methods and provides a more accurate representation of flood risk for use in the FCA than the TAN 15 Development Advice Map [RD1].

5.3.4 A number of points and lines have been used to retrieve model results as shown in appendices G8-01.3 to G8-01.6 from which flood depths and flows have been obtained and which have been used to illustrate the effect of the proposed bypass on flood risk.

5.3.5 More details on the models and results are presented in sections 6.2 to 6.6.

5.4 Modelling and climate change allowance

5.4.1 Guidance in TAN 15 [RD4] indicates that a FCA should be commensurate with the nature and scale of the proposed development. The Proposed Development would not alter the existing route of the A5025, and there would only be a very small increase in the area of hardstanding, which would be dealt with through appropriate drainage provision. Detailed survey and complex hydraulic modelling was considered necessary to identify and assess in more detail the risk of flooding to, or the effects on flood risk from, the proposed A5025 Off-line Highway Improvements. Reliance has therefore been placed on model results over the flood risk maps published by NRW [RD2] and the Welsh Government [RD1].

5.4.2 TAN 15 [RD4] states that consideration must be given to the effects climate change may have on the risk of flooding over the lifetime of a development; to ensure that development does not take place where flooding would be unacceptable either now or in the future.

5.4.3 The Welsh Government has provided guidance (CL-03-16) [RD5] on how the UK climate change projections (UKCP09) [RD6] should be used to determine the future flood consequences for developments in Wales and must be incorporated in all FCAs produced after December 2016. The guidance outlines a potential increase in main river flows by up to 75% (upper estimate) by the 2080s, however, it is recommended in the central estimate of 30% by the 2080s be used for FCAs. Welsh Government guidance on climate change allowances for planning purposes [RD5] has been used where appropriate in assessments of how climate change may affect flood risk.

6 Flood risk assessment

6.1 FCA methodology

6.1.1 The risk assessment methodology used within this FCA is set out in appendix G8-01.2 and is based on the methodology set out in the DMRB [RD12], taking into account the guidance in PPW [RD3] and associated guidance in TAN 15 [RD4]. The guidance recommends that flood risk be assessed through consideration of both the 'importance' of the receptor and the magnitude of potential effects. These are subsequently combined through a matrix to identify the significance of potential effect. The assessment takes into account the embedded and good practice mitigation detailed in section 8.4 of chapter G8 (Application Reference Number: 6.7.8).

Importance of receptor

6.1.2 The importance of a receptor according to the DMRB [RD12] is based on the number and type of those receptors affected. Appendix G8-01.2 presents the typical criteria set out in the DMRB for the importance of flood risk receptors, though these have also been mapped against development categories set out in TAN 15 [RD4] to ensure compliance with that guidance.

6.1.3 Following TAN 15 guidance the A5025 Off-line Highway Improvements can be classified as transport infrastructure. TAN 15 classes the development as "*less vulnerable development*" and this maps to a receptor of medium importance with respect to DMRB terminology. Under TAN 15 guidance an assessment of the built development off-site receptors considers them all to have a very high sensitivity to flooding. Undeveloped land is considered to have a medium sensitivity to flooding.

Magnitude of effect

6.1.4 The DMRB provides typical examples of what constitutes negligible to very high effects on flooding which are principally based on changes to flood levels or depths. Further information on the typical criteria by which the magnitude of effect is defined is presented within appendix G8-01.2.

Significance of effect

6.1.5 Significance of effect is defined through a matrix that takes the importance of the receptor and the magnitude of effect to classify the effect on flood risk within the categories Neutral to Very Large. Further information on the typical criteria against which the category is defined is presented in appendix G8-01.2.

Consideration of seasonality

6.1.6 Flooding can occur at any time of year, although it can exhibit quite different seasonal characteristics. Summer flooding is generally associated with localised, high intensity, convective rainfall events, resulting in rapid runoff response in which the peak flow is the main driver of flood risk. This can be a

particular issue in urban catchments where significant areas of impermeable surfaces result in rapid runoff. Winter events are generally associated with slower moving frontal systems, they are often prolonged and less intensive and they occur on typically wetter catchments, resulting in longer hydrographs with lower peaks but substantially more volume.

6.1.7 The catchments of concern in this study are essentially rural, they are generally small in size and have thin low permeability soils meaning that they are likely to be more susceptible to high intensity summer storms than to winter frontal events; a conclusion that is supported by predicted flood flows and levels from modelling of both winter and summer rainfall profiles. Presentation of the results for a summer event only is therefore based on the source of key flood risks on the proposed A5025 Off-line Highway Improvements during a relatively dry period. Furthermore, the mitigation measures proposed (see chapter G8 (Application Reference Number: 6.7.8)) are effective and appropriate for the hazards identified, and these are equally appropriate and no-less valid whether the hazard is derived from intense periods of runoff during summer events or longer volume-based events in the winter months.

6.2 Section 1 – Valley

FCA screening

6.2.2 Industry guidance [RD16] recommends that an FCA should consider all possible sources of flooding for a given site. This is also reflected in the TAN 15 [RD4] guidance on flood risk. A number of specific mechanisms exist to identify possible sources of flooding, but many of these can be easily discounted. These are discussed below. Table G8-01.1 summarises a range of potential risks and whether these are relevant to section 1 of the A5025 Off-line Highway Improvements.

Table G8-01.1 Screening of potential flood sources for section 1

Flood type	Source	Pathway	Consider further?
Tidal	Irish Sea flooding	Flooding inland from high tides	Yes
	Tidal influence on fluvial flooding	Tidal influence on fluvial flooding	Yes
Fluvial and pluvial	Fluvial flooding	Out-of-bank flows from watercourses	Yes
	Pluvial flooding from surface water runoff	Intense rainfall causing surface water ponding and flows	Yes
	Site development	Increased runoff from impermeable surfaces	Yes
		Loss of in floodplain storage increases water depths in other locations	Yes
Groundwater	Groundwater	Flooding of road due to groundwater emergence	Yes

Flood type	Source	Pathway	Consider further?
Services	Sewerage network	Surface water runoff due to network failure	Yes
	Water mains	Surface water runoff due to network failure	Yes
Reservoir flooding	Failure of reservoir	Sudden and increased fluvial flows due to reservoir failure	Yes

Tidal flood risk

6.2.3 The tidal extents of flooding have initially been assessed using TAN 15 Development Advice Map. Appendix G8-01.1 includes figures that show that the southern section of the proposed A5025 Off-line Highway Improvements, in particular the road junction with the A55, is located in Flood Zone C2, which is defined as an area of the floodplain without significant flood defence infrastructure. Flood Zone C2 shows the combined fluvial and tidal (0.1% AEP) flood extent, equivalent to a 1,000 year return period. As Flood Zone C2 reflects a combination of both tidal and fluvial flooding in this area it is difficult to define precisely the risk of tidal flooding to existing receptors and to the proposed A5025 Off-line Highway Improvements.

6.2.4 As mentioned above, it is also noted that the area benefits from a tidal gate adjacent to Tyddyn Y Cob Farm to the south-west of the A55. Despite the presence of this defence, the area is not shown to benefit from defences by NRW's flood map [RD2], therefore it is assumed that there is a residual risk from tidal flooding in events greater than the standard of protection afforded by the tidal gate.

6.2.5 Tidal flood modelling has been undertaken by Amec Foster Wheeler for both the baseline and the with-development scenario for the range of scenarios presented in section 5.3.2. The resultant tidal flood risk outlines are provided in appendix G8-01.3 , however, the key conclusions of the baseline modelling are:

- The tidal gate does provide protection up to and including the 0.1% AEP tidal flood level.
- Flooding upstream of the tidal gate is a result of tidal gate locking and the backup of water and inundation of low-lying areas.
- The effect of lower frequency tidal flood events is such that the tide gate locking effect occurs for longer and results in more extensive flooding of land upstream.
- There are five existing properties affected by flooding from this source, however, this is only the case with the effects of climate change.

6.2.6 The with-development modelling shows no change in tidal flood level at existing receptors for the 0.5% AEP and 0.1% AEP flood events and a slight benefit of less than 0.01m for existing properties for the 0.1% AEP event with

an allowance for climate change. The latter effect is principally due to the flood compensatory storage located to the west of the proposed bypass.

6.2.7 In line with the requirements of TAN 15 the depth of flooding, velocities of floodwater and rate of rise of flood water have been assessed for existing receptors. These results are shown in tables G8-01.2 to G8-01.4.

6.2.8 Based on the criteria in appendix G8-01.2, the with-development scenario is simulated to have a negligible beneficial magnitude of effect on tidal flooding.

6.2.9 With respect to other parameters, there are instances where velocities are slightly higher or rates of rise slightly higher when climate change is incorporated; however, these are negligible and directly related to the reduction in depths simulated.

6.2.10 The tidal influence on fluvial flooding was also investigated by running a combined 20% AEP fluvial event with a 0.5% AEP tidal event, which represents a current but likely scenario. The effects of climate change on a far less likely scenario was also considered by simulating a 1% AEP fluvial event combined with a 0.5% AEP tidal event with relevant allowances for fluvial flow increases and sea level rise to 2015.

6.2.11 These results are shown in tables G8-01.5 to G8-01.7, which indicates the following findings:

- the current effect of extreme tidal flooding on frequent fluvial flooding is limited, with only one existing receptor affected;
- the with-development scenario marginally reduces the depths, velocities and rate of rise at existing properties under this scenario; and
- the extremely unlikely but worst-case scenario of a 1% fluvial event and a 0.5% tidal event, both with climate change, produces a mixed outcome for the with-development scenario, with some increases in flood level at receptors equivalent to a minor adverse magnitude of effect, whilst at others there was a minor beneficial magnitude of effect.

6.2.12 In all simulated scenarios, the A5025 Off-line Highway Improvements remains free from flooding.

6.2.13 Overall, the proposed route of section 1 of the A5025 Off-line Highway Improvements is expected to have a negligible beneficial magnitude of effect on existing and future tidal flood risk in Valley, a receptor of high importance. This produces an effect of neutral significance. A minor beneficial magnitude of effect is expected on the existing risk of combined tidal and fluvial flooding, which has a slight significance. A minor adverse to beneficial magnitude of effect on a future but extremely unlikely worst-case combined tidal and fluvial flood risk also results in an effect of slight significance.

Table G8-01.2 Baseline and with-development effects on flood depths – tidal flooding

Results point	Location	Maximum water depths (m)								
		0.5% AEP			0.1% AEP			0.1% plus climate change AEP		
		Baseline scenario	Bypass scenario	Difference	Baseline scenario	Bypass scenario	Difference	Baseline scenario	Bypass scenario	Difference
4	Property	0	0	0	0	0	0	0.135	0.127	-0.008
25	Property	0	0	0	0	0	0	0.004	0	-0.004
26	Property	0	0	0	0	0	0	0.230	0.222	-0.008
31	Property	0	0	0	0	0	0	0.071	0.063	-0.008
32	Property	0	0	0	0	0	0	0.330	0.322	-0.008

Table G8-01.3 Baseline and with-development effects on flood velocities – tidal flooding

Results point	Location	Maximum velocity (m/s)								
		0.5% AEP			0.1% AEP			0.1% plus climate change AEP		
		Baseline scenario	Bypass scenario	Difference	Baseline scenario	Bypass scenario	Difference	Baseline scenario	Bypass scenario	Difference
4	Property	0	0	0	0	0	0	0.004	0.012	+0.008
25	Property	0	0	0	0	0	0	<0.001	0	-<0.001
26	Property	0	0	0	0	0	0	0.004	0.004	0
31	Property	0	0	0	0	0	0	0.001	0.001	0
32	Property	0	0	0	0	0	0	0.039	0.091	+0.052

Table G8-01.4 Baseline and with-development effects on rate of rise of flood water – tidal flooding

Results point	Location	Maximum rate of rise (m/h)								
		0.5% AEP			0.1% AEP			0.1% plus climate change AEP		
		Baseline scenario	Bypass scenario	Difference	Baseline scenario	Bypass scenario	Difference	Baseline scenario	Bypass scenario	Difference
4	Property	0	0	0	0	0	0	0.087	0.084	-0.003
25	Property	0	0	0	0	0	0	0.023	0	-0.023
26	Property	0	0	0	0	0	0	0.342	0.331	-0.011
31	Property	0	0	0	0	0	0	0.069	0.069	0
32	Property	0	0	0	0	0	0	0.119	0.122	+0.003

Table G8-01.5 Baseline and with-development effects on flood depths – fluvial and tidal flooding

Results point	Location	Maximum water depths (m)					
		Fluvial 20% and Tidal 0.5%			Fluvial 1% + CC & Tidal 0.5% CC		
		Baseline scenario	Bypass scenario	Difference	Baseline scenario	Bypass scenario	Difference
1	A5	0	0	0	0.057	0.067	+0.010
3	Property	0	0	0	0.428	0.403	-0.025
4	Property	0	0	0	0.561	0.536	-0.025
17	Property	0	0	0	0.129	0.139	+0.010
20	Property	0	0	0	0.330	0.340	+0.010
22	Property	0	0	0	0.261	0.271	+0.010
25	Property	0	0	0	0.416	0.426	+0.010
26	Property	0	0	0	0.643	0.653	+0.010
29	Property	0	0	0	0.271	0.281	+0.010
31	Property	0	0	0	0.497	0.473	-0.024

Results point	Location	Maximum water depths (m)					
		Fluvial 20% and Tidal 0.5%			Fluvial 1% + CC & Tidal 0.5% CC		
		Baseline scenario	Bypass scenario	Difference	Baseline scenario	Bypass scenario	Difference
32	Property	0.097	0.083	-0.014	0.756	0.731	-0.024
37	Property	0	0	0	0.230	0.205	-0.025

Table G8-01.6 Baseline and with-development effects on flood velocities – fluvial and tidal flooding

Results point	Location	Maximum velocities (m/s)					
		Fluvial 20% and Tidal 0.5%			Fluvial 1% + CC & Tidal 0.5% CC		
		Baseline scenario	Bypass scenario	Difference	Baseline scenario	Bypass scenario	Difference
1	A5	0	0	0	0.395	0.443	+0.048
3	Property	0	0	0	0.005	0.004	-0.001
4	Property	0	0	0	0.036	0.029	-0.007
17	Property	0	0	0	0.001	0.002	+0.001
20	Property	0	0	0	0.002	0.002	0
22	Property	0	0	0	0.006	0.004	-0.002
25	Property	0	0	0	0.004	0.014	+0.010
26	Property	0	0	0	0.007	0.006	-0.001
29	Property	0	0	0	0.004	0.002	-0.002
31	Property	0	0	0	0.015	0012	-0.003
32	Property	0.052	0.030	-0.022	0.037	0.054	+0.017
37	Property	0	0	0	0.002	0.002	0

Table G8-01.7 Baseline and with-development effects on rate of rise of flood water – fluvial and tidal flooding

Results point	Location	Maximum rate of rise (m/h)					
		Fluvial 20% and Tidal 0.5%			Fluvial 1% + CC & Tidal 0.5% CC		
		Baseline scenario	Bypass scenario	Difference	Baseline scenario	Bypass scenario	Difference
1	A5	0	0	0	0.132	0.121	-0.011
3	Property	0	0	0	0.101	0.104	+0.003
4	Property	0	0	0	0.101	0.104	+0.003
17	Property	0	0	0	0.515	0.490	-0.025
20	Property	0	0	0	1.220	1.205	-0.015
22	Property	0	0	0	0.446	0.454	+0.009
25	Property	0	0	0	0.253	0.250	-0.003
26	Property	0	0	0	0.530	0.522	-0.008
29	Property	0	0	0	0.296	0.304	+0.008
31	Property	0	0	0	0.101	0.104	+0.003
32	Property	0.104	0.093	-0.011	0.132	0.130	-0.002
37	Property	0	0	0	0.461	0.428	-0.033

Fluvial and pluvial flood risk

Fluvial flood risk

6.2.14 Fluvial flood modelling has been undertaken by Amec Foster Wheeler for both the baseline and the with-development scenario for the range of scenarios presented in section 5.3.2. The resultant fluvial flood risk outlines are provided in appendix G8-01.3, however, the key conclusions of the baseline modelling are:

- Flooding upstream of the A55 and railway bridge is primarily the result of tidal gate locking and the backup of water and inundation of low-lying areas.
- Even when the flow in the watercourses is receding, flood extents remain and continue to expand because of the effect of tide locking.
- There are seven existing properties affected by flooding from this source for the 0.1% AEP event.

6.2.15 In line with the requirements of TAN 15 the depth of flooding, velocities of floodwater and rate of rise of flood water have been assessed for existing receptors. These results are shown in tables G8-01.2 to G8-01.4.

6.2.16 The with-development modelling generally shows no change in fluvial flood level at existing receptors or a benefit of negligible to minor magnitude for all return periods. With respect to other parameters, though there are instances where velocities are slightly higher or rates of rise slightly higher when climate change is incorporated, however, these are negligible and directly related to the reduction in depths simulated.

6.2.17 In all scenarios simulated, the A5025 Off-line Highway Improvements remain free from flooding.

6.2.18 Overall, the proposed route of section 1 of the A5025 Off-line Highway Improvements is expected to have a negligible to minor beneficial magnitude of effect on existing and future fluvial and tidal flood risk in Valley, a receptor of high importance. This produces an effect of neutral to slight significance.

Table G8-01.8 Baseline and with-development effects on flood depths – fluvial flooding

Results point	Location	Maximum depths (m)														
		20% AEP			5% AEP			1% AEP			0.1% AEP			1% AEP + CC		
		Baseline scenario	Bypass scenario	Diff	Baseline scenario	Bypass scenario	Diff	Baseline scenario	Bypass scenario	Diff	Baseline scenario	Bypass scenario	Diff	Baseline scenario	Bypass scenario	Diff
3	Property	0	0	0	0	0	0	0	0	0	0.319	0.310	-0.009	0.339	0.327	-0.012
4	Property	0	0	0	0	0	0	0.129	0.128	-0.001	0.452	0.443	-0.009	0.472	0.460	-0.012
25	Property	0	0	0	0	0	0	0	0	0	0.272	0.270	-0.002	0.332	0.328	-0.004
26	Property	0	0	0	0	0	0	0.062	0.015	-0.047	0.500	0.497	-0.003	0.558	0.555	-0.003
29	Property	0	0	0	0	0	0	0	0	0	0.128	0.126	-0.002	0.187	0.184	-0.003
31	Property	0	0	0	0	0	0	0.066	0.061	-0.005	0.389	0.380	-0.009	0.409	0.396	-0.013
32	Property	0.051	0.039	-0.012	0.180	0.167	-0.013	0.325	0.320	-0.005	0.648	0.639	-0.009	0.667	0.655	-0.012

Table G8-01.9 Baseline and with-development effects on flood velocities – fluvial flooding

Results point	Location	Maximum velocities (m/s)														
		20% AEP			5% AEP			1% AEP			0.1% AEP			1% AEP + CC		
		Baseline scenario	Bypass scenario	Diff	Baseline scenario	Bypass scenario	Diff	Baseline scenario	Bypass scenario	Diff	Baseline scenario	Bypass scenario	Diff	Baseline scenario	Bypass scenario	Diff
3	Property	0	0	0	0	0	0	0	0	0	0.003	0.002	-0.001	0.003	0.003	0
4	Property	0	0	0	0	0	0	0.013	0.013	0	0.025	0.020	-0.005	0.031	0.026	-0.005
25	Property	0	0	0	0	0	0	0	0	0	0.005	0.005	0	0.004	0.004	0
26	Property	0	0	0	0	0	0	0.001	0.001	0	0.006	0.006	0	0.006	0.007	+0.001
29	Property	0	0	0	0	0	0	0	0	0	0.001	0.001	0	0.002	0.004	+0.002

Results point	Location	Maximum velocities (m/s)														
		20% AEP			5% AEP			1% AEP			0.1% AEP			1% AEP + CC		
		Baseline scenario	Bypass scenario	Diff	Baseline scenario	Bypass scenario	Diff	Baseline scenario	Bypass scenario	Diff	Baseline scenario	Bypass scenario	Diff	Baseline scenario	Bypass scenario	Diff
31	Property	0	0	0	0	0	0	0.001	0.001	0	0.010	0.008	-0.002	0.012	0.010	-0.002
32	Property	0.048	0.042	-0.006	0.064	0.032	-0.032	0.121	0.110	-0.010	0.059	0.030	-0.029	0.036	0.081	+0.045

Table G8-01.10 Baseline and with-development effects on rate of rise of flood water – fluvial flooding

Results point	Location	Maximum rate of rise (m/h)														
		20% AEP			5% AEP			1% AEP			0.1% AEP			1% AEP + CC		
		Baseline scenario	Bypass scenario	Diff	Baseline scenario	Bypass scenario	Diff	Baseline scenario	Bypass scenario	Diff	Baseline scenario	Bypass scenario	Diff	Baseline scenario	Bypass scenario	Diff
3	Property	0	0	0	0	0	0	0	0	0	0.108	0.103	-0.005	0.097	0.099	+0.002
4	Property	0	0	0	0	0	0	0.091	0.088	-0.003	0.108	0.104	-0.004	0.097	0.099	+0.002
25	Property	0	0	0	0	0	0	0	0	0	0.262	0.265	+0.003	0.245	0.244	-0.001
26	Property	0	0	0	0	0	0	0.062	0.043	-0.019	0.449	0.469	+0.020	0.535	0.532	-0.003
29	Property	0	0	0	0	0	0	0	0	0	0.315	0.308	-0.007	0.257	0.278	+0.021
31	Property	0	0	0	0	0	0	0.078	0.079	-0.001	0.108	0.104	-0.004	0.097	0.099	+0.002
32	Property	0.094	0.092	-0.020	0.104	0.107	+0.03	0.093	0.088	-0.005	0.134	0.117	-0.017	0.129	0.121	-0.008

Pluvial flood risk

6.2.19 The NRW surface water flood maps show that there are pockets of surface water flood risk in the area around the proposed route of the A5025 Off-line Highway Improvements. This includes a moderate risk of flooding along a field boundary where the roundabout is proposed and, in low-lying areas west of the proposed alignment, an area with a low to high risk, which is indicated to affect a property with a high importance on the eastern edge of Valley. These areas are shown on figure G8-1-7.

6.2.20 The slowly permeable soils which underlie section 1 also contribute towards the surface water risk here as these soils result in limited infiltration potential and therefore areas prone to surface water ponding and contribute to high rates of surface water runoff. This also means that groundwater recharge into the underlying bedrock is reduced. A full soil report is provided in appendix A1 of chapter G7 (Application Reference Number: 6.7.7).

6.2.21 The alignment of the proposed A5025 Off-line Highway Improvements avoids the larger areas of surface water flood risk, with the exception of an area of field drain in the location of the proposed roundabout. Raising the highway above the current ground level would ensure that there is no surface water flood risk to the bypass itself whilst provision of drainage features to maintain existing flow paths would ensure that the raised highway does not create a barrier to flow that could increase the risk of flooding on the upstream side. Further, the proposed compensatory storage area is expected to benefit local surface water flooding in the low-lying areas west of the proposed alignment.

6.2.22 Overall, the proposed route of section 1 of the A5025 Off-line Highway Improvements is expected to have a negligible to minor beneficial magnitude of effect on existing and future surface water flood risk in Valley, a receptor of high importance. This produces an effect of neutral to slight significance.

Risk of runoff to off-site undeveloped areas

6.2.23 As indicated in section 4.5, the runoff from the bypass would be collected by over-the-edge drain, discharged into the Cleifiog Isaf via an existing culvert or by over-the-edge/filter/kerb drains discharged into the Cleifiog Fawr. The drains would be designed to have the capacity to carry flows for a 1 in 1 year rainfall event and cause no flooding in a 1 in 5 year event as per the DMRB standards [RD12] and in line with the IACC requirements, which is likely to be equivalent to or better than highway drainage on the existing A5 and existing A5025.

6.2.24 Due to the high topography of the area to the east of the proposed bypass, it was deemed impractical to provide attenuation ponds outside of the floodplain for this section of the highway, whilst provision on the west of the alignment would result in unnecessary encroachment into the floodplain and effects on flood risk.

6.2.25 The introduction of impermeable surfaces is expected to increase the rate and volume of runoff compared to the natural state where a degree of runoff would

be able to penetrate through the soils. Any additional runoff may contribute to an increase in flow and therefore increase in flood level to areas that are currently shown to flood from surface water, fluvial and tidal sources.

6.2.26 Given the proposed drainage and extent of the floodplain in this area and the mechanisms of flooding, any increase in level is expected to be local and restricted to less than 10mm and only occur in greater than the 20% AEP or 1 in 5 year event. The proposed route of section 1 of the A5025 Off-line Highway Improvements is therefore expected to produce no greater than a negligible magnitude of effect, which may be minor close to the bypass. Undeveloped land affected is considered to have a low sensitivity to flood risk and a negligible to minor magnitude of effect would result in a neutral to slight significance of effect.

Risk of runoff to off-site developed areas of Valley

6.2.27 The risk of effects to developed areas due to the additional impermeable area is less likely due to the distance of the receptors from the bypass and the location of these high importance receptors on the very edge of the floodplain. Their location on the edge of the floodplain means that any negligible to minor effect on flood levels directly caused by the introduction of impermeable surfaces from the A5025 Off-line Highway Improvements must necessarily coincide with the most extreme flood extents associated with other sources of flooding.

6.2.28 The proposed route of section 1 of the A5025 Off-line Highway Improvements is therefore expected to produce no greater than a negligible magnitude of effect on off-site receptors on the edge of the floodplain to the east of Valley. These receptors have a high importance with respect to flood risk; however, a negligible magnitude of effect would result in a neutral significance of effect.

Groundwater flood risk

Groundwater emergence at surface

6.2.29 The majority of section 1 is underlain by tidal flat deposits, with an area to the north and east underlain by glacial till (see figure G7-4 (Application Reference Number: 6.7.48)). The tidal flat deposits are defined by NRW as unproductive strata, whilst the glacial till is Secondary (undifferentiated), albeit that when the till has a clay matrix, it will be of low permeability. These strata have a neutral significance for groundwater supply. The likelihood of encountering groundwater in the superficial deposits is therefore low, although there may be small amounts of groundwater present in any sand and gravel layers within the till (if present these will be limited in volume and extent). Groundwater levels measured following the ground investigation (appendix G7-2 in chapter G7 (Application Reference Number: 6.7.7)) near to this section were found to vary between 0.13m and 1.37m below ground level but there is currently no data regarding seasonal variations.

6.2.30 The superficial deposits (especially those with a clay matrix) are generally of low permeability and have limited water storage capacity such that

groundwater movement is limited. In the unlikely event of groundwater rising above the ground level the area of influence would be small as would the volume of groundwater involved. In all instances during periods of heavy rainfall it will be rainfall runoff across the low permeability drift that will be the concern for flood risk rather than water movement through the superficial deposits.

6.2.31 The bedrock, which is mica schist and psammite of the New Harbour Group (see figure G7-7 (Application Reference Number: 6.7.48)), is classified by NRW as a Secondary B Aquifer, with lower-permeability layers of rock which may store and yield limited amounts of groundwater, though these are not expected to contribute to flooding. Groundwater movement from the bedrock to surface will be restricted by the presence of low permeability superficial deposits which were shown to be over 10m thick by the ground investigation (appendix G7-2 in chapter G7 (Application Reference Number: 6.7.7)), albeit that the boreholes drilled are not along the current alignment. In any areas where the superficial deposits are thin, granular or absent there is potential for groundwater to emerge at the surface, but due to the low permeability and storage characteristics of the bedrock the area concerned and volumes involved would be very small and would be subservient to rainfall runoff.

6.2.32 For the reasons identified above, the A5025 Off-line Highway Improvements are expected to have a negligible magnitude of effect on groundwater and groundwater flood risk, and a neutral significance on this source of flood risk to either the bypass itself or to off-site receptors.

Reservoir flood risk

6.2.33 Section 1 of the A5025 Off-line Highway Improvements sits within the footprint of the expected flood outline if the Llyn Alaw were to fail (figure G8-1-8). In addition to following the route of the Afon Alaw to the coast from Llanfachraeth, some flood water from a reservoir failure is expected to follow unnamed watercourses and field drains parallel to the A5025 from Llanynghenedl to Valley. Both of these flow paths affect the A5025 Off-line Highway Improvements, as well as areas within the south and eastern edge of Valley itself, including the B4545 road and the railway line to the south-west of the A5. The A55 is not shown to be effected.

6.2.34 The modelling of reservoir flood risk by NRW constitutes the worst case scenario and it is unlikely that the extent of flooding would be this large. Reservoir flooding is also extremely unlikely to happen because of the management regime implemented under the Reservoirs Act 1975 where all large reservoirs must be inspected regularly and any essential safety work be undertaken when required.

6.2.35 Despite the potentially high consequences of failure, the magnitude of effect that the A5025 Off-line Highway Improvements are expected to have on flood consequences is expected to be negligible, resulting in a neutral effect on this very unlikely source of flood risk.

Services

6.2.36 Mains water supply and sewers are understood to follow the existing A5025. Section 1 of the A5025 Off-line Highway Improvements would move the main route of the road away from these services and therefore away from any potential hazard posed by their failure. Furthermore, the alignment is outside of areas that are shown to be at risk from surface water flood risk, which represent the most likely areas to be affected should there be a failure of water supply or sewer assets.

6.2.37 Given the above, the magnitude of effect that the proposed A5025 Off-line Highway Improvements are expected to have on flood consequences is expected to be negligible, resulting in a neutral effect on this source of flood risk.

Flood risks – section 1 Valley

6.2.38 The flood risk from the sources outlined above, to the receptors identified in section 3 of this report, are provided in table G8-01.11. This is based on the methodology detailed in appendix G8-01.2.

Table G8-01.11 Flood risk – section 1

Flood type	Source	Pathway	Receptor	Importance	Magnitude of effect	Significance of effect
Tidal	Irish Sea flooding	Flooding inland from high tides	Off-site receptors at Valley	High	Negligible beneficial	Neutral
			Undeveloped off-site receptors	Low	Negligible beneficial	Neutral
			Existing A5	Medium	Negligible beneficial	Neutral
			Section 1 - A5025 Off-line Highway Improvements	Medium	Negligible beneficial	Neutral
		Tidal influence on fluvial flooding	Off-site receptors at Valley	High	Minor beneficial and adverse	Slight
			Undeveloped off-site receptors	Low	Negligible beneficial	Neutral
			Existing A5	Medium	Minor adverse	Slight
			Section 1 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral
Fluvial and pluvial	Fluvial flooding	Flooding from out-of-bank flows from neighbouring watercourses	Off-site receptors at Valley	High	Minor beneficial	Slight
			Undeveloped off-site receptors	Low	Minor beneficial	Neutral
			Existing A5	Medium	Negligible	Neutral
			Section 1 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral
	Pluvial flooding from surface water runoff	Intense rainfall causing surface water flooding to highway	Off-site receptors at Valley	High	Minor beneficial	Slight
			Undeveloped off-site receptors	Low	Minor beneficial	Neutral
			Existing A5	Medium	Negligible	Neutral
			Section 1 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral
	Site development	Increased runoff from impermeable surfaces	Undeveloped off-site receptors	Low	Minor adverse	Neutral

Flood type	Source	Pathway	Receptor	Importance	Magnitude of effect	Significance of effect
		Increased runoff from impermeable surfaces	Developed off-site receptors	High	Negligible	Neutral
Groundwater	Groundwater	Flooding of road due to groundwater emergence	Off-site receptors at Valley	High	Negligible	Neutral
			Undeveloped off-site receptors	Low	Negligible	Neutral
			Existing A5	Medium	Negligible	Neutral
			Section 1 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral
Services	Sewerage network	Surface water runoff due to network failure	Off-site receptors at Valley	High	Negligible	Neutral
			Undeveloped off-site receptors	Low	Negligible	Neutral
	Water mains		Existing A5	Medium	Negligible	Neutral
			Section 1 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral
Reservoir flooding	Failure of reservoir	Runoff due to reservoir failure	Off-site receptors at Valley	High	Negligible	Neutral
			Undeveloped off-site receptors	Low	Negligible	Neutral
			Existing A5	Medium	Negligible	Neutral
			Section 1 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral

6.3 Section 3 – Llanfachraeth

FCA screening

6.3.2 Table G8-01.12 summarises a range of potential risks and whether these are relevant to the A5025 Off-line Highway Improvements section 3.

Table G8-01.12 Screening of potential flood sources for section 3

Flood type	Source	Pathway	Consider further?
Tidal	Irish Sea flooding	Flooding inland from high tides. Section 3 is at the extent of the tidal limit	Yes
	Tidal influence on fluvial flooding	Tidal influence on fluvial flooding	Yes
Fluvial and pluvial	Fluvial flooding	Flooding from out-of-bank flows from watercourses. Development crosses the Afon Alaw and floodplain and other watercourses	Yes
		Increased flood risk to upstream properties due to constriction in flow from road crossing	Yes
	Pluvial flooding from surface water runoff	Intense rainfall causing surface water ponding and flows	Yes
	Site development	Increased runoff from impermeable surfaces	Yes
Groundwater	Groundwater	Flooding of road due to groundwater emergence	Yes
Services	Sewerage network	Surface water runoff due to network failure	Yes
	Water mains	Surface water runoff due to network failure	Yes
Reservoir flooding	Failure of reservoir	Runoff due to reservoir failure	Yes

Tidal flood risk

6.3.3 Tidal flood risk has been included in the hydraulic modelling of the Afon Alaw and Afon Llywenan using Flood Modeller Pro v 4.2 [RD13] and TUFLOW Build 2016-03-AE-w64 [RD14].

6.3.4 Analysis of the flood propagation shows that flooding starts on the right bank of the Afon Alaw estuary and around the area of Neuadd-Wen as a result of the tidal level and estuary flood mechanism. There is limited flooding upstream of the A5025 road bridge on the Afon Alaw. As the event progresses the estuary flooding extends on the right bank and commences on the left bank. By the peak of the event the majority of the flooding is via the estuary,

downstream of the A5025 road bridge. In the upstream area of the A5025 road bridge, the flooding extends to the confluence of the two watercourses. The extents of the tidal flooding are shown on plans in appendix G8-01.4.

6.3.5 Flood levels have been extracted from the model results grids to determine the flood levels that may be experienced. Table G8-01.13 provides the flood levels expected during tidal events of different probabilities at two key nodes in the 1D element of the hydraulic model, which are shown in appendix G8-01.4. Climate change was applied to estimate the effect on tidal levels by 2080 and 2114 as given in the guidance [RD5].

Table G8-01.13 Baseline peak water levels immediately upstream of the proposed A5025 river crossing

Scenario	Afon Alaw ALAW01_1271i (1D) (mAOD)	Afon Llywenan TRIB01_0148 (1D) (mAOD)
T200	4.31	4.29
T1000	4.49	4.47
T1000cc	5.59	5.59

6.3.6 With the incorporation of the bypass into the model the effect on flood levels in the Afon Alaw and Afon Llywenan are shown in table G8-01.14. Water levels in the Afon Alaw are effected more than the Afon Llywenan with a maximum difference in level of 0.02m.

Table G8-01.14 Bypass maximum tidal water level at node and difference to maximum baseline water level

Scenario	Afon Alaw ALAW01_1271i (1D) (mAOD)	Afon Alaw difference (m)	Afon Llywenan TRIB01_0148 (1D) (mAOD)	Afon Llywenan difference (m)
T200	4.33	+0.02	4.29	0
T1000	4.50	+0.01	4.48	+0.01
T1000cc	5.59	0	5.59	0

6.3.7 Analysis of off-site receptors, including adjacent properties and the existing A5025 bridge, indicates that a single property is currently affected by tidal flooding. Table G8-01.15 indicates the predicted flood level at that property.

Table G8-01.15 Baseline peak water levels at property downstream of the proposed A5025 crossing

Scenario	Off-site receptor downstream of proposed A5025 crossing
T200	4.272
T1000	4.463

6.3.8 With the incorporation of the bypass into the model the effect on flood levels in the property are shown in table G8-01.16. Because of the minor constraint on flow caused by the new viaduct, which is responsible for the increase upstream of the viaduct, shown in table G8-01.14, of up to +0.02m, there is a corresponding, albeit negligible, reduction in flood level simulated.

Table G8-01.16 With-development peak water levels at property downstream of the proposed A5025 crossing

Scenario	Off-site receptor downstream of proposed A5025 crossing	Difference (m)
T200	4.272	<0.001
T1000	4.463	<0.001

6.3.9 The conclusion of this analysis is that whilst there is an existing property shown to be at tidal flood risk, the effect of the proposed A5025 Off-line Highway Improvements is beneficial, albeit negligible in magnitude. The significance of effect is therefore neutral.

6.3.10 The tidal influence on fluvial flooding was also investigated by running a combined 1% AEP fluvial event with a 0.5% AEP tidal event, both with the effects of climate change to 2114. Table G8-01.17 provides the flood levels expected during a combined fluvial and tidal event for the baseline and with-development scenarios at two key nodes in the 1D element of the hydraulic model and at the property identified as being at risk downstream of the proposed viaduct.

Table G8-01.17 Simulated maximum peak water levels immediately upstream of the proposed A5025 river crossing – fluvial and tidal flooding

Scenario	Afon Alaw ALAW01_1271i (1D) (mAOD)	Afon Llywenan TRIB01_0148 (1D) (mAOD)	Off-site receptor downstream of proposed A5025 crossing
Baseline	5.66	5.65	5.62
With-development	5.68	5.66	5.61
Difference	+0.02	+0.01	-0.01

6.3.11 Analysis of off-site receptors, including adjacent properties and the existing A5025 bridge, indicates that the property located in the floodplain downstream of the proposed viaduct would benefit, albeit by a negligible amount. Elsewhere, table G8-01.16 indicates that there is a minor magnitude of effect on off-site undeveloped receptors in the floodplain.

6.3.12 The key conclusions of the tidal modelling are as described below.

- Tidal flooding extends as far as the confluence of the Afon Alaw and Afon Llywenan but is limited beyond.
- There is an existing property shown to be at tidal flood risk in a 5% AEP flood event and above.
- The effect of the proposed A5025 Off-line Highway Improvements is simulated to be beneficial, albeit negligible in magnitude.
- The with-development modelling shows a minor magnitude increase in flood levels in undeveloped land upstream within the floodplain.
- In all simulated scenarios, the proposed A5025 Off-line Highway Improvements remain free from flooding.

6.3.13 Overall, the proposed route of section 3 of the A5025 Off-line Highway Improvements is expected to have a minor adverse magnitude of effect on tidal and tidally influenced fluvial flood risk to undeveloped receptors in the floodplain, which have a low importance. This produces an effect of neutral significance. The proposals are expected to have a negligible beneficial magnitude of effect on developed off-site receptors or high importance, which is also of neutral significance.

Fluvial and pluvial flood risk

Fluvial flood risk

6.3.14 Much of the proposed route of the A5025 Off-line Highway Improvements section 3 falls in Flood Zone A and it is therefore considered at a low risk of fluvial flooding. However, section 3 does cross a number of watercourses and these areas need further consideration. The most significant of these is the Afon Alaw and its tributary, Afon Llywenan, where the proposed A5025 Off-line Highway Improvements cross just upstream of their confluence.

6.3.15 Fluvial flood risk hydraulic modelling of the Afon Alaw and Afon Llywenan using Flood Modeller Pro v 4.2 [RD13] and TUFLOW Build 2016-03-AE-w64 [RD14] has been undertaken. For fluvial only modelling the Mean High Water Spring level was used as the downstream boundary of the model and the baseline and with-development models were simulated for the range of scenarios presented in section 5.3.2.

6.3.16 At the 1% AEP event, flood propagation shows that flooding starts on the Afon Alaw upstream of the A5025 road bridge and in the upper and mid reaches of the Llywenan tributary. The existing A5025 road bridge is therefore shown to be a hydraulic control on the flood behaviour, causing the initial out-of-bank flooding upstream. As the event progresses the flooding in these areas extend further and flooding also starts in the upstream reaches of the Afon Alaw and around the area of Neuadd-Wen as a result of the tidal level and estuary flood mechanism. By the peak of the event (peak here refers to the time of the peak of the hydrograph) flooding is seen on both banks along the majority of the Afon Alaw and Llywenan tributary, within the study area.

6.3.17 There is one existing property that is at risk of flooding in all events from the 5% AEP event and above, which is located on the right bank at the river crossing. Elsewhere, the local topography constrains the flood extent upstream of the A5025 road bridge, with little difference seen between flood extents for different event scenarios around the location of the proposed bypass. Further upstream on the Afon Alaw the difference between extents is more apparent, although the Llywenan tributary remains topographically constrained until its most upper reaches. The modelled flood outlines are provided in appendix G8-01.4 (Appendix Reference Number: 6.7.20).

6.3.18 Table G8-01.18 presents the flood levels in the baseline flood levels for key nodes from the 1D model and for a key developed receptor within the floodplain, downstream of the proposed viaduct.

Table G8-01.18 Simulated maximum peak water levels (mAOD)

Scenario	Afon Alaw ALAW01_1271i (1D) (mAOD)	Afon Llywenan TRIB01_0148 (1D) (mAOD)	Off-site receptor downstream of proposed A5025 crossing
5%AEP	4.26	4.04	3.83
1%AEP	4.48	4.33	4.19
0.1%AEP	5.20	5.16	5.05
1%AEP + CC	4.81	4.74	4.63

6.3.19 With the incorporation of the bypass into the model, the water level immediately upstream of the bypass is increased in the Afon Alaw and Afon Llywenan by 0.09m and 0.02m respectively. The increase in extent of flooding at Pont Llanfigael is not sufficient to effect properties upstream of the viaduct in events up to the 0.1% AEP event. The flood levels at the property downstream are shown to remain unaffected (table G8-01.19).

Table G8-01.19 Bypass maximum fluvial water level (mAOD) and difference (m) to maximum baseline water level

Scenario	Afon Alaw ALAW01_1271i (1D) (mAOD)	Afon Alaw difference (m)	Afon Llywenan TRIB01_0148 (1D) (mAOD)	Afon Llywenan Difference (m)	Off-site receptor downstream of proposed A5025 crossing	Off-site receptor difference (m)
5%AEP	4.31	0.05	4.06	0.02	3.83	0
1%AEP	4.57	0.09	4.35	0.02	4.19	0
0.1%AEP	5.27	0.07	5.18	0.02	5.05	0
1%AEP + CC	4.89	0.08	4.75	0.01	4.63	0

6.3.20 The flood mechanism is not significantly effected by the bypass structure and the event at which the flooding commences is not effected (lowest event analysed was the 5% AEP event). The bypass generally reduces flood levels immediately downstream of the bypass structure and local to the structure

itself. However, the one property at risk of flooding in the baseline modelling does not have any change in the depth of flooding.

6.3.21 Mapping showing the areas of increase and decrease in the depths of water is provided in Appendix G8-01.4.

6.3.22 The key conclusions of the fluvial modelling are outlined below.

- Fluvial flooding affects land within the floodplain and a single property on the right bank of the Afon Alaw only.
- There is a property shown to be at fluvial flood risk in a 5% AEP flood event and above.
- The effect of the proposed A5025 Off-line Highway Improvements is simulated to be generally negligible in magnitude downstream, with slightly reduced water levels. Upstream the effect is minor on the Afon Llywenan and moderate on the Afon Alaw from increased levels upstream.
- In all simulated scenarios, the proposed A5025 Off-line Highway Improvements remains free from flooding.

6.3.23 Overall, the proposed route of section 3 of the A5025 Off-line Highway Improvements is expected to have a negligible to moderate magnitude of effect on fluvial flood risk, with the effect dependent upon the location within the floodplain. This produces an effect of neutral to slight significance.

Pluvial flood risk to the A5025 Off-line Highway Improvements section 3

6.3.24 The NRW surface water maps [RD2] have been used to assess the level of surface water flood risk to the proposed route of section 3 of the A5025 Off-line Highway Improvements. There is generally a low risk of pluvial flooding to Section 3. Some risk of surface water flooding has been identified corresponding to the floodplains of the rivers and farm drains along the route.

6.3.25 To the southern end of section 3 is a field drain, south of Erw Goch Back, in which a medium risk of surface water flooding is indicated that is associated with the immediate confines of the drain. The highway would be raised above existing ground level at this location with culverts underneath the road.

6.3.26 The existing crossing of the Afon Alaw and Afon Llywenan is shown to be at high risk of flooding from surface water (greater than a 3.33% AEP). The flood outline of pluvial flooding is not as extensive as Flood Zone C2 of the Development Advice Map, nor as extensive as the fluvial flood extents and effects described above. Despite this, there appears to be an existing low risk to a property on the right bank immediately upstream of the existing crossing. It is anticipated that the viaduct would have a negligible effect on surface water flood risk at this property, as was shown with respect to fluvial flood risks at this location.

6.3.27 Further north there are two other watercourses that the proposed A5025 Off-line Highway Improvements would cross. A small field drain flows towards the

village in a south-westerly direction, which is then culverted beneath Stad Roebuck and Parc Llynnon. The NRW surface water flood map shows that there is currently a risk of surface water flooding along the drain and in the vicinity, though there is no flooding shown affecting the properties on Stad Roebuck or Parc Lynnon.

6.3.28 The route of the proposed A5025 Off-line Highway Improvements cuts across the upper reach of this field drain immediately to the west of the area of flooding shown along the drain and in the vicinity of Stad Roebuck or Parc Lynnon. The A5025 Off-line Highway Improvements at this location would be in a shallow cutting, expected to reduce the catchment area of this field drain, which would reduce the flows and therefore flood risk in this watercourse. The runoff from the catchment intercepted by the road would be captured within the road drainage network and discharged directly into the Afon Alaw at greenfield rates via an attenuation pond.

6.3.29 Further to the north, field drains run from land west of Green Farm, westwards to Llanfachraeth, passing under the existing A5025 close to the village school. The road is to be raised at this location with a culvert under the highway for the drains to pass freely.

6.3.30 Overall, the proposed route of section 3 of the A5025 Off-line Highway Improvements is expected to have a negligible to minor beneficial magnitude of effect on existing and future surface water flood risk. Benefits are likely to be restricted to surrounding low-importance undeveloped land, though there may be benefits to developed receptors of high importance in the vicinity of the school. This produces an effect of neutral to slight significance.

Risk of runoff to off-site areas

6.3.31 As indicated in section 4.5, the runoff from the bypass would be collected by over-the-edge drain and discharged via attenuation ponds into adjacent watercourses at mean annual discharge rates. The drains would be designed to have the capacity to carry flows for a 1 in 1 year rainfall event and cause no flooding in a 1 in 5 year event as per the DMRB standards [RD12] and in line with the IACC requirements.

6.3.32 The introduction of impermeable surfaces would increase the runoff expected when compared to the pre-development case, however, the drainage systems along the proposed route of the A5025 Off-line Highway Improvements would offset this effect and provide betterment relative to the baseline runoff for events above the discharge rate up to the 100 year storm, with an allowance for climate change. This would ensure that there is no increase in flood risk from the introduction of impermeable surfaces, up to the 1% event, to any of the off-site receptors identified.

6.3.33 The proposed route of section 3 of the A5025 Off-line Highway Improvements is expected to produce no greater than a minor beneficial magnitude of effect. Undeveloped land affected is considered to have a low sensitivity to flood risk and a negligible magnitude of effect would result in a neutral significance of effect. Developed receptors have a high sensitivity to flooding and a similar magnitude of effect would result in a slight significance of effect.

Groundwater flood risk

Groundwater emergence at surface

6.3.34 Glacial till covers most of section 3. A thin strip of alluvium comprising clay, silt, sand, gravels and organic soils is present in section 3 along the watercourses associated with the Afon Alaw and extends to the east and west. The deposits are from 0.3m to 3m thick. There are also glaciofluvial sand and gravel deposits to the west of the route. There is a small area in the middle of section 3 (around Llanfachraeth and in isolated areas south of the A5025 bridge across the Afon Alaw) where superficial deposits are absent and bedrock crops out at the surface (see figure G7-4 (Application Reference Number: 6.7.48)).

6.3.35 Groundwater levels were found to be variable at this section with levels ranging between 0.37 and 5.71m below ground level, but there is currently no data regarding seasonal variations.

6.3.36 The superficial deposits are generally of low permeability (with the exception of the small areas of sand and gravel along the watercourses) and have limited water storage capacity such that groundwater movement is limited. In the unlikely event of groundwater rising above the ground level the area of influence would be small as would the volume of groundwater involved. In all instances during periods of heavy rainfall it will be rainfall runoff across the low permeability drift that will be the concern for flood risk rather than water movement through the superficial deposits.

6.3.37 The bedrock underlying section 3 comprises the New Harbour Group which is dominated by psammite and phyllite (see figure G7-7 (Application Reference Number: 6.7.48)). The depth to bedrock measured in the ground investigation along this section ranges from 1.0 to 10.8m below ground level (appendix G7-2 in chapter G7 (Application Reference Number: 6.7.7)) and so is very variable.

6.3.38 Groundwater movement from the bedrock to surface will be restricted by the presence of low permeability superficial deposits. In the area where the superficial deposits are absent there is potential for groundwater to emerge at the surface, but due to the low permeability and storage characteristics of the bedrock the area concerned and volumes involved would be very small and would be subservient to rainfall runoff. Furthermore, the areas around Llanfachraeth where drift is absent are not particularly elevated so groundwater heads in the bedrock are unlikely to build up. There is therefore unlikely to be a significant emergence of groundwater at the surface along section 3.

6.3.39 The proposed A5025 Off-line Highway Improvements are raised above the Afon Alaw and so would not be affected by groundwater associated with any alluvium. Elsewhere the proposed road drainage ditches would manage any shallow groundwater encountered in superficial deposits, discharging it to the Afon Alaw.

6.3.40 For the reasons outlined above, the A5025 Off-line Highway Improvements are expected to have a negligible magnitude of effect on groundwater and groundwater flood risk and a neutral significance on this source of flood risk to either the bypass itself or to off-site receptors.

Reservoir flood risk

6.3.41 The A5025 crosses the Afon Alaw immediately south of the village of Llanfachraeth and the whole of section 3 is within the flood extent from the Llyn Alaw, as shown on the NRW flood maps (figure G8-1-9). A significant proportion of Llanfachraeth lies within areas shown to be potentially at risk, with the exception of a pocket of properties in the north-west of the village and a small pocket to the south-east.

6.3.42 The modelling of reservoir flood risk by NRW constitutes the worst case scenario and it is unlikely that the extent of flooding would be this large. Reservoir flooding is also extremely unlikely to happen because of the management regime implemented under the Reservoirs Act (1975) under which all large reservoirs must be inspected regularly and any essential safety work be undertaken when required.

6.3.43 Despite the potentially high consequences of failure, the magnitude of effect that the proposed A5025 Off-line Highway Improvements is expected to have on the consequences is expected to be negligible, resulting in a neutral effect on this very unlikely source of flood risk.

Services

6.3.44 Mains water supply and sewers follow the existing A5025. The proposals for section 3 of the A5025 Off-line Highway Improvements moves the main route of the road away from these services and any potential hazard associated with them. The road would be raised above the surrounding land in its northern reach and where approaching the proposed new viaduct over the Afon Alaw and Afon Llywenan and therefore it is considered unlikely that any failure of services would affect this section of the road. Elsewhere the road is in a shallow cutting and upgradient of the location of sewers and water mains. In both cases the risk of flooding from services is classed as low and the proposed A5025 Off-line Highway Improvements would have a negligible effect on this risk.

6.3.45 Given the above, the magnitude of effect that the A5025 Off-line Highway Improvements is expected to have on the consequences of flooding from this source is expected to be negligible, resulting in a neutral effect on this source of flood risk.

Flood risks – section 3 Llanfachraeth

6.3.46 The flood risk from the sources outlined above, to the receptors identified in section 3 of this report, are provided in table G8-01.20. This is based on the methodology detailed in appendix G8-01.2.

Table G8-01.20 Flood risk – section 3

Flood type	Source	Pathway	Receptor	Importance	Magnitude of effect	Significance of effect
Tidal	Irish Sea flooding	Flooding inland from high tides	Off-site receptors at Llanfachraeth	High	Negligible beneficial	Neutral
			Undeveloped off-site receptors	Low	Minor adverse	Neutral
			Existing A5025	Medium	Negligible	Neutral
			Section 3 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral
		Tidal influence on fluvial flooding	Off-site receptors at Llanfachraeth	High	Minor beneficial	Slight
			Undeveloped off-site receptors	Low	Minor adverse	Neutral
			Existing A5025	Medium	Negligible	Neutral
			Section 3 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral
Fluvial and pluvial	Fluvial flooding	Flooding from out-of-bank flows from neighbouring watercourses	Off-site receptors at Llanfachraeth	High	Negligible beneficial	Neutral
			Undeveloped off-site receptors	Low	Moderate adverse	Slight
			Existing A5025	Medium	Negligible	Neutral
			Section 3 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral
	Pluvial flooding from surface water runoff	Intense rainfall causing surface water flooding to highway	Off-site receptors at Llanfachraeth	High	Minor beneficial	Slight
			Undeveloped off-site receptors	Low	Minor beneficial	Neutral
			Existing A5025	Medium	Minor beneficial	Slight
			Section 3 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral
	Site development	Increased runoff from impermeable surfaces	Undeveloped off-site receptors	Low	Minor beneficial	Neutral
			Developed off-site receptors at Llanfachraeth	High	Minor beneficial	Slight

Flood type	Source	Pathway	Receptor	Importance	Magnitude of effect	Significance of effect
Groundwater	Groundwater	Flooding of road due to groundwater emergence	Off-site receptors at Llanfachraeth	High	Negligible	Neutral
			Undeveloped off-site receptors	Low	Negligible	Neutral
			Existing A5025	Medium	Negligible	Neutral
			Section 3 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral
Services	Sewerage network	Surface water runoff due to network failure	Off-site receptors at Llanfachraeth	High	Negligible	Neutral
			Undeveloped off-site receptors	Low	Negligible	Neutral
	Water mains		Existing A5025	Medium	Negligible	Neutral
			Section 3 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral
Reservoir flooding	Failure of reservoir	Runoff due to reservoir failure	Off-site receptors at Llanfachraeth	High	Negligible	Neutral
			Undeveloped off-site receptors	Low	Negligible	Neutral
			Existing A5025	Medium	Negligible	Neutral
			Section 3 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral

6.4 Section 5 – Llanfaethlu

FCA screening

6.4.2 Table G08-01.21 summarises a range of potential risks and whether these are relevant to the A5025 Off-line Highway Improvements section 5.

Table G8-01.21 Screening of potential flood sources for section 5

Flood type	Source	Pathway	Consider further?
Tidal	Irish Sea flooding	Tidal flooding encroaches onto highway – location is away from the coast and out of the tidal floodplain	No
Fluvial and pluvial	Fluvial flooding	Section 5 is entirely in Flood Zone A	No
	Pluvial flooding from surface water runoff	Intense rainfall causing surface water ponding and flows	Yes
	Site development	Increased runoff from road affects off-site receptors	Yes
Groundwater	Groundwater	Flooding of road due to groundwater emergence	Yes
Services	Sewerage network	Surface water runoff due to network failure	Yes
	Water mains	Surface water runoff due to mains failure	Yes
Reservoir flooding	Failure of reservoir walls	Not in a reservoir flood risk zone on NRW flood maps	No

Pluvial flood risk

Pluvial flood risk to the A5025 Off-line Highway Improvements section 5

6.4.3 The NRW surface water maps [RD2] have been used to assess the level of surface water flood risk to the proposed route of section 5 of the A5025 Off-line Highway Improvements. There is some risk of pluvial flood risk to the existing A5025 highway just north of the main village (figure G8-1-2). No properties are shown to be inundated in this area; however, low, medium and high flood risk extents are shown abutting properties.

6.4.4 A small length of the existing A5025 just north of Rhos-ty-mawr is shown to have a low surface water flood risk, though no other receptors are affected.

6.4.5 There is further flooding expected to agricultural land to the north of the middle of section 5. A line of mostly low risk (0.1% to 1% AEP event) extends from the proposed A5025 Off-line Highway Improvements northwards towards Cae'r-bryniau. At field boundaries the flood risk is classed as high (>3.33% AEP event), though it is highly localised and affects no other receptors.

6.4.6 With the exception of the area at the very northern extent of section 5, the risk of pluvial flooding to the proposed A5025 Off-line Highway Improvements is classed as low. The bypass is expected to have a negligible magnitude of effect, which would result in an effect of neutral significance.

6.4.7 In the northern limit of section 5 there is a high risk of pluvial flooding indicated. The risk is associated with overland flows from west of the A5025 that are shown to pond adjacent to the road and to spill over in an easterly direction towards a small watercourse called East Drain. As indicated in section 5.3.2, the pluvial flood risk has been hydraulically modelled as part of an assessment of risk to and from the proposed Off-Site Power Station Facilities. Further details can be found in the FCA for the Off-Site Power Station Facilities, provided in appendix E8-1 (flood consequence assessment) (Application Reference Number: 6.5.16).

6.4.8 For the purposes of this assessment, the risk highlighted by the pluvial modelling presented in appendix E8-1 (Application Reference Number: 6.5.16) is both higher, with flow simulated to occur in a 30-year storm event, and greater in extent than that shown on the NRW surface water flood maps. Despite the higher risk indicated, the proposed A5025 Off-line Highway Improvements would not result in any changes to the existing road at this point and therefore the magnitude of effect would be negligible and of neutral significance.

6.4.9 Overall, the proposed route of section 5 of the A5025 Off-line Highway Improvements is expected to have a negligible magnitude of effect on existing and future surface water flood risk. This produces an effect of neutral significance.

Risk of runoff to off-site areas

6.4.10 As indicated in section 4.5, the runoff from section 5 of the A5025 Off-line Highway Improvements would be collected by over-the-edge drain and discharged via attenuation ponds into adjacent watercourses at mean annual discharge rates. The drains would be designed to have the capacity to carry flows for a 1 in 1 year rainfall event and cause no flooding in a 1 in 5 year event as per the DMRB standards [RD12] and in line with the IACC requirements.

6.4.11 The introduction of impermeable surfaces would increase the runoff expected when compared to the pre-development case, however, the drainage systems along the proposed route of the A5025 Off-line Highway Improvements would offset this effect and provide betterment relative to the baseline runoff for events above the discharge rate up to the 100-year storm, with an allowance for climate change. This would ensure that there is no increase in flood risk from the introduction of impermeable surfaces, up to the 1% event, to any of the off-site receptors identified.

6.4.12 Section 5 of the A5025 Off-line Highway Improvements is expected to produce no greater than a minor beneficial magnitude of effect. Undeveloped land affected is considered to have a low sensitivity to flood risk and a negligible magnitude of effect would result in a neutral significance of effect. Developed

receptors have a high sensitivity to flooding and a similar magnitude of effect would result in a slight significance of effect.

Groundwater flood risk

Groundwater emergence at surface

6.4.13 Along the majority of section 5 around Llanfaethlu superficial deposits are absent and bedrock crops out at the surface. Beneath the remainder of the section glacial till is present (see figure G7-5 (Application Reference Number: 6.7.48))

6.4.14 Groundwater levels at section 5 were recorded at between 0.59m and 5.05m below ground level, but there is currently no data regarding seasonal variations. The likelihood of encountering significant volumes of groundwater is low because the alignment is generally located along a ridge where gradients fall away from section 5.

6.4.15 In the small areas where superficial deposits present, these are generally of low permeability (based on geological conditions encountered in boreholes) and have limited water storage capacity such that groundwater movement is limited. In the unlikely event of groundwater rising above the ground level the area of influence would be small as would the volume of groundwater involved. In almost all instances during periods of heavy rainfall it will be rainfall runoff across the low permeability drift that will be the major concern for flood risk rather than water movement through the superficial deposits.

6.4.16 A large proportion of section 5 is not covered by superficial deposits and therefore the bedrock is at the surface. The bedrock beneath the majority of section 5 is the Gwna Group, with Church Bay Tuffs and Skerries Grits of the Skerries Group present in the southwest (see figure G7-8 (Application Reference Number: 6.7.48)). Where the superficial deposits are absent there is potential for groundwater to emerge at the surface, but as noted above, section 5 follows a ridge line and as a high point in the topography there is limited opportunity for hydraulic heads to build up. There is higher land to the west, but this is associated with superficial deposits rather than bedrock. Furthermore, due to the low permeability and storage characteristics of the bedrock, any flood risk would be limited to a very small area and volumes involved would be very small and would be subservient to rainfall runoff such that they would not be significant.

6.4.17 Where the road is in a slight cutting, there could be a reduction in groundwater levels on either side of the proposed cutting. However, maximum groundwater levels recorded by the two boreholes installed within the bedrock were below ground level and below the base of the cutting at its deepest section. Therefore, it is unlikely that there would be any groundwater emergence but in the event of this happening the proposed drainage would manage any exposure to groundwater, discharging it to nearby watercourses.

6.4.18 For the reasons identified above, the proposed A5025 Off-line Highway Improvements are expected to have a negligible magnitude of effect on

groundwater and groundwater flood risk and a neutral significance on this source of flood risk to either the bypass itself or to off-site receptors.

Services

6.4.19 Mains water supply and sewers follow the existing A5025. The proposals for section 5 of the A5025 Off-line Highway Improvements moves the main route of the road away from these services and any potential hazard. The road is also located along high points and would therefore largely be higher than, and upstream of, this risk source.

6.4.20 The magnitude of effect that the proposed A5025 Off-line Highway Improvements is expected to have on the consequences of flooding from this source is negligible, resulting in a neutral effect on this source of flood risk.

Flood risks – section 5 Llanfaethlu

6.4.21 The flood risk from the sources outlined above, to the receptors identified in section 3 of this report, are provided in table G8-01.22. This is based on the methodology detailed in appendix G8-01.2.

Table G8-01.22 Flood risk – section 5

Flood type	Source	Pathway	Receptor	Importance	Magnitude of effect	Significance of effect
Fluvial and pluvial	Pluvial flooding from surface water runoff	Intense rainfall causing surface water flooding to highway	Off-site receptors at Llanfaethlu	High	Negligible	Neutral
			Undeveloped off-site receptors	Low	Negligible	Neutral
			Existing A5025	Medium	Negligible	Neutral
			Section 5 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral
	Site development	Increased runoff from impermeable surfaces	Undeveloped off-site receptors	Low	Minor beneficial	Neutral
			Developed off-site receptors at Llanfaethlu	High	Minor beneficial	Slight
Groundwater	Groundwater	Flooding of road due to groundwater emergence	Off-site receptors at Llanfaethlu	High	Negligible	Neutral
			Undeveloped off-site receptors	Low	Negligible	Neutral
			Existing A5025	Medium	Negligible	Neutral
			Section 5 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral
Services	Sewerage network	Surface water runoff due to network failure	Off-site receptors at Llanfaethlu	High	Negligible	Neutral
			Undeveloped off-site receptors	Low	Negligible	Neutral
	Water mains		Existing A5025	Medium	Negligible	Neutral
			Section 5 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral

6.5 Section 7 - Cefn Coch

FCA screening

6.5.2 Table G08.01.23 summarises a range of potential risks and whether these are relevant to the A5025 Off-line Highway Improvements section 7.

Table G8-01.23 Screening of potential flood sources for section 7

Flood type	Source	Pathway	Consider further?
Tidal	Irish Sea flooding	Tidal flooding encroaches onto highway – location is away from the coast and out of the tidal floodplain	No
Fluvial and pluvial	Fluvial flooding	Out-of-bank flows flood the highway	Yes
	Pluvial flooding from surface water runoff	Intense rainfall causing surface water ponding and flows	Yes
	Site development	Increased runoff from road affects off-site receptors	Yes
Groundwater	Groundwater	Flooding of road due to groundwater emergence	Yes
Services	Sewerage network	Surface water runoff due to network failure	Yes
	Water mains	Surface water runoff due to network failure	Yes
Reservoir flooding	Failure of reservoir	Not in a reservoir flood risk zone on NRW flood maps	No

Fluvial and pluvial flood risk

Fluvial flood risk

6.5.3 Figure G8-1-13 shows the TAN 15 Development Advice Map. The majority of the highway section is in Flood Zone A and therefore at little or no risk of flooding from rivers.

6.5.4 The floodplain of the Afon Cafnan lies to the west of the existing A5025 and immediately west of the A5025 Off-line Highway Improvements. The floodplain of the Afon Cafnan lies predominantly along its left (western) bank, with the only exceptions to this being upstream of the minor road crossing and downstream of Cefn Coch. In both locations there is minor encroachment of the proposed A5025 Off-line Highway Improvements into the floodplain.

6.5.5 Fluvial flood modelling was undertaken by Amec Foster Wheeler for the baseline scenario and to assess the potential effect of a development site that was being considered in this area but which was not taken forward and is not part of current development proposals. The modelling covers the larger watercourses along the length of the A5025. Scenarios that were modelled

are presented in section 5.3.2, however, no with-development modelling was undertaken. A model run was undertaken to identify the effect of encroachment into the floodplain, particularly at the southern end of section 7.

6.5.6 The resultant fluvial flood risk outlines are provided in appendix G8-01.6. The key conclusions of the baseline modelling are given below.

- The fluvial modelling primarily shows the land to the west of the Afon Cafnan as being at risk from flooding, the exception being undeveloped land on either side of the Afon Cafnan, just north of the tributary with the Afon Llygeirian, which is shown to flood in all events, and a small area of land north of properties at grid reference 234153, 390913. This is largely in accordance with the TAN 15 Development Advice Map which shows the area as being in Flood Zone C2.
- The Afon Llygeirian crosses under the A5025 at the southern extent and this crossing has sufficient capacity to pass the 0.1% AEP event. Elsewhere, the minor road at grid reference 234079, 390188 is predicted to be overtopped in the 0.1% AEP event and the downstream structure beneath a minor road at grid reference 234139, 391381 is predicted to be overtopped in events higher than 1% AEP. Smaller local crossings are predicted to overtop in the 5% AEP event.
- One existing property in this reach, located at grid reference 234122, 391338, is predicted to be affected in the 1% AEP event by the Afon Cafnan when the capacity of the structure beneath the minor road immediately downstream is reached.

6.5.7 As indicated above, no with-development modelling has been undertaken, however earlier testing of development scenarios was undertaken that provides an indication of the minor encroachment that is shown in the southern reach of section 7. That testing simulated an increase in water level upstream of the minor road at grid reference 234079, 390188 amounting to 0.005m. Whilst not based on precisely the current design details, this increase is indicative of the expected magnitude of change in this area from the proposed A5025 Off-line Highway Improvements at this location, which amount to a negligible magnitude of change.

6.5.8 As well as the minor encroachment into the floodplain, a number of new culverts are proposed at grid references 234006, 390003 and 234197, 391006. In both cases, the proposed new structures would have at least the same capacity as the structure upstream so as not to present an impediment to existing flows in the watercourses.

6.5.9 Overall, the proposed route of section 7 of the A5025 Off-line Highway Improvements is expected to have a negligible adverse magnitude of effect on existing and future fluvial flood risk in the vicinity of the Afon Cafnan and Afon Llygeirian confluence. This will result in a neutral significance of effect, given that section 7 is an undeveloped area of low importance. This produces an effect of neutral significance. Elsewhere, there would be a negligible

magnitude of effect on fluvial flood risks, which would be of neutral significance.

Pluvial flood risk to the A5025 Off-line Highway Improvements section 7

6.5.10 The NRW surface water flood maps have been used to determine the risk of pluvial flooding to the proposed route of section 7 of the A5025 Off-line Highway Improvements. The pluvial flood outlines are displayed on figure G8-1-14. The pluvial flood zones are associated with the watercourses in the majority of cases. The extents of the pluvial flood zones are not as extensive as the fluvial outlines and there are no existing developed receptors identified. Although there could be some surface water ponding as a result of the slowly permeable soils which create limited infiltration potential and areas prone to surface water ponding, and so contribute to high rates of surface water runoff. Further detail regarding soil characteristics is provided in chapter G7 (Application Reference Number: 6.7.7).

6.5.11 Overall, section 7 of the A5025 Off-line Highway Improvements is expected to have a negligible magnitude of effect on existing and future surface water flood risk. This produces an effect of neutral significance.

6.5.12 In respect of risk of runoff to off-site areas as indicated in section 4.5, the runoff from the bypass would be collected by over-the-edge drain and discharged via attenuation ponds into adjacent watercourses at mean annual discharge rates. The drains would be designed to have the capacity to carry flows for a 1 in 1 year rainfall event and cause no flooding in a 1 in 5 year event as per the DMRB standards [RD12] and in line with the IACC requirements.

6.5.13 The introduction of impermeable surfaces would increase the runoff expected when compared to the pre-development case, however, the drainage systems along the route of the A5025 Off-line Highway Improvements would offset this effect and provide betterment relative to the baseline runoff for events above the discharge rate up to the 100-year storm, with an allowance for climate change. This would ensure that there is no increase in flood risk from the introduction of impermeable surfaces, up to the 1% event, to any of the off-site receptors identified.

6.5.14 Section 7 of the A5025 Off-line Highway Improvements is expected to produce no greater than a minor beneficial magnitude of effect by virtue of attenuating runoff above greenfield runoff rates. Undeveloped land affected is considered to have a low sensitivity to flood risk and a negligible magnitude of effect would result in a neutral significance of effect. Developed receptors have a high sensitivity to flooding and a similar magnitude of effect would result in a slight significance of effect.

Groundwater flood risk

Groundwater emergence at surface

6.5.15 The majority of the site (the exceptions are small areas at the southern end of section 7 and to the west) is underlain by glacial till (figure G7-5 (Application

Reference Number: 6.7.48)). The thickness of the till along this section ranged between 0.2m and 10.2m. The glacial till is defined by NRW as a Secondary (undifferentiated) aquifer. Where this has a clay matrix it will have a low permeability and a negligible significance for groundwater supply. The likelihood of encountering significant groundwater in the superficial deposits is therefore low, although there may be some present in any sand and gravel layers in the till, although this would be limited in volume.

6.5.16 Groundwater levels along section 7 were found during the ground investigation (appendix G7-2 in chapter G7 (Application Reference Number: 6.7.7)) to vary between 0.95m and 5.86m below ground level and so there is not a record of the groundwater rising about the ground level. However, there are no seasonal data regarding groundwater levels.

6.5.17 The superficial deposits are generally of low permeability and have limited water storage capacity such that groundwater movement is limited. In the unlikely event of groundwater rising above the ground level the affected area would be small as would the volume of groundwater involved. In all instances during periods of heavy rainfall it will be rainfall runoff across the low permeability drift that will be the concern for flood risk rather than groundwater movement through the superficial deposits.

6.5.18 Section 7 passes through a number of bedrock units, the main one being mica schist and psammite of the New Harbour Group, whilst the others include Ordovician mudstone and sandstone and Gwna group schist (see figure G7-8 (Application Reference Number: 6.7.48). All the bedrock units are classified by NRW as a Secondary B Aquifer, with lower-permeability layers of rock which may store and yield limited amounts of groundwater, although depending on the lithology there may be more water present in some sections, though these are likely to be limited.

6.5.19 Groundwater movement from the bedrock to surface will be restricted where the glacial till is dominated by clays and is of low permeability. In any areas where the superficial deposits are granular, thin or absent there is potential for groundwater to emerge at the surface, but due to the low permeability and storage characteristics of the bedrock the area concerned and volumes involved would be very small and would be subservient to rainfall runoff.

6.5.20 The topography of Section 7 is very variable with the northern end running along a slight ridge. The area at highest risk of groundwater flooding would be where the road crosses the Nant Llygeirian, but drift deposits are present in this area which would limit any significant groundwater emergence and which would in any event flow (or most likely emerge) into the watercourse. There is high ground to the east but as this is drift covered it is unlikely to provide a driving head for bedrock groundwater beneath section 7.

6.5.21 For the reasons identified above, the proposed A5025 Off-line Highway Improvements are expected to have a negligible magnitude of effect on groundwater and groundwater flood risk and a neutral significance on this source of flood risk to either the bypass itself or to off-site receptors.

Services

6.5.22 Mains water supply and sewers follow the existing A5025. The proposals for section 7 of the A5025 Off-line Highway Improvements moves the main route of the road away from these services; however, the road would continue to lie between these services and receiving watercourses in the event of asset failure and flooding. The proposed road would be bordered by land drainage ditches that would capture any flood water from these sources before passing it towards receiving watercourses via the proposed drainage system.

6.5.23 The magnitude of effect that the A5025 Off-line Highway Improvements is expected to have on the consequences of flooding from this source is negligible, resulting in a neutral effect on this source of flood risk.

Flood risks – section 7 Cefn Coch

6.5.24 The flood risk from the sources outlined above, to the receptors identified in section 3 of this report, are provided in table G8-01.24. This is based on the methodology detailed in appendix G8-01.2.

Table G8-01.24 Flood risk – section 7

Flood type	Source	Pathway	Receptor	Importance	Magnitude of effect	Significance of effect
Fluvial and pluvial	Fluvial flooding	Flooding from out-of-bank flows from neighbouring watercourses	Off-site receptors at Cefn Coch	High	Negligible	Neutral
			Undeveloped off-site receptors	Low	Negligible adverse	Neutral
			Existing A5025	Medium	Negligible	Neutral
			Section 7 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral
	Pluvial flooding from surface water runoff	Intense rainfall causing surface water flooding to highway	Off-site receptors at Cefn Coch	High	Negligible	Neutral
			Undeveloped off-site receptors	Low	Negligible	Neutral
			Existing A5025	Medium	Negligible	Neutral
			Section 7 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral
	Site development	Increased runoff from impermeable surfaces	Undeveloped off-site receptors	Low	Minor beneficial	Neutral
			Developed off-site receptors at Cefn Coch	High	Minor beneficial	Slight
Groundwater	Groundwater	Flooding of road due to groundwater emergence	Off-site receptors at Llanfachraeth	High	Negligible	Neutral
			Undeveloped off-site receptors	Low	Negligible	Neutral
			Existing A5025	Medium	Negligible	Neutral
			Section 7 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral
Services	Sewerage network	Surface water runoff due to network failure	Off-site receptors at Cefn Coch	High	Negligible	Neutral
			Undeveloped off-site receptors	Low	Negligible	Neutral
	Water mains		Existing A5025	Medium	Negligible	Neutral

Flood type	Source	Pathway	Receptor	Importance	Magnitude of effect	Significance of effect
			Section 7 - A5025 Off-line Highway Improvements	Medium	Negligible	Neutral

6.6 Power Station Access Road junction

Power Station Access Road junctionFCA screening

6.6.2 Table G08.01.25 summarises a range of potential risks and whether these are relevant to the Power Station Access Road junction.

Table G8-01.25 Screening of potential flood sources for Power Station Access Road junction

Flood type	Source	Pathway	Consider further?
Tidal	Irish Sea flooding	Tidal flooding encroaches onto highway – location is away from the coast and out of the tidal floodplain	No
Fluvial and pluvial	Fluvial flooding	Out-of-bank flows flood the highway	No
	Pluvial flooding from surface water runoff	Intense rainfall causing surface water ponding and flows	Yes
	Site development	Increased runoff from road affects off-site receptors	Yes
Groundwater	Groundwater	Flooding of road due to groundwater emergence	Yes
Services	Sewerage network	Surface water runoff due to network failure	Yes
	Water mains	Surface water runoff due to network failure	Yes
Reservoir flooding	Failure of reservoir	Not in a reservoir flood risk zone on NRW flood maps	No

Pluvial flood risk to the Power Station Access Road junction

6.6.3 The NRW surface water flood maps were initially used to determine the risk of pluvial flooding to the Power Station Access Road junction on the A5025. The pluvial flood outlines are displayed on figure G8-1-14. The pluvial flood zones are associated with watercourses to the west (Caerdegog Isaf) and east (a tributary of Nant Cemaes). At the proposed junction location there is no pluvial flood risk identified. There is a surface water risk identified to receptors at Caerdegog Isaf downstream.

6.6.4 Pluvial modelling of flood risks associated with the Power Station Main Site has been used to supplement the information presented on the NRW surface water flood maps. In a current 30-minute 50% AEP rainfall event, the location of the junction is shown to be free from surface water flooding, though there are isolated pockets of shallow (less than 0.05m) ponding immediately south of the junction on the existing A5025. The same outcome is shown for all events up to and including the 0.1% AEP rainfall event for both 30-minute and 60-minute storm durations, even allowing for the reasonable expected effects

and the conceivable maximum effects of climate change by 2180 [RD5]. Details on the modelled extents are presented in appendix G8-01.6.

6.6.5 Overall, the Power Station Access Road junction on the A5025 is located on a ridge line and it is not at risk from this source of flooding. The development of the junction is expected to have a negligible magnitude of effect on existing and future surface water flood risk. This produces an effect of neutral significance.

Risk of runoff to off-site areas

6.6.6 As indicated in section 4.5, the runoff from the junction would be collected by over kerb and filter drains and discharged to adjacent land for a small area of the junction or discharged westwards into the Power Station Access Road drainage. The drains would be designed to have the capacity to carry flows for a 1 in 1 year rainfall event and cause no flooding in a 1 in 5 year event as per the DMRB standards [RD12] and in line with the IACC requirements.

6.6.7 The introduction of the junction would slightly increase the area of impermeable surfaces and could therefore increase the runoff expected when compared to the pre-development case, however, the drainage systems proposed at the junction and along the route of the Power Station Access Road would offset this effect and provide betterment relative to the existing road at this point. This would ensure that there is no increase in flood risk from the introduction of impermeable surfaces to any of the off-site receptors identified.

6.6.8 The Power Station Access Road junction is therefore expected to have a negligible magnitude of effect. Undeveloped land affected is considered to have a low sensitivity to flood risk and a negligible magnitude of effect would result in a neutral significance of effect. Developed receptors have a high sensitivity to flooding and a negligible magnitude of effect would also result in a neutral significance of effect.

Groundwater flood risk

Groundwater emergence at surface

6.6.9 The Power Station Access Road junction is underlain by superficial deposits that are expected to be glacial till based on British Geological Survey data [RD17] (see figure G7-6 (Application Reference Number: 6.7.48)). The till is classified as a Secondary (undifferentiated) aquifer by NRW. Where dominated by a clay matrix the superficial deposits are generally of low permeability and have limited water storage capacity such that groundwater movement is limited. In the unlikely event of groundwater rising above the ground level the area of influence would be small as would the volume of groundwater involved. In all instances during periods of heavy rainfall it will be rainfall runoff across low permeability drift that will be the concern for flood risk rather than water movement through the superficial deposits.

6.6.10 The bedrock (mica schist and psammite of the New Harbour Group – see figure G7-9 (Application Reference Number: 6.7.48)) is classified as a

Secondary B Aquifer, with lower permeability layers of rock which may store and yield limited amounts of groundwater, though these are not expected to pose a risk of flooding.

6.6.11 Monitoring at this area has found that the groundwater levels range from between 1m and 4m below ground level.

6.6.12 Groundwater movement from the bedrock to ground surface will be restricted by the presence of low permeability superficial deposits. The likelihood of encountering significant volumes of shallow groundwater is low because the junction is located along a topographical ridge where groundwater would be expected to fall away from the scheme. The proposed drainage would manage any exposure to groundwater, discharging it to drainage features associated with the Power Station Access Road to the west or to land to the east.

6.6.13 The Power Station Access Road junction is therefore expected to have a negligible magnitude of effect on groundwater and groundwater flood risk and a neutral significance on this source of flood risk to either the bypass itself or to off-site receptors.

Services

6.6.14 Mains water supply and sewers follow the existing A5025. The Power Station Access Road junction remains on the same alignment, however, as the location is at a topographical high point the location is considered to be a low risk location of failure and flooding from these services. The proposed drainage at the junction would capture any flood water from these sources before passing it towards receiving drainage ditches or land.

6.6.15 The magnitude of effect that the A5025 Off-line Highway Improvements is expected to have on the consequences of flooding from this source is negligible, resulting in a neutral effect on this source of flood risk.

Flood risks – Power Station Access Road junction

6.6.16 The flood risk from the sources outlined above, to the receptors identified in section 3 of this report, are provided in table G8-01.26. This is based on the methodology detailed in appendix G8-01.2.

Table G8-01.26 Flood risk – Power Station Access Road junction

Flood type	Source	Pathway	Receptor	Importance	Magnitude of effect	Significance of effect
Fluvial and pluvial	Pluvial flooding from surface water runoff	Intense rainfall causing surface water flooding to highway	Developed off-site receptors	High	Negligible	Neutral
			Undeveloped off-site receptors	Low	Negligible	Neutral
			Existing A5025	Medium	Negligible	Neutral
			Power Station Access Road junction	Medium	Negligible	Neutral
	Site development	Increased runoff from impermeable surfaces	Undeveloped off-site receptors	Low	Negligible	Neutral
			Developed off-site receptors	High	Negligible	Neutral
Groundwater	Groundwater	Flooding of road due to groundwater emergence	Developed off-site receptors	High	Negligible	Neutral
			Undeveloped off-site receptors	Low	Negligible	Neutral
			Existing A5025	Medium	Negligible	Neutral
			Power Station Access Road junction	Medium	Negligible	Neutral
Services	Sewerage network	Surface water runoff due to network failure	Developed off-site receptors	High	Negligible	Neutral
			Undeveloped off-site receptors	Low	Negligible	Neutral
	Water mains		Existing A5025	Medium	Negligible	Neutral
			Power Station Access Road junction	Medium	Negligible	Neutral

7 Conclusions

7.1.1 The flood consequences of the proposed A5025 Off-line Highway Improvements have been assessed within this report. Flooding from all sources has been considered, with the risk to both the A5025 Off-line Highway Improvements and off-site receptors determined.

Section 1 – Valley

7.1.2 Section 1 (Valley) is shown to provide negligible benefits to flood risk from tidal sources when considered alone, and would not be at risk itself. The influence that tidal flooding has on fluvial flood risk is notable in this location and under an extreme scenario where extreme tidal and fluvial flood risks are combined and with the effect of climate change, there is predicted to be both minor adverse and minor beneficial effects. Given the very low probability of this scenario the overall conclusion is that the effect on flood risk from this source is negligible. The significance of effect on tidal flood risk is therefore assessed as neutral.

7.1.3 In simulation, the A5025 Off-line Highway Improvements provide minor benefits to the fluvial flood risk in this area, principally by minimising encroachment into the floodplain, by providing compensatory storage and by providing features to maintain existing drainage pathways. These same features also provide minor benefits to pluvial flood risk. The significance of effect on fluvial flood risk is therefore assessed as slight.

7.1.4 Flood risk constraints from tidal and pluvial sources limit the opportunity to attenuate potential increases in surface water runoff from this section, which may result in minor adverse local effects; however, overall the effect on surface water runoff is expected to be negligible, as will the effect on flood risk from groundwater, services and reservoir flooding. The significance of effect on these sources of flood risk is therefore assessed as neutral.

7.1.5 No additional mitigation is proposed to manage any residual risks of flooding to the scheme or elsewhere.

Section 3 – Llanfachraeth

7.1.6 Section 3 (Llanfachraeth) is shown to provide negligible benefits to flood risk from tidal sources to developed receptors when considered alone, and would not be at risk itself. There is however a minor adverse effect on undeveloped land within the floodplain. Tidal flood levels are higher in this location than fluvial flood levels. Despite this, the influence of tidal flooding on fluvial sources is only minor. The significance of effect on tidal flood risk is therefore assessed as slight.

7.1.7 In simulation, the A5025 Off-line Highway Improvements provide minor benefits to the fluvial flood risk in this area, principally providing negligible but beneficial effects to an existing property in the floodplain. As with tidal flooding, there is however a minor adverse effect on undeveloped land within the floodplain. In both cases this is due to a slight reduction in conveyance

introduced by the proposed viaduct, however, further mitigation is likely to result in greater environmental effects. The significance of effect on fluvial flood risk is therefore assessed as slight.

7.1.8 The A5025 Off-line Highway Improvements are predicted to be beneficial to local surface water flooding issues identified, principally through management of surface water generated by the scheme and through changes to land use adjacent to the scheme. The significance of effect on pluvial flood risk is therefore assessed as slight. Overall the effect on groundwater, services and reservoir flooding is expected to be negligible, therefore the significance of effect is assessed as neutral.

7.1.9 No additional mitigation is proposed to manage any residual risks of flooding to the scheme or elsewhere.

Section 5 – Llanfaethlu

7.1.10 Section 5 (Llanfaethlu) is shown not to be at risk of flooding from tidal, fluvial or reservoir sources, therefore the significance of effect is assessed as neutral. It is predicted to have a negligible effect on pluvial flooding and a minor beneficial effect on surface water flood risk locally and downstream, created through management of surface water generated by the scheme and adjacent to the scheme. The significance of effect on pluvial flood risk is therefore assessed as slight. Overall the effect on groundwater, services and reservoir flooding is expected to be negligible, therefore the significance of effect is assessed as neutral.

7.1.11 No additional mitigation is proposed to manage any residual risks of flooding to the scheme or elsewhere.

Section 7 – Cefn Coch

7.1.12 Section 7 (Cefn Coch) is shown not to be at risk of flooding from tidal or reservoir sources and is simulated to have an overall negligible effect on fluvial flood risk despite small increases in flood level in upstream undeveloped areas. The significance of effect on these sources of flood risk is therefore assessed as neutral.

7.1.13 The A5025 Off-line Highway Improvements are predicted to have a minor beneficial effect on surface water flood risk locally and downstream, created through management of surface water generated by the scheme and adjacent to the scheme. Overall the effect on groundwater, services and reservoir flooding is expected to be negligible. The significance of effect on fluvial flood risk is therefore assessed as slight.

7.1.14 No additional mitigation is proposed to manage any residual risks of flooding to the scheme or elsewhere.

Power Station Access Road junction

7.1.15 The proposed junction for the Power Station Access Road on the A5025 is shown to lie on a topographical high point and it is therefore not at flood risk from any source. The significance of effect is therefore assess as neutral.

7.1.16 The A5025 Off-line Highway Improvements at this location is predicted to have a negligible effect on all sources of flood risk locally and downstream.

7.1.17 No additional mitigation is proposed to manage any residual risks of flooding to the scheme or elsewhere.

8 References

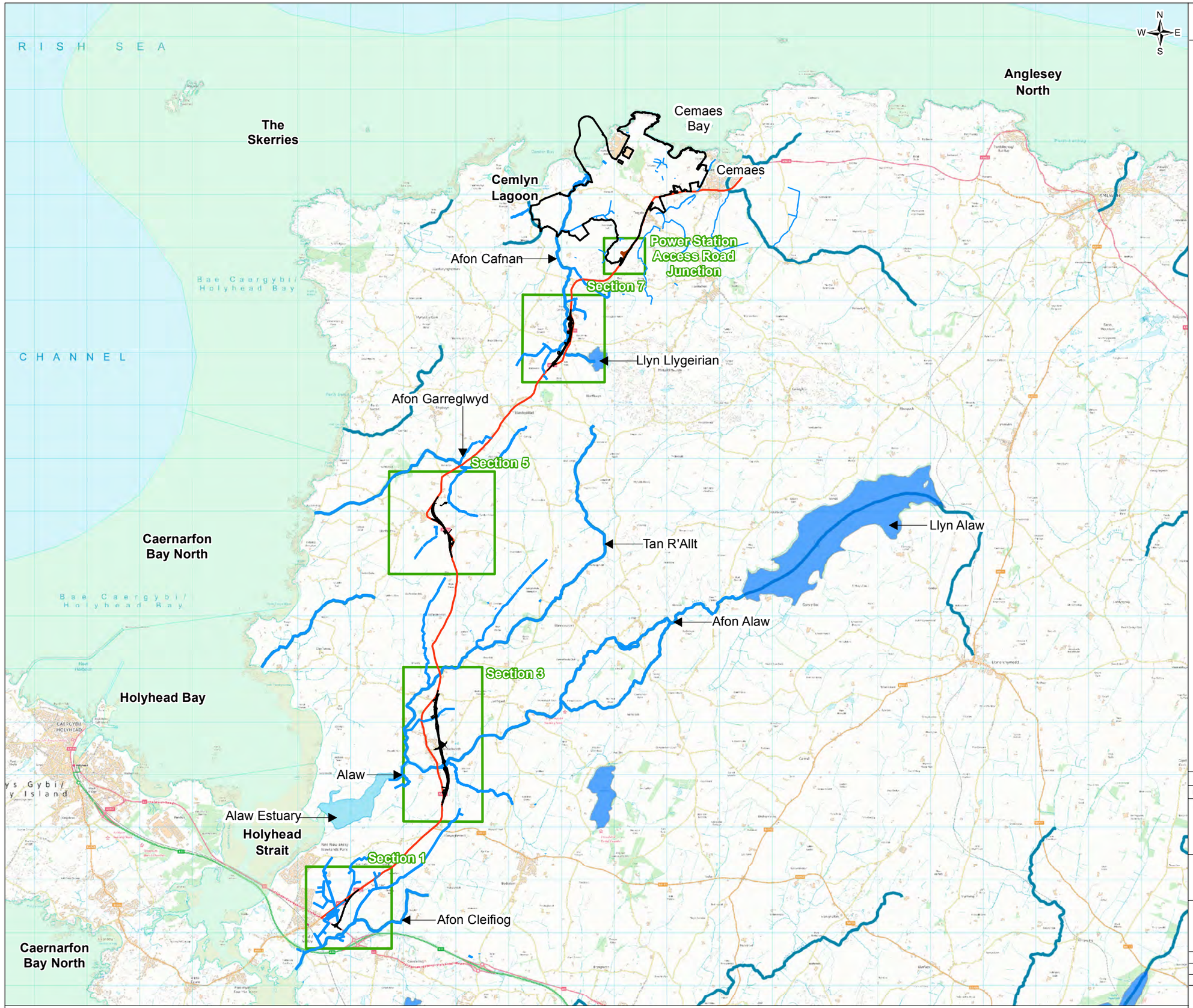
Schedule of references

ID	Reference
RD1	Welsh Government. 2017. *Technical Advice Note* (TAN) *15 Development Advice Map*. [Online] [Accessed: May 2017]. Available from https://maps.cyfoethnaturiolcymru.gov.uk/Html5Viewer/Index.html?configBase=https://maps.cyfoethnaturiolcymru.gov.uk/Geocortex/Essentials/REST/sites/Flood_Risk/viewers/Flood_Risk/virtualdirectory/Resources/Config/Default
RD2	Natural Resources Wales. 2016. *Flood Risk Map*. [Online] [Accessed: April 2017] Available from: https://naturalresources.wales/our-evidence-and-reports/maps/flood-risk-map/?lang=en
RD3	Welsh Government. 2016. *Planning Policy Wales* (PPW). Edition 9 [Online] [Accessed: April 2017] Available from: http://gov.wales/topics/planning/policy/ppw/?skip=1&lang=en
RD4	Welsh Government. 2004. *Technical Advice Note* (TAN) *15: Development and Flood Risk*. [Online] [Accessed: October 2016]. Available from: http://wales.gov.uk/docs/desh/publications/040701tan15en.pdf
RD5	Welsh Government. 2016. *Flood Consequence Assessments: Climate Change Allowances*. [Online] [Accessed: April 2017]. Available from: http://gov.wales/docs/desh/publications/160831guidance-for-flood-consequence-assessments-climate-change-allowances-en.pdf
RD6	Department for Environment, Food and Rural Affairs. 2009. *UK Climate Projections*. [Online] [Accessed: April 2017] Available from: http://ukclimateprojections.metoffice.gov.uk/22530
RD7	Isle of Anglesey County Council (IACC) and Gwynedd Council. 2017. *Anglesey and Gwynedd Joint Local Development Plan 2011-2026, Written Statement.* [Online] [Accessed: September 2017] Available from: http://www.anglesey.gov.uk/planning-and-waste/planning-policy/joint-local-development-plan-anglesey-and-gwynedd/
RD8	Isle of Anglesey County Council and Gwynedd Council. 2013. *Anglesey and Gwynedd Joint Local Development Plan, Topic Paper 8: Strategic Flood Consequence Assessment (Level 1)*. [Online] [Accessed: October 2016] Available from: http://www.anglesey.gov.uk/download/31094
RD9	Isle of Anglesey County Council. undated *Preliminary Flood Risk Assessment*. [Online] [Accessed: October 2016] Available from: http://webarchive.nationalarchives.gov.uk/20140328084622/http://cdn.environment-agency.gov.uk/flho1111bvfk-e-e.pdf
RD10	Isle of Anglesey County Council. 2013. *Anglesey Local Flood Risk Management Strategy*. [Online] [Accessed: October 2016] Available from: http://www.anglesey.gov.uk/download/32358
RD11	Natural Resources Wales. 2015. *Western Wales River Basin Management Plan 2015-2021*. [Online] [Accessed: April 2017] Summary available from: https://naturalresources.wales/media/676165/wwrbdsummary.pdf

ID	Reference
RD12	Highways England. 2016. *Design Manual for Roads and Bridges*. Volume 4 Geotechnics and Drainage. Section 2 Drainage. Part 3. HD33/06 Surface and sub-surface drainage systems for highways.
RD13	CH2M. 2015. *Flood Modeller Pro v4.2* modelling software.
RD14	BMT Group Limited. 2015. *TUFLOW* Build 2016-03-AE-w64 modelling software.
RD15	Wallingford HydroSolutions. 2017. *InfoWorks ICM v7.5* modelling software.
RD16	Lancaster, J. W., Preene, M. and Marshall. C. T. 2004. *Development and flood risk: guidance for the construction industry*. Report C624. CIRIA, London.
RD17	British Geological Survey. 2017. Geological Maps [Online] [Accessed: July 2017]. Available from: http://mapapps.bgs.ac.uk/geologyofbritain/home.html
RD18	Highways England. 2009. *Design Manual for Roads and Bridges*. Volume 11 Environmental Assessment. Section 3 Environmental Assessment Techniques. Part 10. HD45/09 Road drainage and the water environment.

Appendix G8-01.1 Figures

FIGURE G8-1-1



Legend

- Wylfa Newydd Development Area
- Offline Road Improvement Locations
- A5025 Off-line Highway Improvements
- Power Station Access Road Junction
- A5025
- Main rivers
- Ordinary watercourses
- Fluvial WFD water body
- Lacustrine WFD water body
- Transitional WFD water body
- Coastal WFD water body

Rev.	Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
0	OCT 17	Initial Issue	HT	RA	SH	RB

Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
ENVIRONMENTAL STATEMENT

Drawing Title: STUDY AREA - WATERBODIES AND OTHER WATERCOURSES

Scale @ A3	1:70,000	DO NOT SCALE
Jacobs No.	60PO8077	
Client No.		

Drawing No. 60PO8077_DCO_A5025_G_08_01_01

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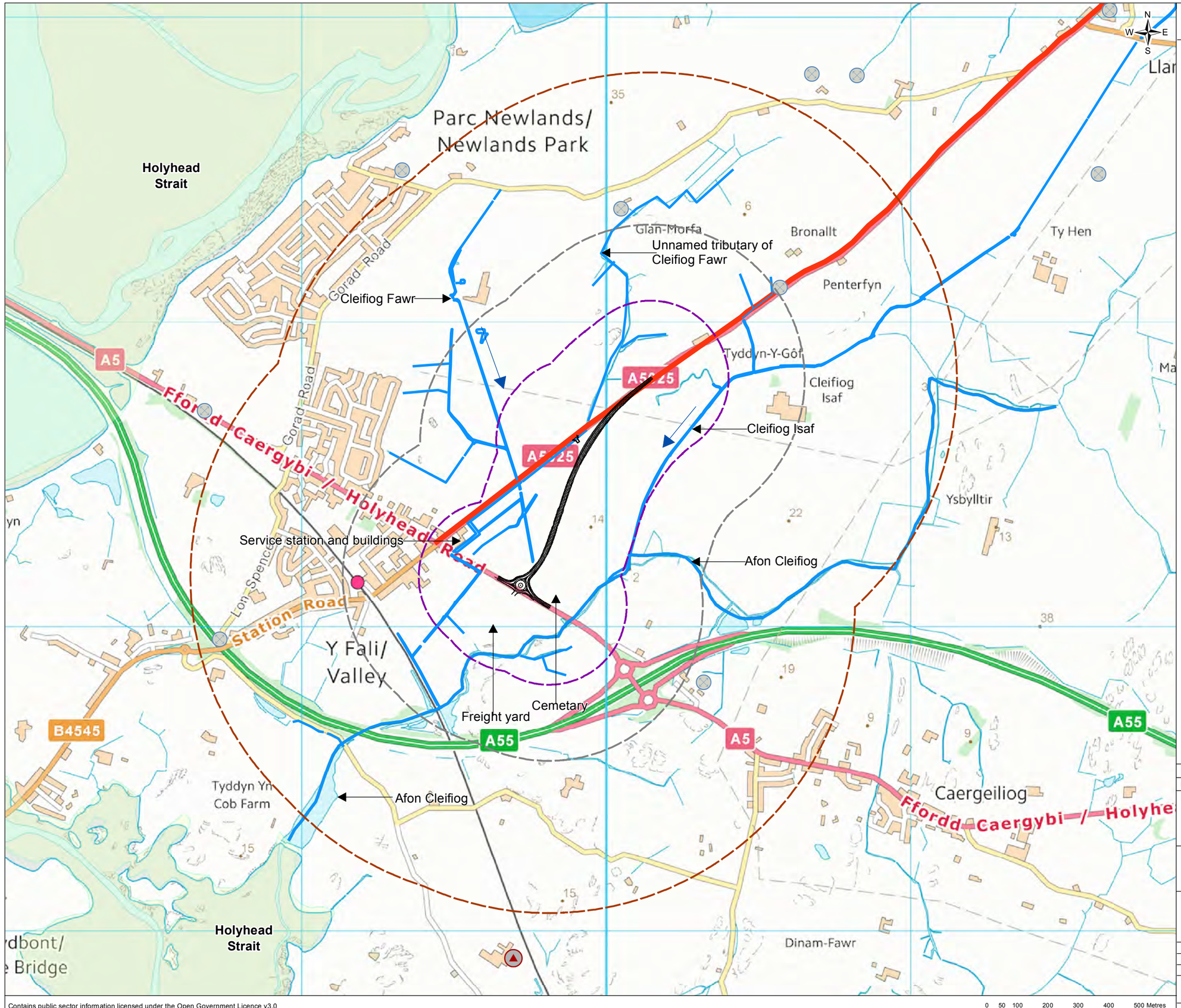
0 500 1,000 2,000 3,000 Metres

FIGURE G8-1-2



Legend

- A5025 Off-line Highway Improvements (Section 1)
- Fluvial geomorphology 250m study area
- Surface water and groundwater 500m study area
- HAWRAT 1km study area
- A5025
- Private Water Supply (PWS) - scoped out
- Well - scoped out
- Main rivers
- Ordinary watercourses
- Fluvial WFD water body
- Transitional water body
- Coastal WFD water body

* For location of this section see figure G8-1-1
** The only wells shown are those within the 500m groundwater study areas

Rev.	Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
0	OCT 17	Initial Issue	HT	RA	SH	RB

Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
ENVIRONMENTAL STATEMENT

Drawing Title: STUDY AREA - SECTION 1

Scale @ A3	1:12,000	DO NOT SCALE
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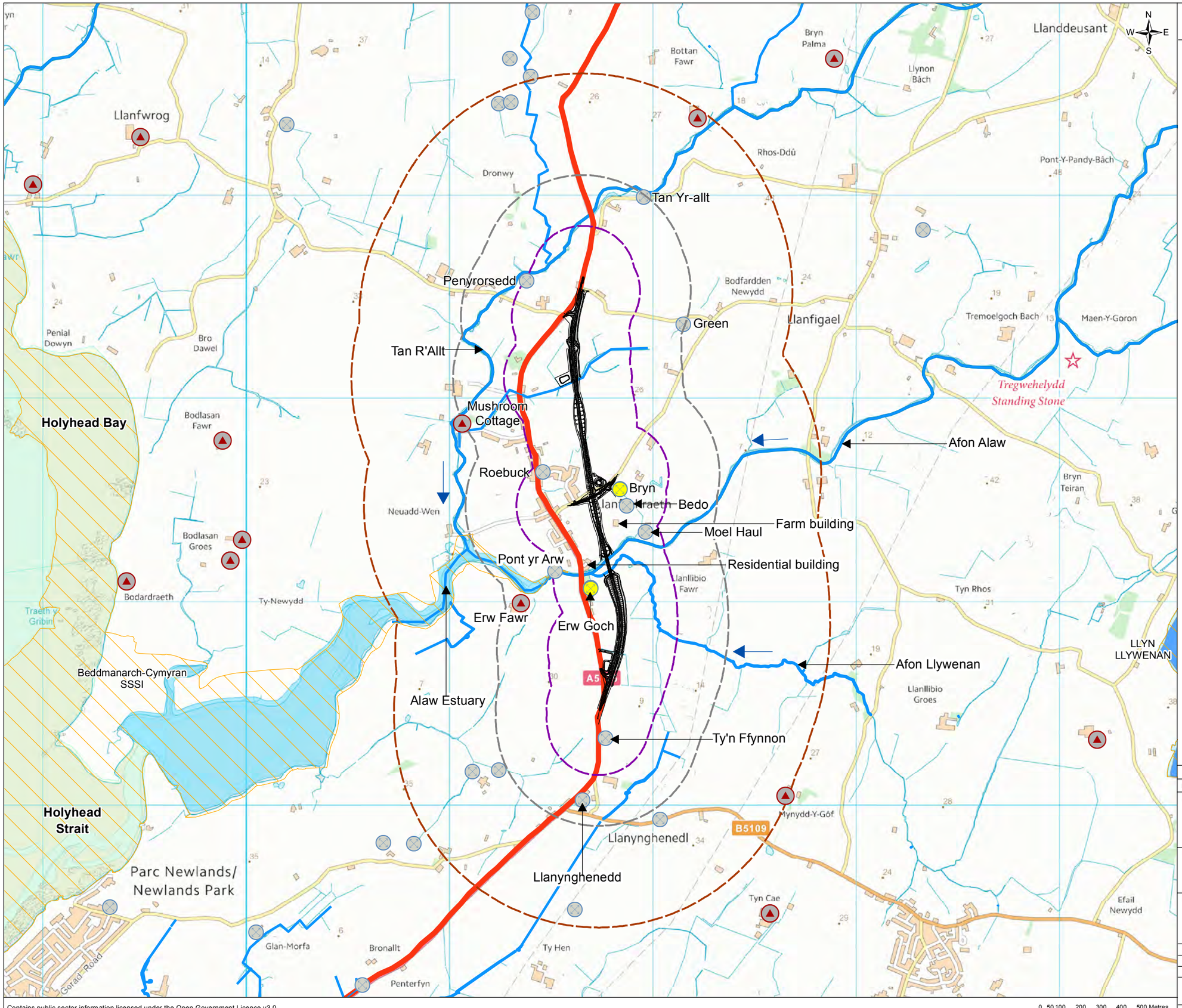
0 50 100 200 300 400 500 Metres

FIGURE G8-1-3



Legend

- A5025 Off-line Highway Improvements (Section 3)
- Site of Special Scientific Interest (SSSI)
- Fluvial geomorphology 250m study area
- Surface water and groundwater 500m study area
- HAWRAT 1km study area
- A5025
- Private Water Supply (PWS) - scoped out
- Well - scoped out
- Well - scoped in
- Main rivers
- Ordinary watercourses
- Fluvial WFD water body
- Lacustrine WFD water body
- Transitional WFD water body
- Coastal WFD water body

* For location of this section see figure G8-1-1
** The only wells shown are those within the 500m groundwater study areas

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0	OCT 17	Initial Issue	HT	RA	SH	RB

Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
ENVIRONMENTAL STATEMENT

Drawing Title: STUDY AREA - SECTION 3

Scale @ A3	1:18,000	DO NOT SCALE
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Drawing No. 60PO8077_DCO_A5025_G_08_01_03

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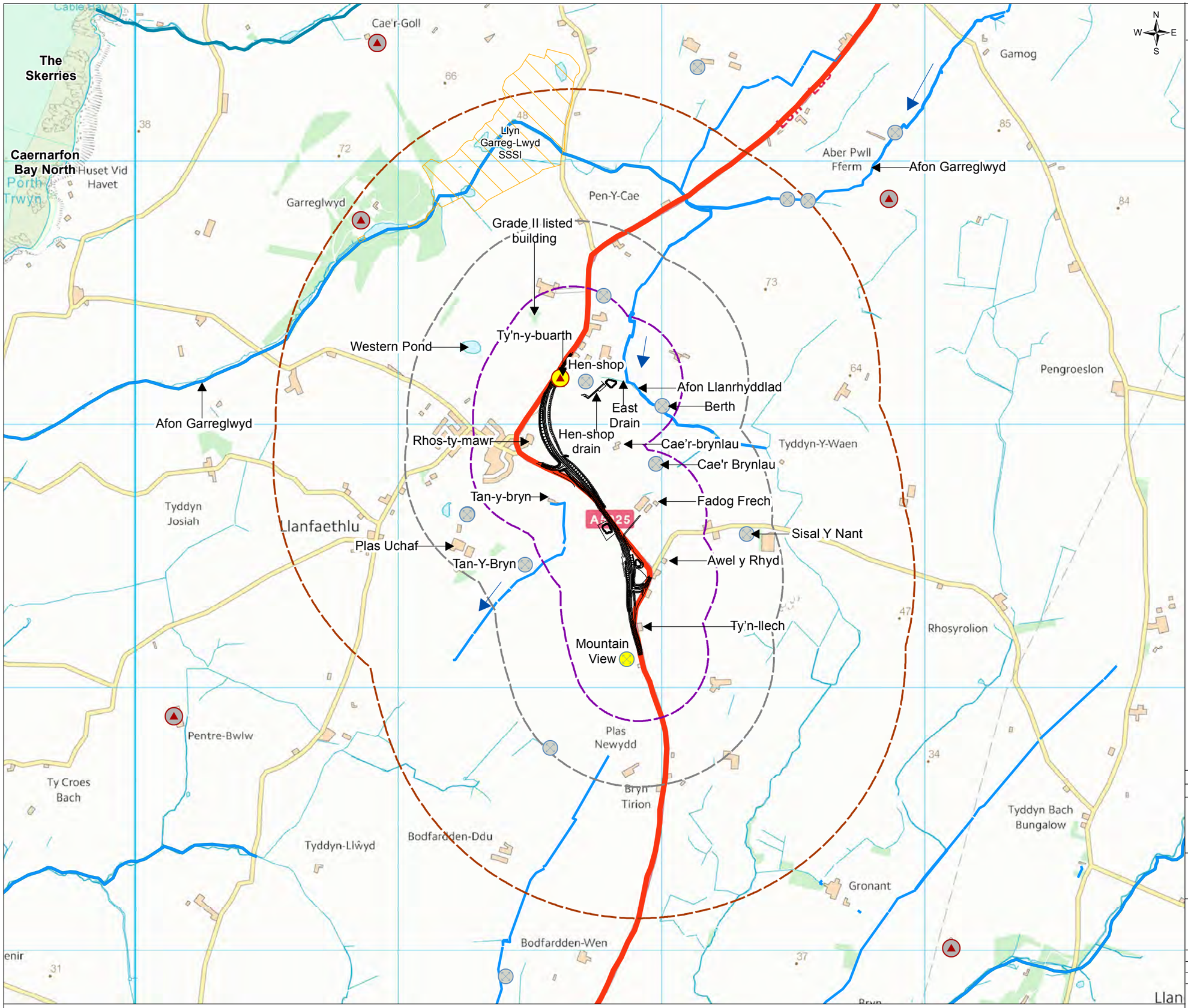
0 50 100 200 300 400 500 Metres

FIGURE G8-1-4



Legend

- A5025 Off-line Highway Improvements (Section 5)
- Site of Special Scientific Interest (SSSI)
- Fluvial geomorphology 250m study area
- Surface water and groundwater 500m study area
- HAWRAT 1km study area
- A5025
- Private Water Supply (PWS) - scoped in
- Private Water Supply (PWS) - scoped out
- Well - scoped out
- Well - scoped in
- Main rivers
- Ordinary watercourses
- Fluvial WFD water body
- Coastal WFD water body

* For location of this section see figure G8-1-1
** The only wells shown are those within the 500m groundwater study areas

Rev.	Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
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Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
ENVIRONMENTAL STATEMENT

Drawing Title: STUDY AREA - SECTION 5

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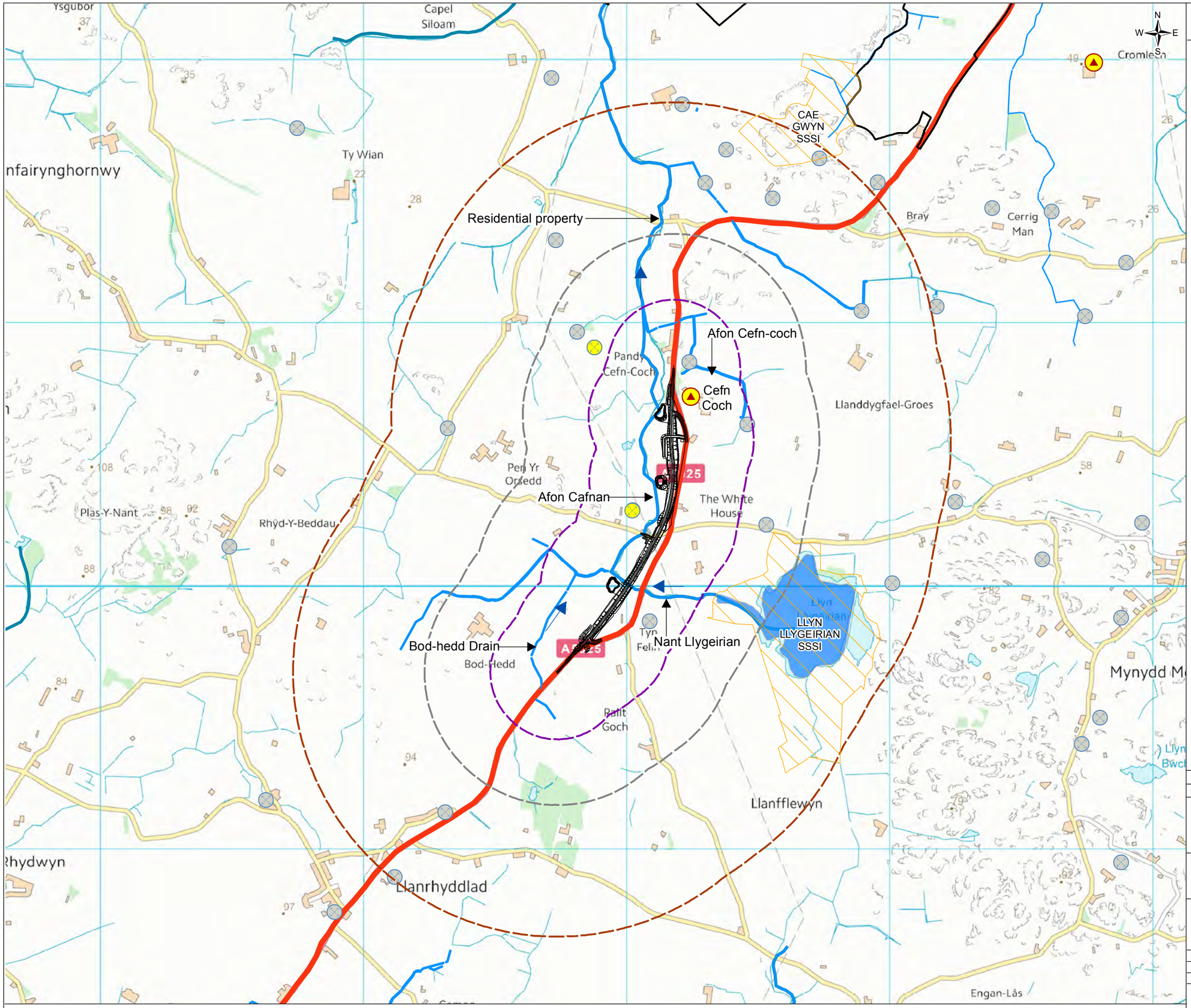
FIGURE G8-1-5



Legend

- A5025 Off-line Highway Improvements (Section 7)
- Site of Special Scientific Interest (SSSI)
- Wylfa Newydd Development Area
- Fluvial geomorphology 250m study area
- Surface water and groundwater 500m study area
- HAWRAT 1km study area
- A5025
- Private Water Supply (PWS) - scoped in
- Well - scoped out
- Well - scoped in
- Main rivers
- Ordinary watercourses
- Fluvial WFD water body
- Lacustrine WFD water body

* For location of this section see figure G8-1-1
** The only wells shown are those within the 500m groundwater study areas

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Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
ENVIRONMENTAL STATEMENT

Drawing Title: STUDY AREA - SECTION 7

Scale @ A3	1:14,000	DO NOT SCALE
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Client No.		

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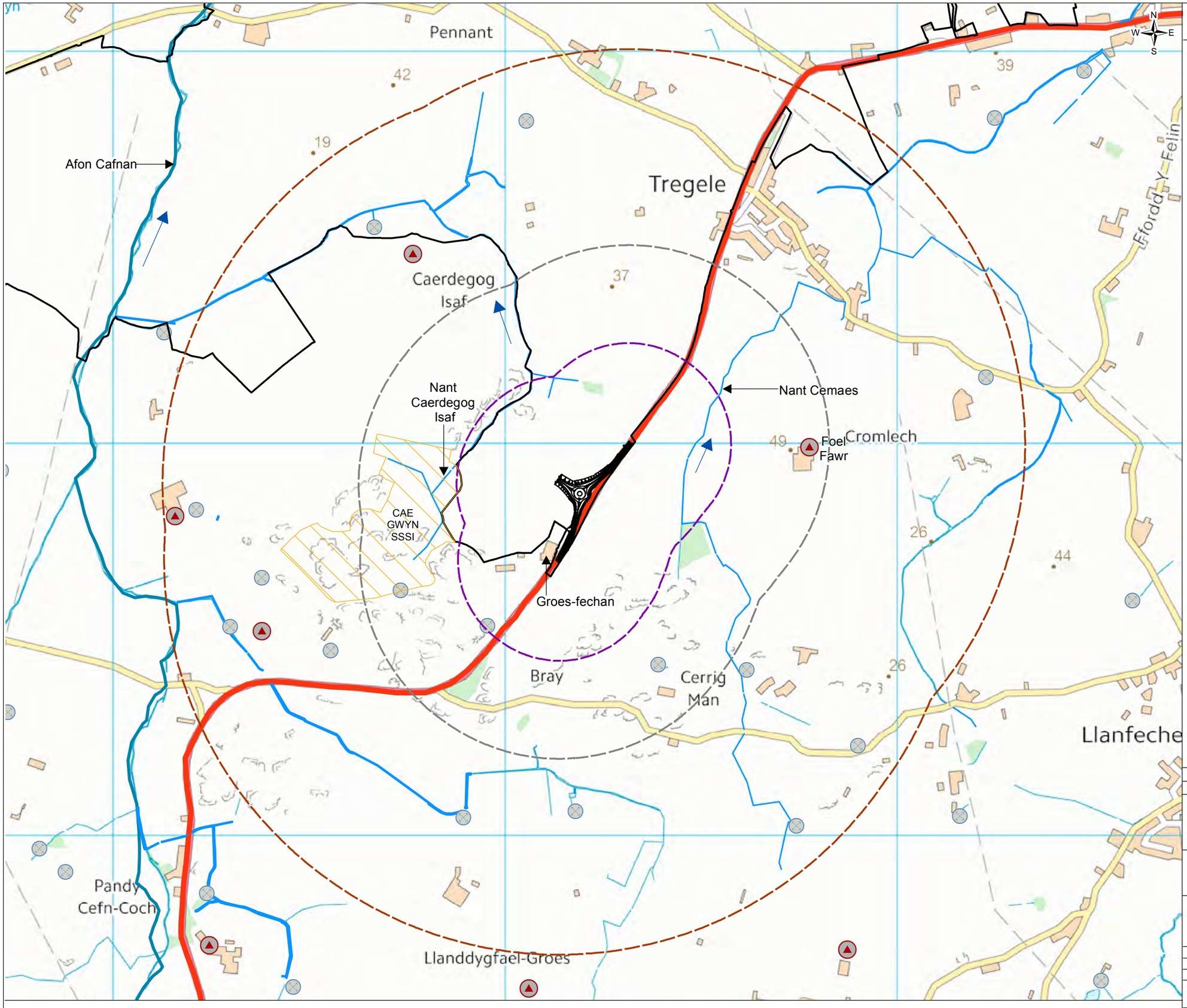
FIGURE G8-1-6



Legend

- Power Station Access Road Junction
- Site of Special Scientific Interest (SSSI)
- Wylfa Newydd Development Area
- Fluvial geomorphology 250m study area
- Surface water and groundwater 500m study area
- HAWRAT 1km study area
- A5025
- Private Water Supply (PWS) - scoped out
- Well - scoped out
- Main rivers
- Ordinary watercourses
- Fluvial WFD water body

* For location of this section see figure G8-1-1
** The only wells shown are those within the 500m groundwater study areas

Rev.	Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
0	OCT 17	Initial Issue	HT	RA	SH	RB

Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
ENVIRONMENTAL STATEMENT

Drawing Title: STUDY AREA - POWER STATION ACCESS ROAD JUNCTION

Scale @ A3	1:9,383	DO NOT SCALE
Jacobs No.	60PO8077	
Client No.		

Drawing No. 60PO8077_DCO_A5025_G_08_01_06

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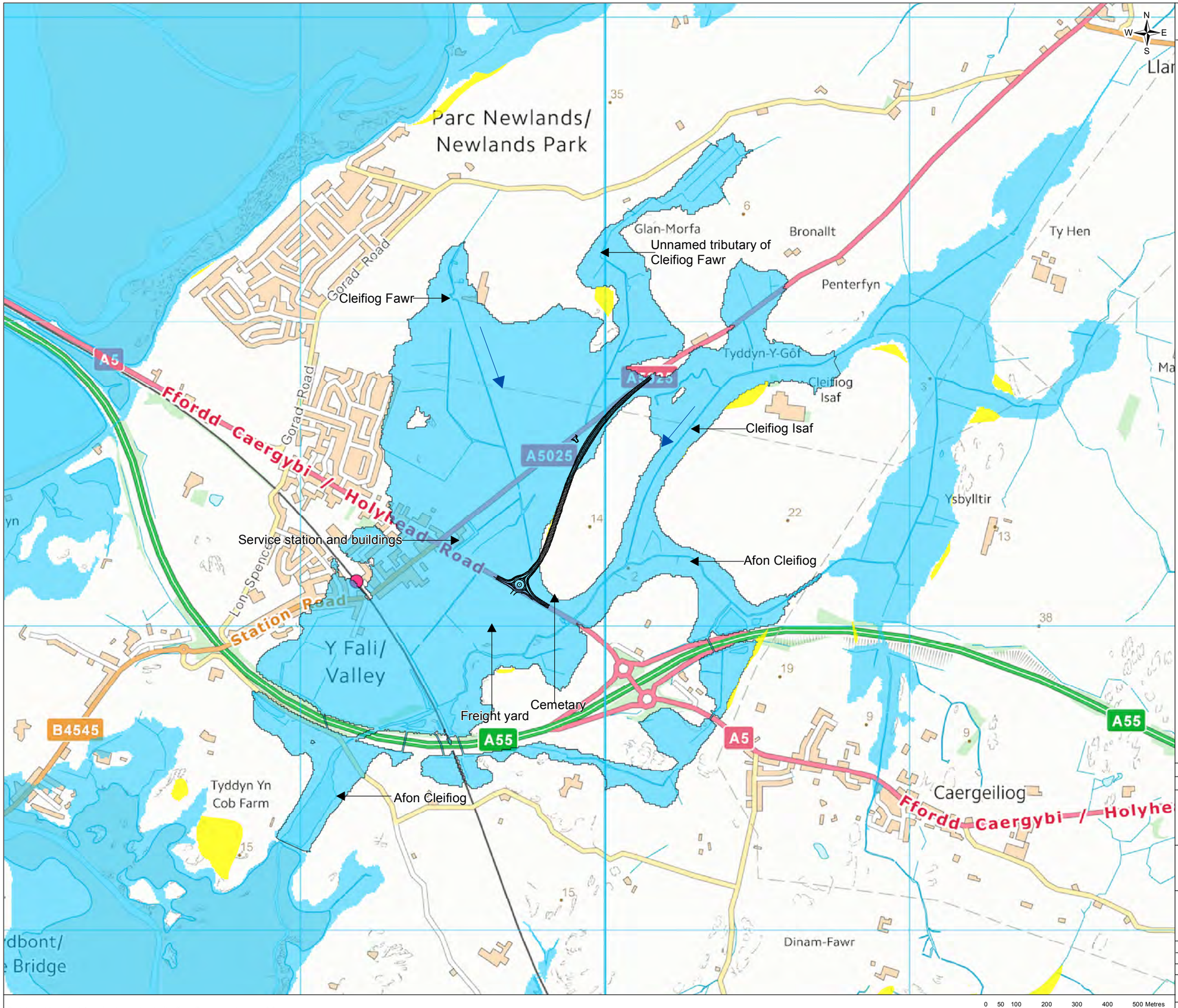
0 50 100 200 300 400 500 Metres

FIGURE G8-1-7



Legend

- A5025 Off-line Highway Improvements (Section 1)
- Flood Zone A
- Flood Zone B
- Flood Zone C2

Rev.	Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
0	JUL 17	Initial Issue	HT	AJ	SH	RB

Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
FLOOD CONSEQUENCE ASSESSMENT

Drawing Title: SECTION 1 TAN15 DEVELOPMENT ADVICE MAP

Scale @ A3	1:12,000	DO NOT SCALE
Jacobs No.	60PO8077	
Client No.		

Drawing No.: 60PO8077_DCO_VOL_G_APP_08_01_01_07

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FIGURE G8-1-8

Legend

- A5025 Off-line Highway Improvements (Section 1)
- High surface water flood risk - extent
- Medium surface water flood risk - extent
- Low surface water flood risk - extent

Parc Newlands/
Newlands Park

Glan-Morfa

Bronallt

Ty Hen

Penterfyn

Unnamed tributary of Cleifiog Fawr

Cleifiog Fawr

Gorad Road

A5

A5025

Tyddyn-Y-Gôf

Cleifiog Isaf

Cleifiog Isaf

Fford Caergybi / Holyhead Road

Service station and buildings

Afon Cleifiog

Station Road

Y Fali/
Valley

Freight yard

Cemetary

A55

A5

B4545

Tyddyn Yn
Cob Farm

Afon Cleifiog

Caergeiliog

Ffordd Caergybi

Dinam-Fawr

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0 50 100 200 300 400 500 Metres

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Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
FLOOD CONSEQUENCE ASSESSMENT

Drawing Title: SECTION 1 NRW SURFACE WATER FLOOD MAP

Scale @ A3	1:12,000	DO NOT SCALE
Jacobs No.	60PO8077	
Client No.		

Drawing No.: 60PO8077_DCO_VOL_G_APP_08_01_01_08

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Natural Resources Wales © NRW

FIGURE G8-1-9

Legend

- A5025 Off-line Highway Improvements (Section 1)
- Reservoir flood risk

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0	JUL 17	Initial Issue	RM	AJ	SH	RB

Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
FLOOD CONSEQUENCE ASSESSMENT

Drawing Title: SECTION 1 FLOOD RISK FROM RESERVOIRS

Scale @ A3	1:12,000	DO NOT SCALE
Jacobs No.	60PO8077	
Client No.		

Drawing No.: 60PO8077_DCO_VOL_G_APP_08_01_01_09

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FIGURE G8-1-10

Legend

- A5025 Off-line Highway Improvements (Section 3)
- Flood Zone A
- Flood Zone B
- Flood Zone C2

Llanfwrog
Dronwy
Bottan Fawr
Bryn Palma
Llynon Bâch
Llanddeusant
Rhos-Ddû
Pont-Y-Pandy-Bâch
Bodfardden Newydd
Llanfigael
Tremoelgoch Bach
Maen-Y-Goron
Penial Dowyn
Bro Dawel
Bodlasan Fawr
Tan R'Allt
Afon Alaw
Bryn Teiran
Llanfachraeth
Neuadd-Wen
Moel Haul
Farm building
Residential building
Bodlasan Groes
Pont yr Arw
Llanllibio Fawr
Tyn Rhos
Bodardraeth
Ty-Newydd
Traeth y Gribin
Erw Goch
Afon Llywenan
A5
Llanllibio Groes
Alaw Estuary
Erw Fawr
Tay'n Ffynnon
Mynydd-Y-Gôf
B5109
Llanynghenedl
Llanynghenedd
Parc Newlands/ Newlands Park
Tyn Cae
Efail Newydd
Glan-Morfa
Bronallt
Ty Hen
Penterfyn
Gorad-Road

Tregwehelydd
Standing Stone

N
W
E
S

0 50 100 200 300 400 500 Metres

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Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
FLOOD CONSEQUENCE ASSESSMENT

Drawing Title: SECTION 3 TAN15 DEVELOPMENT ADVICE MAP

Scale @ A3	1:18,000	DO NOT SCALE
Jacobs No.	60PO8077	
Client No.		

Drawing No.: 60PO8077_DCO_VOL_G_APP_08_01_01_10

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FIGURE G8-1-11

Legend

- A5025 Off-line Highway Improvements (Section 3)
- High surface water flood risk - extent
- Medium surface water flood risk - extent
- Low surface water flood risk - extent

Llanfwrog
Dronwy
Bottan Fawr
Bryn Palma
Llynon Bâch
Llanddeusant
Rhos-Ddû
Pont-Y-Pandy-Bâch
Bodfardden Newydd
Llanfigael
Tremoelgoch Bach
Maen-Y-Goron
Tregwehelydd Standing Stone
Penial Dowyn
Bodlasan Fawr
Tan R'Allt
Afon Alaw
Neuadd-Wen
Llanfachraeth
Farm building
Moel Haul
Residential building
Pont yr Arw
Bodlasan Groes
Bodardraeth
Ty-Newydd
Llanllibio Fawr
Tyn Rhos
Traeth y Gribin
Erw Goch
Afon Llywenan
A5025
Alaw Estuary
Erw Fawr
Llanllibio Groes
Tay'n Ffynnon
Mynydd-Y-Gôf
B5109
Llanynghenedl
Llanynghenedd
Parc Newlands/ Newlands Park
Tyn Cae
Efail Newydd
Glan-Morfa
Bronallt
Ty Hen
Penterfyn
Gorad-Road
Bryn Teiran

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Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
FLOOD CONSEQUENCE ASSESSMENT

Drawing Title: SECTION 3 NRW SURFACE WATER FLOOD MAP

Scale @ A3	1:18,000	DO NOT SCALE
Jacobs No.	60PO8077	
Client No.		

Drawing No.: 60PO8077_DCO_VOL_G_APP_08_01_01_11

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FIGURE G8-1-12

Legend

- A5025 Off-line Highway Improvements (Section 3)
- Reservoir flood risk

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Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
FLOOD CONSEQUENCE ASSESSMENT

Drawing Title: SECTION 3 FLOOD RISK FROM RESERVOIRS

Scale @ A3	1:12,000	DO NOT SCALE
Jacobs No.	60PO8077	
Client No.		

Drawing No. 60PO8077_DCO_VOL_G_APP_08_01_01_12

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FIGURE G8-1-13

Legend

- A5025 Off-line Highway Improvements (Section 5)
- Flood Zone B
- Flood Zone C2

Cable Bay
Cae'r-Goll
Gamog
Lon Las
Aber Pwll Fferm
Afon Garreglwyd
Huset Vid Havet
Porth Trwyn
Garreglwyd
Pen-Y-Cae
Grade II listed building
Ty'n-y-buarth
Western Pond
Afon Llanrhyddlad
East Drain
Afon Garreglwyd
Rhos-ty-mawr
Hen-shop drain
Cae'r-brynlau
Tyddyn-Y-Waen
Pengroeslon
Tan-y-bryn
Fadog Frech
A5025
Tyddyn Josiah
Llanfaethlu
Plas Uchaf
Awel y Rhyd
Ty'n-llech
Rhosyrolion
Pentre-Bwlw
Plas Newydd
Ty Croes Bach
Bryn Tirion
Tyddyn Bach Bungalow
Tyddyn-Llŵyd
Bodfardden-Ddu
Gronant
Bodfardden-Wen
Llan
enir
38
72
48
66
85
84
73
64
47
34
37
31
63

N
W E
S

Rev.	Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
0	JUL 17	Initial Issue	RM	AJ	SH	RB

Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
FLOOD CONSEQUENCE ASSESSMENT

Drawing Title: SECTION 5 TAN15 DEVELOPMENT ADVICE MAP

Scale @ A3	1:14,000	DO NOT SCALE
Jacobs No.	60PO8077	
Client No.		

Drawing No. 60PO8077_DCO_VOL_G_APP_08_01_01_13

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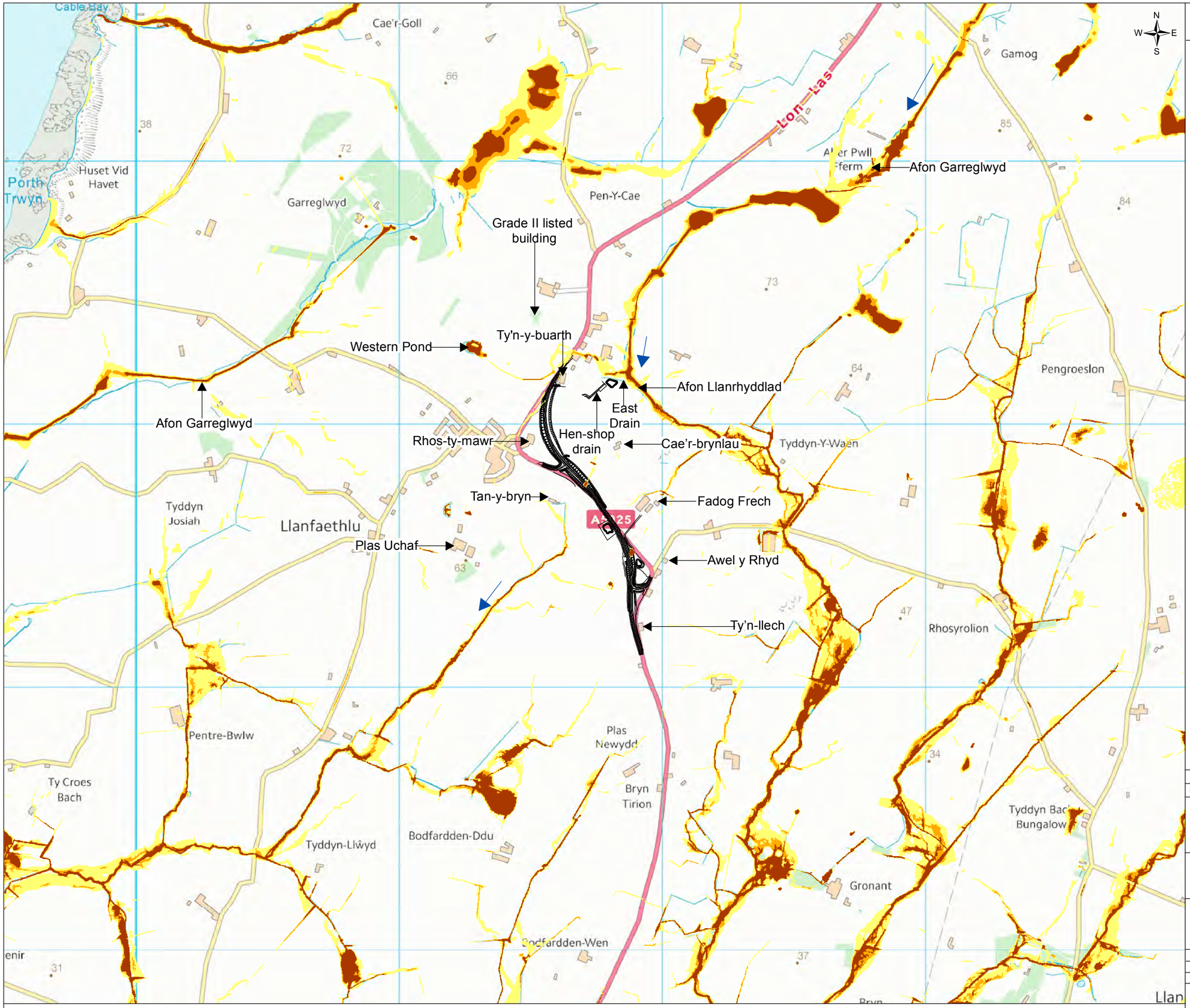
FIGURE G8-1-14



Legend

- A5025 Off-line Highway Improvements (Section 5)
- High surface water flood risk - extent
- Medium surface water flood risk - extent
- Low surface water flood risk - extent

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Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
FLOOD CONSEQUENCE ASSESSMENT

Drawing Title: SECTION 5 NRW SURFACE WATER FLOOD MAP

Scale @ A3	1:14,000	DO NOT SCALE
Jacobs No.	60PO8077	
Client No.		

Drawing No.: 60PO8077_DCO_VOL_G_APP_08_01_01_14

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FIGURE G8-1-15

Legend

- A5025 Off-line Highway Improvements (Section 7)
- Wylfa Newydd Development Area
- Flood Zone B
- Flood Zone C2

Residential property

Afon Cefn-coch

Afon Cafnan

Bod-hedd Drain

Nant Llygeirian

Capel Siloam
Ty Wian
Cromlech
Bray
Cerrig Man
Pandy Cefn-Coch
Llanddygfael-Groes
Pen Yr Orsedd
The White House
Plas-Y-Nant
Rhŷd-Y-Beddau
Llyn Llygeirian
Tyn Felin
Bod-Hedd
Rallt Goch
Mynydd Mech
Llyn Bwch
Llanfflewyn
Llanrhyddlad
Engan-Lâs

A5025

N W E S

0 50 100 200 300 400 500 Metres

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Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
FLOOD CONSEQUENCE ASSESSMENT

Drawing Title: SECTION 7 TAN15 DEVELOPMENT ADVICE MAP

Scale @ A3	1:14,000	DO NOT SCALE
Jacobs No.	60PO8077	
Client No.		

Drawing No. 60PO8077_DCO_VOL_G_APP_08_01_01_15

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FIGURE G8-1-16

Legend

- A5025 Off-line Highway Improvements (Section 7)
- Wylfa Newydd Development Area
- High surface water flood risk - extent
- Medium surface water flood risk - extent
- Low surface water flood risk - extent

Residential property

Afon Cefn-coch

Afon Cafnan

Bod-hedd Drain

Nant Llygeirian

Capel Siloam
Cromlech
Bray
Cerrig Man
Pandy Cefn-Coch
Llanddygfael-Groes
Pen Yr Orsedd
The White House
Plas-Y-Nant
Rhŷd-Y-Beddau
Bod-Hedd
Tyn Felin
Rallt Goch
Mynydd Mech
Llyn Bwch
Llanfflewyn
Llanrhyddlad
Engan-Las

A5025

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Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
FLOOD CONSEQUENCE ASSESSMENT

Drawing Title: SECTION 7 NRW SURFACE WATER FLOOD MAP

Scale @ A3	1:14,000	DO NOT SCALE
Jacobs No.	60PO8077	
Client No.		

Drawing No. 60PO8077_DCO_VOL_G_APP_08_01_01_16

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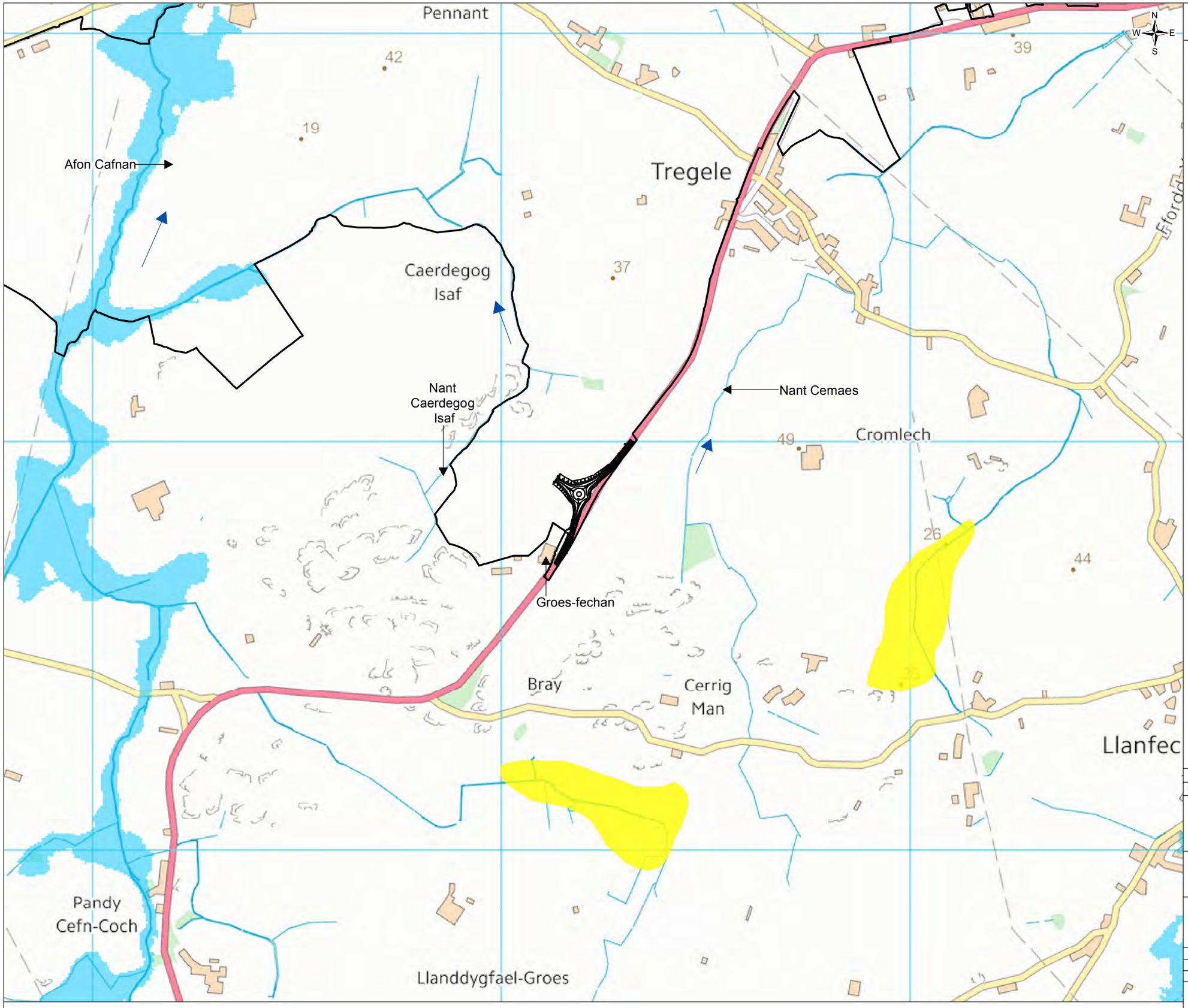
FIGURE G8-1-17



Legend

- Power Station Access Road Junction
- Wylfa Newydd Development Area
- Flood Zone B
- Flood Zone C2

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0 50 100 200 300 400 500 Metres

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Client

HORIZON NUCLEAR POWER

Project

WYLFA NEWYDD PROJECT
FLOOD CONSEQUENCE ASSESSMENT

Drawing Title

POWER STATION ACCESS ROAD JUNCTION
TAN15 DEVELOPMENT ADVICE MAP

Scale @ A3	1:9,000	DO NOT SCALE
Jacobs No.	60PO8077	
Client No.		

Drawing No.

60PO8077_DCO_VOL_G_APP_08_01_01_17

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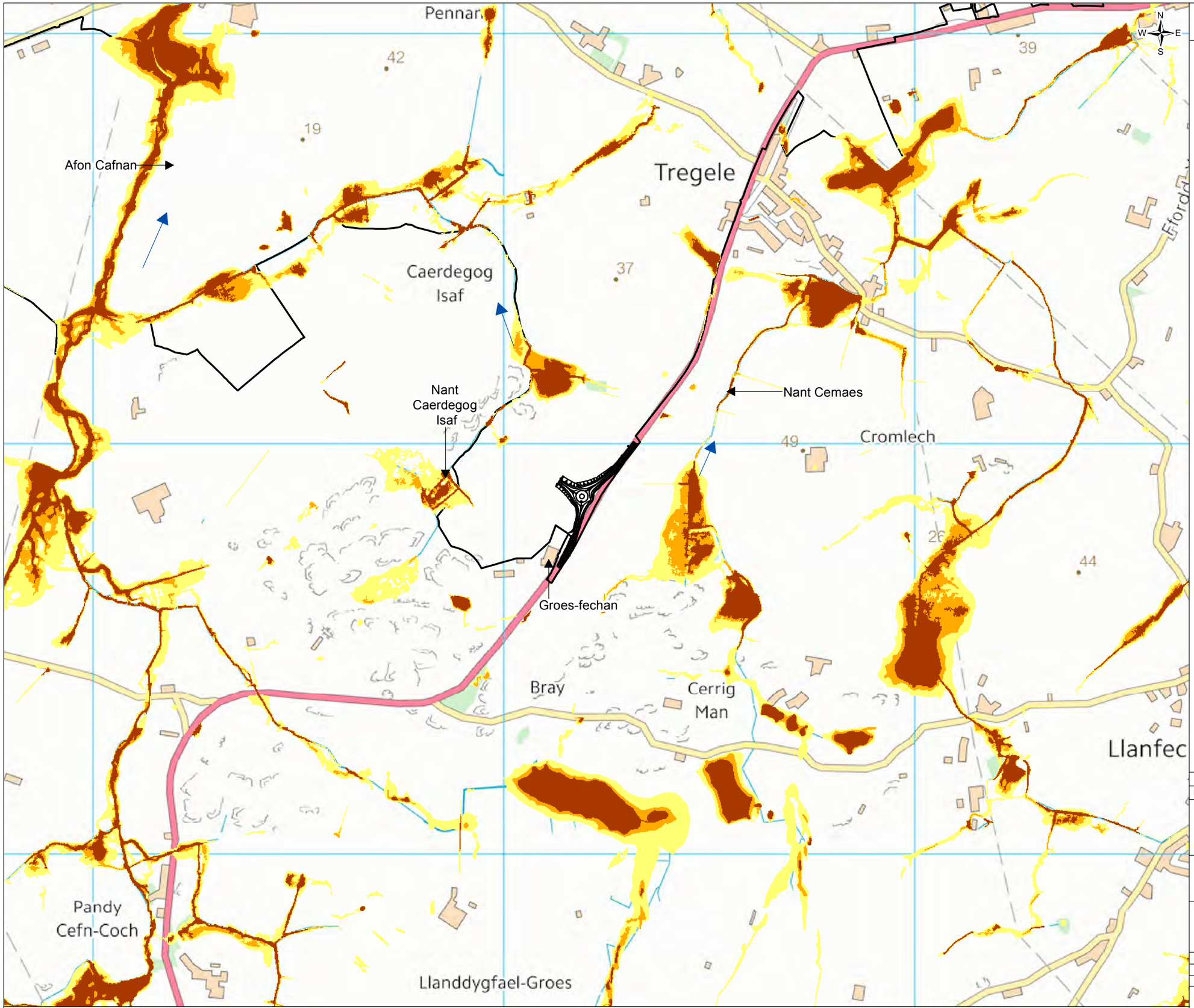
FIGURE G8-1-18



Legend

- Power Station Access Road Junction
- Wylfa Newydd Development Area
- High surface water flood risk - extent
- Medium surface water flood risk - extent
- Low surface water flood risk - extent

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0 50 100 200 300 400 500 Metres

Rev.	Date	Purpose of revision	Drawn	Check'd	Rev'd	Appr'd
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Client: HORIZON NUCLEAR POWER

Project: WYLFA NEWYDD PROJECT
FLOOD CONSEQUENCE ASSESSMENT

Drawing Title: POWER STATION ACCESS ROAD JUNCTION
NRW SURFACE WATER FLOOD MAP

Scale @ A3	1:9,000	DO NOT SCALE
Jacobs No.	60PO8077	
Client No.		

Drawing No. 60PO8077_DCO_VOL_G_APP_08_01_01_18

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Appendix G8-01.2 Assessment methodology

Assessment methodology

8-1.1.1 In order to allow for the wider assessment of flood risk, a generalised assessment methodology has been developed that is consistent with the DMRB environmental assessment approach [RD18] in general, but which is consistent with TAN 15 [RD4].

8-1.1.2 In line with the DMRB approach [RD18], the key to the classification is consideration of both the 'importance' of the receptor and the magnitude of potential effect that is brought about by the proposed development. These are subsequently combined through a matrix to identify the significance of potential effect:

- the importance (or sensitivity) of the receptor – takes into account the type and number of receptors in the floodplain;
- the magnitude of potential effect – primarily takes account of the effect on flood levels of the proposed development but where necessary could account for effects on other factors such as velocity, hazard, duration of flooding or the rate of rise as defined by TAN 15 [RD4].

Importance of the receptor

8-1.1.3 When considering new developments, the classification of importance or sensitivity is based (where possible) directly on the technical guidance set out within the DMRB [RD18]. Given this, the sensitivity of the receptor is ranked as shown in table G8-01.27. Suggested TAN 15 categories are presented, however, it should be noted that the DMRB categories do not explicitly relate to the vulnerability of an individual receptor and professional judgement should be used to adjust sensitivity if it is considered necessary.

Table G8-01.27 Classification of sensitivity of receptor

Importance of receptor	Typical DMRB classification	Equivalent TAN 15 category
Very high	Floodplain or defence protecting more than 100 residential properties from flooding	Emergency Services
High	Floodplain or defence protecting between 1 and 100 residential properties or industrial premises from flooding	Highly Vulnerable
Medium	Floodplain or defence protecting 10 or fewer industrial properties from flooding	Less Vulnerable
Low	Floodplain with limited constraints and a low probability of flooding of residential and industrial properties	Unclassified

Magnitude of effect

8-1.1.4 To classify the severity of the potential effects, it is typically necessary to look at the nature and scale of the individual effects. These include, but are

not confined to the extent, depth and duration of flooding, and the velocity of flood waters. The DMRB guidance restricts its typical effects to those on depth, hence only examples related to depth are presented. Professional judgement should be used to adjust magnitude of hazard based on similar principles if it is considered appropriate.

8-1.1.5 The magnitude of effect is shown below in table G8-01.28.

Table G8-01.28 Classification of magnitude of potential hazard

Magnitude of hazard	Typical DMRB criteria
Major adverse	Increase in peak flood level (1% annual probability) >100mm
Moderate adverse	Increase in peak flood level (1% annual probability) >50mm
Minor adverse	Increase in peak flood level (1% annual probability) >10mm
Negligible	Negligible change in peak flood level (1% annual probability) <+/- 10mm
Minor beneficial	Reduction in peak flood level (1% annual probability) >10mm
Moderate beneficial	Reduction in peak flood level (1% annual probability) >50mm
Major beneficial	Reduction in peak flood level (1% annual probability) >100mm

Significance of effect

8-1.1.6 The magnitude of the hazard and the sensitivity of the receptor are combined using a matrix (shown below in table G8-01.29) to determine the significance of the potential effect, if realised.

Table G8-01.29 Matrix for determining the significance of the potential effect

		Magnitude of impact			
		Negligible	**Minor**	**Moderate**	**Major**
Importance	**Very high**	Neutral	Moderate/large	Large/very large	Very large
	High	Neutral	Slight/moderate	Moderate/large	Large/very large
	Medium	Neutral	Slight	Moderate	Large
	Low	Neutral	Neutral	Slight	Slight/moderate

8-1.1.7 Typically, effects assessed as slight or less are considered acceptable. If the assessment results in moderate or high risk, this is considered significant (i.e. equivalent to a significant effect under *The Town and Country Planning (Environmental Effect Assessment) Regulations 2011*), and additional mitigation measures would be required to facilitate development.

8-1.1.8 In some situations, the risk assessment procedure will result in an artificially low assessment of risk. This is particularly the case in situations where consequences of very rare flooding (i.e. breach scenarios) are so extreme that any residual risk, however low, would not be allowed. In such instances, the assessed risk would be elevated. Such decisions must always be accompanied by detailed justification.

Appendix G8-01.3 Section 1 flood modelling results

Horizon Nuclear Power

Wylfa Newydd DCO Project – Offline A5025 Bypass, Valley, Anglesey, NW Wales

Hydrology and Hydraulic Modelling Factual Report

January 2018

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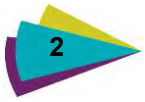

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1. Introduction

As part of the Wylfa Newydd DCO Project, several highway enhancement projects have been identified, one of which is a bypass proposed around the crossroad junction between the A5 and A5025 in Valley, which is the subject of this technical note. The proposed bypass route passes through agricultural land and crosses small watercourses to the north east of the A5/A5025 junction, shown on Figure 4.1.1D-2D modelling will be undertaken to support the assessment of the proposed A5025 bypass at Valley, Anglesey, NW Wales. Modelling will determine the baseline (present day) fluvial flood risk to the bypass location and nearby receptors, and the future risk including climate change impacts. The significance of the impacts and justification of the design are included within the Flood Consequence Assessment (FCA) associated with proposed bypass footprint. The FCA will also detail the highway proposals at the Valley bypass location and provide context to the wider Wylfa Newydd DCO Project.

1.1 Purpose of this report

This factual report has been produced for the purpose of describing the hydrological and hydraulic modelling undertaken to support the Wylfa Newydd DCO Project, specifically for the proposed Offline A5025 bypass proposal at Valley, Anglesey, NW Wales. This factual report does not present an assessment of the results. This factual report provides a detailed statement of the hydrological and hydraulic modelling methods applied, assumptions made and the limitations within the approaches. The report also details the data used together with the results of QA and validation checks.

1.2 Purpose of modelling

1D-2D Modelling has been undertaken to support the assessment of the proposed Offline A5025 bypass at Valley, Anglesey, NW Wales. The modelling documented in this report has re-defined the baseline (present day) fluvial and tidal flood risk to the bypass location at Valley and nearby receptors. The modelling also quantifies the impacts of future risk (both with and without the proposed bypass and associated mitigation measures) including an allowance for climate change impacts. A range of design flood events have been modelled to establish the full extent of baseline flood risk, which the project has used to inform the design of bypass and associated mitigation measures. The modelling has also been used to determine the impact of the bypass design on fluvial and tidal flood risk elsewhere in the Valley area. A summary of the model scenarios represented by the hydraulic model is shown in Table 1.1; hydrological assessment is required for the fluvial scenarios only. A full Joint Probability analysis of fluvial flows and tidal levels has not been undertaken but two single pre-defined combined fluvial-tidal events have been assessed.

Table 1.1 Summary of model scenarios

Source	Hydrology method	Event	Season	Storm Duration	Epoch	Climate change[1]
Fluvial	ReFH1 with FEH99 rainfall data to WINFAP 3.3.4 peak (The MHWS tidal curve (peak at 49 hours) was applied to all fluvial model runs)	1:5, 1:20, 1:100, 1:1000 year AEP	Winter	49 hours	2017	n/a
		1:100 year AEP	Winter	49 hours	2114[2]	30% increase in flows

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Source	Hydrology method	Event	Season	Storm Duration	Epoch	Climate change[1]
Tidal	QMED[3] applied as the fluvial inflow boundary for the Tidal only model simulations.	1:200, 1:1000 year AEP	n/a	n/a	2014	n/a
		1:1000 year AEP	n/a	n/a	2114	Sea level rise (1.1m)
Fluvial/Tidal	ReFH1 with FEH99 rainfall data to WINFAP 3.3.4 peak	1:5 year AEP 1:200 year AEP	Winter n/a	49 hours n/a	2017	n/a
Fluvial/Tidal	ReFH1 with FEH99 rainfall data to WINFAP 3.3.4 peak	1:100 year AEP 1:200 year AEP	Winter n/a	49 hours n/a	2114 [2] 2114	30% increase 1.1m increase

AEP = Annual exceedance probability
[1] The climate change guidance adopted in the modelling is drawn from the Welsh Government Guidance (published 23-08-16) in which the values for the 2020s, 2050s and 2080s are provided and in a footnote to Table 1.
[2] The guidance states the FCAs should apply the 2080s uplift value to fluvial flows to represent climate change. The 2080s represents the period between 2070-2115.
[3] QMED (median annual maximum flood)

1.3 Overview of modelling approach

To fulfil the requirements of the Flood Consequence Assessment (FCA) and Natural Resources Wales (NRW) it was necessary to construct a detailed 1D-2D flood model of the Valley area to determine the impact of the proposed A5025 bypass. The requirements were to develop a robust baseline flood risk position against which the impacts of the propose bypass could be robustly compared. Current planning policy guidance requires an assessment of the flood consequences of the development to third parties for an appropriate range of fluvial flows and tidal flood levels up to and including the 1:1,000 year AEP event. With climate change needing to be considered on all fluvial flows up to and including the 1:100 year AEP event and on all tidal flood levels up to and including the 1:1,000 year AEP event.

There were no existing models that could be used. The 1D-2D approach was adopted as it was known that an embankment was going to be proposed and that this would potentially have an impact. The 1D-2D modelling platform is deemed superior to a 1D only model as it better defines the spatial impact of development on water levels and flood depths.

The coupled 1D-2D hydraulic modelling software used was Flood Modeller - TUFLOW. These are industry standard software packages, widely used for flood modelling.

1.4 Key assumptions

A channel topographic survey was conducted in October 2015 of the channels and associated structures. LiDAR data was used to represent the floodplain topography. The following key assumptions have been made:

- It was assumed that the modelled watercourses are not undergoing regular maintenance, and thus ‘soft bed’ channel survey readings have been utilised in the model build.
- GIS catchment delineation has been conducted to estimate contributing catchment areas to the smaller drainage channels running through the proposed bypass footprint (see hydrology report).
- Access prohibited certain reaches of watercourse being surveyed. In these areas, the LiDAR has been used to determine cross sections shapes to provide a more accurate representation of the channel that the nearest survey locations when compared to site visit and survey photos.

The tidal barrier (see

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- Figure 4.1 for location) has been included in the 1D and 2D model as per design drawings provided by NRW. The barrier is assumed to operate by having flapped outfalls on the three culverts which connect the upstream watercourse and the estuary which prevent the ingress of tidal waters upstream. The crest level of the embankment has been taken from the data provided by NRW.
- A site visit undertaken in November 2014, and survey photographs, have suggested the channels are reasonably regular and consistent along its length, with few substantial changes in shape for width. This has informed requested survey cross sections spacing, and allowed for interpolate sections to be added to aid model conveyance and stability.
- Aerial photography and site visits have suggested banks are not heavily vegetated for the most part of the modelled channel reaches, and thus assumptions that 1m LiDAR resolution is satisfactory to pick out bank levels and channels between surveyed cross sections.
- Model extents have been determined in order to prevent any model boundary influence on the focus area around the proposed bypass footprint location. The model is not intended as a catchment-wide flood extent assessment.

The model is considered the best representation of the various watercourses which flow in and around Valley. The use of the available data was appropriate for this study as the main purpose is to provide an estimate of flood extent across the proposed bypass footprint and determine the potential impact of the proposed developments. The model has been built for the purpose of flood risk mapping; therefore, it has been optimised for high flows.

1.5 Model review

In addition to internal model QA checks the model was reviewed externally on behalf of NRW (January 2017). A full review of both the 1D and 2D components was undertaken, including analysis of the various fluvial and tidal scenario outputs with and without climate change allowance.

A technical review certificate was produced, the key findings of which are tabulated in Appendix E. Appendix E also provides details on the action taken to address the respective review comment, with supporting information where applicable.

The model details provided hereafter incorporate any review updates.

1.6 Document structure

The remainder of this report is structured as follows:

- Section 2 - Available data: Identifies data collated or commissioned to aid model build, catchment and structure representation. Discusses any lack of data where appropriate;
- Section 3 - Hydrology: Details the fluvial hydrology assessment;
- Section 4 - Model Overview: Details the representation of the modelled channels in the 1D model domain, and the 2D model domain, including any assumptions made for representations or stability;
- Section 5 - Model Runs: Lists the baseline model scenarios run, including file structures;
- Section 6 - Model Results: Summarises baseline model results, including flood extents and depths;
- Section 7 - Bypass Modelling: Details approach to bypass inclusion and summary of impact on flood levels; and
- Section 8 - Sensitivity Testing: Lists sensitivity runs carried out on the 1D-2D model, and discusses outputs.

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2. Data summary

The 1D-2D model was built following collation of a number of datasets to represent the Valley catchment topography, floodplain, structures, channel and banks. Table 2.1 below details the datasets collated, and provides a description of the contents of each data set.

Table 2.1 Data summary

Item	Comments
Cross-section survey	Maltby Land Surveys Ltd; June-July 2015. Surveyed drains: DRAI01, DRAI02, DRAI03, DRAI04, DRAI05, DRAI06, DRAI07, DRAI08, DRAI09. Overall location plan: channel and structure locations. Drain cross sections: bed level (soft/hard); bank levels; water levels; location photos. Structure surveys: culverts/bridges/obstructions/walls. Tidal barrage survey: inlets; outlets; tidal flaps (some dimensions limited in detail due to access issues). The survey was undertaken in line with standard NRW specification.
Topography	LiDAR 1m resolution Digital Terrain Model. From Environment Agency (EA) Geomatics, obtained March 2015. The LiDAR has a vertical accuracy of +/- 0.15m.
Other Topographic Data	Tidal barrage topographic survey (NRW, received September 2015)
Mapping data	Ordnance Survey (OS) MasterMap (supplied by URS, October 2014)
Gauging stations	No gauging stations in the catchment
Calibration / verification events	No calibration events identified due to no gauged data available
Flood history	Photos provided by Isle of Anglesey County Council (IACC).

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3. Hydrology assessment

This section summarises the process to derive the hydrology inputs for the hydraulic modelling. A detailed hydrology assessment technical report is provided in Appendix B. The hydrology for Valley was developed over a number of months, completing in March 2016 and the report issued to NRW for review in June 2016 (Document Number: 203025-0000-AA40-RPT-0016). The review was completed and all required modifications incorporated into the hydrology assessment in 2016. In the intervening period industry standard hydrological methods and software have been updated. It was however agreed with NRW at a meeting on the 12/04/2017 that it was not necessary to update the Valley hydrology prior to the DCO application, but that this may need to be reviewed in future as part of detailed design.

The fluvial hydrology inputs to the hydraulic model were hydrographs (flow/time) for a single critical storm duration, optimised at the bypass location, and a range of events. The hydrology inputs have been calculated for the current baseline at Valley.

3.1 Catchment overview

The Valley watercourse, and its tributary Glan Morfa, are located near the proposed bypass route. The Valley watercourse is currently culverted under the A5, flowing into the Cleifiog watercourse just upstream of the railway approximately 250m south of Valley. Given the relatively low-lying nature of the topography, water levels on the Cleifiog watercourse near the confluence with the Valley watercourse could influence predicted water levels at the study area and therefore need to be considered as part of the hydrological assessment.

The Cleifiog flows south-west from Llanynghenedl, flowing into Holyhead Bay via a tidal sluice gate approximately 1km south of Valley. The Maes Y Wrach flows west from south of Bodedern through an extensive marshy area just north of the A55, to discharge into the Cleifiog watercourse near Pen-caledog. The Caergeiliog watercourse flows through Caergeiliog to discharge into the Maes Y Wrach watercourse in the marshy area. There is also a drain linking the Cleifiog watercourse with the Maes Y Wrach. Flow in the Cleifiog, including the Maes Y Wrach tributary, is constrained by the A5 culvert upstream of the confluence with the Valley watercourse. A location plan showing these watercourses and their associated FEH catchments is provided in Appendix B (Figure 1.1).

The area north and east of Valley, where the proposed A5025 bypass is located, is relatively flat with numerous drainage channels and watercourses and the catchments serving them are not well defined. In addition, normal flow directions may reverse under higher flow conditions. As a result, flow mechanisms in the area of the proposed bypass are complex. Furthermore, there are no flow or water level gauge data or detailed topographic survey available to fully understand the system, either during normal flow conditions or extreme events.

Hydrological assessment locations (HAL) were chosen to represent the inflow at the upper extent of the model (HAL 5 – on Valley watercourse, HAL 4 – on Glan Morfa, HAL 6 – on Cleifiog, HAL 7 – on Maes Y Wrach) and to calculate inflows from intervening catchments on the Cleifiog (represented by HALs 3, 2 and 1), as shown in Appendix B (Figure 2.2).

3.2 Method of hydrograph calculation

Hydrological assessment was undertaken for the Valley watercourse and Glan Morfa tributary, and Cleifiog and Maes Y Wrach tributary to determine the fluvial inflow. Design flow hydrographs were required to model the following fluvial events: 1:5 year, 1:20 year, 1:100 year and 1:1,000 year AEP events. A further hydrograph was required for the QMED event (1:2 year AEP) in combination with tidal flood modelling.

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Catchment boundary and catchment descriptors

The four watercourse catchments identified on the FEH CD-ROM 3 were compared to that derived using OS mapping and topographic data. This showed there were some issues with catchment identification and boundaries, illustrated in Appendix B (Figure 2.1).

A single FEH based catchment was identified representing both hydrological assessment locations 4 and 5, which was not consistent with available topographic data. The FEH catchment 4 and 5 predominantly overlaps most of topographic catchment 5, but there are additional areas to the east and west. Also, two thirds of topographic catchment 4 significantly overlaps FEH Catchment 6 (representing the upper Cleifiog catchment). The FEH catchment 7 does not include the Caergeiliog watercourse, as FEH identifies the Maes Y Wrach flowing south via the Caergeiliog watercourse. The following representation has been undertaken in the hydrological assessment:

- Flows were derived for FEH catchment 4 and 5, and then area weighted to represent the appropriate catchment at each hydrological assessment location;
- Flows were derived for FEH catchment 6, and then area weighted to remove area represented by hydrological assessment location 4; and
- Flows were derived for FEH catchment at about 1km northeast of Pen-Caledog (NGRSH 30900 78550 in Caergeiliog) and applied at hydrological assessment location 7.

The key hydrological parameters for each location presented in Table 3.1.

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Table 3.1 Key hydrological parameters

Hydrological assessment location (HAL)	Watercourse	Location description	National Grid References (NGR)	AREA (km^2)	SAAR (mm/yr)	FARL	BFIHOST	URBEXT 2000
1	Cleifiog	Outflow to sea	SH 29000 78350	5.88	879	1.00	0.387	0.0326
2	Cleifiog	Upstream of railway	SH 29350 78700	5.46	879	1.00	0.387	0.0337
3	Cleifiog	Between the railway and A5	SH 29700 78900	3.91	884	1.00	0.387	0.0032
4	Glan Morfa	Upper catchment	SH 30055 80000	0.57	See FEH Catchment 4 and 5 [1]			
5	Valley	Upper catchment	SH 29617 79727	0.30	See FEH Catchment 4 and 5 [1]			
	Glan Morfa and Valley	FEH Catchment 4 and 5	SH 29600 79700	0.58	861	1.00	0.385	0.0085
6	Cleifiog	Upper catchment	SH 30250 79600	1.77	See FEH Catchment 6 [2]			
	Cleifiog	FEH Catchment 6	SH 30250 79600	2.23	889	1.00	0.388	0.0000
7	Maes Y Wrach	Upper catchment	SH 30900 78550 [3]	4.46	906	1.00	0.387	0.0095

Source: FEH CD-ROM 3. From 9 November 2015 FEH CD-ROM data have been available online, however, as this hydrological assessment was largely completed before the launch of the FEH Web Service (CEH, 2016) and it is understood that there is no significant difference to the catchment descriptor data, use of the FEH CD-ROM 3 catchment descriptor data are considered appropriate.
[1] Catchments associated with hydrological assessment locations 4 and 5 are not correctly identified on the FEH CD-ROM and therefore the hydrological assessment was undertaken using FEH Catchment 4 and 5 and the results were scaled on an area-weighted basis for hydrological assessment locations 4 and 5.
[2] Hydrological assessment location 6 on the FEH CD-ROM would double-count flows from hydrological assessment location 4 and therefore the hydrological assessment was undertaken for the FEH Catchment 6 and the results area-weighted for hydrological assessment location 6.
[3] This catchment includes the Caergeiliog watercourse which is a tributary of the Maes Y Wrach.

Deriving hydrographs

Current guidance from Natural Resources Wales (NRW), in the form of Technical Guidance: Flood Estimation (NRW, 2016), identifies two recommended methods to estimate flow for events up to and including a 1:1,000 year AEP event:

- Flood Estimation Handbook (FEH) statistical method; and
- Revitalised Flood Hydrograph (ReFH) method.

NRW's preferred approach for estimating peak flows up to and including a 1:100 year AEP event is the FEH statistical method based on Technical Guidance: Flood Estimation (NRW, 2016). The FEH statistical method uses pooled annual maxima flow data from a group of hydrologically similar gauged catchments to calculate peak flows only. ReFH1 was used to derive the flow hydrograph shape for the required events, and then adjusted to fit the FEH statistical peak flow. To derive the FEH statistical 1:1,000 year AEP peak flow, the ratio method was applied based on the ReFH1 peak flows.

WINFAP-FEH 3 software was used with v3.3.4 peak flow data[1] to develop a growth curves for the Cleifiog at hydrological assessment location 1, used as a proxy for the Valley watercourse and applied to all hydrological assessment locations. A value of QMED was derived using catchment descriptors, adjusted using the 102001 Cefni at Bodffordd, adjusted for urbanisation and adjusted by area for hydrological assessment locations 4, 5 and 6. Subsequent discussions with NRW has identified that the Cefni at Bodffordd gauge was not considered suitable for use as a donor, however, the average uplift of 10% to peak flood values was considered to be conservative and changes to the hydrology assessment were not deemed necessary.

The ReFH method was used with ReFH1 software[2] and FEH99 rainfall to derive hydrograph shapes for the required events. Hydrographs were scaled by a ratio of FEH statistical peak flow to ReFH1 peak flow based on catchment descriptors to achieve an equivalent FEH statistical peak for the 49 hour volume event (based on a storm duration of 49 hours).

Season profile

As the hydrograph was scaled to the FEH statistical peak, the winter profile (representing greater volume than a summer profile) was used as this represented a conservative approach. It was therefore considered reasonable to adopt the winter profile as the critical season.

Storm duration

As the catchment areas are relatively small, it is expected that the same event will occur across all the catchments simultaneously. Both the peak flow value and volume events were checked to determine the storm duration and it was found that 49 hour storm produces higher water level in the study area because of the topography and the constricted culvert under the A5 road. A critical storm duration of 49 hours was optimised for the bypass location, calculated for hydrological assessment location 1 using a simplified 1D model. The derived hydrograph was then fit to the equivalent FEH statistical peak.

Climate change allowance

Climate change is applied by using a 30% uplift on the 1:100 year AEP event as per current guidance (Llywodraeth Cymru/Welsh Government, 2016). This is the central estimate for climate change allowance for the 2080s. Although this has been applied to the peak flows for this report, when representing in the model the entire hydrograph was scaled to this adjusted peak.

3.3 Hydrographs for fluvial scenarios

This section presents the hydrographs which were used in the Flood Modeller Pro – TUFLOW hydraulic modelling, based on the approached presented in Section 3.2. The inflow hydrographs derived for the headwaters of each catchment (hydrological assessment locations 4, 5, 6 and 7) were applied directly in the hydraulic model as point inflows to the upstream extent of the hydraulic model representation of Glan Morfa, Valley, Cleifiog and Maes Y Wrach, respectively.

Lateral inflow hydrographs to represent flows from intervening areas on the Cleifiog are determined through subtracting the upstream hydrograph from the downstream hydrograph. Lateral inflow between hydrological assessment locations 3 and 2 was applied both to the Cleifiog and Valley watercourse as appropriate.

[1] WINFAP-FEH v 3.3.4 was the current software at the start of the project, subsequently updated to v4 (May 2016), v4.1 (May 2016) and v5 (April 2017). However, the additional three water years of gauge data available with v5 is not expected to significantly change the growth curve.
[2] ReFH 1 was the current software at the start of the project, subsequently updated to ReFH 2.1 and 2.2. However, the changes associated with the recent software updates are not expected to significantly change the results as the hydrograph will be adjusted to the peak flow derived from the FEH statistical method.

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The peak flow values are listed in Table 3.2. The derived hydrographs are shown on Figure 3.1 and Figure 3.2, for higher and lower flow respectively.

Table 3.2 Final hydrograph peak flows (m^3/s) to be modelled

Event	Cleifiog (HAL1-HAL2)	Cleifiog (HAL2-HAL3-HAL4-HAL5)	Cleifiog (HAL3-HAL6)	Glan Morfa (HAL4)	Valley (HAL5)	Cleifiog (HAL6)	Maes Y Wrach (HAL7)
	Lateral inflow	Lateral inflow	Lateral inflow	Point inflow	Point inflow	Point inflow	Point inflow
QMED	0.3	0.5	0.7	0.2	0.1	0.7	2.1
1:5 year AEP	0.4	0.6	0.9	0.3	0.2	1.0	2.7
1:20 year AEP	0.6	0.8	1.1	0.4	0.2	1.2	3.4
1:100 year AEP	0.8	1.0	1.5	0.5	0.3	1.6	4.5
1:100 year AEP+CC	1.0	1.3	1.9	0.6	0.3	2.1	5.8
1:1000 year AEP	1.2	1.6	2.2	0.8	0.4	2.5	6.9

AEP = Annual exceedance probability
CC = Climate change
HAL = Hydrological assessment location

Figure 3.1 Final hydrographs to be modelled (higher flows)

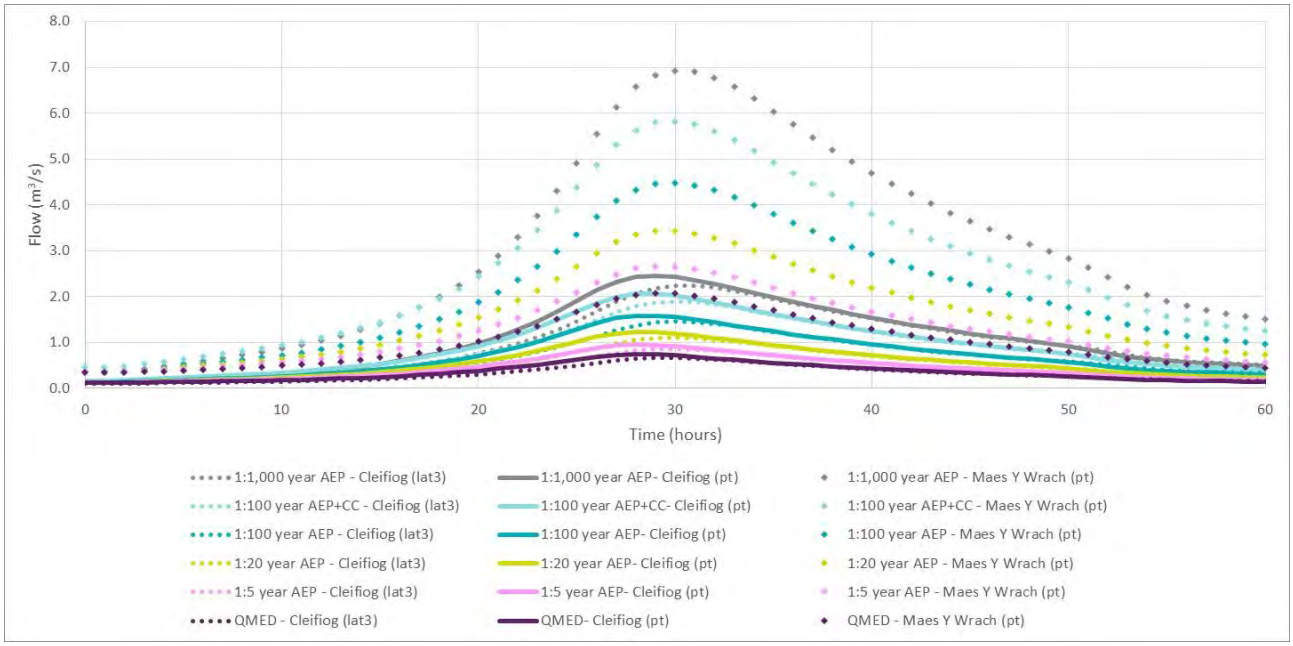

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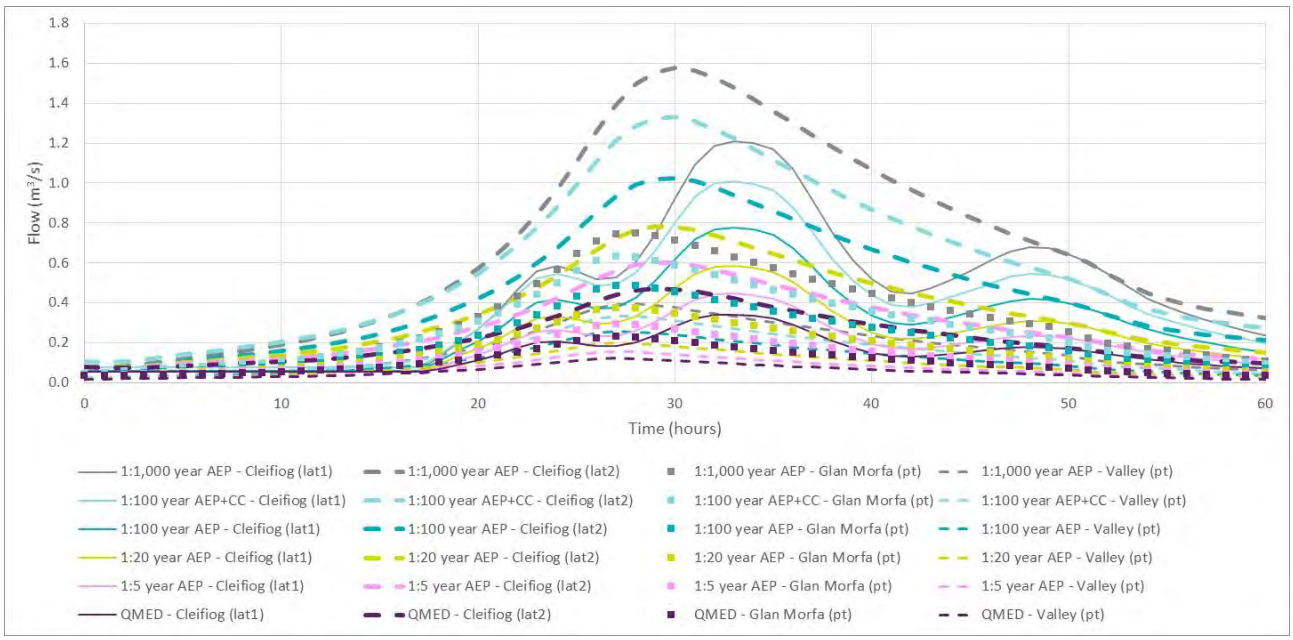
Figure 3.2 Final hydrographs to be modelled (lower flows)



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4. Hydraulic modelling

4.1 Model overview

This section provides an overview of the coupled 1D and 2D hydraulic model built to represent flood flow around the Valley bypass development area. The software chosen (Table 4.1), model extents (Table 4.2) and model schematic (Figure 4.1), are detailed below.

Table 4.1 Model approach and software

Item	Comments
Model approach	Coupled 1D 2D hydraulic modelling approach.
Model software	1D Model: Flood Modeller v4.2 (previously known as ISIS). 2D Model: TUFLOW Build 2016-03-AE-w64 (single precision).

Table 4.2 Model extent

Watercourse	Channel representation	Floodplain representation	Upstream limit	Downstream limit	Length/area of model
Entire model	Flood Modeller	TUFLOW	230206 379992	229122 378018	2.4 km^2
Cleifiog Isaf (Drain 01)	Flood Modeller	TUFLOW	230269 379643	228896 378238	2.1 km
Valley Watercourse (Drain 02)	Flood Modeller	TUFLOW	229622 379744	229457 378741	1.3 km
Glan Morfa (Drain 07)	Flood Modeller	TUFLOW	230075 379986	229721 379477	0.6 km

229000 230000 231000

380000 379000 378000

N

Cemetary

Tidal Barrier

6 7 8

1 2 3 4 5 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40

Key

Roughness Zones (Mannings n coefficient)

- 0.015 - Road
- 0.025 - Path, Roadside
- 0.035 - Inland Water
- 0.08 - Rough Grassland, Scrub, Trees
- 0.3 - Buildings, Glasshouse
- 0.04 - Grass, General surface

- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Surveyed watercourses
- Proposed bypass location

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

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Figure 4.1
A5025 Valley 1D-2D Hydraulic Model

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file: H:\Projects\35989 Wylfa NNB Modelling\Design\Task\05_A5025 Bypass\Modelling\Valley\Baseline_Results_May_17\Maps

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4.2 1D model

The Valley 1D model components have been built in Flood Modeller Pro, and represents the main Valley watercourses. The overview of the 1D baseline model set up is detailed in Table 4.3.

Table 4.3 1D baseline model overview

Item	Comments
Software & version	Flood Modeller (previously ISIS) version 4.2 (Latest available release at model review stage).
1D model purpose	The 1D 'Flood Modeller' model represents only the channel geometry. Standard cross section units and structure units have been used to represent the watercourses being modelled.
Watercourse survey	Detailed channel and structure survey was commissioned as part of the project. See Section 2 for summary of data received. Note when the survey was commissioned the main river data we had suggested the main route of the Valley watercourse (Drain 02) upstream of the existing A5025 was that surveyed. Recent updates on the NRW mapping website suggests this is no longer the case. However, the survey obtained was deemed sufficient for this study as the area is upstream of the area of interest and the culvert under the existing A5025 along Valley watercourse (Drain 02) was surveyed and acts as a constriction to flow. Therefore, flood extents within the proposed bypass footprint are not impacted.
Initial conditions	Initial conditions have been derived as standard using 'Flood Modeller'.
Upstream boundary	Approximately 0.3-0.7 km upstream of the bypass location on both watercourses. Allows sufficient distance for boundary effects to dissipate upstream of area of interest.
Inflow boundaries	**CLEIFIOG ISAF (DRAIN 01/HAL6)** QTBDY - DRAI01_2116 (Hydrological Assessment Location HAL6 in Table 3.2) ▶ NGR SH 30250 79600; ▶ No minimum flow; and ▶ Flow m^3/s, 104.00 hrs duration, last flow extended as a base flow continuation. **VALLEY WATERCOURSE (DRAIN 02/HAL5)** DRAI02_1318 (Hydrological Assessment Location HAL 5 in Table 3.2) ▶ NGR SH 29617 79727; ▶ Minimum flow 0.05 m^3/s; and ▶ Flow m^3/s, 104.00 hrs duration, last flow extended as a base flow continuation. **GLAN MORFA (DRAIN 07/HAL4)** DRAI07_0645 (Hydrological Assessment Location HAL 4 Table 3.2) ▶ NGR SH 30055 80000; ▶ Minimum flow 0.05 m^3/s; and ▶ Flow m^3/s, 104.00 hrs duration, last flow extended as a base flow continuation.

Item	Comments
Lateral catchment weighting	Hydrographs and associated peak flows for intervening catchments are applied as a series of lateral inflow points. **Cleifiog Isaf (Drain 01)** ▶ Maes-Y-Wrach, representing flow from the large Caergeiliog catchment to the east (HAL 7 in Table 3.2), applied to the 2D domain directly to better represent the amount of flow which enters the Cleifiog catchment via a narrow drain. ▶ 01_1119_h, representing inflow from small catchment to the east downstream of A5 (inflow 3 in Table 3.2) ▶ 01_0428_h (one third* of HAL2 in Table 3.2), representing intervening lateral inflows between inflow 01_1119_h and the railway. ▶ 01_0012_h (HAL1 in Table 3.2) representing intervening lateral inflows between inflow the railway and tidal barrier. **Valley Watercourse (Drain 02)** ▶ DRAI02_1043L, (one twelfth* of HAL2 in Table 3.2), representing intervening lateral inflow upstream of the A5025. ▶ DRAI08_0316, (one twelfth* of HAL2 in Table 3.2), representing intervening lateral inflow to the proposed bypass footprint between the A5025 and A5. ▶ DRAI09_0154, (one twelfth* of HAL2 in Table 3.2), representing intervening lateral inflow to the proposed bypass footprint between the A5025 and A5. ▶ DRAI02_0367L, (one sixth* of HAL2 in Table 3.2), representing intervening lateral inflow between the A5 and railway. ▶ DRAI02_0253L, (one sixth* of HAL 2 in Table 3.2), representing intervening lateral inflow at the location of a point source inflow to the channel from town drainage network. **Glan Morfa (Drain 07)** ▶ DRAI07_0290L, (one twelfth* of HAL2 in Table 3.2), representing intervening lateral inflow upstream of the A5025. (*HAL 2 as calculated in the hydrological assessment (Appendix B) report was divided up between the lateral inflows based on contributing catchment area.).

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Item	Comments

Downstream boundary	Node DRAI01_0000
	▶ NGR SH 29036 78247
	▶ Head-Time boundary node
	▶ Tidal boundary data has been derived using NRW guidance and data (provided January 2015), and is based on the following steps:
	  ▶ Holyhead tide levels and Admiralty harmonics used in Flood Modeller tide module to create Holyhead tide curves.
	  ▶ A unit surge curve has been obtained from NRW to represent surges at Holyhead.
	Unit surge has been scaled to extreme sea levels provided by NRW, for 1:200 year and 1:1000 year AEP events, present day and 2114.

	Peak sea level (mAOD)		
Epoch	MHWS	1:200 year AEP	1:1000 year AEP
Present day (2014)	2.6	3.7	3.9
Future (2114)	3.6	4.7	5.0

▶ Scaled surge applied to Holyhead tide curves to produce downstream tidal boundaries for 1:200 year and 1:1000 year AEP events present day and 2114.

▶ Note the values provided by NRW in 2015 were based on the 2011 (EA) climate change guidance, it is acknowledged that during the course of the project new guidance has been issued on sea level rise by the Welsh government (2016). The sea level rise when calculated for the period of 2014-2114 using the 2016 guidance is 1.0m (when rounded to 1dp) as such the future sea level values used in the model are still valid.

▶ MHWS level obtained from Admiralty tide data, the Flood Modeller derived tide curve was adjusted to this level.

▶ Tidal cycles set to peak at 47 hours to provide the 'worst-case' tide locking scenario. This was determined as part of the hydrology assessment, se Appendix B for more details.

▶ Total tidal data length 124 hours, to maintain tidal boundary for full length of fluvial hydrograph and model run time

Item	Comments	
Backwater length	This is a calculation to work out how far upstream you would expect the model downstream boundary to influence the model results upstream. The calculation ensures that the downstream boundary is far enough from the proposed bypass footprint to not influence the fluvial result Modelled backwater length: 1.2 km (from downstream boundary to development location) Recommended backwater length (Samuels, 1989): ~ 4.5 km *0.7 x (Depth/Slope)* *Max flood depth at downstream boundary: ~ 2.4 m* *Max bed height at model upstream boundary: ~ 0.887 mAOD* *Min bed height at model downstream boundary: ~ -0.020 mAOD* *Slope: 0.887 - -0.020* Model downstream boundary taken as tidal outfall to estuary. Model cannot be extended any further to allow for any further backwater length.	
Model length (km)	Drain 01: 2.1 km Drain 02: 1.3 km Drain 07: 0.6 km **Total: 4.2 km** *See* Table 4.2 *for model channel and tributary grid references*	
Total number of nodes and structures	**River section (total)**	95
	River section (surveyed)	42
	River section (copied)	12
	River section (using LiDAR data[3])	3
	River sections (interpolated using Flood Modeller Pro)	38
	Junctions	26
	Bridges	1
	Orifices	13
	Conduits (culverts upstream and downstream)	22
	Culvert inlet (general loss)	10
	Culvert outlet	7
	Inline spills	4
	Spills over structures	6
	QTBDY	12 (3 main, 9 lateral)
	HTDBDY	1 (tidal) 2 (dummy links to 2D model)

[3] LIDAR data was used in lieu of survey data. LIDAR represented the shape of the channel well in the reach between DRAI02_0666 and DRAI02_0367 well and only minor edits were made to ensure the invert of the channel sections were consistent with the overall channel gradient.

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Item	Comments
Interpolates and copy sections	Site visits have suggested the Valley watercourse channel is reasonably regular and consistent along its length, with few substantial changes in shape or width. This has informed requested survey cross sections spacing, and allowed for interpolate sections to be added to aid model convergence and stability. Where there was no survey data: • 02_0367uu cross section taken from LIDAR, bed adjusted to reflect slope downstream of 0666d. • DRAI02_0367u cross section taken from LIDAR, bed adjusted to reflect slope downstream of 0666d. • 02_0367du cross section taken from LIDAR, bed adjusted to reflect slope downstream of 0666d. It was deemed appropriate to take these sections from LIDAR as the LIDAR data was detailed (1m), and the site visit showed this area to be well maintained with little or no vegetation in the channel or along the banks, therefore providing confidence in the LIDAR values.
Labelling/ numbering system	DRAI**_#### Where ** represents drain number; #### represents chainage from drains downstream boundary Node names may be suffixed by the following: _u upstream copy of surveyed node _d downstream copy of surveyed node _ci culvert inlet _co culvert outlet _cu culvert unit upstream face _cd culvert unit downstream face _s spill unit _b bridge unit _h lateral hydrological inflow unit Where labelling exceeds the permitted number of characters, the 'DRAI' prefix has been dropped from the node label.
Structure representation	See Appendix C - Structure representation
Structure coefficients	Structure coefficients have been determined following inspection of the structure survey drawings and photos. Standard values have been used, based on best practice guidance and modeller experience. Structure coefficients would usually be adjusted during a calibration process if sufficient data is available. For this project modelling, sensitivity testing has been undertaken instead, as there was not sufficient calibration data.
Hydraulic roughness values	See Appendix D – Channel roughness representation. 1D roughness values taken from published descriptions of Manning's roughness values in Chow (1959) and Syme (2008)
Other information / alterations made to model	Originally four other drains were surveyed across the proposed bypass footprint (Drain 03, 05, 08, 09 as seen in the location plan in Appendix C). However, due to ongoing stability problems with the model it was decided to remove these from the 1D model and include the survey data in the 2D model only. The individual capacity and conveyance along these small shallow field drains was not deemed to be significantly affecting the flood extents to the proposed bypass footprint. Causing all channels to be out of bank and under depth of water. For stability purposes: • DRAI02_1043 uses the cross section of DRAI02_1055 as it is more representative of open channel upstream of culvert. • DRAIN01_1371 bed lowered in line with upstream section (DRAI01_1378) for stability. • DRAIN01_0395 95 bed lowered in line with upstream section (DRAI01_0428) for stability. • DRAI02_0367 two points removed to better represent channel cross section and remove representation of wing wall.

See Appendix C for details of structure representation in the hydraulic model.

See Appendix D for details of channel roughness representation in the hydraulic model.

4.3 2D model

The Valley 2D model domain has been built in TUFLOW and represents the floodplain and wider catchment of the Cleifiog, Glan Morfa and Valley watercourses. The overview of the 2D baseline model set up is detailed in Table 4.4.

Table 4.4 2D model overview

Item	Comments
Resolution of grid/2D cell size	2 meters The level of detail required to model floodplain, requires a relatively detailed cell size. The LIDAR resolution in the area is 1m and it is best practice for the grid-size to be no smaller than twice the resolution of the LIDAR.
Orientation of grid	South West (orientation of main flow direction)
Model extent	Bounded in the south by the Estuary, and the topographic catchment boundaries in the southeast and northwest. The north and northeast extent of the model area is 0.5 km upstream of the proposed bypass footprint. The model extent in the north has been snapped to the top of the 1D model to ensure water is 'forced' to flow downstream towards the proposed bypass footprint.
2D boundary conditions	Point source inflows are represented in 1D model. 2D downstream boundary represented adjacent to the final 1D cross section. The 2D downstream boundary Is the same head-time tidal curve as applied to the 1D downstream boundary. There was no controlled boundary along the northern, eastern and western limits of the 2D domain (i.e. the edge of the 2D domain acts as a glass wall where topography does not naturally contain the flood extent). The southern /south western boundary uses a tidal head-time (HT) boundary. This allows tidal inflow to the model domain when the tide level is higher than ground level, outflow will occur if the tide level in the boundary condition be permits.
Ground model	LIDAR DTM with 1m resolution purchased from Environment Agency Geomatics, October 2014. The initial LIDAR based DTM has been checked thoroughly for possible missing flow routes, such as road bridges, culverts beneath railway embankments etc., as well as null LIDAR areas.
Topographic modifications	2d_bc_Vall_Base_032: Adjusts some bank levels where it was necessary to stabilise the model and better represent the banks based on survey data. 2d_zsh_Vall_Bridge_004: Re-inserts bridge levels that have been scraped off the LiDAR in conversion to a DTM. 2d_zsh_Vall_DTM_001: Fills holes in the LIDAR data by tinning across the hole using ground values from LIDAR. 2d_zln_Vall_Culv_002, 2d_zln_Vall_Drai03, 2d_zln_Vall_Drai05, 2d_zln_Vall_Drai08, 2d_zln_Vall_Drai09: Uses the topographic cross section survey data to for a series of parallel 'thin' zlines to better represent the ditches in the 2D model. 2d_zln_Vall_Maes_001 interpolates a channel, based on LiDAR data along the reach of the Maes-Y-Wrach in the 2D model using a thick continuous z line.
Representation of buildings	Buildings have been represented at ground level with an increased roughness of n=0.3. This approach allows for impedance to flow given by the buildings and for flood volume to be dissipated within the area of the buildings.
Representation of flood defences	The tidal barrier is represented using a z shape polygon (2d_zsh_Vall_DEF_002) with the crest set to a level of 4.8mAOD. Then two further z lines set to 2.4mAOD and 1.2mAOD to represent the slope of the embankment on the upstream side.

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Item	Comments	
Representation of river banks	LiDAR used to represent river banks. No bank top survey is available, and Flood Modeller sections are not regular enough to represent whole bank length. No bank survey is available or has been commissioned for the project. The LIDAR is assumed to be representative of the bank heights observed. Checks have been carried out between the bank levels in the surveyed cross section data and the LIDAR to ensure they are acceptably consistent. Aerial photography and site visits have suggested banks are not heavily vegetated for the most part of the modelled channel reaches, and thus assumptions that 1m LiDAR resolution is satisfactory to pick out bank levels and channels between surveyed cross sections. In some locations 2d_bc_Vall_Base_032 adjusts some bank levels where it was necessary to better represent the banks based on survey data along the Valley watercourse and Glan Morfa through and upstream of the proposed bypass footprint.	
1D-2D Link	The 1D-2D link has been digitised along the top of bank (2d_bc_Vall_Base_032). The 'Flood Modeller' cross sections are a width consistent with the 1D-2D link and deactivated area in the 2D TUFLOW model. Slight alterations of locations of banks were occasionally made in the 1D-2D link to ensure the 1D banks matched the 2D LiDAR bank locations, however bank levels were generally in agreement when located correctly.	
Initial conditions	Initial water levels of have been applied based on adjoining 1D model section initial conditions. This has been applied to stabilise the 1D-2D link. Aside from specific areas of initial water level added for stability in areas where there are lakes and ponds adjacent to the watercourse channels, the model will start as a 'dry' model with no previous flooding in the floodplain. However, the simulation covers a long enough period to ensure the flood zoning is representative of the maximum flood extent.	
Delineation of roughness areas	OS Mastermap and publicly available aerial photography was used to determine 2D surface type of floodplain areas (2d_mat_Vall_Base_003 and 2d_mat_Stability_005).	
Hydraulic roughness values	**2D surface**	**Roughness value** (Chow, 1959; Syme, 2008)
	Land/grass/general surface	0.04
	Buildings/glasshouses/structures	0.3
	Rough grassland/ scrub / trees	0.08
	Inland water	0.035
	Path/roadside/rail	0.025
	Road	0.015
	Stability	0.1

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5. Model runs

The 1D-2D Valley model build described in Section 4 has been run for baseline fluvial and tidal flood events, for a range of annual exceedance probabilities. The model was then run with bypass design development scenarios. The following section lists the document structures and naming conventions for the model run files (Table 5.1), along with details of each baseline model run completed (Table 5.2).

Table 5.1 Model folder structure and file names

Folder	File	Description
Flood Modeller		
▶ **Dat (Flood Modeller model data file)**	Vall_Base_058.dat	Baseline model 1D network.
	Vall_Base_058_S1.dat Vall_Base_058_S2.dat Vall_Base_058_S3.dat Vall_Base_058_S4.dat Vall_Base_058_S5.dat Vall_Base_058_S6.dat	Sensitivity scenario models 1D network: S1 denotes Manning's roughness coefficient being increased by 50% for the given baseline simulation. S2 denotes Manning's roughness coefficient being decreased by 50% for the given baseline simulation. S3 denotes structural coefficients being increased by 20% for the given baseline simulation. S4 denotes structural coefficients being decreased by 20% for the given baseline simulation. S5 denotes "failure" of tidal gates by outfall orifice units not set to be flapped. S6 denotes the timing of the tide being altered to coincide with the fluvial peak.
▶ **Ied (Flood Modeller event data file)**	Vall_F5_v3.ied Vall_F20_v303.IED Vall_F100_v3.IED Vall_F100cc_v3.IED Vall_F1000_v3.IED Vall_QMED_v3.IED Vall_QMEDcc_v3.IED	Baseline event file for fluvial events.
	Vall_MHWS_v5.IED Vall_MHWS_2115_v5.IED Vall_T200_v5.IED Vall_T200_2115_v5.IED Vall_T1000_v5.IED Vall_T1000_2115_v5.IED	Baseline event file for tidal events.
	Vall_MHWS_Shft_v6.IED	Sensitivity event file where the timing of the tide is being altered to coincide with the fluvial peak.
▶ **Ief (Flood Modeller run data file)**	VALL_BASE_1D58_2D41_F5.ief VALL_BASE_1D58_2D41_F5T200.ief VALL_BASE_1D58_2D41_F20.ief VALL_BASE_1D58_2D41_F100.ief VALL_BASE_1D58_2D41_F100cc.ief VALL_BASE_1D58_2D41_F100ccT200cc.ief VALL_BASE_1D58_2D41_F1000.ief VALL_BASE_1D58_2D41_T200.ief	Baseline simulation file for 1D2D model, where 1D058 refers to the 1D dat file used in the simulation, and 2D041 refers to the 2D bc file. F and T denotes if the results represent a Fluvial or Tidal event.

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Folder	File	Description
	VALL_BASE_1D58_2D41_T1000.ief VALL_BASE_1D58_2D41_T1000cc.ief VALL_BASE_1D58_2D41_F100_S1.ief VALL_BASE_1D58_2D41_F100_S2.ief VALL_BASE_1D58_2D41_F100_S3.ief VALL_BASE_1D58_2D41_F100_S4.ief VALL_BASE_1D58_2D41_F5T200_S5.ief VALL_BASE_1D58_2D41_F100_S6.ief	'cc' denotes where the results have been run for an event which includes climate change impacts. Simulation file for sensitivity runs 1D2D model.
Iic (Flood Modeller Initial Conditions file)	VALL_BASE_049_031_F100_FEH_V3.iic	Baseline initial conditions for 1D model.
Results	F5 o VALL_BASE_1D58_2D41_F5 F5T200 o VALL_BASE_1D58_2D41_F5T200 o VALL_BASE_1D58_2D41_F5T200_S5 F20 o VALL_BASE_1D58_2D41_F20 F100 o VALL_BASE_1D58_2D41_F100 o VALL_BASE_1D58_2D41_F100_S1 o VALL_BASE_1D58_2D41_F100_S2 o VALL_BASE_1D58_2D41_F100_S3 o VALL_BASE_1D58_2D41_F100_S4 o VALL_BASE_1D58_2D41_F100_S6 F100cc o VALL_BASE_1D58_2D41_F100cc F100ccT200cc o VALL_BASE_1D58_2D41_F100ccT200cc F1000 o VALL_BASE_1D58_2D41_F1000 T200 o VALL_BASE_1D58_2D41_T200 T1000 o VALL_BASE_1D58_2D41_T1000 T1000cc o VALL_BASE_1D58_2D41_T1000cc	Standard Flood Modeller 1D results files for each baseline or sensitivity run including: .exy, .uic, .zzd, .zzl, .zzn, .zzu, .zzx
TUFLOW		
Bcdbase (Flood Modeller Initial Conditions file)	bc_dbase_Vall_006_F5.csv bc_dbase_Vall_006_F5T200.csv bc_dbase_Vall_006_F20.csv bc_dbase_Vall_006_F100.csv bc_dbase_Vall_006_F100cc.csv bc_dbase_Vall_006_F100ccT200cc.csv bc_dbase_Vall_006_F1000.csv bc_dbase_Vall_006_T200.csv bc_dbase_Vall_006_T1000.csv bc_dbase_Vall_006_T1000_2115.csv bc_dbase_Vall_Shft_007_F100.csv Vall_MAESYWRACH_003.csv Vall_MHWS_006.csv Vall_MHWS_Shft_007.csv Vall_Tide_001.csv	bcdbase holds the boundary condition links for the 2D domain. For Valley, this holds the link to the tidal boundary. 2015 / 2115 refers to the epoch for the scenario (present or future). The bcdbase links to two further csv files which hold the relevant calculated tidal time series and time series for the Maes-Y-Wrach catchment.

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Folder	File	Description
Checks (TUFLOW check file)	F5 o VALL_041_Base_F5 F5T200 o VALL_041_Base_F5T200 o VALL_041_Base_F5T200_S5 F20 o VALL_041_Base_F20 F100 o VALL_041_Base_F100 o VALL_041_Base_F100_S1 o VALL_041_Base_F100_S2 o VALL_041_Base_F100_S3 o VALL_041_Base_F100_S4 o VALL_041_Base_F100_S6 F100cc o VALL_041_Base_F100cc F100ccT200cc o VALL_041_Base_F100ccT200cc F1000 o VALL_041_Base_F1000 T200 o VALL_041_Base_T200 T1000 o VALL_041_Base_T1000 T1000cc o VALL_041_Base_T1000cc	Standard TUFLOW check files in MID/MIF MapInfo format, including: 1d_to_2d_check; grd_check; bcc_check; zpt_check. F and T denotes if the results represent a Fluvial or Tidal event. 'cc' denotes where the results have been run for an event which includes climate change allowance.
Run (TUFLOW run file)	VALL_041_Base_F5.tcf VALL_041_Base_F5T200.tcf VALL_041_Base_F20.tcf VALL_041_Base_F100.tcf VALL_041_Base_F100cc.tcf VALL_041_Base_F100ccT200cc.tcf VALL_041_Base_F1000.tcf VALL_041_Base_T200.tcf VALL_041_Base_T200cc.tcf VALL_041_Base_T1000.tcf VALL_041_Base_T1000cc.tcf VALL_041_Base_F100_S1.tcf VALL_041_Base_F100_S2.tcf VALL_041_Base_F100_S3.tcf VALL_041_Base_F100_S4.tcf VALL_041_Base_F5T200_S5.tcf VALL_041_Base_F100_S6.tcf	Standard TUFLOW run files. Base denotes the baseline scenario model is being run. Simulation file for sensitivity runs TUFLOW model.
Model (TUFLOW model file)	Vall_Base_032.tbc Vall_Base_037.tgc Vall_03.tmf Vall_nhigh_001.tmf Vall_nlow_001.tmf	Standard TUFLOW model files: tbc – details the boundary conditions tgc – details the geometry files tmf – details the material layer and roughness values Base denotes the baseline scenario model is being run. nhigh or nlow denote the increase and decrease in manning's n respectively for the sensitivity runs.

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Folder	File	Description
Results	F5 o VALL_041_Base_F5 F5T200 o VALL_041_Base_F5T200 F5T200_S5 o VALL_041_Base_F5T200_S5 F20 o VALL_041_Base_F20 F100 o VALL_041_Base_F100 F100_S1 o VALL_041_Base_F100_S1 F100_S2 o VALL_041_Base_F100_S2 F100_S3 o VALL_041_Base_F100_S3 F100_S4 o VALL_041_Base_F100_S4 F100cc o VALL_041_Base_F100cc F100ccT200cc o VALL_041_Base_F100ccT200cc F100MHWS_S6 o VALL_041_Base_F100_S6 F1000 o VALL_041_Base_F1000 T200 o VALL_041_Base_T200 T1000 o VALL_041_Base_T1000 T1000cc o VALL_041_Base_T1000cc	Standard TuFLOW 2D results files for each baseline and sensitivity run including: .2dm, .ALL, .hV, .mat, _d.dat, _h.dat, _MB.csv, _MB1.dat, _MB2.dat, _MB2D.csv, _PO.csv, _POMM.csv, _q.dat, _Times.dat, _TS.mid/mif, _v.dat.zzx, and _ZUK0.dat.

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Table 5.2 Design flow model runs

Items	Comments
Baseline design event[4]	Fluvial 1:5 year AEP (F5) Combined Fluvial 1:5 year AEP and Tidal 1:200 year AEP (F5T200) Fluvial 1:20 year AEP (F20) Fluvial 1:100 year AEP (F100) Fluvial 1:1,000 year AEP (F1000) Fluvial 1:100 year AEP plus 30% climate change (F100cc) Combined Fluvial 1:100 year AEP plus 30% climate change and Tidal 1:200 year AEP plus future sea level rise (F100ccT200c) Tidal 1:200 year AEP (T200) Tidal 1:1000 year AEP (T1000) Tidal 1:1,000 year AEP plus future sea level rise (T1000cc)
Model run parameters and settings	Default parameters were used for all settings except those listed below: ▶ Automatic Preissmann Slot for River Sections ▶ Orifice linearization head (m): 0.1 ▶ Tidal 1:200 year AEP event was run with Theta of 0.85 to enable model to run. Where parameters have been changed, they have been adjusted within the bounds of common practice and following advise provided by the software developer.

[4] Where F denotes fluvial and T denotes tidal. For fluvial runs a MHWS downstream boundary was applied. For tidal runs a QMED flow was applied to the watercourse. The number refers to the AEP event e.g. 20 = 1:20 year AEP event. CC denotes climate change, this has been determined as a 30% increase for fluvial flows with tide levels increased in line with NRW projected extreme sea level data for 2114.

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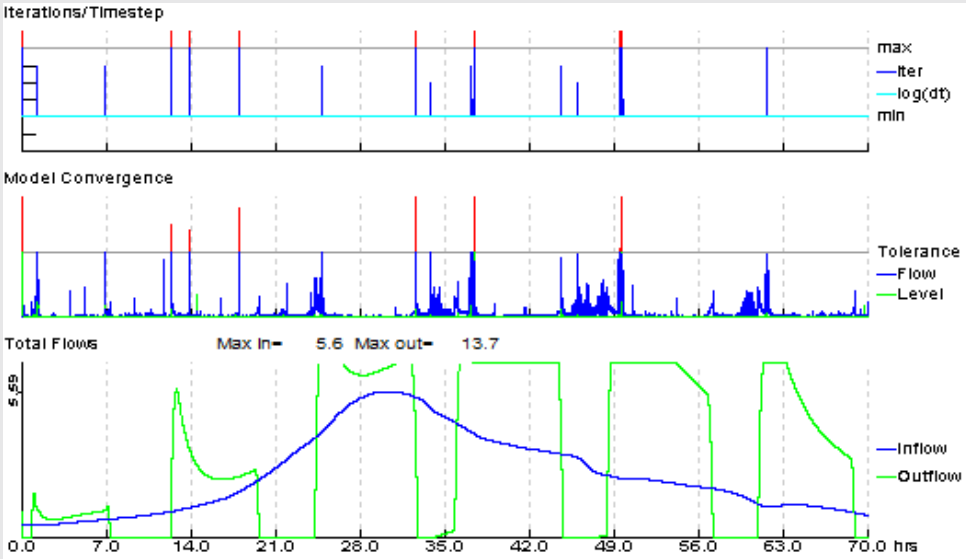
Items	Comments
1D model stability	Flow and Stage graphs for 1D long section and cross sections do not highlight any oscillations or instabilities. 1D convergence .bmp files (see the figure below) indicate some minor non-convergence in the model. The influence of tidal signature can be seen in bmp file.



Datafile: ...\FLOODMODELLER\DAT\WALL_BASE_058.DAT
Results: C:\WALLEY\F100\WALL_BASE_1D58_2D41_F100.zzl
Ran at 09:17:08 on 21/04/2017
Ended at 09:30:40 on 24/04/2017
Start Time: 0.000 hrs
End Time: 70.000 hrs
Timestep: 1.0 secs

Current Model Time: 70.00 hrs
Percent Complete: 100 %

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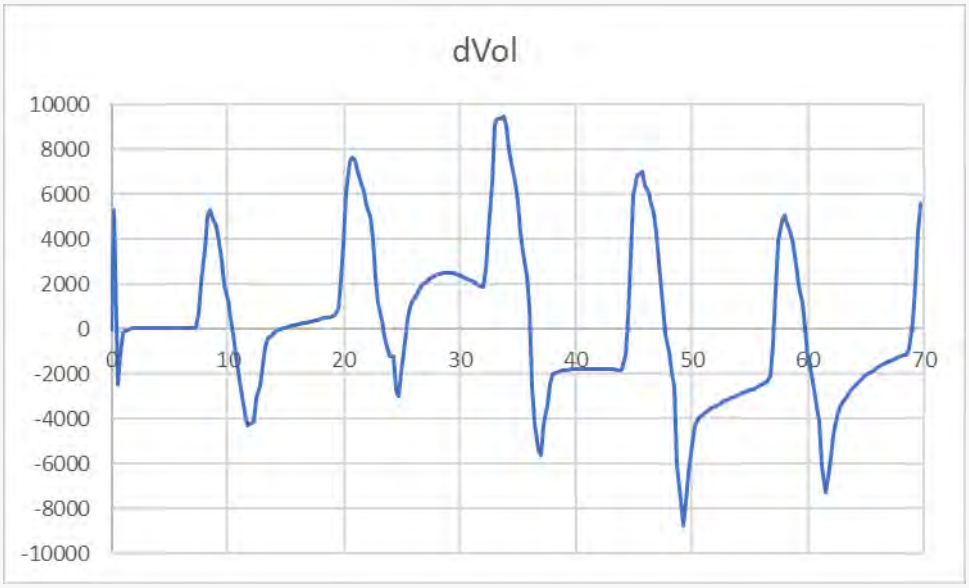
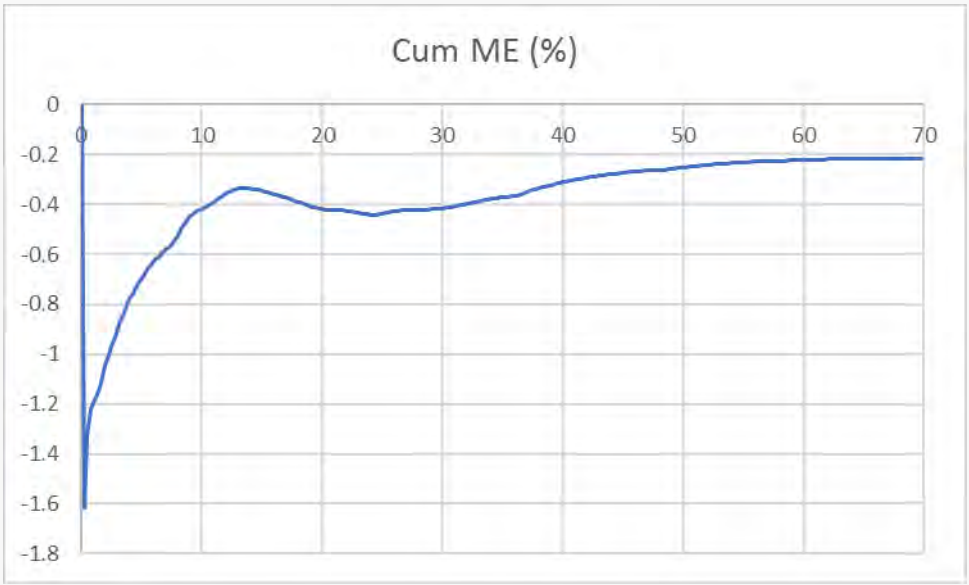
Items	Comments
2D model stability	Mass Balance error and dVol time-series plots are stable and show no oscillations or instabilities.  
Model warnings	The following model warnings have been flagged in the 1D and 2D model. These have been reviewed and are not deemed to be affecting the model results. ▶ Warning W2058 Model convergence criteria were not met for one or more timesteps during the run. ▶ Warning W2019 Water level rose beyond the max level of section data. Solution computed assuming extra 3m wall for non-CES sections, or max depth x 1.5m for CES sections, at max breadth *(*this is not an issue as the model is an integrated 1d-2d model where out of bank areas are represented in the 2d TUFLOW model.)* ▶ Warning W2267 No sub/supercritical depth could be found at node label1 ▶ Warning W2263 Backflow encountered at CULVERT INLET unit; outlet control equations will be imposed. ▶ WARNING 2073 - Object ignored. Only Points, Lines, Polylines & Region Centers used. ▶ CHECK 2231 - No ZP points snapped to HX line. HX line not used to modify Zpts.

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6. Baseline model results

Analysis of the flood mechanism is discussed in Section 6.1 and a summary of the results obtained from the baseline hydraulic modelling are discussed in Section 6.2. These results present the current day and future flood risk (with climate change) to the study area in the baseline condition. Results are presented as peak flood depths at a number of 2D result points in the vicinity of the proposed bypass location and via maps illustrating the fluvial and tidal flood extents. Appendix A contains the following flood depth and extent maps which depict the baseline flood estimates:

Figure 6.1 A5025 Valley baseline peak fluvial flood extents;

Figure 6.2 A5025 Valley baseline peak fluvial depth 1:5 year AEP present day;

Figure 6.3 A5025 Valley baseline peak fluvial depth 1:20 year AEP present day;

Figure 6.4 A5025 Valley baseline peak fluvial depth 1:100 year AEP present day;

Figure 6.5 A5025 Valley baseline peak fluvial depth 1:1000 year AEP present day;

Figure 6.6 A5025 Valley baseline peak fluvial depth 1:100 year AEP climate change (30%);

Figure 6.7 A5025 Valley baseline peak tidal flood extents;

Figure 6.8 A5025 Valley baseline peak tidal depth 1:200 year AEP present day;

Figure 6.9 A5025 Valley baseline peak tidal depth 1:1000 year AEP present day;

Figure 6.10 A5025 Valley baseline peak tidal depth 1:1000 year AEP climate change (2114);

Figure 6.11 A5025 Valley baseline peak depth from combined fluvial (1:5 year AEP present day) and tidal (1:200 year AEP present day);

Figure 6.12 A5025 Valley baseline peak depth from combined fluvial (1:100 year AEP climate change +30%) and tidal (1:200 year AEP climate change 2114).

Note: This is a factual report detailing the results of the hydraulic modelling. Please see the parent FCA report for further discussion and comparisons against the existing Flood Zone maps.

6.1 Flooding mechanisms

The mechanisms of flood propagation vary according to each of the different return periods modelled described in Section 4. Flood propagation mechanisms varies depending if the event being simulated is a fluvially dominated or tidally dominated event. This section also describes the flooding mechanisms associated with the 1:100 year AEP fluvial event and the 1:1,000 year AEP tidal events.

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Tidal 1:1,000 year AEP event

Analysis of the flood propagation shows that the tidal barrage provides protection against flooding up to and above the 1:1000 year tide level. The flood extent seen upstream of the tidal barrage during the tidal events are a consequence of fluvial flooding from QMED flow that occurs due to the tidal gate locking. Flood extents upstream of the barrage are larger for lower frequency tidal events as these events result in tide levels being higher for longer and therefore preventing discharge to the sea from the Valley watercourses. The propagation of the flood in these events follows the pattern of that described for the fluvial events.

Fluvial 1:100 year AEP event

Analysis of the flood propagation shows that flooding starts on the Valley watercourses upstream of the A55 and railway bridge, the commencement of flooding coincides with the first tide locking period. As the event progresses the flooding in these areas extends further and flooding also starts upstream of the A5 and across the field containing the proposed bypass footprint. By the peak of the event (peak here refers to the time of the peak of the hydrograph) the field containing the proposed bypass footprint (bounded by the existing A5025 and A5) is inundated, with some flooding observed upstream of the existing A5025. As the hydrograph recedes the flood extent continues to increase as a consequence of the tide locking impeding the discharge of flow from the system. Across the field containing the proposed bypass footprint the existing A5, A5025 and high ground to the north and east control the extent of flooding. Flood propagation of the 1:100 year AEP fluvial event is shown on Figure 6.13.

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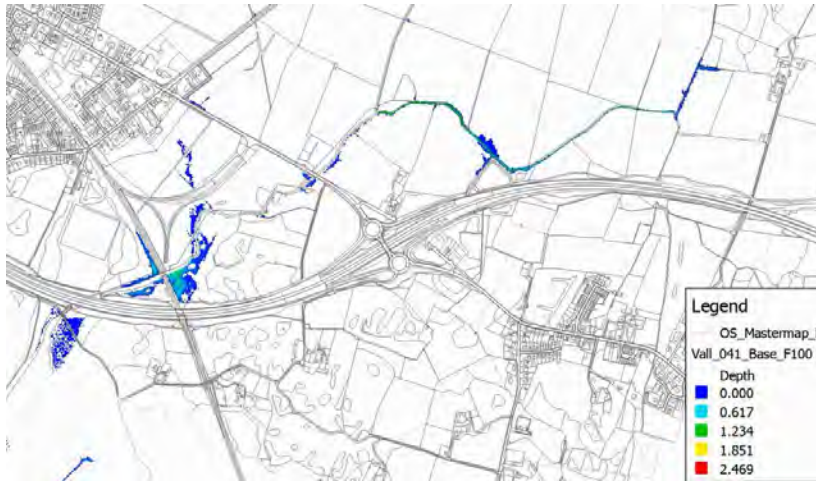
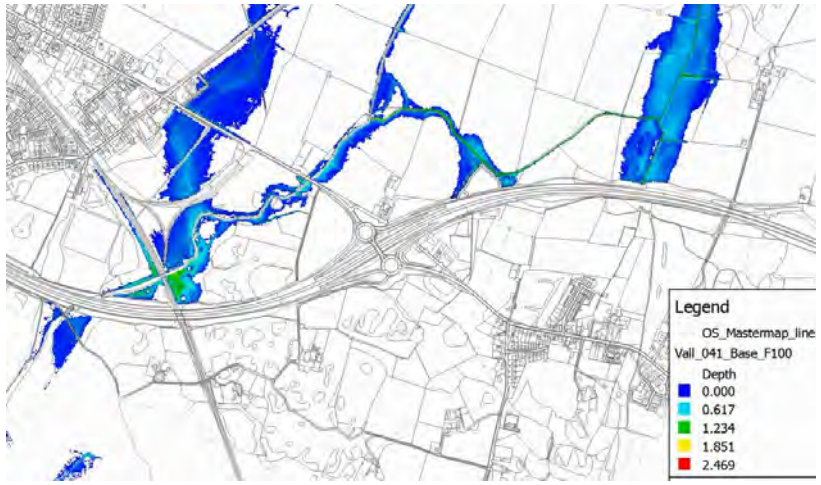
Figure 6.13 Fluvial 1:100 year AEP event – flood propagation

13:45 hours

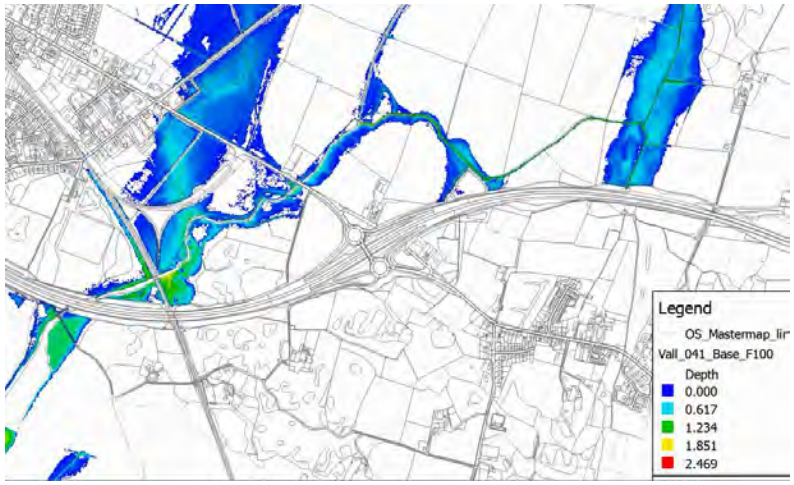


22:45 hours

28:00 hours



46:30 hours



Note: times denote time elapsed from the onset of the storm event

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6.2 Flood extents and levels

The peak water levels have been output for a number of result points across the 2D domain. These result points relate to potential receptors in and around the bypass location (buildings). From the water levels the peak flood depths at each affected receptor have been calculated and are detailed in Table 6.1

A snapshot of the fluvial and tidal flood extents associated with these depths are shown in Figure 6.14 and 6.15 respectively. The maximum peak is observed in the combined fluvial 1:100 year AEP plus climate change and tidal 1:200 year plus climate change event.

Figure 6.14 Fluvial flood extent at proposed bypass location

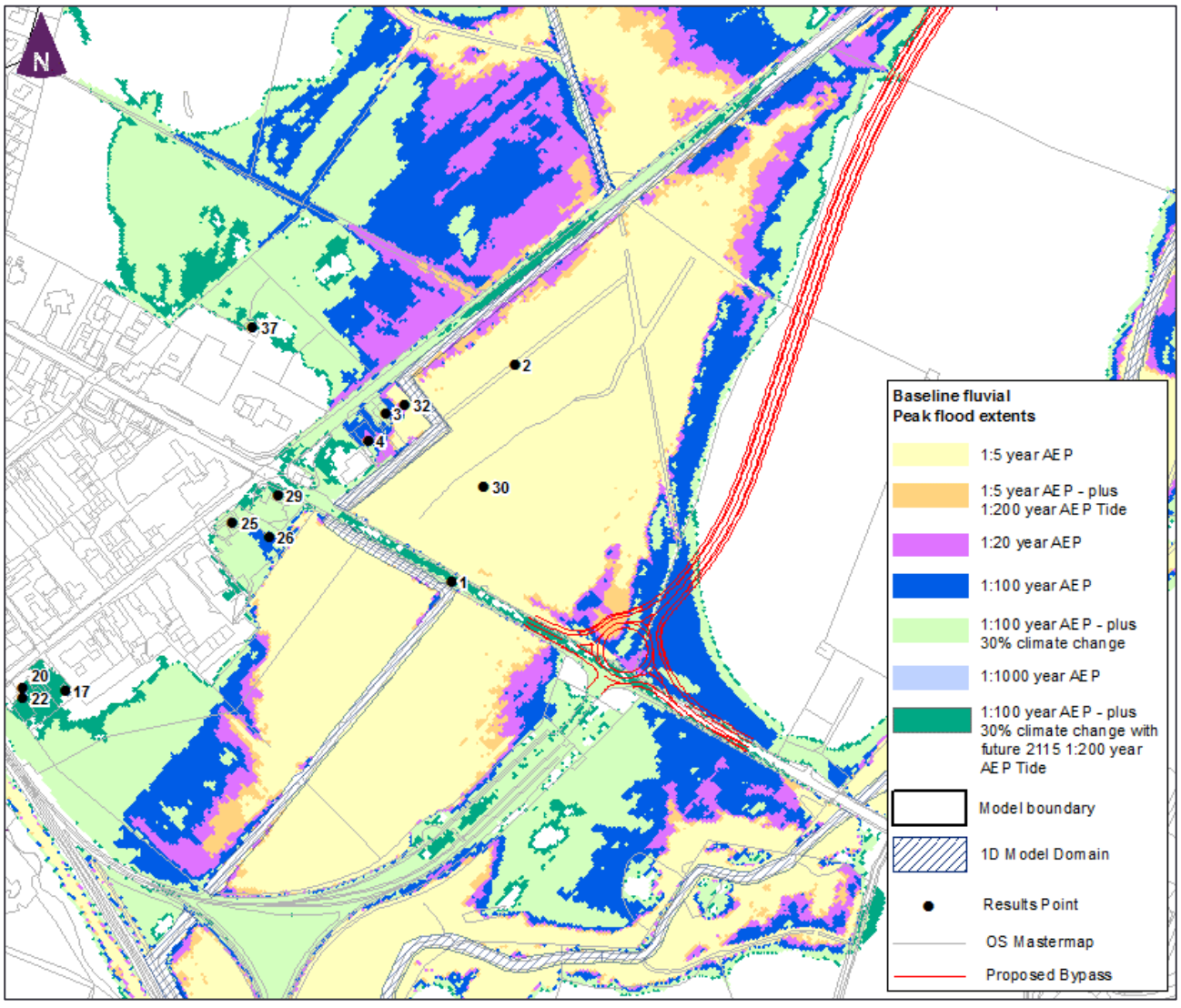

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Figure 6.15 Tidal flood extent at proposed bypass location

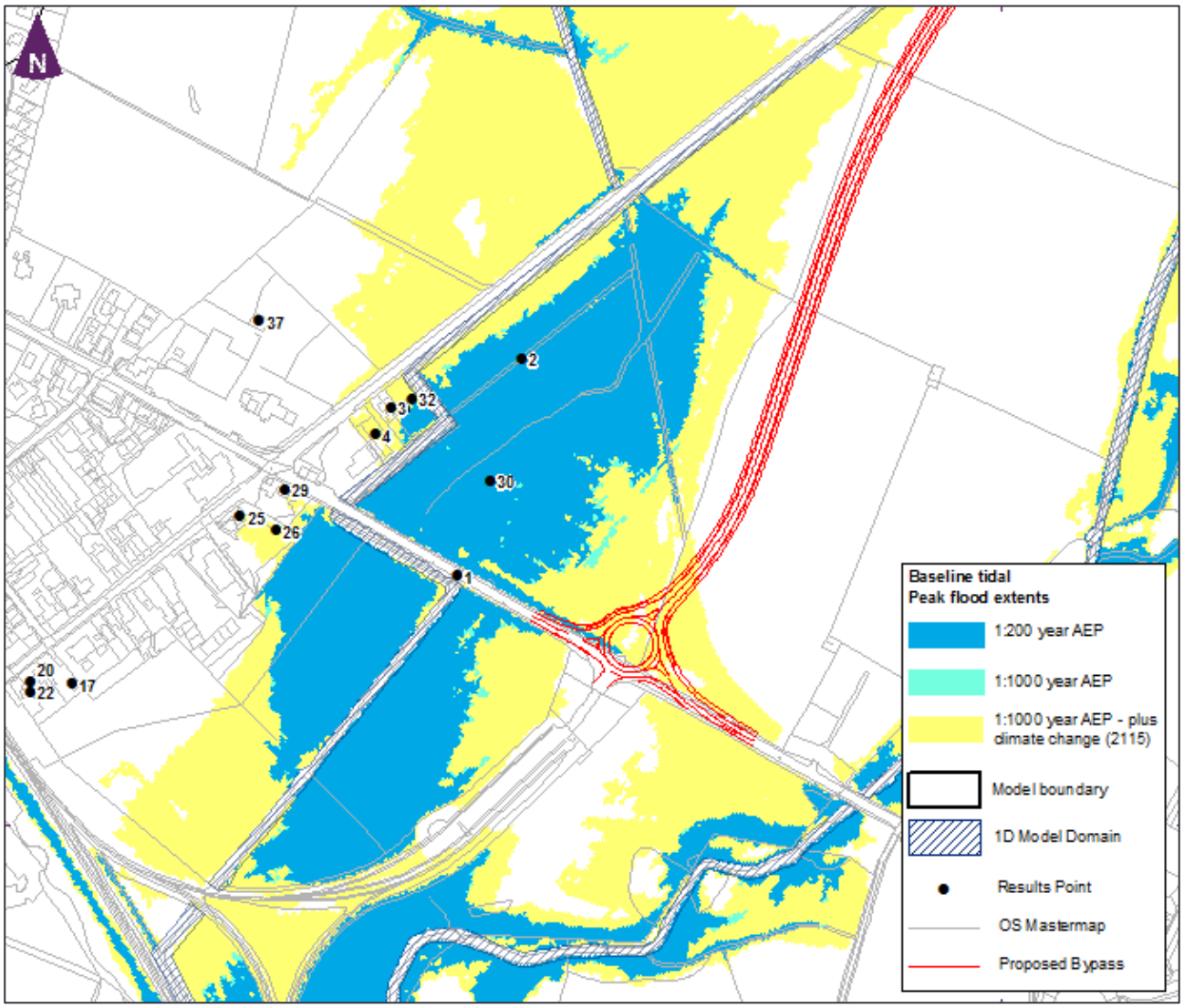

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Table 6.1 Baseline peak flood depths (m) at receptors in and around bypass location

Results point	Peak flood depth at results points (m)									
	Fluvial					Tidal			Combined	
	1:5 year AEP	1:20 year AEP`	1:100 year AEP	1:100 year AEP plus climate change	1:1,000 year AEP	1:200 year AEP	1:1,000 year AEP	1:1,000 year AEP plus climate change	1:5 year AEP and 1:200 year AEP Tide	1:100 year AEP plus climate change and future 1:200 year AEP tide
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06
2	0.57	0.70	0.84	1.18	1.16	0.49	0.49	0.85	0.61	1.27
3	0.00	0.00	0.00	0.34	0.32	0.00	0.00	0.00	0.00	0.43
4	0.00	0.00	0.13	0.47	0.45	0.00	0.00	0.13	0.00	0.56
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.13
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.26
25	0.00	0.00	0.00	0.33	0.27	0.00	0.00	0.00	0.00	0.42
26	0.00	0.00	0.06	0.56	0.50	0.00	0.00	0.23	0.00	0.64
29	0.00	0.00	0.00	0.19	0.13	0.00	0.00	0.00	0.00	0.27
30	0.19	0.32	0.47	0.81	0.79	0.11	0.12	0.47	0.24	0.90
31	0.00	0.00	0.07	0.41	0.39	0.00	0.00	0.07	0.00	0.50
32	0.05	0.18	0.32	0.67	0.65	0.00	0.00	0.33	0.10	0.76
37	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00	0.23

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7. Proposed bypass modelling

7.1 Modelling approach

Analysis of the impact of the bypass structure on the flood risk and the changes to the flood mechanism is discussed in this Section. Background to the structure inclusion within the model and summary of the results obtained from the hydraulic modelling are discussed. Results are presented as depths extracted from a series of 2D result points in the vicinity of the proposed bypass location and in difference depth grids illustrating the impact spatially across the Valley area.

Appendix A contains the following flood depth and extent maps which describe the bypass flood hazard:

Figure 7.1 A5025 Valley 'with bypass' peak fluvial depth 1:5 year AEP present day

Figure 7.2 A5025 Valley 'with bypass' peak fluvial depth 1:20 year AEP present day

Figure 7.3 A5025 Valley 'with bypass' peak fluvial depth 1:100 year AEP present day

Figure 7.4 A5025 Valley 'with bypass' peak fluvial depth 1:1000 year AEP present day

Figure 7.5 A5025 Valley 'with bypass' peak fluvial depth 1:100 year AEP climate change (30%)

Figure 7.6 A5025 Valley 'with bypass' peak tidal depth 1:200 year AEP present day

Figure 7.7 A5025 Valley 'with bypass' peak tidal depth 1:1000 year AEP present day

Figure 7.8 A5025 Valley 'with bypass' peak tidal depth 1:1000 year AEP climate change (2115)

Figure 7.9 A5025 Valley 'with bypass' peak combined fluvial depth 1:5 year AEP present day and peak tidal depth 1:200 year AEP present day

Figure 7.10 A5025 Valley 'with bypass' peak combined fluvial depth 1:100 year AEP climate change (30%) and peak tidal depth 1:200 year AEP climate change (2115)

Figure 7.11 A5025 Valley peak fluvial depth difference - 1:5 year AEP present day

Figure 7.12 A5025 Valley peak fluvial depth difference - 1:20 year AEP present day

Figure 7.13 A5025 Valley peak fluvial depth difference - 1:100 year AEP present day

Figure 7.14 A5025 Valley peak fluvial depth difference - 1:1000 year AEP present day

Figure 7.15 A5025 Valley peak fluvial depth difference - 1:100 year AEP climate change (30%)

Figure 7.16 A5025 Valley peak tidal depth difference - 1:200 year AEP present day

Figure 7.17 A5025 Valley peak tidal depth difference - 1:1000 year AEP present day

Figure 7.18 A5025 Valley peak tidal depth difference - 1:1000 year AEP climate change (2115)

Figure 7.19 A5025 Valley peak tidal depth difference combined fluvial depth 1:5 year AEP present day and peak tidal depth 1:200 year AEP present day

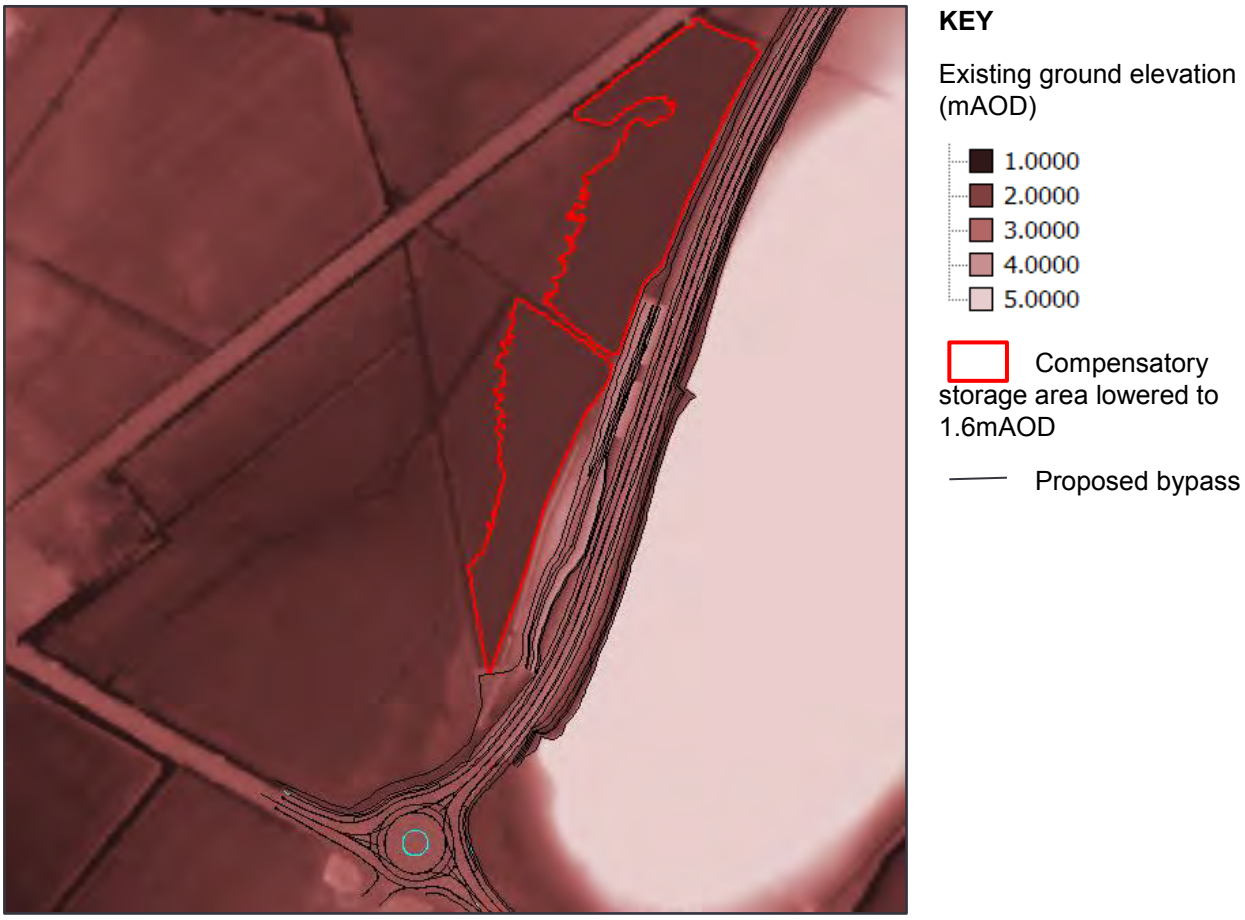
Figure 7.20 A5025 Valley peak tidal depth difference combined fluvial 1:100 year AEP climate change (30%) and Tidal 1:200 year AEP climate change (2115)

The 'with bypass' modelling encompassed one key changes to the baseline topography:

New DTM (valleytrig_junev2_topo_comparea.asc) to incorporate the bypass embankment levels and the flood storage area proposed to mitigate the flood risks (these features are depicted on Figures 7.1 to 7.20). The ground levels of the flood storage area will be deigned to allow it to fully drain after a flood event.

The detailed extent of the design was taken from X-REF_DF5_OFL_02.dwg and elevations of both the bypass and associated drainage was taken from VALLEY_3DS_AMEC_02.dwg. Further information on how the area of compensatory flood storage was calculated is in Appendix F. Figure 7.21 below shows a location plan of the proposed compensatory storage area.

Figure 7.21 Proposed area of compensatory storage



7.2 Flooding mechanisms

Analysis of the 'with bypass' flood mechanism shows the same behaviour as the baseline flood mechanism. Analysis of the flood propagation shows that flooding starts on the Valley Watercourses upstream of the A55. As the event progresses flooding propagates upstream. The field containing the proposed bypass footprint begins to flood from the south west corner, the constrictive culvert under the A5. The flood then propagates up the drainage channels that dissect the field containing the proposed bypass footprint until the maximum extent of flooding across the field is achieved. The maximum extent is determined by topography and the existing A5 and A5025 roads which are raised above the floodplain.

The compensatory flood storage included as part of the design fills as would be expected as the flood propagates upstream across the floodplain within the field containing the proposed bypass footprint. The inclusion of the bypass is shown to cut off a flow route from the Cleifiog catchment to the Valley to the south of the cemetery in higher fluvial return period events (1:1,000 year AEP and 1:100 year AEP with an allowance for climate change).

The impact on the resultant flood depths is analysed in Section 7.3.

7.3 Impact on flood depths

The impact of the bypass on water levels and therefore flood depths is described in two ways:

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1) By means of change in depth of flooding at the previously analysed 2D result points; and

2) By mapping the difference in flood depths across the 2D domain grid for each scenario assessed.

Flood depths

The impact of the bypass and associate compensatory flood storage on peak flood depths in the vicinity of the proposed bypass footprint is shown in Figure 7.22(below) and Table 7.2. Generally, there is either no change or a reduction in flood risk to receptors for all events. The exception being the extreme combined Fluvial 1:100 year and Tidal 1:200 year AEP event plus climate change where there is a very slight (0.01m) increase in risk along the Cleifiog and downstream of the A5 (see final image in Figure 7.23 below).

The impact of the bypass on flood depths across the floodplain is shown for each scenario in Figure 7.22and Figure 7.23. Analyses of the results show that, with the exception of the combined fluvial 1:100 year and tidal 1:200 year AEP events with climate change, the increase in water levels is confined to the compensatory storage area adjacent to the bypass, and the new road drainage channels associated with the bypass. Reduction in water level is observed across the field containing the proposed bypass footprint and in some return periods in the fields immediately upstream of the A5025 and downstream of the A5 along the Valley watercourse.

7.4 Summary of bypass impact

- The inclusion of the bypass and associated flood storage area generally results in no change or a slight reduction (0.01m) in flood risk across the Valley area as a consequence of the inclusion of additional flood storage across with the field containing the proposed bypass footprint.
- The exception is the less frequent fluvial events (1:1000 year AEP and 1:100 year AEP with an allowance for climate change), where the bypass interrupts a flow route around the cemetery (located on Figure 4.1) resulting in a maximum impact of 0.08m increase on peak flood depths (fluvial 1:100 year AEP event with allowance for climate change).
- The flood mechanism is not significantly impacted by the bypass and associated compensatory storage.

Table 7.1 Bypass peak fluvial flood depths (m) at receptors in and around bypass location

	Peak flood depth at results points (m)									
Results point	**1:5 year AEP**	**Difference***	**1:20 year AEP`**	**Difference***	**1:100 year AEP**	**Difference***	**1:100 year AEP plus climate change**	**Difference***	**1:1,000 year AEP**	**Difference***
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.55	-0.01	0.68	-0.01	0.84	0.00	1.17	-0.01	1.15	-0.01
3	0.00	0.00	0.00	0.00	0.00	0.00	0.33	-0.01	0.31	-0.01
4	0.00	0.00	0.00	0.00	0.12	0.00	0.46	-0.01	0.44	-0.01
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.27	0.00

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Peak flood depth at results points (m)

Results point	1:5 year AEP	Difference*	1:20 year AEP`	Difference*	1:100 year AEP	Difference*	1:100 year AEP plus climate change	Difference*	1:1,000 year AEP	Difference*
26	0.00	0.00	0.00	0.00	0.01	-0.05	0.56	0.00	0.50	0.00
29	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.00	0.13	0.00
30	0.18	-0.01	0.31	-0.01	0.46	0.00	0.80	-0.01	0.78	-0.01
31	0.00	0.00	0.00	0.00	0.06	0.00	0.40	-0.01	0.38	-0.01
32	0.04	-0.01	0.17	-0.01	0.32	0.00	0.66	-0.01	0.64	-0.01
37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.14	0.00	0.00

* where negative values denote a decrease in flood depth and positive values denote an increase in flood depth.

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Table 7.2 Bypass peak tidal and combined flood depths (m) at receptors in and around bypass location

	Peak flood depth at results points (m)									
	Tidal						Combined			
Results Points	1:200 year AEP	Difference*	1:1000 year AEP	Difference*	1:1000 year AEP plus climate change	Difference*	1:5 year AEP and 1:200 year AEP Tide	Difference*	1:100 year and 1:200 year AEP plus climate change	Difference*
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.01
2	0.48	0.00	0.49	0.00	0.84	-0.01	0.60	-0.01	1.25	-0.03
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	-0.03
4	0.00	0.00	0.00	0.00	0.13	-0.01	0.00	0.00	0.54	-0.03
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.01
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.34	0.01
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	0.01
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.01
26	0.00	0.00	0.00	0.00	0.22	-0.01	0.00	0.00	0.65	0.01
29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.01
30	0.11	0.00	+0.12	0.00	0.47	-0.01	0.23	-0.01	0.88	-0.02
31	0.00	0.00	0.00	0.00	0.06	-0.01	0.00	0.00	0.47	-0.03
32	0.00	0.00	0.00	0.00	0.32	-0.01	0.08	-0.01	0.73	-0.03
37	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.21	-0.03

* where negative values denote a decrease in flood depth and positive values denote an increase in flood depth.

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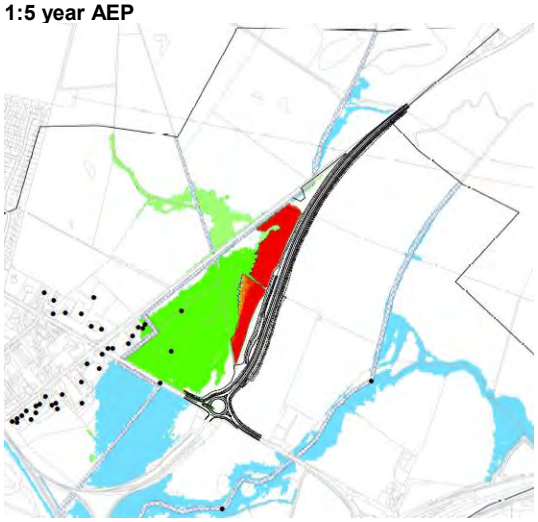
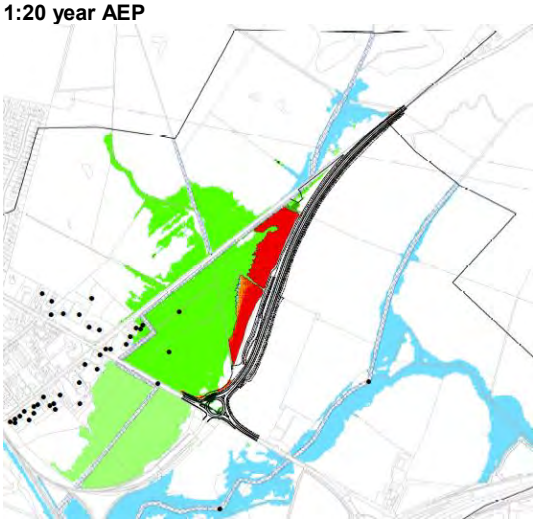
Figure 7.22 Fluvial depth difference grids (m)

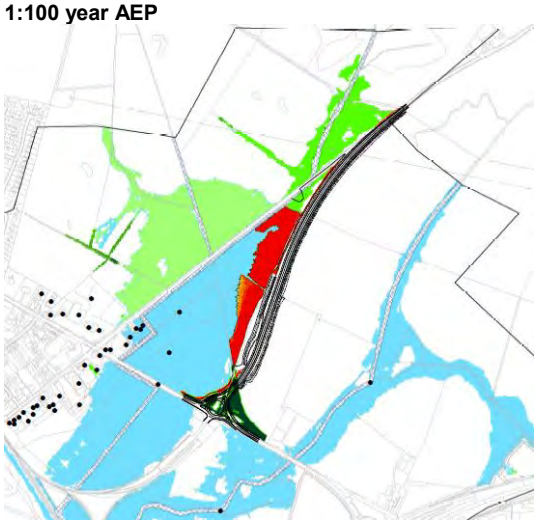
1:5 year AEP



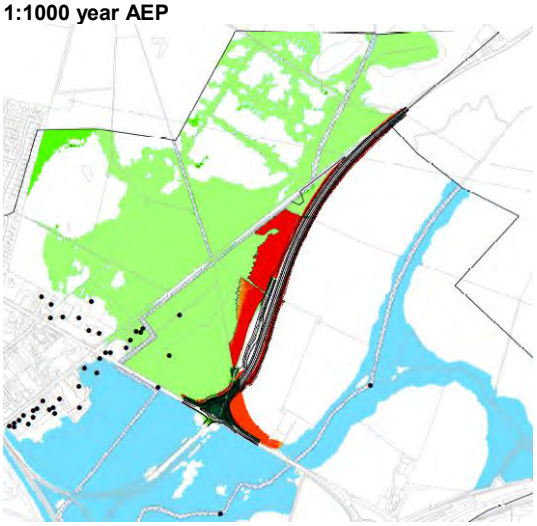
1:20 year AEP



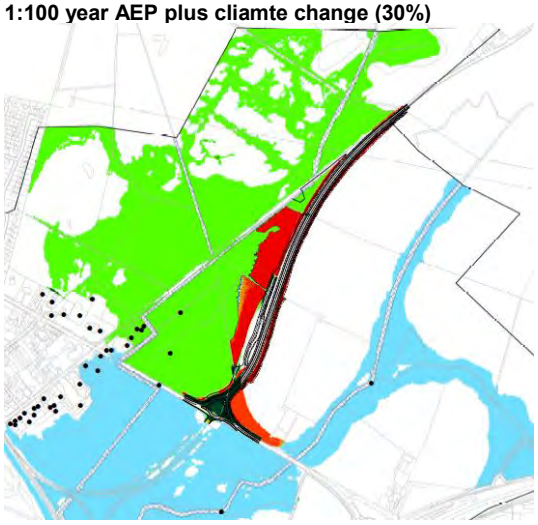
1:100 year AEP



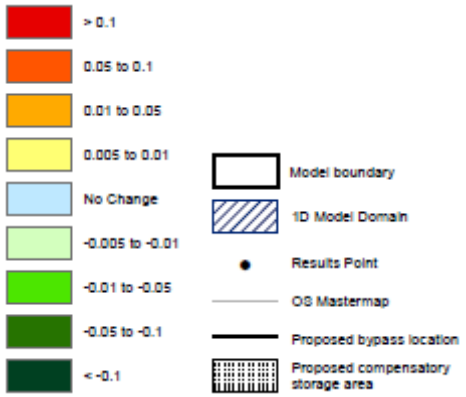
1:1000 year AEP



1:100 year AEP plus cliamte change (30%)



Key



Note negative values denote a decrease in flood depth and positive values denote an increase in flood depth.

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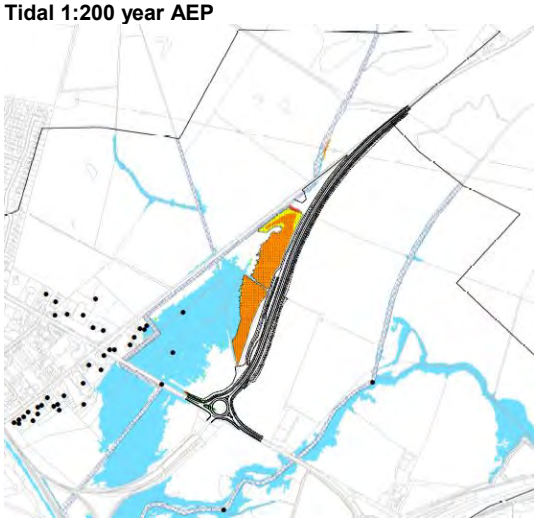
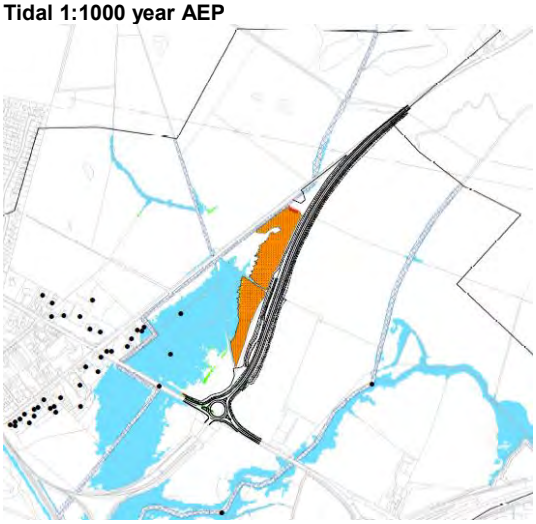
Figure 7.23 Tidal and combined depth difference grids (m)

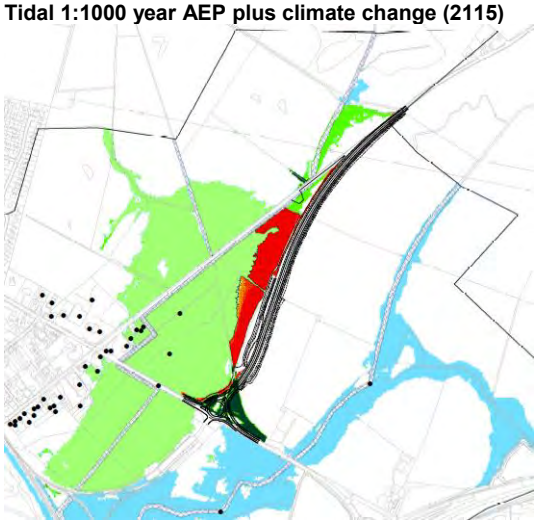
Tidal 1:200 year AEP



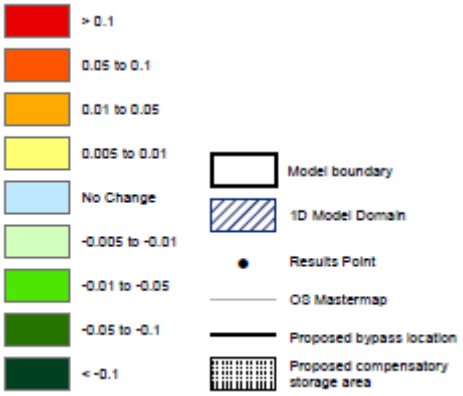
Tidal 1:1000 year AEP



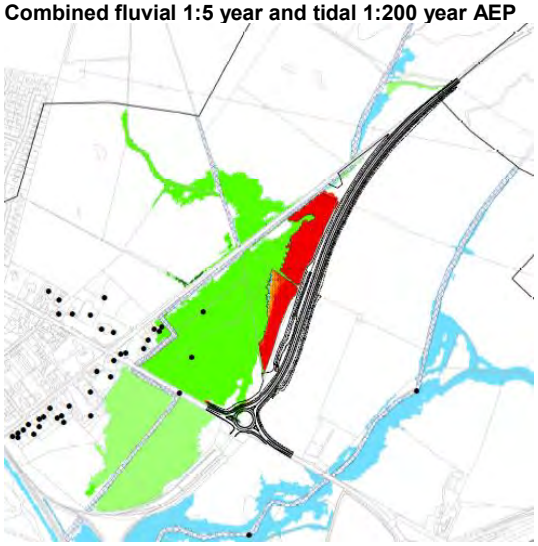
Tidal 1:1000 year AEP plus climate change (2115)



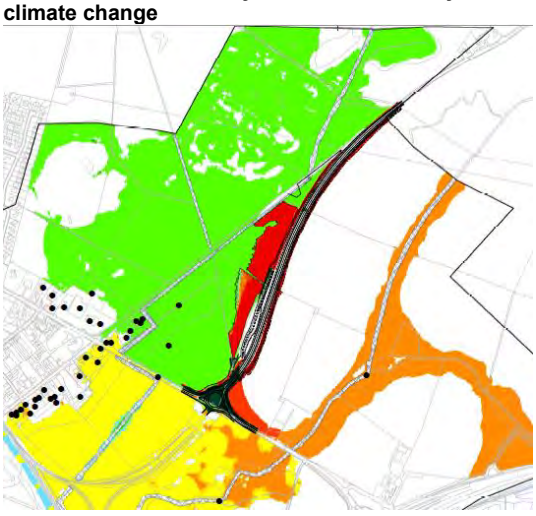
Key



Combined fluvial 1:5 year and tidal 1:200 year AEP



Combined fluvial 1:100 year and tidal 1:200 year AEP plus climate change



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8. Sensitivity testing

The purpose of sensitivity testing is to test the validity of the underlying assumptions in the model, and ensure the model is behaving as expected under various underlying uncertainties. Sensitivity testing provides a means of assessing how sensitive the predicted depths are to changes in the model parameters and assumptions. If a parameter is changed then the resultant flood depth could change. The objective of the sensitivity testing is to highlight the potential range of change associated with adjusted parameters to provide confidence in the value selected.

Section 8.1 details the sensitivity tests undertaken, and their application in the 1D and 2D model domains. A discussion on the results then follows in Section 8.2 with summary of conclusion in Section 8.3.

Sections 8.4 and 8.5 provide a discussion of some additional model runs that were performed to enhance the understanding of flood risk and mechanisms in the study area. These are discussed separately to the sensitivity tests as they are not looking to test the impact of certain model parameters or assumptions, rather they are additional model scenarios. The scenarios discussed are:

- Tidal boundary timing; and
- Higher climate change allowance.

8.1 Sensitivity test method

Sensitivity of the model predictions to a number of model parameter values have been tested, Table 8.1 details the tests and describes the changes made to the 1D and 2D model domains. All sensitivity tests have been performed for present day scenarios. Tests 1 to 4 and 6 to 10 have been undertaken using the 1:100 year AEP fluvial flood event with MHWS tidal boundary. Whilst test 5 has been undertaken using the combined 1:5 year AEP fluvial and 1:200 year AEP tidal flood event.

Table 8.1 Sensitivity test methods

Test	Description
Test 1 & 2	1. Manning's (n) roughness increased 2. Manning's (n) roughness decreased
1D application	All cross section Manning's n roughness values increased and decreased by 50%, including bridges and structures where relevant (i.e. conduit friction)
2D application	All 2D roughness values were adjusted to an absolute value rather than by a percentage. As surface type is not changing it is deemed more realistic to test an upper and lower bound of the value adopted for each surface type. Land/Grass/general surface – baseline 0.04; test 0.05 / 0.03 (max/min, rough grass) Buildings/glasshouses/structures – baseline 0.30; test 0.5 / 0.01 (max/min, building) Rough grassland/ scrub/Trees – baseline 0.08; test 0.11 / 0.06 (max/min, mixed vegetation) Inland Water/Tidal Water – baseline 0.035; test 0.045 / 0.025 (max/min, inland water) Path/Roadside – baseline 0.025; test 0.03 / 0.02 (max/min, pavement) Road – baseline 0.015; test 0.017 / 0.013 (max/min, road) Stability – baseline 0.10; remains as 0.10 for model stability.
Test 3 & 4	3. Structure coefficient increased (+ 20%) 4. Structure coefficient decreased (- 20%)

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Test	Description
1D application	The following structure coefficients increased and decreased by 20% from default value: Culvert Inflow – K; M; C; Y; Ki Orifice – Weir Flow; Surcharged Flow Bridge – Orifice discharge coefficient (where applied) Spill units – Weir coefficient.
2D application	No change in 2D domain
Test 5	5. Failure of tidal gates
1D application	The three flapped outfalls at downstream, limit of model changed to open outfalls.
2D application	No change in 2D domain
Tests 6 & 7	Railway Culvert (01_0721) blockage: 6. All three culvert barrels 50% blocked 7. All three culvert barrels 90% blocked
1D application	Blockage units created upstream of culverts (three in total)
2D application	No change in 2D domain
Tests 8 & 9	1D roughness increased to represent in channel vegetation growth throughout the model, tested on both the Baseline and Bypass models. 8. 1D channel roughness increased to Manning's n 0.07 9. 1D channel roughness increased to Manning's n 0.08
1D application	Changes to the channel section roughness values in the .dat file
2D application	No change in 2D domain
Test 10	Lateral inflow hydrograph derivation
Inflow hydrology	This test on the sensitivity of model predictions to hydrological inputs investigated the effect of applying lateral inflows derived using an alternative method to that detailed in Section 3. The baseline approach is detailed in Section 3.2, this was based on subtracting the upstream hydrographs from the downstream hydrograph, and applying the resulting hydrograph laterally to the remainder of the reach. The alternative approach developed in this test is based on disaggregating the contributing catchment area, amending the catchment descriptors pertinent to the intervening area and deriving the hydrograph using ReFH1. This allows for the comparison of the resultant hydrographs from the two methods, and the assessment of any impact.

8.2 Sensitivity test summary results

The following sub-sections detail the differences in water levels from the baseline and the sensitivity runs undertaken for the same event. Differences in peak flood depth are sampled from 2D result points in the vicinity of the proposed bypass location.

Test 1 & 2: Manning's n roughness (+/- 50%)

Modelled peak flood depths for Manning's n roughness sensitivity tests are shown to generally be within 0.06m difference from the peak flood depths of the same baseline 1:100 year AEP fluvial event (Table 8.2). With one outlier results point 26 being 0.17m different. Differences in water levels are within the range that would be expected for a Manning's roughness sensitivity test.

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Table 8.2 Sensitivity tests 1 and 2 summary results – 1:100 year AEP fluvial event

Result Points	1:100 year AEP Baseline	Test 1 (m)	Difference* (m)	Test 2 (m)	Difference* (m)
1	0.00	0.00	0.00	0.00	0.00
2	0.84	0.90	0.06	0.80	-0.04
3	0.00	0.06	0.06	0.00	0.00
4	0.13	0.19	0.06	0.08	-0.04
17	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00
26	0.06	0.23	0.17	0.00	-0.06
29	0.00	0.00	0.00	0.00	0.00
30	0.47	0.53	0.06	0.42	-0.04
31	0.07	0.13	0.06	0.02	-0.04
32	0.32	0.39	0.06	0.28	-0.04
37	0.00	0.00	0.00	0.00	0.00

* where negative values denote a decrease in flood depth and positive values denote an increase in flood depth.

Test 3 & 4: Structure coefficient (+/- 20%)

Sensitivity tests on structure coefficients show modelled peak flood depths to be within 0.02m difference from the peak flood depths of the same baseline 1:100 year AEP fluvial event (Table 8.3). The differences in water levels are minimal and within the range that would be expected for a structure coefficient sensitivity test of +/- 20%.

Table 8.3 Sensitivity tests 3 and 4 summary results – 1:100 year AEP fluvial event

Result Points	1:100 year AEP Baseline	Test 3 (m)	Difference* (m)	Test 4 (m)	Difference* (m)
1	0.00	0.00	0.00	0.00	0.00
2	0.84	0.83	-0.01	0.84	0.00
3	0.00	0.00	0.00	0.00	0.00
4	0.13	0.12	-0.01	0.13	0.00
17	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00

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Result Points	1:100 year AEP Baseline	Test 3 (m)	Difference* (m)	Test 4 (m)	Difference* (m)
25	0.00	0.00	0.00	0.00	0.00
26	0.06	0.00	-0.06	0.08	0.02
29	0.00	0.00	0.00	0.00	0.00
30	0.47	0.46	-0.01	0.47	0.00
31	0.07	0.05	-0.01	0.07	0.00
32	0.32	0.31	-0.01	0.33	0.00
37	0.00	0.00	0.00	0.00	0.00

* where negative values denote a decrease in flood depth and positive values denote an increase in flood depth.

Test 5: Failure of the tidal gates

Failure of the tidal gates within the tidal barrier embankment results in extensive tidal flooding. Figure 8.1 shows how extensive the flooding would be if these tidal gates failed. The proposed bypass location still sits mostly outside of the extent of flooding, with the exception of the roundabout junction where the bypass joins the existing A5. A failure in the tidal gates results in flood depths increased by greater than 0.5m in places (see Table 8.4).

Table 8.4 Sensitivity test summary results – 1:100 year AEP fluvial event

Result Points	1:5 year AEP and 1:200 year AEP Tide Baseline	Test 5 (m)	Difference* (m)
1	0.00	0.09	0.09
2	0.61	1.16	0.55
3	0.00	0.32	0.32
4	0.00	0.45	0.45
17	0.00	0.17	0.17
20	0.00	0.37	0.37
22	0.00	0.30	0.30
25	0.00	0.46	0.46
26	0.00	0.69	0.69
29	0.00	0.31	0.31
30	0.24	0.79	0.55
31	0.00	0.39	0.39
32	0.10	0.65	0.55
37	0.00	0.00	0.00

* where negative values denote a decrease in flood depth and positive values denote an increase in flood depth.

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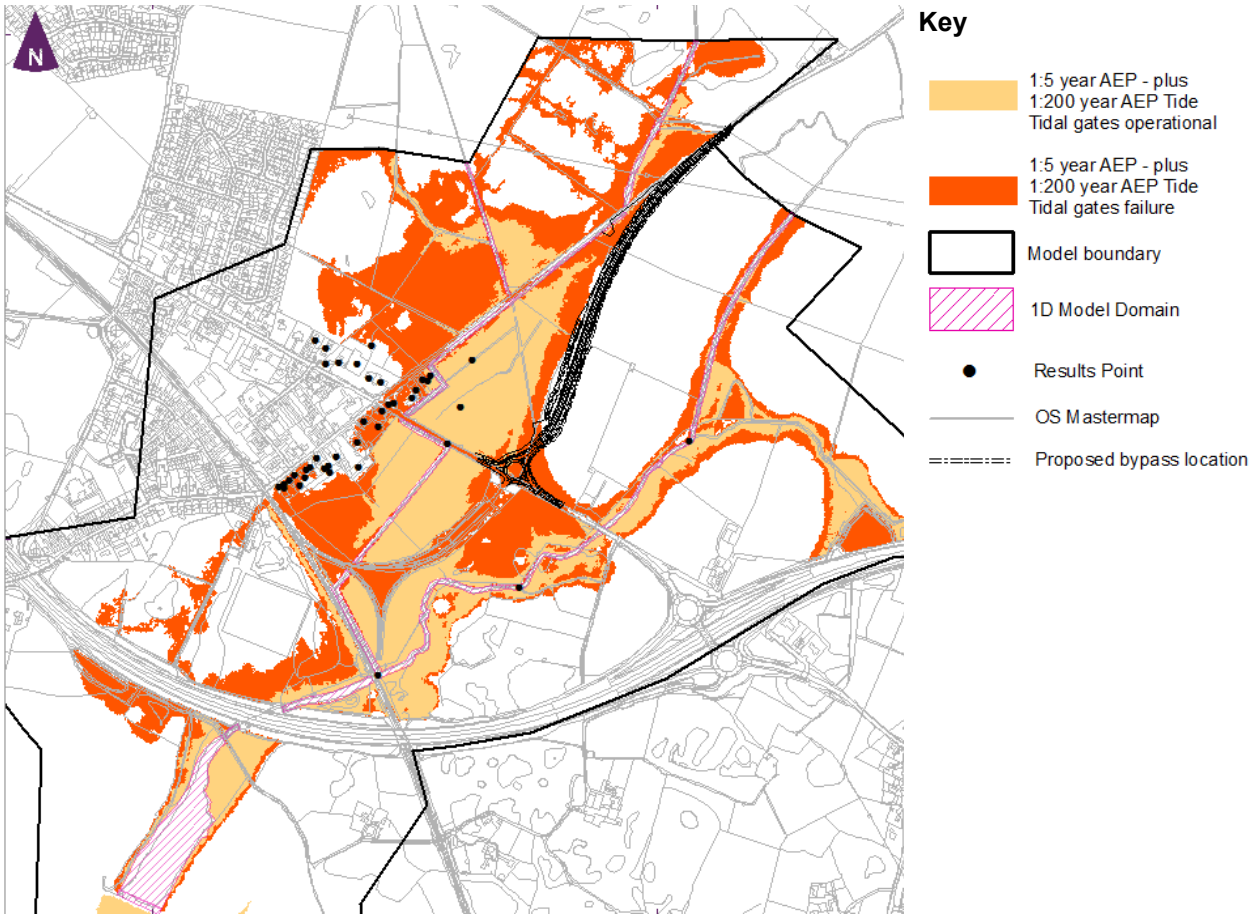
Figure 8.1 Combined fluvial 1:5 year and tidal 1:200 year AEP flood extents with and without tidal gates



Tests 6 & 7: Culvert blockage (50% and 90%)

Two sensitivity tests were run to determine the model's sensitivity to blockage of the culverts associated with the Railway Crossing (model node identifier: 01_0721) downstream of the proposed bypass footprint. For test 6 the blockage units were set to 50%, and increased further to 90% blocked for test 7. Summary results are displayed in Table 8.5. As expected, test 7 (90% blocked culvert) reports the highest peak depths and the largest increases compared to the Baseline model. The difference in peak depths for all summary results points in test 7 range between 0.21m and 0.73m. The difference in peak depth in test 6 ranges between 0.00m and 0.22m is 0.96 m at results point 26.

Table 8.5 Sensitivity tests 6 and 7 summary results – 1:100 year AEP fluvial event

Result Points	1:100 year AEP Baseline	Test 6 (50%)	Difference* (m)	Test 7 (90%)	Difference* (m)
1	0.00	0.00	0.00	0.21	0.21
2	0.84	0.96	0.12	1.47	0.63
3	0.00	0.11	0.11	0.63	0.63
4	0.13	0.25	0.12	0.76	0.63

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Result Points	1:100 year AEP Baseline	Test 6 (50%)	Difference* (m)	Test 7 (90%)	Difference* (m)
17	0.00	0.00	0.00	0.28	0.28
20	0.00	0.00	0.00	0.48	0.48
22	0.00	0.00	0.00	0.41	0.41
25	0.00	0.05	0.05	0.57	0.57
26	0.06	0.28	0.22	0.79	0.73
29	0.00	0.00	0.00	0.42	0.42
30	0.47	0.59	0.12	1.10	0.63
31	0.07	0.18	0.11	0.70	0.63
32	0.32	0.44	0.12	0.96	0.64
37	0.00	0.00	0.00	0.43	0.43

* where negative values denote a decrease in flood depth and positive values denote an increase in flood depth.

Tests 8 & 9: 1D roughness

A total of four tests were run to test the Baseline and Bypass models' sensitivity to changes in the 1D roughness to represent an unmaintained vegetated channel network. The 1D roughness for channels were increased to 0.07 in tests 8a and 8b, and increased further to 0.08 in tests 9a and 9b. Tests 'a' were run using the Baseline model and tests 'b' were run using the Bypass model. A summary of the Baseline model 1D roughness test results are displayed in Table 8.5, and the equivalent test results on the Bypass model are displayed in Table 8.7.

Both roughness tests on the Baseline model report increases in peak depth in some locations (Table 8.6). As expected, test 9a reports a slightly higher increase in peak depth compared to test 8a. The largest increase in both test 8a and 9a is located at point 26, where the peak depth increases by to 0.22 in test 8a and 0.25m in test 9a.

Table 8.6 Sensitivity tests 8a and 9a Baseline summary results – 1:100 year AEP fluvial event

Result Points	1:100 year AEP Baseline	Test 8a (n is 0.07)	Difference* (m)	Test 9a (n is 0.08)	Difference* (m)
1	0.00	0.00	0.00	0.00	0.00
2	0.84	0.95	0.11	0.98	0.14
3	0.00	0.11	0.11	0.14	0.14
4	0.13	0.24	0.11	0.27	0.14
17	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00
25	0.00	0.05	0.05	0.08	0.08

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Result Points	1:100 year AEP Baseline	Test 8a (n is 0.07)	Difference* (m)	Test 9a (n is 0.08)	Difference* (m)
26	0.06	0.28	0.22	0.31	0.25
29	0.00	0.00	0.00	0.00	0.00
30	0.47	0.58	0.11	0.61	0.14
31	0.07	0.18	0.11	0.21	0.14
32	0.32	0.44	0.12	0.47	0.15
37	0.00	0.00	0.00	0.00	0.00

* where negative values denote a decrease in flood depth and positive values denote an increase in flood depth.

Similar to the Baseline model roughness tests, the Bypass roughness tests also report an increase in peak depth compared to the Bypass model (Table 8.7). As expected, test 9b reports a slightly higher increase in peak depth compared to test 8b. As with the Baseline tests are produced the largest increase in both test 8b and 9b is located at point 26, where the peak depth increases by to 0.27 in test 8b and 0.30m in test 9b.

The Baseline and Bypass tests overall are reporting similar, and often identical results, which provides confidence that the models are responding similarly to the changes, and that the flood storage option planned as part of the bypass scenario will operate as expected even if the system is more widely and heavily vegetated.

Table 8.7 Sensitivity tests 8b and 9b Bypass summary results – 1:100 year AEP fluvial event

Result Points	1:100 year AEP Bypass	Test 8b (n is 0.07))	Difference* (m)	Test 9b (n is 0.08)	Difference* (m)
1	0.00	0.00	0.00	0.00	0.00
2	0.84	0.95	0.11	0.98	0.14
3	0.00	0.11	0.11	0.14	0.14
4	0.12	0.24	0.12	0.27	0.15
17	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00
22	0.00	0.00	0.00	0.00	0.00
25	0.00	0.05	0.05	0.08	0.08
26	0.01	0.28	0.27	0.31	0.30
29	0.00	0.00	0.00	0.00	0.00
30	0.46	0.58	0.12	0.61	0.15
31	0.06	0.18	0.12	0.21	0.15
32	0.32	0.44	0.12	0.47	0.15
37	0.00	0.00	0.00	0.00	0.00

* where negative values denote a decrease in flood depth and positive values denote an increase in flood depth.

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Test 10: Lateral inflow hydrograph derivation

In Section 3.3 three lateral inflow hydrographs were generated based on hydrographs derived at six hydrologic assessment locations (HALs). Table 3.2 shows the subtraction method used for the lateral inflow hydrographs. In this test the hydrographs were generated using a catchment disaggregation approach to test the sensitivity of the model predictions to the hydrograph generation approaches. The disaggregation of intervening catchment area resulted in hydrographs with a decreased peak flow for inflow 1 and inflow 3, however it resulted in an increased peak flow for inflow 2. Similarly, total flow volumes from hydrographs for inflow 1 and inflow 3 were decreased and it was increased for inflow 2 as shown in the Table 8.8. The changes are considered to be insignificant.

As can be seen from Table 8.8, the disaggregation approach shows a tendency of shortening of time to peak, however the overall peak and total volume area generally reduced in the disaggregation approach. This adds confidence to the hydrograph generated in Section 3.3 and confirms that the hydrographs used in the modelling are reasonable and not underestimates.

Table 8.8 Comparison of inflow hydrographs from Subtraction and Disaggregation method

Contributing Catchment between HALs as indicated: -	**Cleifiog, inflow 1** **(HAL1-HAL2)**	**Cleifiog, inflow 2** **(HAL2-HAL3-HAL4-HAL5)**	**Cleifiog, inflow 3** **(HAL3-HAL6)**	**Remarks**
Inflow type and area (km^2)	Lateral inflow (0.42)	Lateral inflow (1.25)	Lateral inflow (1.57)	
Event:		1:100 year AEP		
Peak flow (m^3/s), subtraction method	0.777	1.024	1.459	
Peak flow (m^3/s), disaggregation method	0.432	1.189	1.448	
Peak time (hrs), subtraction method	33	30	30	
Peak time (hrs), disaggregation method	27	28	28	
Inflow Volume (m^3), subtraction method	74048	116107	168345	
Inflow Volume (m^3), disaggregation method	49293	128281	162684	
change (hrs) in peak arrival time	-6	-2	-2	(-) means shortened time in hours
change (%) in inflow volume	-33	10	-3	(-) means decrease % volume

The maximum change observed at selected results points is a reduction in flood depth by 0.01m in the floodplain (Table 8.9). The disaggregation approach resulted in differences to the peak in-channel water levels in the range of -0.02m to 0.02m compared to the subtraction approach detailed in Section 3. This

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shows a mixed results of water level differences, however the differences are not significant. This shows the model is not sensitive to the derivation approach of lateral inflow hydrographs, with the lateral hydrograph method applied to the Baseline design runs yielding a slightly more conservative result.

Table 8.9 Sensitivity test 10 model results: lateral Inflow hydrograph derivation for 1:100 year AEP fluvial event

Result Points	1:100 year AEP Baseline	Test 10 (disaggregation approach)	Difference* (m)
1	0.00	0.00	0.00
2	0.84	0.83	-0.01
3	0.00	0.00	0.00
4	0.12	0.12	0.00
17	0.00	0.00	0.00
20	0.00	0.00	0.00
22	0.00	0.00	0.00
25	0.00	0.00	0.00
26	0.01	0.00	-0.01
29	0.00	0.00	0.00
30	0.46	0.46	0.00
31	0.06	0.06	0.00
32	0.32	0.32	0.00
37	0.00	0.00	0.00

* negative values denote a decrease in flood depth and positive values denote an increase in flood depth.

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8.3 Sensitivity test conclusions

In summary, the results from the sensitivity tests performed indicate that the model is responding appropriately and as expected to the changes, with water level differences observed being commensurate with the degree of change applied to the model parameters, thus not causing a significant impact on flood results in the study area.

It is concluded that the model parameters used and the method to derive the lateral inflow hydrographs adopted for the hydraulic model are appropriate.

The blockage sensitivity and the global increase in channel roughness to represent increased vegetation growth does result in an increase in flood depths across the field containing the proposed bypass footprint as would be expected. This highlights the need for channel maintenance as asset inspection. However, what the test has shown is that even if there was an increase in vegetation in the watercourses across the field containing the proposed bypass footprint the proposed flood storage area as part of the bypass option would maintain flood depths to baseline depths, no increase in flood depth was observed across field containing the proposed bypass footprint.

8.4 Tidal boundary timing test

In addition to assessing the sensitivity to key parameters (as detailed above), the sensitivity of the model to the choice of peak tide was undertaken for the fluvial 1:100 year AEP event.

As part of the hydrology assessment 21 different peak tide timing events were modelled using the simplified 1D Flood Modeller model (see Section 5.2 of Appendix B). The assessment sought to determine which combination of critical storm duration and peak tide timing resulted in the highest water level in the field containing the proposed bypass footprint. From the hydrology assessment (see Appendix B for more details) a peak tide at 47 hours was selected as the downstream boundary.

Nevertheless, a comment was raised in the NRW model review (2017) that a sensitivity test should be undertaken to test the impact of having a tide peak which is coincident with the fluvial peak.

The timing of the fluvial hydrograph peaks varies from 27 hours to 33 hours. For this sensitivity test the timing of the peak tide was adjust so it peaked at 29 hours, the time the largest flow to the model (Cleifiog inflow DRAIN 01/HAL6) peaks. The resultant depth difference grid is shown in Figure 8.2. Analysis of the results shows coinciding the tidal peak with the fluvial peak for the 1:100 year AEP event shows an increase in peak flood depth of between 0.01m and 0.05m across much of the field containing the proposed bypass footprint – with isolated pockets experiencing differences between 0.05 and 0.1m. There is an equivalent fall in flood depth in the adjacent Cleifiog catchment. The increase and decrease in extent in the respective catchments are negligible and no additional receptors are at risk.

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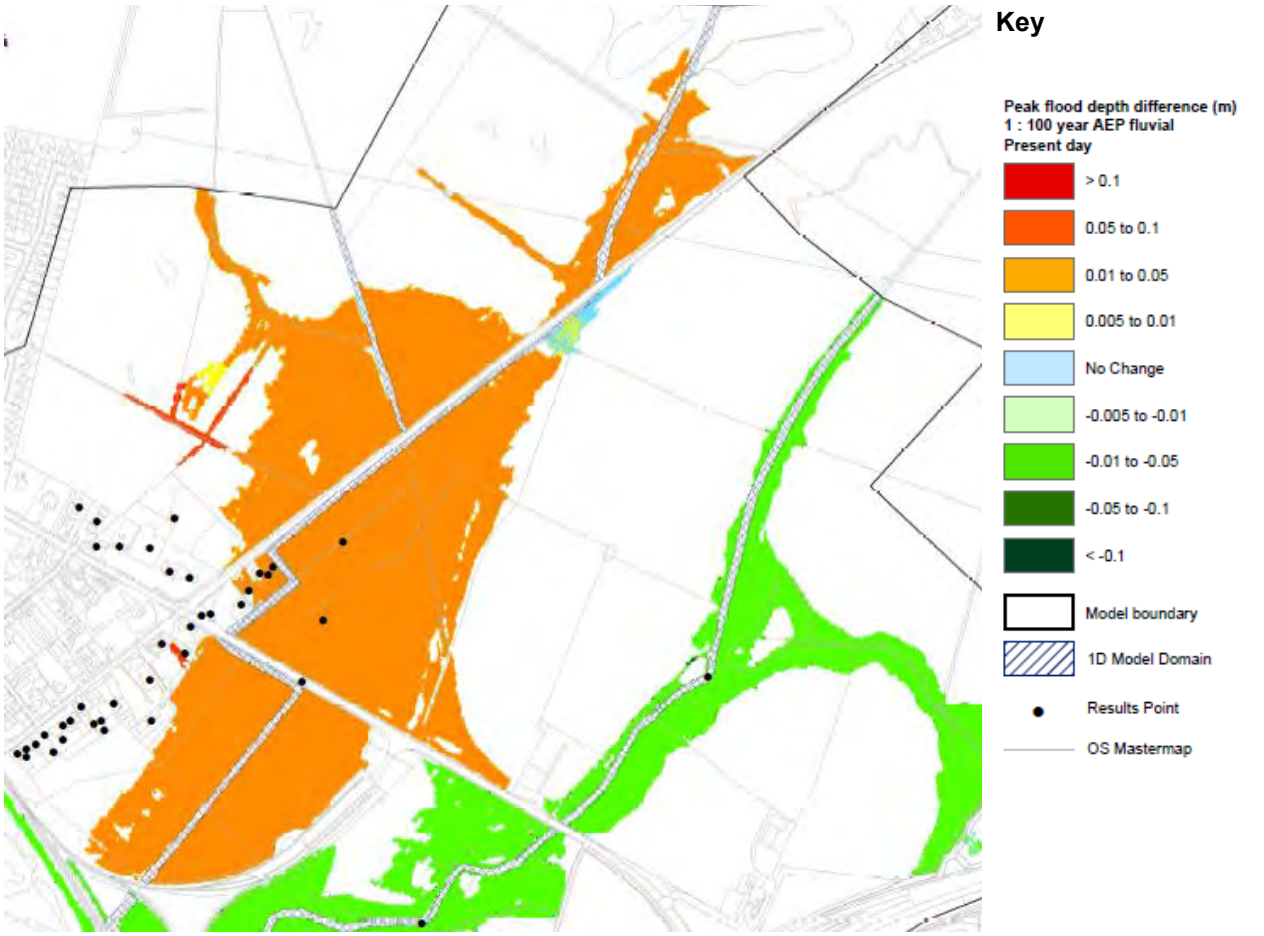
Figure 8.2 Tide timing sensitivity test depth difference (m)



8.5 Higher climate change allowance test

Climate change was applied by using a 30% uplift on the 1:100 year AEP event as per current guidance (Llywodraeth Cymru/Welsh Government, 2016). This is the central estimate for climate change allowance for the 2080s. Following discussions with NRW it was suggested a higher allowance be run as a sensitivity test to determine whether the proposed bypass would be placed at risk of flooding under this future climate scenario. A higher estimate of 70% was applied (it is noted that current guidance states the highest increases in climate change could be up to 75% for this part of Wales, so any future modelling should use this slightly larger uplift value).

From Figure 8.3 it is evident that across the wider Valley area the higher climate allowance would result in a wider flood extent. However, along the alignment of the proposed route of the Bypass there is very little increase in flood extent. Further confirming the influence of the topography of the extent of flooding in this area. Figure 8.5 shows that the junction with the existing A5025 would be at risk of flooding in this extreme future climate scenario. The remaining route of the Bypass is located along the edge of the flood extent and is raised and therefore remains above the predicted flood level in this higher climate change allowance scenario.

Figure 8.4 shows the depth difference plot looking at the impact of the bypass route and compensatory storage on the flood extent and depth across the floodplain in this extreme future climate scenario. For this scenario, the flood depths are shown to decrease across the field containing the proposed bypass footprint.

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Figure 8.3 Baseline 1:100 year AEP flood extents for three climate scenarios

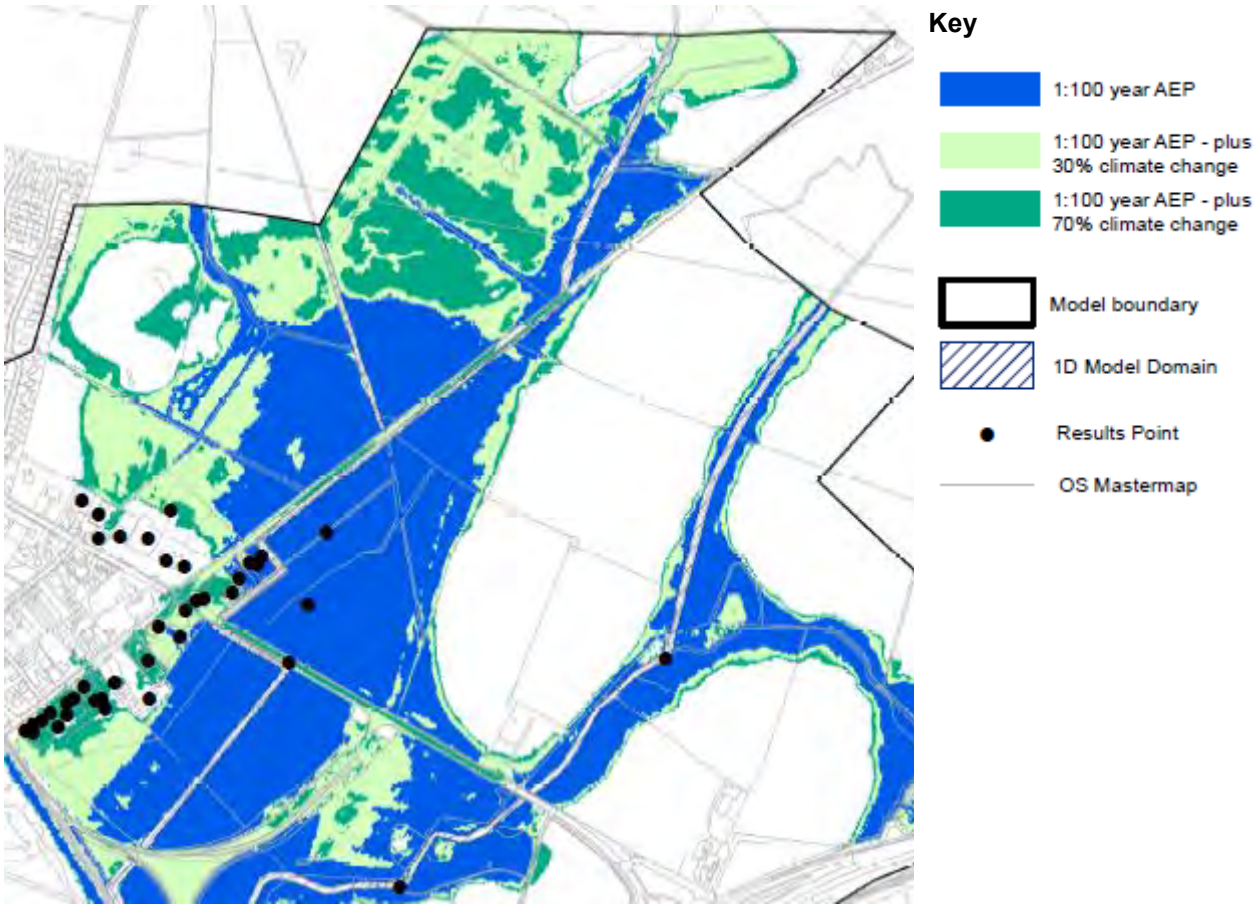

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Figure 8.4 Peak fluvial depth difference - 1:100 year AEP climate change (70%)

Note: negative values denote a decrease in flood depth and positive values denote an increase in flood depth.

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Figure 8.5 Peak fluvial flood extent - 1:100 year AEP climate change (70%) – with bypass and compensatory storage

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379000
378000
N

Key

Baseline fluvial
Peak flood extents

- 1:5 year AEP
- 1:5 year AEP - plus 1:200 year AEP Tide
- 1:20 year AEP
- 1:100 year AEP
- 1:100 year AEP - plus 30% climate change
- 1:1000 year AEP
- 1:100 year AEP - plus 30% climate change with future 2115 1:200 year AEP Tide
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

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Figure 6.1
A5025 Valley baseline peak fluvial flood extents

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229000
230000
231000
380000
379000
378000
N

Key

Peak flood depth (m)
Baseline
1 : 5 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 20/04/2017
Corresponding data:
35989-C1357i1_A5025_Vall_Base_F5.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

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Figure 6.2
A5025 Valley baseline peak fluvial depth 1:5 year AEP present day

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229000
230000
231000
380000
379000
378000
N

Key

Peak flood depth (m)
Baseline
1 : 20 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 20/04/2017
Corresponding data:
35989-C1358i1_A5025_Vall_Base_F20.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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A5025 - Valley
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Figure 6.3
A5025 Valley baseline peak fluvial depth 1:20 year AEP present day

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229000
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231000
380000
379000
378000
N

Key

Peak flood depth (m)
Baseline
1 : 100 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 22/04/2017
Corresponding data:
35989-C1359i1_A5025_Vall_Base_F100.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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A5025 - Valley
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Figure 6.4
A5025 Valley baseline peak fluvial depth 1:100 year AEP present day

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229000
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231000
380000
379000
378000
N

Key

Peak flood depth (m)
Baseline
1 : 1000 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 15/04/2017
Corresponding data:
35989-C1360i1_A5025_Vall_Base_F1000.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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Figure 6.5
A5025 Valley baseline peak fluvial depth 1:1000 year AEP present day

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229000
230000
231000
380000
379000
378000
N

Key

Peak flood depth (m)
Baseline
1 : 100 year AEP fluvial
Climate change (30%)

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 12/04/2017
Corresponding data:
35989-C1361i1_A5025_Vall_Base_F100cc.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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A5025 - Valley
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Figure 6.6
A5025 Valley baseline peak fluvial depth 1:100 year AEP climate change (30%)

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231000
380000
379000
378000
N

Key

Baseline tidal
Peak flood extents

- 1:200 year AEP
- 1:1000 year AEP
- 1:1000 year AEP - plus climate change (2115)
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

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Figure 6.7
A5025 Valley baseline peak tidal flood extents

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380000
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N

Key

Peak flood depth (m)
Baseline
1 : 200 year AEP tidal
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 19/05/2017
Corresponding data:
35989-C1362i1_A5025_Vall_Base_T200.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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A5025 - Valley
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Figure 6.8
A5025 Valley baseline peak tidal depth 1:200 year AEP present day

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380000
379000
378000
N

Key

Peak flood depth (m)
Baseline
1 : 1000 year AEP tidal
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 25/04/2017
Corresponding data:
35989-C1363i1_A5025_Vall_Base_T1000.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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A5025 - Valley
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Figure 6.9
A5025 Valley baseline peak tidal depth 1:1000 year AEP present day

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379000
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Key

Peak flood depth (m)
Baseline
1 : 1000 year AEP tidal
Climate change (2115)

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 03/05/2017
Corresponding data:
35989-C1364i1_A5025_Vall_Base_T1000cc.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
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Figure 6.10
A5025 Valley baseline peak tidal depth 1:1000 year AEP climate change (2115)

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378000
N

Key

Peak combined flood depth (m)
Baseline
1 : 5 year AEP fluvial and
1:200 year AEP tidal
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 28/04/2017
Corresponding data:
35989-C1365i1_A5025_Vall_Base_F5T200.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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A5025 - Valley
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Figure 6.11
A5025 Valley baseline peak combined depth fluvial 1:5 year AEP present day and tidal 1:200 year AEP present day

May 2017 35989-Lon500i1 beltl

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229000
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231000
380000
379000
378000
N

Key

Peak combined flood depth (m)
Baseline
1 : 100 year AEP fluvial
Climate change (30%)
and 1:200 year AEP tidal
Climate change (2115)

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

Model boundary

1D Model Domain

Results Point

OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 15/04/2017
Corresponding data:
35989-C1366i1_A5025_Vall_Base_F100ccT200cc.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 6.12
A5025 Valley baseline peak combined depth fluvial 1:100 year AEP climate change (30%) and tidal 1:200 year AEP climate change

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229000
230000
231000
380000
379000
378000

Key

Peak flood depth (m)
With bypass & compensatory storage
1 : 5 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

Model boundary

1D Model Domain

Results Point

OS Mastermap

Proposed bypass location

Proposed compensatory storage area

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 24/06/2017
Corresponding data:
35989-C1421i1_A5025_Vall_Bypass_F5.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 7.1
A5025 Valley 'with bypass and compensatory storage' peak fluvial depth 1:5 year AEP present day

June 2017 35989-Lon547i1 hurtf

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229000
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231000
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379000
378000
N

Key

Peak flood depth (m)
Bypass & compensatory storage
1 : 20 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 27/06/2017
Corresponding data:
35989-C1422i1_A5025_Vall_Bypass_F20.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 7.2
A5025 Valley 'with bypass and compensatory storage' peak fluvial depth 1:20 year AEP present day

June 2017 35989-Lon548i1 hurtf

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229000
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N

Key

Peak flood depth (m)
Bypass & compensatory storage
1 : 100 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 27/06/2017
Corresponding data:
35989-C1423i1_A5025_Vall_Bypass_F100.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 7.3
A5025 Valley 'with bypass and compensatory storage' peak fluvial depth 1:100 year AEP present day

June 2017 35989-Lon549i1 hurtf

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229000
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N

Key

Peak flood depth (m)
Bypass & compensatory storage
1 : 1000 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

Model boundary
1D Model Domain
Results Point
OS Mastermap
Proposed bypass location
Proposed compensatory storage area

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 28/06/2017
Corresponding data:
35989-C1424i1_A5025_Vall_Bypass_F1000.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 7.4
A5025 Valley 'with bypass and compensatory storage' peak fluvial depth 1:1000 year AEP present day

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229000
230000
231000
380000
379000
378000
N

Key

Peak flood depth (m)
With bypass & compensatory storage
1 : 100 year AEP fluvial
Climate change (30%)

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 23/06/2017
Corresponding data:
35989-C1425i1_A5025_Vall_Bypass_F100cc.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 7.5
A5025 Valley 'with bypass and compensatory storage' peak fluvial depth 1:100 year AEP climate change (30%)

June 2017 35989-Lon551i1 hurtf

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229000
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Key

Peak flood depth (m)
Bypass & compensatory storage
1 : 200 year AEP tidal
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 03/07/2017
Corresponding data:
35989-C1426i1_A5025_Vall_Bypass_T200.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 7.6
A5025 Valley 'with bypass and compensatory storage' peak tidal depth 1:200 year AEP present day

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229000
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N

Key

Peak flood depth (m)
Bypass & compensatory storage
1 : 1000 year AEP tidal
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 29/06/2017
Corresponding data:
35989-C1427i1_A5025_Vall_Bypass_T1000.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
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Figure 7.7
A5025 Valley 'with bypass and compensatory storage' peak tidal depth 1:1000 year AEP present day

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229000
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378000
N

Key

Peak flood depth (m)
Bypass & compensatory storage
1 : 1000 year AEP tidal
Climate Change (2115)

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 29/06/2017
Corresponding data:
35989-C1428i1_A5025_Vall_Bypass_T1000cc.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

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Figure 7.8
A5025 Valley 'with bypass and compensatory storage' peak tidal depth 1:1000 year AEP climate change (2115)

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378000
N

Key

Peak flood depth (m)
With bypass & compensatory storage
1 : 5 year AEP fluvial and
1:200 year AEP tidal
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 24/06/2017
Corresponding data:
35989-C1429i1_A5025_Vall_Bypass_F5T200.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

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Figure 7.9
A5025 Valley 'with bypass and compensatory storage' peak combined depth fluvial 1:5 year AEP present day and tidal 1:200 year AEP

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378000
N

Key

Peak flood depth (m)
With bypass & compensatory storage
1:100 year AEP fluvial
Climate change (30%) and
1:200 year AEP tidal
Climate change (2115)

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 28/06/2017
Corresponding data:
35989-C1430i1_A5025_Vall_Bypass_F100cc T200cc.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 7.10
A5025 Valley 'with bypass and compensatory storage' peak combined depth fluvial 1:100 year AEP climate change (30%) and tidal 1:200 year AEP climate change (2115)

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230000

380000

379000

N

Key

Peak flood depth difference (m)
1 : 5 year AEP fluvial
Present day

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 100 200 300
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 7.11
A5025 Valley peak fluvial depth difference - 1:5 year AEP present day

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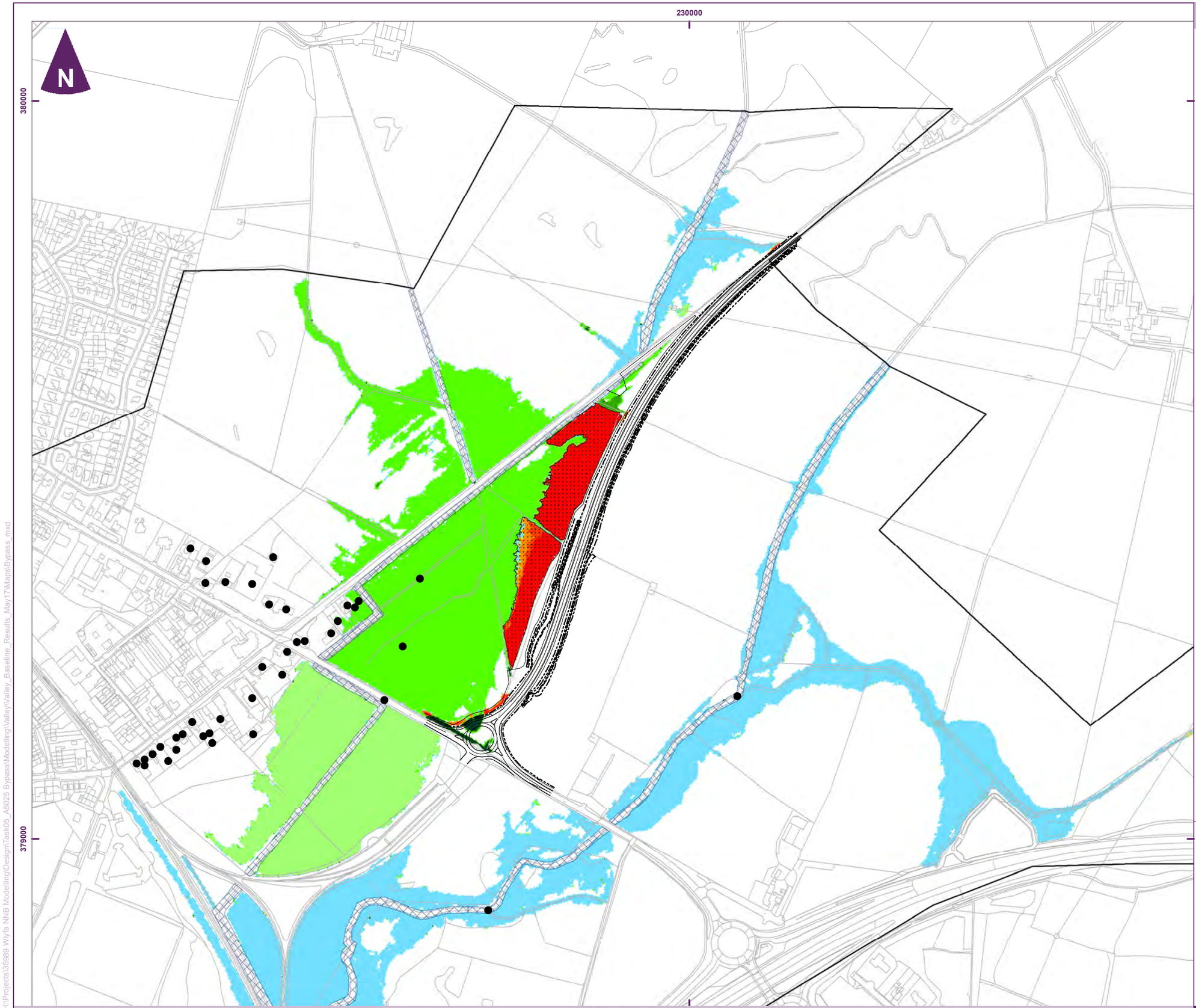

Key

Peak flood depth difference (m)
1 : 20 year AEP fluvial
Present day

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 100 200 300
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

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Figure 7.12
A5025 Valley peak fluvial depth difference - 1:20 year AEP present day

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230000

380000

379000

N

Key

Peak flood depth difference (m)
1 : 100 year AEP fluvial
Present day

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 100 200 300
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 7.13
A5025 Valley peak fluvial depth difference - 1:100 year AEP present day

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N

Key

Peak flood depth difference (m)
1 : 1000 year AEP fluvial
Present day

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 100 200 300
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 7.14
A5025 Valley peak fluvial depth difference - 1:1000 year AEP present day

June 2017 35989-Lon560i1 hurtf

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N

Key

Peak flood depth difference (m)
1 : 100 year AEP fluvial
Climate change (30%)

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 100 200 300
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 7.15
A5025 Valley peak fluvial depth difference - 1:100 year AEP climate change (30%)

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N

Key

Peak flood depth difference (m)
1 : 200 year AEP tidal
Present day

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 100 200 300
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 7.16
A5025 Valley peak tidal depth difference - 1:200 year AEP present day

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230000

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379000

N

Key

Peak flood depth difference (m)
1 : 1000 year AEP tidal
Present day

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 100 200 300
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 7.17
A5025 Valley peak tidal depth difference - 1:1000 year AEP present day

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230000

380000

379000

N

Key

Peak flood depth difference (m)
1 : 1000 year AEP tidal
Climate change (2115)

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 100 200 300
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 7.18
A5025 Valley peak tidal depth difference - 1:1000 year AEP plus climate change (2115)

July 2017 35989-Lon564i1 hurtf

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file: H:\Projects\35989 Wylfa NNB Modelling\Design\Task05_A5025 Bypass\Modelling\Valley\Valley_Baseline_Results_May17\Maps\Bypass_mxd

230000

380000

379000

N

Key

Peak flood depth difference (m)
1 : 5 year AEP fluvial and
1:200 year AEP tidal
Present day

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 100 200 300
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 7.19
A5025 Valley peak fluvial depth difference - 1:5 year AEP present day and tidal 1:200 year AEP present day

June 2017 35989-Lon565i1 hurtf

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229000

230000

379000

N

Key

Peak flood depth difference (m)
1 : 100 year AEP fluvial
Climate change (30%)
and 1:200 year AEP tidal
Climate change (2115)

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- OS Mastermap
- Proposed bypass location
- Proposed compensatory storage area

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 100 200 300
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

amec foster wheeler

Figure 7.20
A5025 Valley peak depth difference - fluvial 1:100 year AEP climate change (30%) and tidal 1:200 year AEP climate change (2115).

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Appendix B
Detailed Hydrology Report

Hydrology Assessment

1 Introduction

As part of the Wylfa Newydd DCO Project, several highway enhancement projects have been identified, one of which is a bypass proposed around the crossroad junction between the A5 and A5025 in Valley, which is the subject of this technical note. The proposed bypass route passes through agricultural land and crosses small watercourses to the north east of the A5/A5025 junction, shown on Figure 1.1.

1D-2D modelling will be undertaken to support the assessment of the proposed A5025 bypass at Valley, Anglesey, NW Wales. Modelling will determine the baseline (present day) fluvial flood risk to the bypass location and nearby receptors, and the future risk including climate change impacts.

Hydrological assessment has determined the inflows which will be represented in the hydraulic model. Natural Resources Wales (NRW) guidance (NRW, 2015) states that a FCA must consider the 1:100 year annual exceedance probability (AEP) and 1:1000 year AEP events, including climate change on fluvial flows up to and including the 1:100 year AEP events. A 1:2 year AEP event is used to test the joint tidal flood risk. In addition, to provide a range of flood events the 1:5 year AEP and 1:20 year AEP events have been determined to represent in the hydraulic modelling study.

The purpose of this hydrological assessment is to determine appropriate inflows, required as input to the hydraulic model of the proposed A5025 bypass at Valley. This report defines the hydrological catchments which will be represented in the Valley hydraulic model and the flows which have been derived using two industry standard methods: The Flood Estimation Handbook (FEH) (Institute of Hydrology (IOH), 1999) statistical method and the revitalised flood hydrograph method (ReFH) described in Supplementary Report 1 to the FEH (Centre for Ecology & Hydrology (CEH), 2007)[5]. The results of the hydrological assessment and the flows to be represented in the hydraulic model are presented in this technical note.

This technical note has the following sections:

- Section 2: Catchment definition;
- Section 3: Hydrology approach;
- Section 4: Derivation of flows using FEH statistical method;
- Section 5: Derivation of flows using ReFH1 method;
- Section 6: Final peak flows;
- Section 7: Representation of flows in the hydraulic model; and
- Section 8: References.

[5] ReFH1 was the current methodology at the start of the project. Although the methodology was subsequently updated to ReFH 2.2 (May 2016), the hydrology for this project has not been updated as the modelling had already been completed.

2 Catchment definition

2.1 Overview

The area north and east of Valley, where the bypass is located, is relatively flat with numerous drainage channels and watercourses and the catchments serving them are not well defined. In addition, normal flow directions may reverse under higher flow conditions. As a result, flow mechanisms in the area of the proposed bypass are complex. Furthermore, there are no flow or water level gauge data or detailed topographic survey available to fully understand the system, either during normal flow conditions or extreme events.

The Valley watercourse, and its tributary Glan Morfa, are located near the proposed bypass route. The Valley watercourse is a small tributary of the Cleifiog and is currently culverted under the A5, flowing into the Cleifiog just upstream of the railway approximately 250m south of Valley. The Cleifiog flows south-west from Llanynghenedl, flowing into Holyhead Bay approximately 1km south of Valley (Figure 1.1). The extent of any influence from the proposed A5025 bypass is expected to be limited to the immediate vicinity of the proposed bypass, bounded by the A5 to the south-west (raised), the A5025 to the north-west (raised) and an area of high ground to the east between the bypass location and the Cleifiog.

The hydraulic model needs to ensure that water levels in the Cleifiog at the confluence with the Valley watercourse are represented appropriately as this could influence levels and flows near the bypass. Flow in the Cleifiog at the confluence is itself influenced constrained by the A5 culvert upstream. In addition, flows from the adjacent Maes Y Wrach catchment (Figure 1.1) may also flow into the Cleifiog approximately 250m upstream of the A5 culvert, although the nature of this connection is unclear. According to FEH, there is no connection from the adjacent Maes Y Wrach catchment to the Cleifiog watercourse. However, Ordnance Survey (OS) mapping and the 50k river network indicate that Maes Y Wrach does discharge into the Cleifiog watercourse, as shown on Figure 1.1. Because of this discrepancy, it was necessary to consider this issue in greater detail in Section 2.2.

2.2 Maes Y Wrach connectivity

OS mapping, the 50k river network and the NRW Flood Risk Map (Appendix E) show the Maes Y Wrach watercourse flowing from south of Bodedern to the Cleifiog watercourse near Pen-caledog. There is also a drain linking the Cleifiog watercourse with the Maes Y Wrach watercourse (referred to in this document as the Cleifiog Isaf drain). The Caergeiliog watercourse flows through Caergeiliog to the Maes Y Wrach watercourse just north of the A55. These features are shown on Figure 1.1.

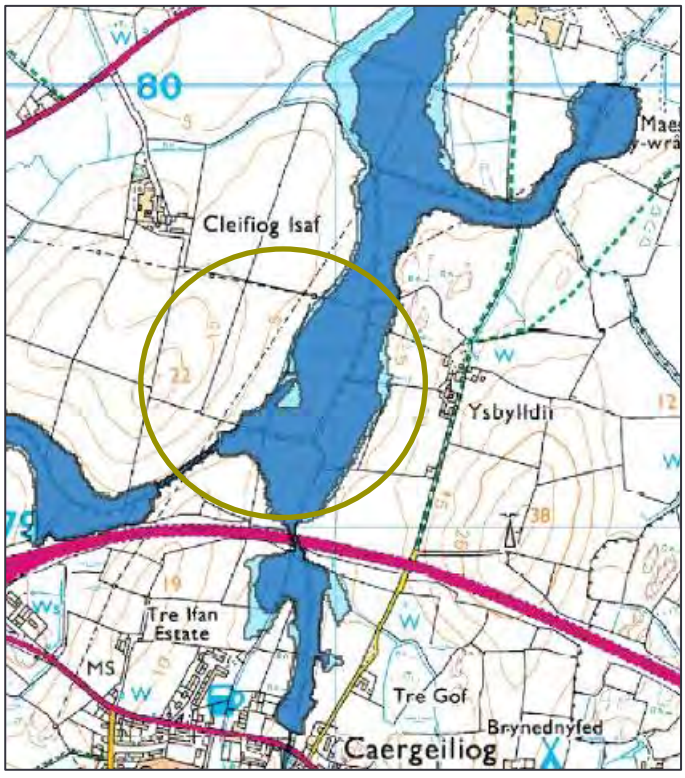
The connections between watercourses and drains on flat ground can affect how flow moves around the area and there may be more than one route, depending on the relative water levels under different flow conditions. In order to develop a better understanding of flow paths in the area LiDAR and the NRW Flood Risk Map (risk of flooding from rivers and the sea and risk of flooding from surface water) were reviewed. The main flow influences can be summarised as follows:

- The dominant flow path of the Cleifiog watercourse is west around Cleifiog Isaf. This route was identified on the OS 1:50k mapping, NRW Flood Risk Map and 1:50k river network and LiDAR indicated a lower elevation along this route. However, during extreme events water could flow overland and through the slightly higher Cleifiog Isaf drain to the Maes Y Wrach watercourse (flow route not explicitly modelled, see Section 2.3);
- The Maes Y Wrach watercourse flows through a marsh area east of Cleifiog Isaf. The marsh area is extensive, shown on both the ‘risk of flooding from rivers and the sea’ and ‘risk of flooding from surface water’ layers of the NRW Flood Risk Map. During a flood event this area may receive flow from the Maes Y Wrach watercourse and overland flows from the Cleifiog watercourse. The marsh area is likely to provide significant attenuation during a flood event;
- From the marsh area water flows westwards via the Maes Y Wrach watercourse into the Cleifiog watercourse, however, high flows west may be constrained by floodplain topography in

which case water might back up southwards via the Caergeiliog watercourse and low lying ground towards Caergeiliog;

- NRW staff were not aware of any structures present that could influence flows on the Maes Y Wrach watercourse to the Cleifiog watercourse or south along the Caergeiliog watercourse (meeting held 26 June 2015 with Iwan Huws and Emyr Gareth from NRW);
- Topographic levels in Caergeiliog indicate that the Caergeiliog watercourse flows northwards to the Maes Y Wrach watercourse. The Caergeiliog watercourse flows north under the A5 and A55. If these culverts, particularly that under the A55, were to become blocked they could influence water levels in the area. If this was to occur, flow from the Caergeiliog watercourse would either be reduced or cut off and some attenuation storage would be disconnected from the Maes Y Wrach watercourse (though this is a relatively small area compared to the attenuation available north of the A55). As a result, the influence on water levels associated with the Maes Y Wrach watercourse and downstream was not considered to be significantly changed; and
- The main flow path from the marsh area east of Cleifiog Isaf, based on LiDAR, is westwards along Maes Y Wrach. However, flows are largely constrained to the immediate channel with only limited flow in the floodplain as the ground rises steeply. During extreme events flow through this reach is constrained, effectively backing up and attenuating in the marsh area east of Cleifiog Isaf. This area can be seen in the Fluvial Flood Zones at Valley which are provided in Appendix E, and from which an extract is reproduced as Plate 2.1.

Plate 2.1 Extract from NRW Fluvial Flood Zones at Valley



2.3 Representation of Cleifiog and Maes Y Wrach flows for the A5025 bypass

Given the relatively flat topography in the vicinity of the proposed A5025 bypass at Valley, peak water levels at the proposed A5025 bypass may be influenced by water levels at the confluence of the Valley and Cleifiog watercourses. However, water levels and flows in the Cleifiog at the confluence, and downstream of the A5

crossing, are constrained by flow through the culvert under the A5. Although considered unlikely to have a significant influence on peak levels at the proposed A5025 bypass, it is necessary to consider both watercourses in greater detail to ensure that flows both from the Cleifiog and Maes Y Wrach upstream of the A5025 are accurately represented.

Cleifiog watercourse

In addition to influencing water levels at the confluence with the Valley watercourse, overland flow from the Cleifiog watercourse directly to the proposed A5025 bypass at Valley is also considered. The watercourses near the bypass (Valley watercourse and Glan Morfa) are separated from the Cleifiog watercourse by an area of high ground between the A5025 and A5. It is possible that there is some connectivity from overland flow from the Cleifiog watercourse across lower ground to the north and then west, which could influence water levels in the study area. Therefore, hydrological assessment is required at this location on the Cleifiog (Hydrological Assessment Location 6, Figure 2.1) and the area will be represented in the model.

It is possible that, during extreme events, some flow from the Cleifiog watercourse may flow to the east to the Maes Y Wrach watercourse, however, the proportion of water is not known. It is also likely that this water would return to the Valley catchment via the Maes Y Wrach watercourse. As such the Cleifiog watercourse catchment, as identified on FEH and shown on Figure 2.1, is a reasonable representation of the divide between the Cleifiog and Maes Y Wrach catchments and that inflows from hydrological assessment location 6 (Figure 2.1) can be applied as a single point inflow to the Cleifiog watercourse in the model.

Maes Y Wrach watercourse

Flow from the Maes Y Wrach catchment is expected to be attenuated in the marsh area and therefore peak water levels immediately upstream of the A5 culvert are unlikely to be significantly increased by representing inflows from this catchment within the hydraulic modelling. The flow through the A5 culvert and subsequent peak levels at the confluence with the Valley watercourse are expected to be influenced even less. However, following concerns expressed by NRW, the hydrological assessment was expanded to include the Maes Y Wrach catchment (hydrological assessment location 7, Figure 2.1).

2.4 Hydrological assessment

Hydrological assessment has been undertaken for the locations identified on Figure 2.1 and 2.2. Hydrological assessment locations were chosen to represent the inflow at the upper extent of the hydraulic model (5-Valley watercourse, 4-Glan Morfa watercourse, 6 – Cleifiog watercourse and 7 – Maes Y Wrach) and intervening catchments on the Cleifiog watercourse (3, 2 and 1).

There were some initial issues with the catchment boundaries available using the FEH CD-ROM, particularly for the smaller northern hydrological assessment locations (4 and 5). In general, the FEH CD-ROM identifies catchments of 0.5km^2 and greater, subject to the accuracy of its digital terrain (DTM) model. For Catchments 4 and 5 the FEH CD-ROM defines a single tributary north-east of Valley (FEH Catchment 4 and 5 shown on Figure 2.1) with a catchment area of 0.58km^2, but this does not align with available topographical data. Instead, catchment boundaries were determined from GIS using 10m OS contour data, and the resulting catchment areas were used in the hydrology calculations. Later, after LiDAR data had been obtained for the project, it was confirmed that the catchment extents (shown on Figure 2.1), were sufficiently similar to those obtained using 10m OS contour data to not need adjustment.

A comparison between the FEH catchments identified on the FEH CD-ROM 3 and LiDAR based catchments is shown on Figure 2.1. This shows that FEH Catchment 4 and 5 overlaps most of topographic catchment 5, but there are additional areas to the east and west. Also, two thirds of topographic catchment 4 significantly overlaps FEH Catchment 6 (representing the upper Cleifiog catchment). It is likely that there is a discrepancy in the DTM model used to derive the FEH catchments in this location. Catchment areas derived from FEH and LiDAR are presented in Table 2.1.

Table 2.1 Catchment areas for Valley

Catchment	National Grid Reference (NGR)	Area (km^2) from FEH	Area (km^2) from LiDAR
FEH Catchment 4 and 5[(a)]	SH 29600 79700	0.58	
Hydrological assessment location 4[(b)]	SH 30055 80000		0.57
Hydrological assessment location 5[(b)]	SH 29617 79727		0.30
Hydrological assessment location 6	SH 30250 79600	2.23	1.77
TOTAL		2.81	2.64

Note: (a) Shown on Figure 2.1 in yellow.
(b) Catchments associated with hydrological assessment locations 4 and 5 are not accurately identified on the FEH CD-ROM and therefore FEH Catchment 4 and 5 has been used to calculate flows at these locations.

Catchment boundaries from the FEH are included in Appendix A and catchment descriptors in Appendix B.

As topographic catchments 4 and 5 are not accurately represented within FEH, the hydrological assessment has derived flows based on FEH Catchment 4 and 5 (shown on Figure 2.1) which has been area-weighted to represent the appropriate catchment at each hydrological assessment location. Flows for hydrological assessment location 6 have been calculated using the FEH catchment, but then area-weighted to reduce the peak flow and ensure that flows are not double-counted. FEH catchments were used to represent hydrological assessment locations 1, 2, 3 and 7. The FEH catchment associated with Maes Y Wrach flows south and therefore taking the FEH catchment to hydrological assessment location 7 would not include the Caergeiliog catchment area. Instead the FEH catchment has been selected to SH 30900 78550 in Caergeiliog, but applied at hydrological assessment location 7 (as shown on Figure 2.1). This ensures that the extent of the FEH catchment includes the Caergeiliog watercourse as well as the full extent of the Maes Y Wrach catchment (a small area contributing to the lower reach of the Maes Y Wrach watercourse between hydrological assessment location 7 and the confluence is already incorporated in the FEH catchments representing the Cleifiog).

All catchment descriptor data exported from FEH CD-ROM 3[6] for each of the seven hydrological assessment locations is provided in Appendix B, with the key hydrological parameters for each location presented in Table 2.2. Key hydrological parameters include:

- Catchment area (AREA);
- Standard annual average rainfall (SAAR) for the period 1961-1990;
- The degree of flood peak attenuation within the catchment from reservoirs and lakes indicated by the FARL value (with a value of 1 indicating no attenuation), and
- A measure of catchment responsiveness indicated by the base flow index (BFIHOST).

[6] From 9 November 2015 FEH CD-ROM data have been available online, however, as this hydrological assessment was largely completed before the launch of the web service and it is understood that there is no significant difference to the catchment descriptor data, use of the FEH CD-ROM 3 catchment descriptor data are considered appropriate.

Table 2.2 Hydrological assessment location data for Valley catchment

Hydrological assessment location (HAL)	Watercourse	Location Description	National Grid Reference (NGR)	AREA (km^2)	SAAR (mm/yr)	FARL	BFIHOST	URBEXT 2000
1	Cleifiog	Outflow to sea	SH 29000 78350	5.88	879	1.00	0.387	0.0326
2	Cleifiog	Upstream of railway	SH 29350 78700	5.46	879	1.00	0.387	0.0337
3	Cleifiog	Between the railway and A5	SH 29700 78900	3.91	884	1.00	0.387	0.0032
4	Glan Morfa	Upper catchment	SH 30055 80000	0.57	See FEH Catchment 4 and 5[a]			
5	Valley	Upper catchment	SH 29617 79727	0.30	See FEH Catchment 4 and 5[a]			
	Glan Morfa and Valley	FEH Catchment 4 and 5	SH 29600 79700	0.58	861	1.00	0.385	0.0085
6	Cleifiog	Upper catchment	SH 30250 79600	1.77	See FEH Catchment 6[b]			
	Cleifiog	FEH Catchment 6	SH 30250 79600	2.23	889	1.00	0.388	0.0000
7	Maes Y Wrach	Upper catchment	SH 30900 78550[c]	4.46	906	1.00	0.387	0.0095

Note: (a) Catchments associated with hydrological assessment locations 4 and 5 are not correctly identified on the FEH CD-ROM and therefore the hydrological assessment was undertaken using FEH Catchment 4 and 5 and the results were scaled on an area-weighted basis for hydrological assessment locations 4 and 5.
(b) Hydrological assessment location 6 on the FEH CD-ROM would double-count flows from hydrological assessment location 4 and therefore the hydrological assessment was undertaken for the FEH Catchment 6 and the results area-weighted for hydrological assessment location 6.
(c) This catchment includes the Caergeiliog watercourse which is a tributary of the Maes Y Wrach.

Inflow hydrographs identified for hydrological assessment locations 4, 5, 6 and 7 will be represented as point inflows in the model, and the inflow hydrographs for hydrological assessment locations 1, 2 and 3 will be used to calculate the lateral inflows represented within the model. Greater detail on how inflows will be applied is provided in Section 7.

3 Hydrology approach

3.1 Deriving hydrographs

Current guidance from Natural Resources Wales (NRW), in the form of Technical Guidance: Flood estimation (NRW, 2016), identifies two recommended methods to estimate flow for events up to and including a 1:1000 year AEP event:

- Flood Estimation Handbook (FEH) statistical method; and
- Revitalised Flood Hydrograph (ReFH) method.

NRW's preferred approach for estimating peak flows up to and including the 1:100 years AEP event is the FEH statistical method based on Technical Guidance: Flood Estimation (NRW, 2016).

The FEH statistical method uses pooled annual maxima flow data from a group of hydrologically similar gauged catchments to calculate peak flows only. To provide the full hydrograph, required by the hydraulic model, a ReFH derived hydrograph is scaled to the FEH statistical method peak flow. It is recommended that the ratio method is applied to identify the 1:1,000 year AEP event, using a ratio of ReFH based estimates for the 1:100 year and 1:1000 year AEP events.

As part of the hydrological assessment, both the FEH statistical and ReFH methods were undertaken to derive hydrographs to be represented in the hydraulic model.

3.2 Season profile

As the hydrograph was fit to the FEH statistical peak, the winter profile (representing greater volume than a summer profile) was used as this represented a conservative approach. It was therefore considered reasonable to adopt the winter profile as the critical season.

3.3 Storm duration

ReFH1 based hydrographs can be derived from either a peak flow critical storm duration, based on catchment descriptors, or from a volume critical storm duration. The low-lying catchments near the proposed bypass location are particularly sensitive to volume, and therefore the greatest peak flow may not result in the worst-case flood depth and extent. Instead, a longer duration volume critical event, with a lower peak flow and larger volume, may return the worst-case flood extent and depth.

Both peak flow and volume critical events were derived for this hydrological assessment. The peak flow critical event based on ReFH1 was used as part of the ratio method to derive the 1:1000 year AEP event. The volume critical event based on ReFH1 was derived through an iterative process using a hydraulic model to ensure the worst-case flood depths and extents were identified. A comparison of both flood depths and inundation extents from short duration event (i.e. 5.25 hour peak event) and the long duration event (i.e. 49 hour volume event) showed that the longer duration storm is critical as is expected for this type of low lying area (see Figure 3.3). Therefore, the longer storm duration 49 hour is taken forward for further hydrological assessment unless stated otherwise. The derivation of both events is described in detail in Sections 4 and 5.

229000
230000
231000
380000
379000
378000
N

Key

Inundation extent for different storm duration

Baseline
1 : 100 year AEP fluvial
Present day

- 5.25 hrs storm
- 49.00 hrs storm
- Model boundary
- 1D Model Domain
- OS Mastermap

Notes:
The inundation area have been derived using maximum depths achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 22/04/2017

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Valley
Hydraulic Modelling

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Figure 3.3
A5025 Valley baseline Inundation comparison fluvial event 1:100 year AEP present day

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4 Derivation of peak flows using FEH statistical method

Flows were derived using the statistical method set out in the FEH method, using WINFAP-FEH 3 software with v3.3.4 peak flow data[7]. The method derives a pooling group of catchments for which there are reliable gauged annual maxima (or peak over threshold) flows and which are hydrologically similar to the subject site. Gauged sites suitable for pooling are included in the HiFlows-UK database now hosted on the National River Flow Archive (NRFA) website (CEH, 2015a). A growth curve is derived from the pooled gauged data and applied to the median of annual maximum flood (QMED) for the subject site.

The median flood is derived theoretically for ungauged sites, i.e. the subject sites, but refined using data from an appropriate donor site, if available. A further urban adjustment is applied to account for the urban extent within the catchment.

4.1 Median annual flood – based on catchment descriptors

A median annual flood estimate (QMED) has been identified using the catchment descriptor equation given in the Environment Agency (EA) Flood Estimation Guidelines (EA, 2015), at page 43:

$$QMED = 8.3062 \times AREA^{0.8510} \times 0.1536^{1000/SAAR} \times FARL^{3.4451} \times 0.0460^{BFIHOST\wedge 2}$$

where, AREA, SAAR, FARL and BFIHOST are the FEH catchment descriptors: area, standard average annual rainfall, flow attenuation index by reservoirs or lakes, and baseflow index described by hydrology of soil type (HOST) classification, respectively (see Appendix B for all FEH catchment descriptors).

The unadjusted median flood estimates based on catchment descriptors are shown in Table 4.3.

4.2 Adjusting the median annual flood – donor catchments

Where flows are derived using the FEH statistical approach with no gauged data at the subject site, an adjustment to the median flood should always be considered with data from a donor site (or sites) where possible and appropriate. The latest method for determining donor sites (in WINFAP-FEH 3), chooses a donor based solely on distance from the subject catchment, and the influence of the donor catchment falls off as the distance between the donor catchment centroid and the subject site catchment centroid increases. Proposed donor sites with centroids further than 10km have only a small influence on the median flood estimate. The EA Flood Estimation Guidelines (EA, 2015) confirms that hydrological similarity should also be considered when choosing a donor catchment.

Donor catchments have been considered based on data from the NRFA website (CEH, 2015b). There are no HiFlows-UK sites on Anglesey which identify QMED values, which means there are no suitable HiFlows-UK donor sites within a reasonable distance of the catchments of interest. A wider search of the NRFA website found other gauges which were considered as potential donor stations and summarised in terms of suitability in Table 4.1. Although no HiFlows-UK data was available for the Cefni at Bodffordd, it was the closest gauge, being the only one of the gauges listed which is on Anglesey. Flow data provided by NRW for the Cefni at Bodffordd was used to determine an annual maximum (AMAX) series for fourteen full water years and thus identify QMED for the gauge. This approach represents a conservative assumption.

[7] WINFAP-FEH peak flow data version 4 and 4.1 were released in May 2016, but as the hydrological assessment had already been undertaken it was not re-calculated with the updated dataset. The hydrological assessment undertaken for the Cefn Coch (which was undertaken in May 2016) was reviewed and determined that peak flows derived using v3.3.4 and were slightly higher compared to those derived using v4.1. It is expected that this would also apply to the Valley catchment.

Table 4.1 Potential donor stations

Station	Centroid Distance (km)	Consideration	Considered as a donor
102001: Cefni at Bodffordd	13	QMED determined from 15-min flow data	Yes
65006: Seiont at Peblig Mill	34	Suitable for QMED according to HiFlows-UK, but has a very low FARL value (0.85) compared to 1.0 for site	No
65004: Gwyrfai at Bontnewydd	34	Suitable for QMED according to HiFlows-UK, but has a very low FARL value (0.862) compared to 1.0 for site	No
65015: Llyfni at Pont Y Cim	34	No QMED value available	No
65005: Erch at Pencaenewydd	37	Suitable for QMED according to HiFlows-UK	Yes
65008: Peris at Nant Peris	38	No QMED value available	No
65014: Colwyn at Hafod Wydr	40	No QMED value available	No
65007: Dwyfor at Garndolbenmaen	41	Suitable for QMED according to HiFlows-UK	Yes
65001: Glaslyn at Beddgelert	42	Suitable for QMED according to HiFlows-UK, but has a low FARL value (0.896) compared to 1.0 for site	No
66012: Lledr at Pont Gethin	50	No QMED value available	No
66011: Conwy at Cwmlanerch	55	Suitable for QMED according to HiFlows-UK, but is substantially larger than the subject site (345km^2) compared to 6km^2 for site	No
67010: Gelyn at Cynefail	64	Suitable for QMED according to HiFlows-UK	Yes

Note: Sites are listed based on approximate direct-line distance from Valley, from closest to furthest away.

Gauge stations 102001, 65005, 65007 and 67010, were identified as potential donor sites, based on relevant catchment characteristics, particularly FARL and BFIHOST, and also AREA and SAAR. These HiFlows-UK sites were identified on HiFlows-UK as suitable for deriving QMED. Adjustment factors were derived using a ratio with the weighting factor applied, as per the EA Flood Estimation Guidelines (EA, 2015):

$$QMEDs, adj = QMEDs, cds \times (QMEDg, obs / QMEDg, cds)^a$$

$$a = 0.4598 \times \exp(-0.02 \times d_{ij}) + (1 - 0.4598) \times \exp(-0.4785 \times d_{ij}).$$

where, QMEDs, adj is the median flood at the subject site, adjusted with the donor sites (m^3/s);

QMEDs, cds is the median flood at the subject site using catchment descriptors (m^3/s);

QMEDg, obs is the gauged median flood at the donor site (m^3/s);

QMEDg, cds is the median flood at the gauged site using catchment descriptors (m^3/s);

and

d_{ij} is the distance between centroids of the subject and donor catchments (km).

As the Valley watercourse catchment was not specifically identified on the FEH CD-ROM, hydrological assessment location 1 was used as a proxy to assess donor sites. The four donor catchments have similar hydrological parameters to hydrological assessment location 1. Catchment details and adjustment factor are presented in Table 4.2.

Table 4.2 Donor sites to refine median annual flood (QMED)

	Valley	Cefni at Bodfforddd	Erch at Pencaenewydd	Dwyfor at Garndolbenmaen	Gelyn at Cynefail
NRFA Ref	-	102001	65005	65007	67010
AREA (km^2)	5.88	21.01	18.1	52.4	13.1
SAAR (mm)	879	1061	1470	2047	2008
FARL	1.00	0.964	0.991	0.968	0.969
BFIHOST	0.387	0.448	0.439	0.404	0.251
URBEXT	3.3%	0.1%	0.1%	0.0%	0.0%
Centroid X	230273	242964	239276	253667	283511
Centroid Y	379631	380648	343239	345655	343520
Distance between centroids (km)	-	10.9-13.3	37.0-38.1	40.2-42.0	62.8-65.1
QMEDcds (m^3/s)	2.81	9.01	14.62	52.26	21.56
QMEDobs (m^3/s)	-	11.85	10.85	40.38	16.36
QMEDobs/ QMEDcds	-	1.315	0.742	0.773	0.759
Record length	-	14	40	38	47
Suitable for QMED (as stated on HiFlows-UK)	-	-	yes	yes	yes
Factors affecting runoff (from NRFA HiFlows-UK site)	-	Weir susceptible to blockage	None	Flows affected by reservoirs and public water supply abstractions	None
Adjustment factor as a % (QMEDs,adj / QMEDcds)	-	110%	94%	95%	97%

Note: Valley data presented for hydrological assessment location 1, however, the data is very similar for the other catchments.

For the Valley proxy catchment, the Cefni at Bodfforddd is significantly closer than the other sites and has similar catchment characteristics - it has therefore been used as a single donor to adjust the subject site median flood for all Valley hydrological assessment locations. Subsequent discussions with NRW has identified that the Cefni at Bodfforddd gauge was not considered suitable for use as a donor, however, as the hydrology assessment and hydraulic modelling had already been completed and the approach represents an uplift of 10% which is conservative, no change was made to the hydrology.

4.3 Adjusting the median annual flood – urbanisation

The median flood values determined using catchment descriptors assume a rural catchment. The flow values were adjusted for urbanisation using the PRUAF method (Kjeldsen, 2010) in line with the EA Flood Estimation Guidelines (EA, 2015). This method is incorporated in WINFAP-FEH 3 (although referred to in

WINFAP-FEH 3 as dating from 2009, the paper was issued in 2010), but for this work, it was calculated separately. The urban adjustment factor (UAF) is given by:

$$UAF = (1+URBEXT_{2000})^{0.37} \times PRUAF^{2.16}$$

$$PRUAF = 1+0.47URBEXT_{2000} \times (BFIHOST/ (1-BFIHOST)).$$

where, PRUAF = percent runoff urban adjustment factor, and URBEXT and BFIHOST are standard FEH catchment descriptors (see Appendix B).

4.4 Summary of median flood estimate and adjustment

The initial estimate of the median flood from catchment descriptors, adjustment factors from donor sites and for urbanisation, and the final adjusted median flood values are given in Table 4.3. The final adjusted median flood values are taken forward for developing the flood frequency values, in the next section.

Table 4.3 Derivation of median annual flood estimate

	Hydrological assessment location						
	1	**2**	**3**	**4**	**5**	**6**	**7**
Initial median flood Q_{MED} (m^3/s) using catchment descriptors	2.81	2.64	2.01	0.37	0.20	1.00	2.36
Adjustment factor from donor sites	1.10	1.10	1.10	1.10	1.10	1.10	1.10
Urban adjustment factor	1.03	1.03	1.00	1.01	1.01	1.00	1.00
Final adjusted median flood Q_{MED} (m^3/s)	3.20	3.01	2.22	0.41	0.22	1.39	2.62

Note: Adjusted median annual flood values have been calculated using urban adjustment factors with four decimal places and therefore the values reported for the adjusted median flood values may be slightly different than those calculated based on the reported values.

4.5 Peak flood flow estimates using FEH statistical method

Pooling groups were derived initially for each catchment using WINFAP-FEH 3.3.4. WINFAP-FEH 3.3.4, dating from August 2014, was the latest version of peak flow data (as at 22/06/2015) available from the CEH website (CEH, 2015a). These peak flow data were used with the WINFAP-FEH 3 software for this analysis. When choosing hydrologically similar catchments for the pooling group, the file path in the software was set to choose files from the subset identified as suitable for pooling.

The WINFAP-FEH 3 software was used to derive a pooling group of hydrologically similar catchments for each subject site. This was then used to derive a growth curve for flood frequency estimation. A review of the initial pooling groups for each site identified that the pooling groups contained almost all of the same stations, with only two stations being replaced by two alternatives for FEH Catchment 4 and 5 and FEH catchment 6. As these minor differences are not likely to significantly influence the growth curve, growth curves were derived for hydrological assessment location 1 and applied to all assessment locations. The pooling group for hydrological assessment location 1 was reviewed and amended where necessary as described below. The final pooling group data is provided in Appendix C. Flow results are given in Table 4.4.

Hydrological assessment location 1 – (Applied to all hydrological assessment locations)

Seventeen gauged stations with records suitable for pooling group construction were selected by the software. These had a combined record length of 527 station-years, greater than the 500 station-years, a minimum recommended for estimating the 1:100 year AEP event flow. One short record site (49006 Camel

at Camelford) was removed from the group as the record was shorter than eight years, leaving a record length of 521 station-years.

Catchment parameter SPRHOST was found to be less than 20%, indicating a permeable catchment, for two sites (27073 Brompton Beck at Snainton Ings and 26802 Gypsey Race at Kirby Grindalythe). The annual maxima were reviewed and two and one water year(s), respectively, were considered to be non-flood years (AMAX< QMED/2). Non-flood AMAX data were removed from these gauges, leaving a record length of 518 years. The flood estimation handbook (FEH) method recommends an adjustment for permeable catchments to account for non-flood years contained in the AMAX data series. A separate sensitivity test that was undertaken to explore the impact has been detailed in section 4.7.

A heterogeneity parameter H2 of 3.762 indicated that the pooling group was heterogeneous and a review of the pooling group was desirable. Review of the sites showed that:

- The pooled sites had rainfall ranging from 616mm/year to 1904mm/year compared to the subject site (879mm/year). These are between 70% and 217% of the subject site rainfall. The higher value is more than twice that of the subject site and this station (25003 Trout Beck at Moor House) could have been considered to have too high rainfall to be included. However, in this case, the similarity rankings of alternative sites needed to make up the required record length would be worse (the pooled sites had a similarity distance of 3.3 or lower and alternative sites would have higher values) and even less like the subject site in general. Therefore it was decided to make no changes to the pooling group based on rainfall;
- FARL at the subject site is 1.00 (no reservoirs or significant lakes) and for the pooled sites values ranged from 0.942 – 1.00, which was considered satisfactory;
- BFIHOST varies considerably across the pooling group (0.196 - 0.959) compared to the subject site (0.387). It was not appropriate to remove all sites with significantly higher or lower values, since replacement catchments would be less similar overall (BFIHOST is no longer used by WINFAP-FEH 3 to identify catchment similarity);
- The URBEXT2000 is low for the subject site (0.0326) and for all the pooled sites (0 - 0.014). Sites for the pooling group should all be rural, with urban adjustment applied separately if required. From EA Flood Estimation Guidelines (EA, 2015), URBEXT2000 ≤0.125 indicates essentially rural; therefore, all pooled sites were rural and it was not necessary to remove sites on this basis;
- Sites 11 (25019 Leven at Easby) and 6 (45816 Haddeo at Upton) had a slightly higher growth curve than the other sites, but none of the catchment descriptors were significantly different to the subject site, and review of station/rating notes does not suggest there are anomalous data. Therefore, it was not considered appropriate to remove these sites;
- None of the sites was identified as discordant (a measure identifying individual stations that are strongly different from the group-average); and
- The Generalised Logistic (GL) distribution gave an acceptable fit to the data, with a Z value of 0.1178 compared to the limit of (absolute value) 1.64 for acceptable fit.

As a result of the pooling group review, no further stations were removed or added to the group. The GL distribution is recommended since it was the only distribution to give an acceptable fit.

Adjusting the growth curve for urbansiaton

It is recommended that the growth curve (which represents a rural catchment) should be adjusted where URBEXT2000 is equal to, or exceeds 0.03 (EA, 2006). Of the Valley catchments only hydrological assessment locations 1 and 2 (which include part of the Valley settlement within the catchment boundary) have URBEXT2000 values greater than 0.03 (hydrological assessment location 1 URBEXT2000 = 0.0326; hydrological assessment location 2 URBEXT2000 = 0.0337) and are classified as ‘slightly urbanised’. Urban adjustment of the growth curve was applied when determining the growth factors.

FEH statistical method peak flow derivation

The growth curve derived for hydrological assessment location 1 was applied to the median flood estimates for each hydrological assessment location to give peak flows, which are shown in Table 4.4. Results for the acceptable pooled growth curve distribution for hydrological assessment location 1 was reviewed, and the preferred distribution identified. The GL distribution was used as the adopted distribution.

Table 4.4 FEH statistical method peak flows (m^3/s)

Annual exceedance probability	Growth Factors (based on HAL 1)	Hydrological Assessment Location						
		1	2	3	4	5	6	7
1:2 year	1	3.2	3.0	2.2	0.41	0.22	1.1	2.6
1:5 year	1.351	4.3	4.1	3.0	0.56	0.29	1.5	3.5
1:10 year	1.606	5.1	4.8	3.6	0.66	0.35	1.8	4.2
1:20 year	1.881	6.0	5.7	4.2	0.77	0.41	2.1	4.9
1:50 year	2.295	7.3	6.9	5.1	0.94	0.50	2.5	6.0
1:100 year	2.658	8.5	8.0	5.9	1.1	0.58	2.9	7.0
1:1000 year [1])	4.288	13.7	12.9	9.5	1.8	0.93	4.7	11.2

Adopted distribution = GL distribution
[1] The FEH statistical method results for the 1:1000 year AEP event are provided for information only and therefore included in grey text. As noted in Section 3.1 and 4.6, the ratio method was applied to derive equivalent 1:1000 year AEP event flows to be used in the hydraulic model.

4.6 Ratio method

NRW's preferred approach for estimating peak flows up to and including a 1:100 year AEP event is the FEH statistical method based on Technical Guidance: Flood Estimation (NRW, 2016). Peak flows for less frequent events should be estimated using the 'ratio' method, where the flood growth curve from ReFH1 is applied to the FEH statistical 1:100 year AEP event. The equivalent 1:1000 year AEP event is determined as below:

$$Equivalent\ 1{:}1000\ year\ AEP\ FEH\ statistical = \frac{1{:}1000\ year\ AEP\ \ ReFH1}{1{:}100\ year\ AEP\ ReFH1} * 1{:}100\ year\ AEP\ FEH\ statistical$$

The ReFH1 ratio (1:1000 year AEP/1:100year AEP) for all hydrological assessment locations are provided in Table 4.5, calculated from ReFH1 peak flow rates provided in Table 5.2. The resulting 1:1000 year AEP peak flows are provided in Table 4.5.

Table 4.5 Revised 1:1000 year AEP event peak flow estimates using ratio method

Annual exceedance probability	Hydrological assessment location						
	1	2	3	4	5	6	7
ReFH1 1:1000 year AEP/1:100 year AEP flow ratio	1.76	1.76	1.76	1.78	1.78	1.77	1.76
Revised 1:1000 year AEP event	15.0m^3/s	14.1m^3/s	10.4m^3/s	1.9m^3/s	1.0m^3/s	5.2m^3/s	12.2m^3/s

Note: Ratio method flow values have been calculated using peak flows and ratios with four decimal places and therefore the values reported for the ratio method 1:1000 year AEP event may be slightly different than those calculated based on the reported values.

4.7 Sensitivity to permeable catchment adjustment

In Section 4.5, the FEH statistical peak flood values were derived from a pooling group with the removal of non-flood data from AMAX series of permeable catchments. The growth curve was derived considering all AMAX data as flood-year values irrespective of the non-flood year proportion. The aim of this test was to look into the effect of permeable catchment adjustment on the flood growth curve as prescribed in Chapter 19 of Flood Estimation Handbook Volume 3. The adjustment is applied to account for the non-flood years that usually appears in the AMAX data series of permeable catchments. This adjustment assumes Generalised Logistic distribution of AMAX data and hence growth factor for 1:2 year AEP flood (QMED) is preserved to be 1 as recommended in FEH methods.

The pooling group for this test was taken same as that was used in section 4.5 (see Table C1, Appendix C). The growth curve derived for HAL 1 from the pooling group was adjusted for permeable catchment in which statistical parameters L-CV and L-SKEW are adjusted for stations having SPRHOST less than 20%. Two such stations (27073 and 26802) were identified for the adjustment. The adjusted flood growth factors and corresponding peak flow values were derived for 1:5 year, 1:10 year, 1:20 year, 1:50 year and 1:100 year AEP events. A comparison with the growth factors and peak flow values are presented in Table 4.6 to understand the sensitivity of the adjustment.

Table 4.6 FEH Statistical peak flows (m3/s) for HAL1 catchment

Annual exceedance probability	FEH Statistical Peak flow				Peak flow percentage change (%)
	Flood years only growth factor	Flood years only peak flow (m^3/s)	Permeable-adjusted growth factor	Permeable-adjusted peak flow (m^3/s)	
1:2 year	1.000	3.200	1.000	3.200	0.0
1:5 year	1.351	4.323	1.360	4.352	0.7
1:10 year	1.606	5.139	1.620	5.184	0.9
1:20 year	1.881	6.019	1.900	6.080	1.0
1:50 year	2.295	7.344	2.318	7.418	1.0
1:100 year	2.658	8.506	2.682	8.582	0.9

The results show that the permeable catchment adjustment has an effect of increasing the peak flow. The increment is less than 1% for the range of AEP events considered in this test. This is considered to be negligible and proves that the hydrological estimates to be insensitive to the adjustment. This is because of having very small number of non-flood years relative to the total number of AMAX data in the pooing group. The growth factors and corresponding peak flows reported in section 4.5 are reasonably appropriate.

5 Derivation of peak flows using ReFH

ReFH1 based hydrographs can be derived from either a peak flow event with critical storm duration based on catchment descriptors or from a volume event with a longer critical storm duration. As described in Section 3 both were required for the hydrological assessment at Valley. ReFH1 was used in the ISIS v3.7 software[8] to derive flow hydrographs for the required events. As the catchment areas are relatively small, it is expected that the same event will occur across all the catchments simultaneously.

Storm duration determination for peak flow event was based on catchment descriptors taken from HAL 1, whereas it was based on water levels at bypass location for peak volume event.

5.1 ReFH method - peak flow event

The critical storm duration for a peak flow event, which is based on catchment descriptors, was chosen for all hydrological assessment locations to be the same duration as hydrological assessment location 1 (see Figure 2.2 for hydrological assessment locations). Although this may slightly underestimate peak flows on the tributaries, if the shorter storm duration were to be applied it would underestimate peak flows on the Cleifiog watercourse to a greater degree. Relevant parameters for hydrological assessment location 1 are shown in Table 5.1.

Table 5.1 Storm duration from catchment descriptors and timestep parameters for hydrological assessment location 1

Parameter	Value
Critical storm duration (hr) from catchment descriptors	5.18
Storm duration for peak flow event (hr)	5.25
Timestep (hr)	0.25

Note: there must be an odd integer number of timesteps in the storm duration to derive the design storm profile

As previously noted, Valley hydrological assessment locations 4 and 5 were too small to be defined by the FEH CD-ROM. The slightly larger, downstream catchment (FEH Catchment 4 and 5) was used, as discussed in Section 2 and flows were factored by catchment areas for these two hydrological assessment locations.

Catchment area (FEH Catchment 4 and 5 to SH 29600 79700) = 0.58km^2;

Valley hydrological assessment location 4 area = 0.57km^2; and

Valley hydrological assessment location 5 area = 0.30km^2.

FEH catchment 6 was factored by catchment area to avoid double-counting area already represented in hydrological assessment location 4 as discussed in Section 2.

Catchment area (FEH catchment 6) = 2.23km^2;

Valley hydrological assessment location 6 area = 1.77km^2.

ReFH1 method peak flows – peak flow event

ReFH1 generated peak flows for all hydrological assessment locations are shown in Table 5.2. Summary ReFH1 reports from the ISIS software are included as Appendix D.

[8] ReFH 1 was the current software at the start of the project, subsequently updated to ReFH 2.2. However, the changes associated with this most recent software update are not expected to change the results significantly.

Table 5.2 ReFH1 method peak flows for peak flow event (m^3/s) for a storm duration of 5.25 hr

Annual exceedance probability	Use	Hydrological assessment location						
		1	2	3	4	5	6	7
1:2 year	Derivation of scaling factor	2.6	2.6	1.9	0.38	0.20	0.93	2.0
1:5 year	Derivation of scaling factor	3.4	3.4	2.5	0.50	0.27	1.2	2.6
1:20 year	Derivation of scaling factor	4.7	4.7	3.4	0.69	0.37	1.7	3.5
1:100 year	Derivation of scaling factor, ratio method	6.6	6.6	4.8	0.98	0.52	2.4	5.0
1:1000 year[1]	Derivation of scaling factor, ratio method	11.5	11.6	8.4	1.7	0.93	4.2	8.8

[1] The ReFH1 1:1000 year AEP event peak flows were used in applying the ratio method to estimate peak flows for the 1:1000 year AEP event, documented in Section 3.

5.2 ReFH method – volume event

To assess the storm duration associated with a critical volume event it was necessary to represent the physical constraint of topography and culverts in a hydraulic model. As storm duration assessment requires numerous model runs, it is not efficient to undertake using a 1D-2D model given the significantly long run times (>24 hours). Therefore, a simplified 1D hydraulic model was constructed to undertake the critical storm duration assessment.

An 'off-line' simplified 1D model was developed to identify the appropriate storm duration quickly and efficiently. Floodplain storage was represented using reservoir units with the key constraints, i.e. the culverts, represented. ReFH1 inflow units for a 1:100 year AEP event were used to enable the representation of various storm durations. A scale factor was applied to adjust the ReFH1 flows to the equivalent FEH statistical value flow, i.e. FEH statistical peak flow/ReFH1 peak flow, as discussed further following the storm duration results. The simplified 1D model was set up to ensure that the peak tide coincided with the peak water level at the study area and results compared to determine the critical volume event.

Peak levels at the bypass location could potentially be influenced by the timing of the peak tide. Initial indicative model runs were undertaken combined with a steady-state peak tide level to narrow down the critical storm duration for a range of events from 5.25 hours to 100.25 hours. This indicated that the critical storm duration was between 30 and 60 hours. An iterative process was undertaken, using key storm durations, to determine the critical storm duration. This resulted in runs for 40, 45, 50 and 55 hour storm durations. Each key storm duration was combined with 21 different mean high water spring (MHWS) tide curves delayed by hourly increments with the diurnal MHWS peak occurring between 35 and 55 hours (i.e. 21 shifts). For each storm duration the peak water level and associated timing of the tidal curve was identified. Peak water levels at the bypass location, for the associated tide timing, were compared and are presented in Table 5.3.

Table 5.3 Storm duration assessment results

Storm Duration (hrs)	Tidal peak (hrs)	Maximum Water Level near the bypass location (mAOD)[1]	Difference from peak (m)
40	40	1.795	0.004
45	42	1.797	0.002
50	47	1.799	-
55	49	1.795	0.004

[1] Maximum water levels from the simplified 1D model have been reported to three decimals to compare relative differences to determine the volume critical duration, however, should not be considered as providing an accurate absolute level.

The assessment indicated that although the 50 hour storm duration gave the highest maximum water level at the bypass location for the storm durations tested, there was very little difference between the 40 and 55 hour storm durations using the simplified 1D model (≤0.004m). Furthermore, the results are not particularly sensitive to the timing of the tide (≤0.011m for the 50 hour storm duration with a tide peaking between 45 and 49 hours). As a one hour time step is being applied at Valley, a 49 hour storm duration was taken forward as this results in the required odd number integer multiple for the storm profile. The worst-case timing of the tide is with a peak at 47 hours as shown in Table 5.3.

Scaling factor

As stated in Section 3.3, the ReFH1 hydrograph shape, based on a storm duration from catchment descriptors, is scaled to the FEH statistical method peak flows. If the volume critical, 49 hour storm duration, hydrographs are fit to the FEH statistical peak, this will introduce extra volume to the event. Instead a ratio of FEH statistical peak flow to ReFH1 peak flow based on catchment descriptors is derived and applied as a scaling factor to the ReFH1 method using the 49 hour storm duration. Scaling factors based on the ratio of FEH statistical to ReFH1 method peak flows are provided in Table 5.4, they are based on peak flows provided in Table 4.4 and Table 5.2.

Table 5.4 Scaling factors to derive equivalent FEH statistical peak with volume event ReFH1 hydrograph

Annual exceedance probability	Hydrological assessment location						
	1	**2**	**3**	**4**	**5**	**6**	**7**
1:2 year	1.24	1.17	1.20	1.10	1.09	1.18	1.34
1:5 year	1.27	1.19	1.22	1.11	1.11	1.21	1.38
1:20 year	1.29	1.20	1.23	1.12	1.11	1.22	1.39
1:100 year	1.30	1.21	1.24	1.11	1.11	1.21	1.40
1:100 year+CC[1]	1.69	1.57	1.61	1.45	1.44	1.57	1.82
1:1000 year	1.30	1.21	1.24	1.11	1.11	1.21	1.40

Note: Scaling factors have been calculated using peak flows with four decimal places and therefore the values reported for the scaling factors may be slightly different than those calculated based on the reported values.
[1] The 1:100 year AEP+CC factors are an uplift from a 1:100 year AEP ReFH1 hydrograph and therefore the scaling factors also include the 30% uplift representing climate change as per current guidance (Welsh Government and NRW, 2016).

ReFH1 method peak flows – volume event

Using the scaling factors, to uplift the ReFH1 peak flows to the FEH statistical method peak flow, with a ReFH1 volume event hydrograph (storm duration of 49 hours), the FEH statistical method equivalent peak flows were derived and are presented in Table 5.5 and the hydrographs shown on Figure 5.1. A comparison of the peak event and volume event hydrographs are shown on Figure 5.2 for the 1:100 year AEP event. This shows that although the hydrograph peak flow is reduced for the longer duration volume event, the corresponding volume of water is increased.

Table 5.5 FEH statistical method equivalent peak flows for volume event (m^3/s)

Annual exceedance probability	Hydrological assessment location						
	1	2	3	4	5	6	7
1:2 year	2.5	2.2	1.6	0.23	0.12	0.75	2.1
1:5 year	3.2	2.8	2.1	0.29	0.16	0.95	2.7
1:20 year	4.1	3.7	2.7	0.38	0.20	1.2	3.4
1:100 year	5.3	4.8	3.5	0.49	0.26	1.6	4.5
1:100 year +CC	7.0	6.2	4.5	0.63	0.33	2.1	5.8
1:1000 year	8.3	7.3	5.4	0.75	0.40	2.5	6.9

Peak flows based on equivalent FEH statistical peak flow for a storm duration of 49 hours

Figure 5.1 Final FEH statistical method equivalent peak flow hydrographs

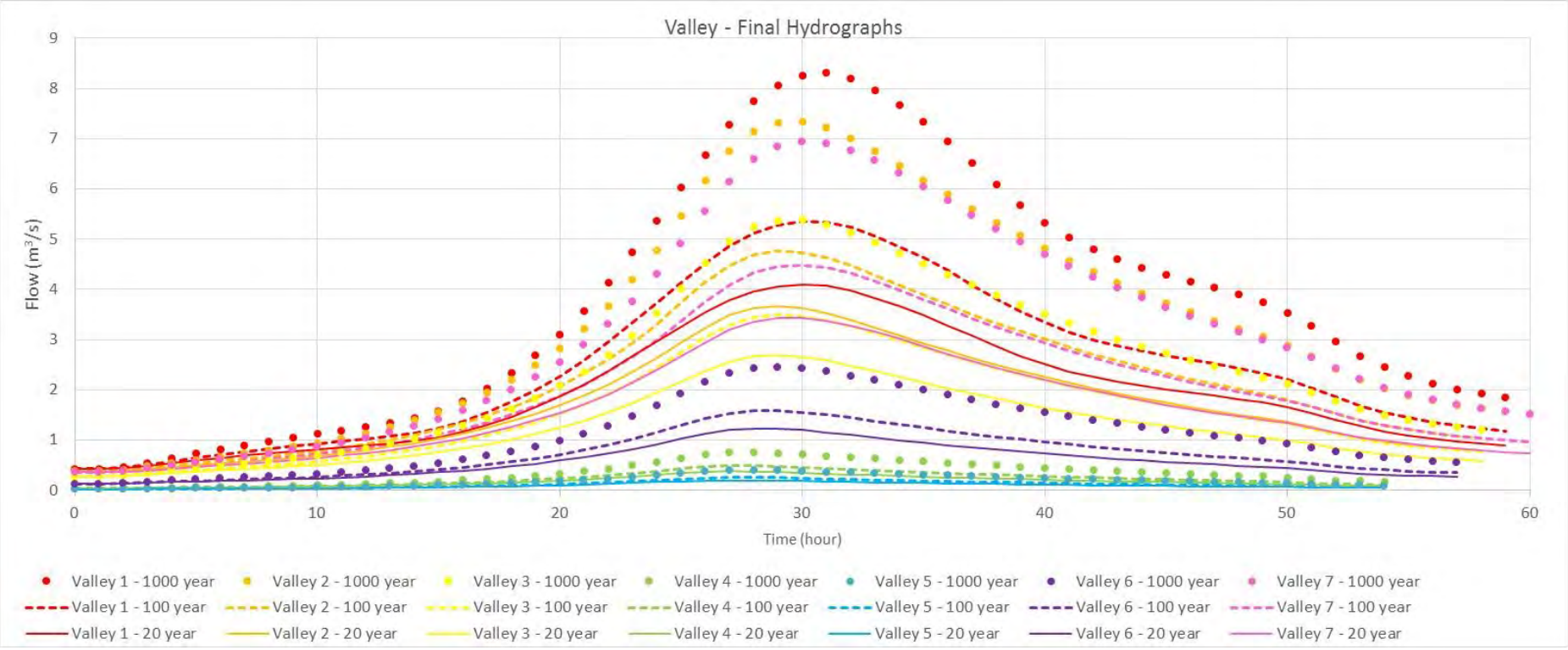

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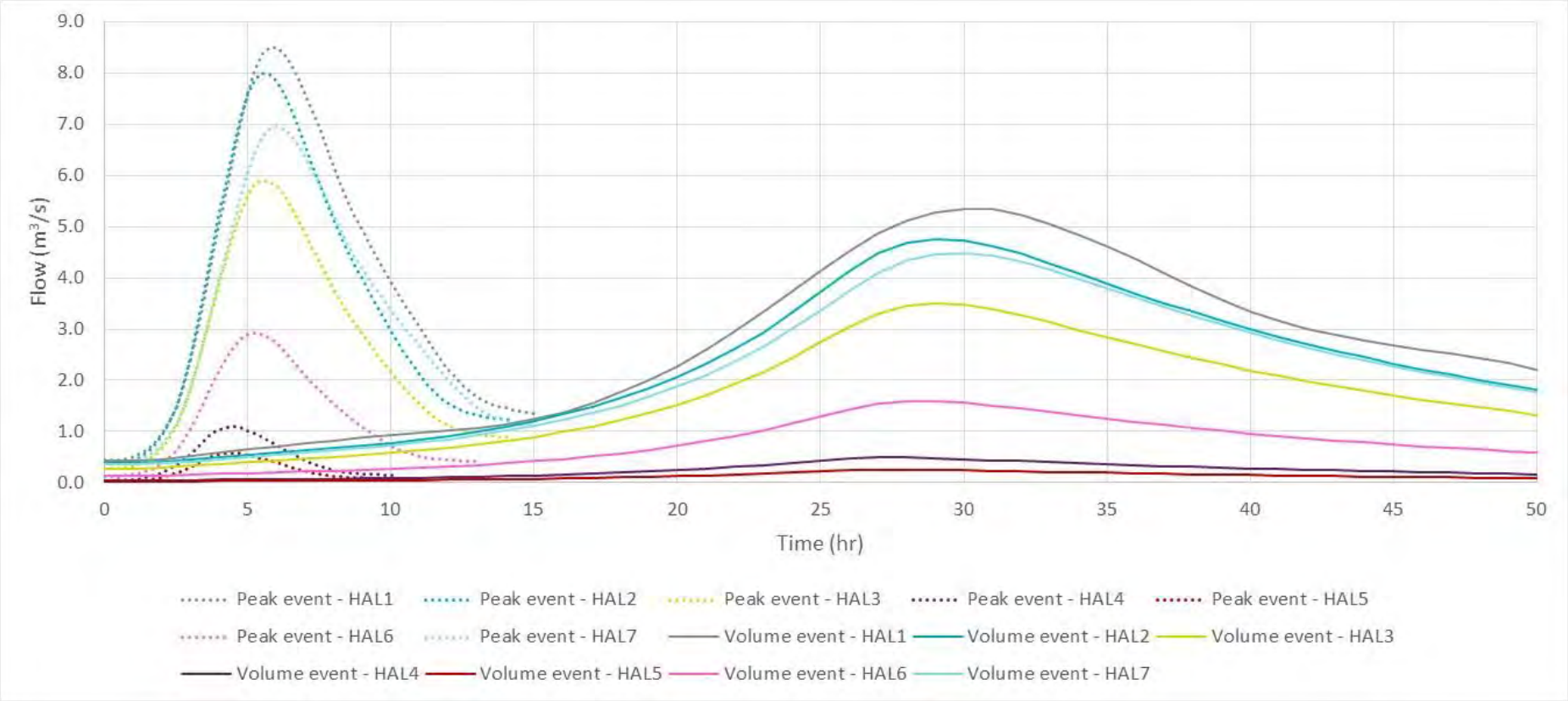
Figure 5.2 Comparison of peak event vs volume event hydrographs for 1:100 year AEP event



6 Summary of method and derived peak flows

6.1 Derivation of modelled flows

Following advice from Technical Guidance: Flood Estimation (NRW, 2016) the following approach was adopted here:

- Peak flow results from the FEH statistical method have been used for more frequent events – up to and including the 1:100 year AEP event;
- The ratio of the 1:1000 year AEP to 1:100 year AEP flows are determined from the ReFH results. The ratio was then applied to the 1:100 year AEP event FEH statistical method peak flow value to determine an equivalent 1:1000 year AEP flow; and
- The hydrographs from the ReFH method have been scaled using a set of factors that result in different peak flows to those obtained using FEH statistical method.

In this case the most appropriate approach to derive the ReFH1 hydrographs was considered to be the volume critical, long storm duration approach. This was based on the derived FEH statistical based peaks through a ratio based scaling factor to ensure that additional volume was not introduced to the hydrological estimates.

6.2 Final peak flows and hydrographs

Final peak flows to be modelled are given in Table 6.1 and the hydrographs with peak flow are shown on Figure 5.1. These are based on scaling the FEH statistical peak flows to a ReFH1 volume event (49 hour storm duration). Climate change allowance is applied by using a 30% uplift on the 1:100 year AEP event as per current guidance (Welsh Government, 2016). Although this has been applied to the peak flow for this report, when representing in the model the entire hydrograph will be scaled to this adjusted peak.

Table 6.1 Peak flows to be represented in the hydraulic model (m^3/s)

Annual exceedance probability	Method	Hydrological Assessment Location						
		1	2	3	4	5	6	7
1:2 year	Adjusted catchment descriptors	2.5	2.2	1.6	0.23	0.12	0.75	2.1
1:5 year	FEH statistical	3.2	2.8	2.1	0.29	0.16	0.95	2.7
1:20 year	FEH statistical	4.1	3.7	2.7	0.38	0.20	1.2	3.4
1:100 year	FEH statistical	5.3	4.8	3.5	0.49	0.26	1.6	4.5
1:100 year +CC[1]	FEH statistical + 30%	7.0	6.2	4.5	0.63	0.33	2.1	5.8
1:1000 year[2]	Ratio	8.3	7.3	5.4	0.75	0.40	2.5	6.9

[1] 1:100 year AEP event accommodating climate change has been determined by using a 30% uplift as per current guidance (Welsh Government and NRW, 2016)
[2] 1:1000 year AEP event has been determined from the ratio method rather than directly from the FEH statistical method.

6.3 Uncertainty

This hydrological assessment has presented an appropriate consideration of hydrology for the catchments influencing the study area. However, it is recognised that there are still limitations in the methods applied. Assumptions made include the following:

- The 1:1000 year AEP growth factors are best estimated from rainfall-runoff methods and a ratio applied to statistical method estimates from the 1:100 year AEP event; and
- The FEH Catchment 4 and 5 produces a hydrograph that is proportionate to area and that it is appropriate to area-weight the hydrograph.

Limitations:

- Historic flood events were not identified, as data were not available; and
- The FEH Catchment 4 and 5 is at the limit of catchment area for the FEH statistical assessment.

The assessment of QMED from catchment descriptors is one of the more uncertain aspects of the assessment. Confidence limits have been calculated based on EA Flood Estimation Guidelines (EA, 2015) and presented in Table 6.2. These are based on the volume event QMED values, i.e. scaled from the catchment descriptor based value of QMED. The 95% confidence limit is between half and twice the central estimate.

Derivation of growth factors is also uncertain, being based on a diverse set of catchment descriptors. There is no simple method to derive confidence intervals for pooled growth curves.

Table 6.2 Confidence Limits in QMED

	Hydrological assessment location						
	1	**2**	**3**	**4**	**5**	**6**	**7**
QMED (m^3/s)	2.5	2.2	1.6	0.23	0.12	0.75	2.1
68% confidence limit (lower)	1.7	1.5	1.1	0.2	0.1	0.5	1.5
68% confidence limit (upper)	3.5	3.2	2.3	0.3	0.2	1.1	3.0
95% confidence limit (lower)	1.2	1.1	0.8	0.1	0.1	0.4	1.0
95% confidence limit (upper)	5.0	4.5	3.3	0.5	0.2	1.5	4.2

Confidence intervals for the pooled growth curves is not currently available for the statistical method, however, a qualitative assessment has been undertaken and is presented in Table 6.3.

Table 6.3 Uncertainty in the Pooling Group

Parameter	Comments	Certainty
Length of flood peak record	518 station-years of pooled record to determine 100 year event maximum.	High
Choice of pooling group	Similarity of most gauges (similarity distance) was greater than 3 for all sites in the pooling group except three.	Medium
Choice of distribution	Goodness-of-fit test for hydrological assessment location 1 was 0.12 which indicates a good fit.	High

The uncertainty in both QMED and the growth curve will combine to produce a combined uncertainty.

Again, it is considered that the hydrological assessment has produced the best estimate (central estimate), however, it is acknowledged that there is an uncertainty in many of the components that are used to determine this estimate. It is recommended that the modelling undertake sensitivity runs based on the above confidence limits, however, the specific limits will be separately described as part of the hydraulic modelling study.

7 Representation of flows in the hydraulic model

The final peak flow hydrographs represent the total flow at each hydrological assessment location and, for locations within the same catchment, would over-estimate flows if applied directly in the hydraulic model. Hydrographs and associated peak flows for hydrological assessment locations 4, 5, 6 and 7 can be applied as derived since they represent the headwater catchments of the Glan Morfa watercourse, Valley watercourse, the Cleifiog watercourse and Maes Y Wrach watercourse, respectively.

Lateral inflow hydrographs for the Valley watercourse to be applied within the model were determined through the consideration of hydrographs for hydrological assessment locations 1, 2, 3 and 6. Hydrological assessment location 6 includes the headwater inflow and hydrographs were adjusted to 'remove' the upstream inflow already represented in point inflows.

- **Lateral inflow between hydrological assessment locations 3 and 6** - The inflow hydrograph was derived by subtracting the hydrographs for hydrological assessment location 6 from the hydrograph for hydrological assessment location 3. Hydrological assessment location 6 represents the headwater catchment for the Valley watercourse. Hydrological assessment location 7 does not need to be removed as on FEH the catchment drains south away from the Cleifiog and therefore did not contribute to the hydrology developed for locations on the Cleifiog;
- **Lateral inflow between hydrological assessment locations 2 and 3** - The inflow hydrograph was derived by subtracting the hydrographs for hydrological assessment locations 3, 4 and 5 from the hydrographs for hydrological assessment location 2; and
- **Lateral inflow between hydrological assessment locations 1 and 2** - The inflow hydrograph was derived by subtracting the hydrograph for hydrological assessment location 2 from the hydrographs for hydrological assessment point 1. This calculation resulted in a small negative flow on the rising limb which was over-written with baseflow.

Hydrographs should be applied as point inflows at the upstream model extents for hydrological assessment locations 4, 5, 6 and 7. The derived lateral inflow hydrographs between hydrological assessment locations 6 and 3, 3 and 2, and 2 and 1 can also be applied as point inflows at appropriate junctions near to each associated hydrological assessment location. This was considered to be an acceptable approach in a system that is largely low-gradient with only 2km between hydrological assessment locations 3 and 1, and where catchment lag is expected to be negligible particularly for the long storm duration associated with a volume event. Simplifying the representation of inflow hydrographs to point inflows, rather than applying flows laterally along the appropriate reach, is not expected to have a significant influence on the results.

8 References

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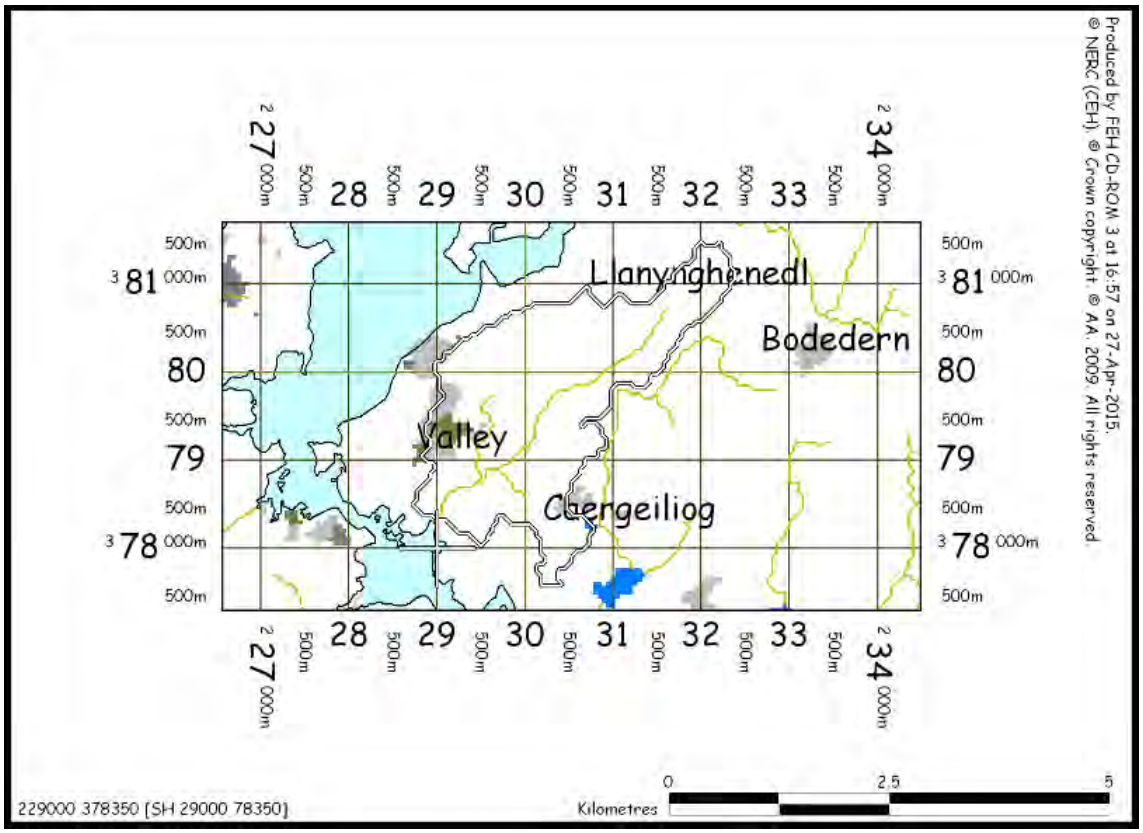
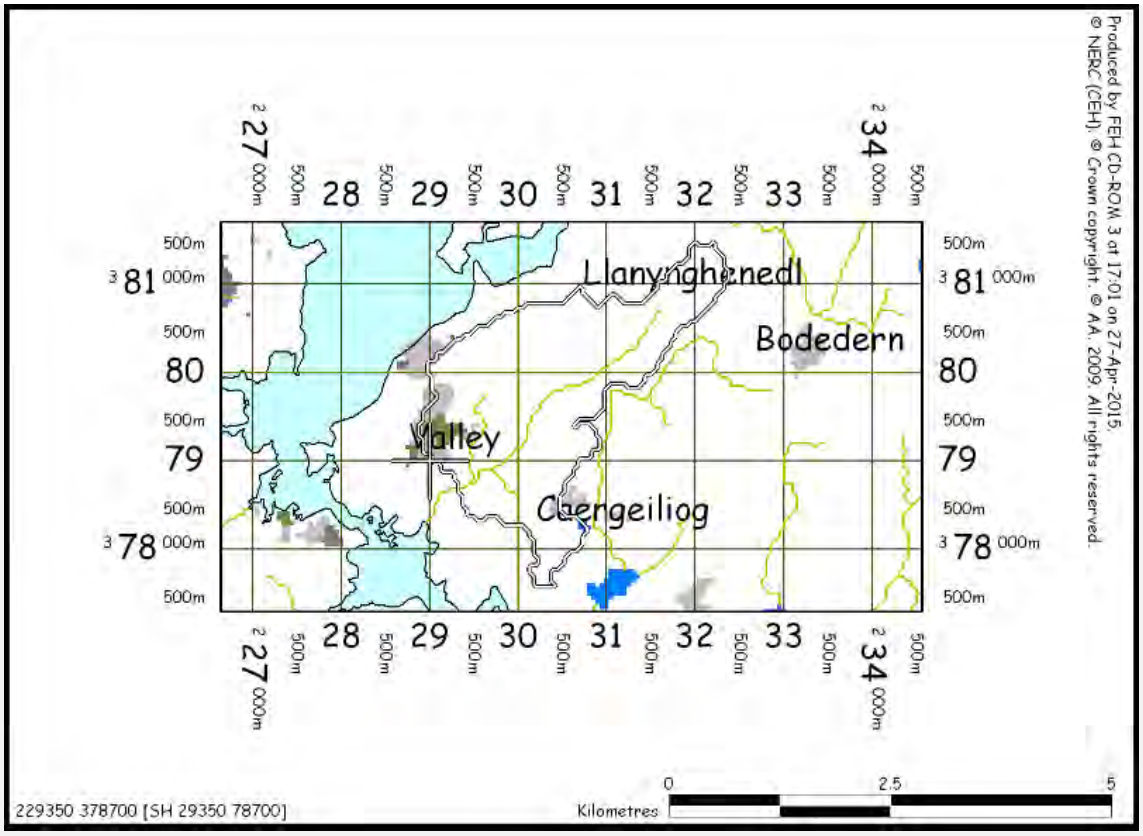
Appendix A
FEH catchments

Hydrological Assessment Location 1

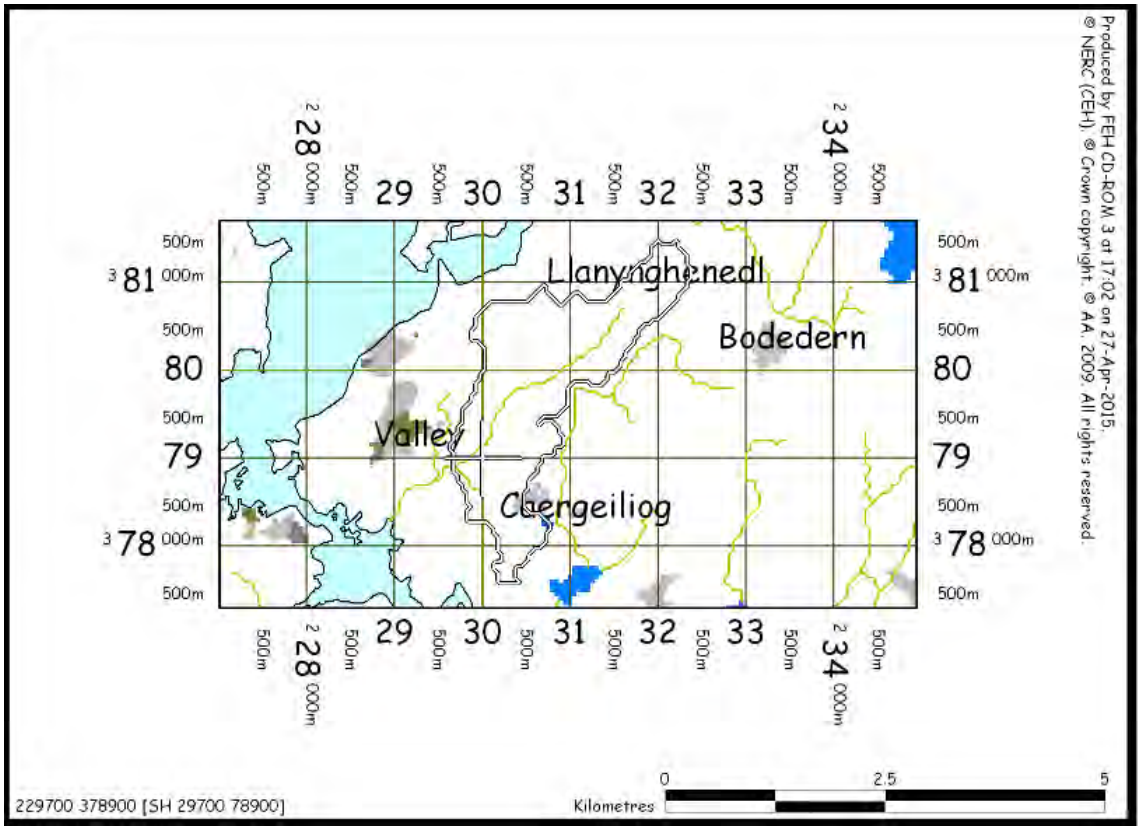


Hydrological Assessment Location 2

© Amec Foster Wheeler Ltd

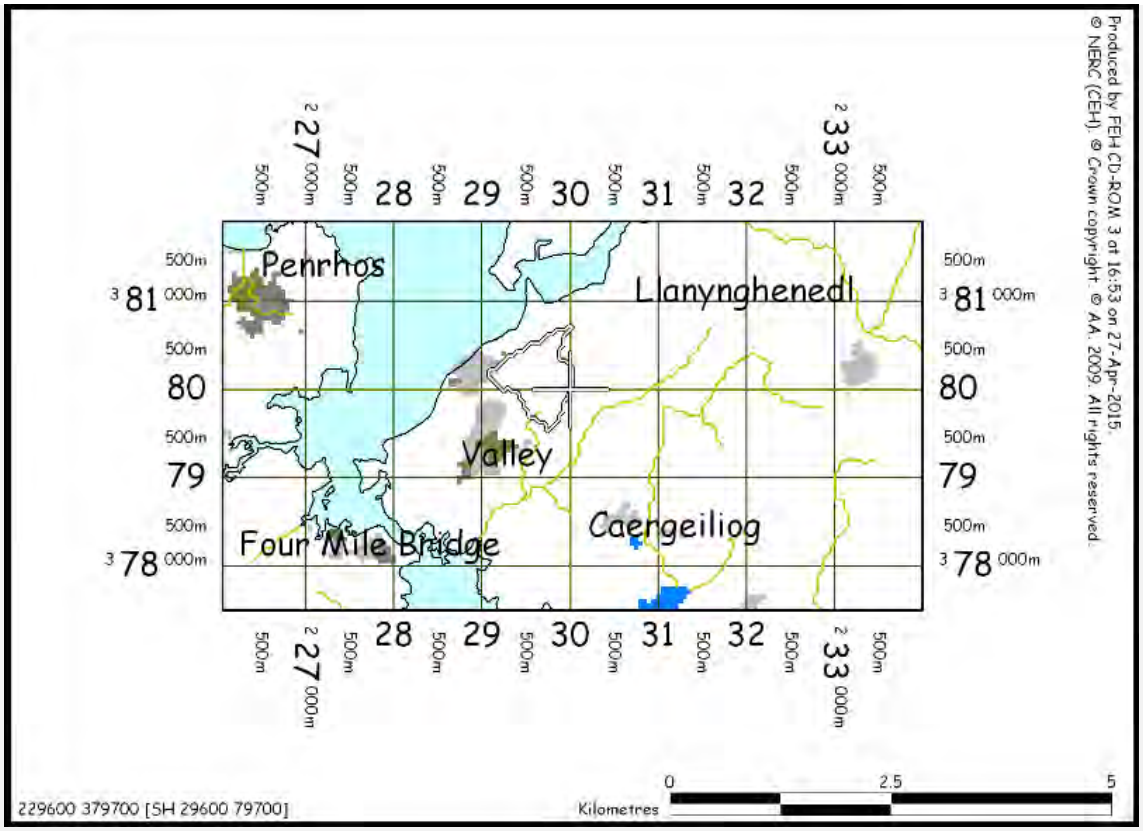


Hydrological Assessment Location 3



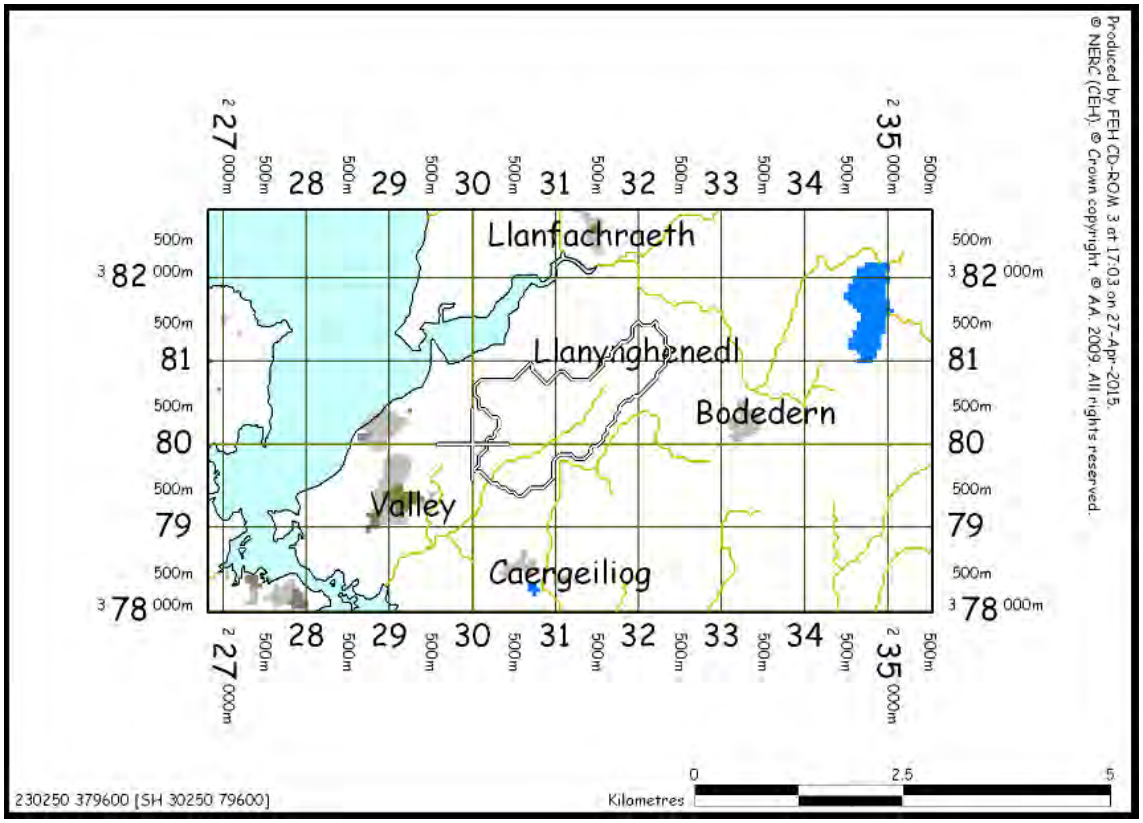
FEH Catchment 4 and 5

© Amec Foster Wheeler Ltd

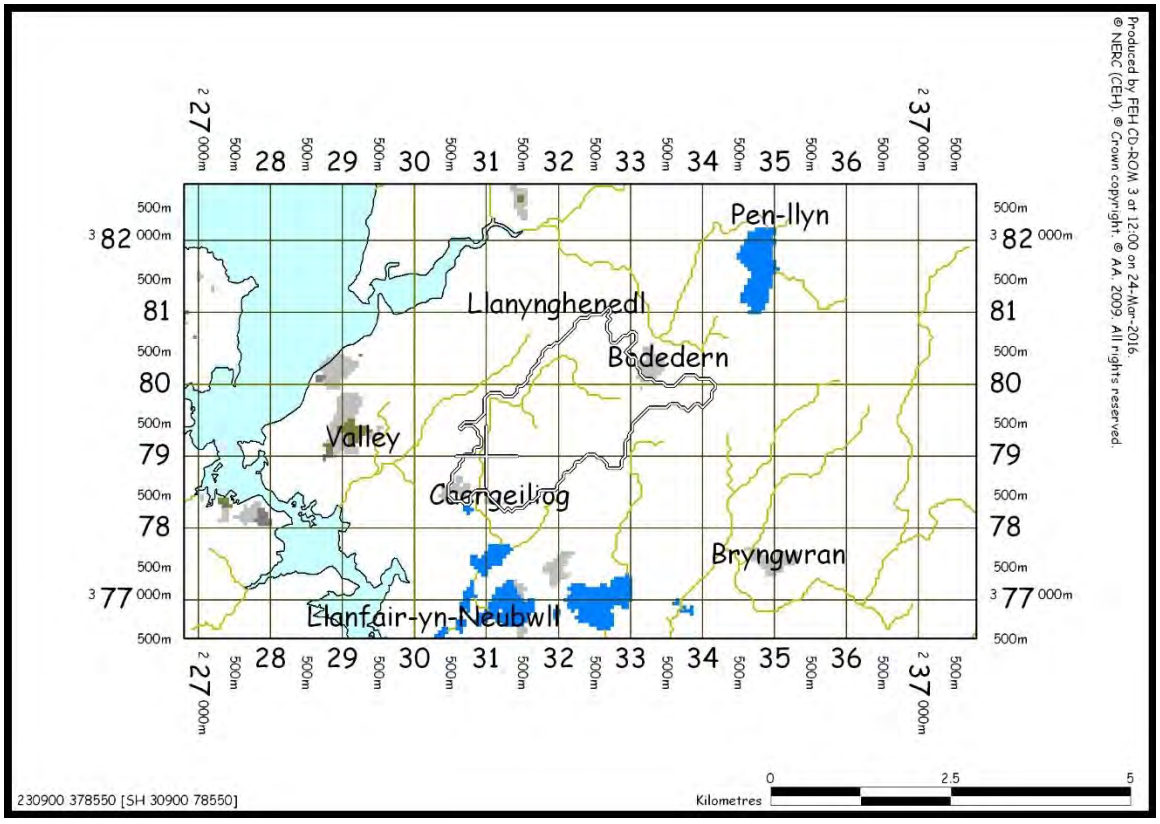


FEH Catchment 6

© Amec Foster Wheeler Ltd



Hydrological Assessment Location 7



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Appendix B
FEH Catchment Descriptors

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Appendix C
Final Pooling Groups

Table C.1 Final Pooling Group – Hydrological Assessment Location 1

Station	Years	Discord	AREA	SAAR	FARL	URBEXT	BFIHOST	SPRHOST
27073 (Brompton Beck @ Snainton Ings)	32	0.347	8.06	721	1	0.008	0.887	17.77
20002 (West Peffer Burn @ Luffness)	41	1.934	26.31	616	0.996	0.002	0.471	32.18
76011 (Coal Burn @ Coalburn)	35	1.686	1.63	1096	1	0	0.196	58.93
203046 (Rathmore Burn @ Rathmore Bridge)	30	0.977	22.51	1043	1	0	0.43	36.88
27051 (Crimple @ Burn Bridge)	40	0.324	8.15	855	1	0.006	0.309	40.77
45816 (Haddeo @ Upton)	19	0.986	6.81	1210	1	0.005	0.59	31.27
26802 (Gypsey Race @ Kirby Grindalythe)	13	0.421	15.85	757	1	0	0.959	5.67
28033 (Dove @ Hollinsclough)	33	0.617	7.93	1346	1	0	0.403	42.49
25003 (Trout Beck @ Moor House)	39	0.873	11.46	1904	1	0	0.227	59.85
72014 (Conder @ Galgate)	45	0.274	28.99	1183	0.975	0.006	0.443	35.96
25019 (Leven @ Easby)	34	1.352	15.07	830	1	0.004	0.525	38.58
47022 (Tory Brook @ Newnham Park)	19	0.561	13.45	1403	0.942	0.014	0.431	44.18
49003 (de Lank @ de Lank)	46	0.384	21.61	1628	0.998	0	0.379	47.75
73015 (Keer @ High Keer Weir)	21	0.473	30.06	1158	0.976	0.003	0.486	35.79
25011 (Langdon Beck @ Langdon)	26	1.588	12.79	1463	1	0.001	0.237	58.21
206006 (Annalong @ Recorder)	48	1.641	13.66	1720	0.98	0	0.336	51.75

Discord=Discordancy

Two gauges were identified as being permeable (SPRHOST<20%). These were investigated to identify influence of non-flood years in the dataset, i.e. annual maximums less than QMED/2, which were then removed from the dataset:

27073 (Brompton Beck @ Snainton Ings) two non-flood years (chance of flood year 0.94);

26802 (Gypsey Race @ Kirby Grindalythe) one non-flood year (chance of flood year 0.92).

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Appendix D
ISIS Summary Reports of ReFH Hydrograph Generation

Valley1
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.027; Season set to WINTER

***** end of data read warnings *****

FILE=2D39.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley1
****
Catchment Characteristics
****
Easting : 229000 Northing : 378350
Area : 5.880 km2
DPLBAR : 2.550 km
DPSBAR : 16.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.027)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 2.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 5.176 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.961
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.741
DDF storm depth : 20.828 mm
Design storm depth : 14.828 mm
Peak rainfall [design] : 1.765 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 1.000
Maximum runoff : 50.6%
Minimum runoff : 45.6%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.755 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.593
Unit hydrograph kink abscissa : 5.510 hours
Unit hydrograph time base : 9.907 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 27.964
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.334
Maximum Baseflow : 0.570 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 2.147 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 2.578 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley1
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.027; Season set to WINTER

***** end of data read warnings *****

FILE=78A9.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley1
****
Catchment Characteristics
****
Easting : 229000 Northing : 378350
Area : 5.880 km2
DPLBAR : 2.550 km
DPSBAR : 16.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.027)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 5.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 5.176 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.961
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.741
DDF storm depth : 27.710 mm
Design storm depth : 19.728 mm
Peak rainfall [design] : 2.349 mm
==========
Loss model

```
==========================================
Cmax flag                  : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                 :  293.299
Cini flag                  : ReFH Design Standard
Cini value                 :  133.612
alpha_T flag               : ReFH Design Standard
alpha_T value              :    1.000
Maximum runoff             :     52.2%
Minimum runoff             :     45.6%
==========================================
Routing model
==========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    2.755 hours
Up flag                    : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                    : ReFH Design Standard
Uk value used              :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    0.593
Unit hydrograph kink abscissa :    5.510 hours
Unit hydrograph time base    :    9.907 hours
==========================================
Baseflow model
==========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                   :   27.964
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                   :    1.009
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                  :    0.334
Maximum Baseflow           :    0.691 m3/s
==========================================
Output summary
==========================================
Direct runoff hydrograph peak :    2.906 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :    3.393 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Valley1
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.027; Season set to WINTER

***** end of data read warnings *****

FILE=B9A2.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley1
****
Catchment Characteristics
****
Easting : 229000 Northing : 378350
Area : 5.880 km2
DPLBAR : 2.550 km
DPSBAR : 16.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.027)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 20.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 5.176 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.961
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.741
DDF storm depth : 40.130 mm
Design storm depth : 28.570 mm
Peak rainfall [design] : 3.401 mm
==========
Loss model

```
==========================================
Cmax flag                 : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                :  293.299
Cini flag                 : ReFH Design Standard
Cini value                :  133.612
alpha_T flag              : ReFH Design Standard
alpha_T value             :    0.940
Maximum runoff            :     52.5%
Minimum runoff            :     42.9%
==========================================
Routing model
==========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    2.755 hours
Up flag                   : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                   : ReFH Design Standard
Uk value used             :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    0.593
Unit hydrograph kink abscissa :    5.510 hours
Unit hydrograph time base    :    9.907 hours
==========================================
Baseflow model
==========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                  :   27.964
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                  :    1.009
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                 :    0.334
Maximum Baseflow          :    0.881 m3/s
==========================================
Output summary
==========================================
Direct runoff hydrograph peak :    4.104 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :    4.677 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Valley1
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.027; Season set to WINTER

***** end of data read warnings *****

FILE=F7AA.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley1
****
Catchment Characteristics
****
Easting : 229000 Northing : 378350
Area : 5.880 km2
DPLBAR : 2.550 km
DPSBAR : 16.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.027)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 100.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 5.176 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.961
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.741
DDF storm depth : 60.503 mm
Design storm depth : 43.075 mm
Peak rainfall [design] : 5.128 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 0.830
Maximum runoff : 52.4%
Minimum runoff : 37.9%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.755 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.593
Unit hydrograph kink abscissa : 5.510 hours
Unit hydrograph time base : 9.907 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 27.964
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.334
Maximum Baseflow : 1.161 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 5.862 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 6.558 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley1
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.027; Season set to WINTER
return period = 1000.0; ReFH not calibrated for events greater than 150 yr.

***** end of data read warnings *****

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****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley1
****
Catchment Characteristics
****
Easting : 229000 Northing : 378350
Area : 5.880 km2
DPLBAR : 2.550 km
DPSBAR : 16.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.027)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 1000.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 5.180 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.961
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.741
DDF storm depth : 108.184 mm
Design storm depth : 77.020 mm
Peak rainfall [design] : 9.680 mm
==========

Loss model
==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 0.700
Maximum runoff : 58.0%
Minimum runoff : 32.0%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.757 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.593
Unit hydrograph kink abscissa : 5.513 hours
Unit hydrograph time base : 9.913 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 27.980
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.334
Maximum Baseflow : 1.894 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 10.496 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 11.546 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley2
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.027; Season set to WINTER

***** end of data read warnings *****

FILE=856C.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley2
****
Catchment Characteristics
****
Easting : 229350 Northing : 378700
Area : 5.460 km2
DPLBAR : 2.120 km
DPSBAR : 16.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.027)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 2.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 4.633 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.962
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.741
DDF storm depth : 20.842 mm
Design storm depth : 14.853 mm
Peak rainfall [design] : 1.867 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 1.000
Maximum runoff : 50.6%
Minimum runoff : 45.6%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.466 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.615
Unit hydrograph kink abscissa : 4.932 hours
Unit hydrograph time base : 8.867 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 26.900
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.311
Maximum Baseflow : 0.549 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 2.166 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 2.579 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley2
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.027; Season set to WINTER

***** end of data read warnings *****

FILE=CA14.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley2
****
Catchment Characteristics
****
Easting : 229350 Northing : 378700
Area : 5.460 km2
DPLBAR : 2.120 km
DPSBAR : 16.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.027)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 5.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 4.633 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.962
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.741
DDF storm depth : 27.733 mm
Design storm depth : 19.765 mm
Peak rainfall [design] : 2.484 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 1.000
Maximum runoff : 52.3%
Minimum runoff : 45.6%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.466 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.615
Unit hydrograph kink abscissa : 4.932 hours
Unit hydrograph time base : 8.867 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 26.900
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.311
Maximum Baseflow : 0.666 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 2.933 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 3.402 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley2
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.027; Season set to WINTER

***** end of data read warnings *****

FILE=57C6.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley2
****
Catchment Characteristics
****
Easting : 229350 Northing : 378700
Area : 5.460 km2
DPLBAR : 2.120 km
DPSBAR : 16.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.027)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 20.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 4.633 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.962
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.741
DDF storm depth : 40.173 mm
Design storm depth : 28.630 mm
Peak rainfall [design] : 3.598 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 0.940
Maximum runoff : 52.5%
Minimum runoff : 42.9%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.466 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.615
Unit hydrograph kink abscissa : 4.932 hours
Unit hydrograph time base : 8.867 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 26.900
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.311
Maximum Baseflow : 0.853 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 4.145 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 4.700 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley2
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.027; Season set to WINTER

***** end of data read warnings *****

FILE=D78F.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley2
****
Catchment Characteristics
****
Easting : 229350 Northing : 378700
Area : 5.460 km2
DPLBAR : 2.120 km
DPSBAR : 16.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.027)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 100.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 4.633 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.962
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.741
DDF storm depth : 60.583 mm
Design storm depth : 43.175 mm
Peak rainfall [design] : 5.427 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 0.830
Maximum runoff : 52.5%
Minimum runoff : 37.9%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.466 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.615
Unit hydrograph kink abscissa : 4.932 hours
Unit hydrograph time base : 8.867 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 26.900
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.311
Maximum Baseflow : 1.126 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 5.926 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 6.603 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley2
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.027; Season set to WINTER
return period = 1000.0; ReFH not calibrated for events greater than 150 yr.

***** end of data read warnings *****

FILE=F705.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley2
****
Catchment Characteristics
****
Easting : 229350 Northing : 378700
Area : 5.460 km2
DPLBAR : 2.120 km
DPSBAR : 16.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.027)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 1000.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 4.627 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.962
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.741
DDF storm depth : 108.363 mm
Design storm depth : 77.227 mm
Peak rainfall [design] : 9.706 mm
==========

Loss model
==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 0.700
Maximum runoff : 58.1%
Minimum runoff : 32.0%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.463 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.616
Unit hydrograph kink abscissa : 4.925 hours
Unit hydrograph time base : 8.856 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 26.869
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.311
Maximum Baseflow : 1.846 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 10.607 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 11.613 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley3
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.001; Season set to WINTER

***** end of data read warnings *****

FILE=EAC4.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley3
****
Catchment Characteristics
****
Easting : 229700 Northing : 378900
Area : 3.910 km2
DPLBAR : 1.940 km
DPSBAR : 18.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.001)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 2.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 4.643 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.966
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.742
DDF storm depth : 20.898 mm
Design storm depth : 14.984 mm
Peak rainfall [design] : 1.883 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 1.000
Maximum runoff : 50.6%
Minimum runoff : 45.6%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.464 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.441
Unit hydrograph kink abscissa : 4.929 hours
Unit hydrograph time base : 8.862 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 28.522
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.223
Maximum Baseflow : 0.387 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 1.566 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 1.860 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley3
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.001; Season set to WINTER

***** end of data read warnings *****

FILE=E8DC.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley3
****
Catchment Characteristics
****
Easting : 229700 Northing : 378900
Area : 3.910 km2
DPLBAR : 1.940 km
DPSBAR : 18.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.001)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 5.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 4.643 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.966
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.742
DDF storm depth : 27.816 mm
Design storm depth : 19.944 mm
Peak rainfall [design] : 2.507 mm
==========
Loss model

```
==========================================
Cmax flag                  : Catchment descriptors
Cmax donor correction factor   :     1.000
Cmax value                 :   293.299
Cini flag                  : ReFH Design Standard
Cini value                 :   133.612
alpha_T flag               : ReFH Design Standard
alpha_T value              :     1.000
Maximum runoff             :      52.3%
Minimum runoff             :      45.6%
==========================================
Routing model
==========================================
Time-to-peak (Tp) flag        : Catchment descriptors
Tp donor correction factor     :     1.000
Instantaneous UH time to peak  :     2.464 hours
Up flag                    : ReFH Design Standard
Dimensionless UH peak         :     0.650
Uk flag                    : ReFH Design Standard
Uk value used              :     0.800
Dimensionless UH kink ordinate :     0.270
UH ordinate multiplier        :     0.441
Unit hydrograph kink abscissa  :     4.929 hours
Unit hydrograph time base      :     8.862 hours
==========================================
Baseflow model
==========================================
Baseflow lag (BL) flag        : Catchment descriptors
BL donor correction factor     :     1.000
BL value                   :    28.522
Baseflow recharge (BR) flag    : Catchment descriptors
BR donor correction factor     :     1.000
BR value                   :     1.009
Initial Baseflow (BF0) flag    : ReFH Design Standard
BF0 value                  :     0.223
Maximum Baseflow           :     0.468 m3/s
==========================================
Output summary
==========================================
Direct runoff hydrograph peak  :     2.122 m3/s
Minimum allowable flow         :     0.000 m3/s
Total flow hydrograph peak     :     2.453 m3/s
Hydrograph scaling factor      :     1.000
Simulation results using       : Full hydrograph

************************************************************
```

Valley3
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.001; Season set to WINTER

***** end of data read warnings *****

FILE=35F6.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley3
****
Catchment Characteristics
****
Easting : 229700 Northing : 378900
Area : 3.910 km2
DPLBAR : 1.940 km
DPSBAR : 18.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.001)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 20.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 4.643 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.966
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.742
DDF storm depth : 40.306 mm
Design storm depth : 28.900 mm
Peak rainfall [design] : 3.632 mm
==========
Loss model

```
==========================================
Cmax flag                 : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                :  293.299
Cini flag                 : ReFH Design Standard
Cini value                :  133.612
alpha_T flag              : ReFH Design Standard
alpha_T value             :    0.940
Maximum runoff            :     52.6%
Minimum runoff            :     42.9%
==========================================
Routing model
==========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    2.464 hours
Up flag                   : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                   : ReFH Design Standard
Uk value used             :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    0.441
Unit hydrograph kink abscissa :    4.929 hours
Unit hydrograph time base    :    8.862 hours
==========================================
Baseflow model
==========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                  :   28.522
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                  :    1.009
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                 :    0.223
Maximum Baseflow          :    0.597 m3/s
==========================================
Output summary
==========================================
Direct runoff hydrograph peak :    3.001 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :    3.391 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Valley3
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.001; Season set to WINTER

***** end of data read warnings *****

FILE=BBF6.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley3
****
Catchment Characteristics
****
Easting : 229700 Northing : 378900
Area : 3.910 km2
DPLBAR : 1.940 km
DPSBAR : 18.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.001)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 100.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 4.643 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.966
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.742
DDF storm depth : 60.805 mm
Design storm depth : 43.598 mm
Peak rainfall [design] : 5.480 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 0.830
Maximum runoff : 52.6%
Minimum runoff : 37.9%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.464 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.441
Unit hydrograph kink abscissa : 4.929 hours
Unit hydrograph time base : 8.862 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 28.522
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.223
Maximum Baseflow : 0.786 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 4.294 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 4.768 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley3
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.001; Season set to WINTER
return period = 1000.0; ReFH not calibrated for events greater than 150 yr.

***** end of data read warnings *****

FILE=C9FF.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley3
****
Catchment Characteristics
****
Easting : 229700 Northing : 378900
Area : 3.910 km2
DPLBAR : 1.940 km
DPSBAR : 18.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.001)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 1000.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 4.638 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.966
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.742
DDF storm depth : 108.818 mm
Design storm depth : 78.024 mm
Peak rainfall [design] : 9.807 mm
==========

Loss model
==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 0.700
Maximum runoff : 58.4%
Minimum runoff : 32.0%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.462 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.441
Unit hydrograph kink abscissa : 4.924 hours
Unit hydrograph time base : 8.854 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 28.496
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.223
Maximum Baseflow : 1.284 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 7.699 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 8.398 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley4
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.006; Season set to WINTER

***** end of data read warnings *****

FILE=663B.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley4
****
Catchment Characteristics
****
Easting : 229600 Northing : 379700
Area : 0.570 km2
DPLBAR : 0.660 km
DPSBAR : 13.400 m/km
PROPWET : 0.450
BFIHOST : 0.385
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.006)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 2.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 2.565 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.982
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.736
DDF storm depth : 20.785 mm
Design storm depth : 15.035 mm
Peak rainfall [design] : 1.890 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 291.859
Cini flag : ReFH Design Standard
Cini value : 133.452
alpha_T flag : ReFH Design Standard
alpha_T value : 1.000
Maximum runoff : 50.9%
Minimum runoff : 45.8%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 1.379 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.115
Unit hydrograph kink abscissa : 2.757 hours
Unit hydrograph time base : 4.957 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 22.350
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.004
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.032
Maximum Baseflow : 0.067 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 0.328 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 0.375 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley4
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.006; Season set to WINTER

***** end of data read warnings *****

FILE=A181.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley4
****
Catchment Characteristics
****
Easting : 229600 Northing : 379700
Area : 0.570 km2
DPLBAR : 0.660 km
DPSBAR : 13.400 m/km
PROPWET : 0.450
BFIHOST : 0.385
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.006)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 5.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 2.565 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.982
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.736
DDF storm depth : 27.672 mm
Design storm depth : 20.017 mm
Peak rainfall [design] : 2.516 mm
==========
Loss model

```
==========================================
Cmax flag                  : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                 :  291.859
Cini flag                  : ReFH Design Standard
Cini value                 :  133.452
alpha_T flag               : ReFH Design Standard
alpha_T value              :    1.000
Maximum runoff             :     52.5%
Minimum runoff             :     45.8%
==========================================
Routing model
==========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    1.379 hours
Up flag                    : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                    : ReFH Design Standard
Uk value used              :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    0.115
Unit hydrograph kink abscissa :    2.757 hours
Unit hydrograph time base    :    4.957 hours
==========================================
Baseflow model
==========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                   :   22.350
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                   :    1.004
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                  :    0.032
Maximum Baseflow           :    0.082 m3/s
==========================================
Output summary
==========================================
Direct runoff hydrograph peak :    0.444 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :    0.498 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Valley4
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.006; Season set to WINTER

***** end of data read warnings *****

FILE=80AE.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley4
****
Catchment Characteristics
****
Easting : 229600 Northing : 379700
Area : 0.570 km2
DPLBAR : 0.660 km
DPSBAR : 13.400 m/km
PROPWET : 0.450
BFIHOST : 0.385
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.006)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 20.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 2.565 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.982
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.736
DDF storm depth : 40.111 mm
Design storm depth : 29.015 mm
Peak rainfall [design] : 3.647 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 291.859
Cini flag : ReFH Design Standard
Cini value : 133.452
alpha_T flag : ReFH Design Standard
alpha_T value : 0.940
Maximum runoff : 52.9%
Minimum runoff : 43.0%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 1.379 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.115
Unit hydrograph kink abscissa : 2.757 hours
Unit hydrograph time base : 4.957 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 22.350
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.004
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.032
Maximum Baseflow : 0.107 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 0.627 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 0.693 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley4
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.006; Season set to WINTER

***** end of data read warnings *****

FILE=7873.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley4
****
Catchment Characteristics
****
Easting : 229600 Northing : 379700
Area : 0.570 km2
DPLBAR : 0.660 km
DPSBAR : 13.400 m/km
PROPWET : 0.450
BFIHOST : 0.385
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.006)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 100.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 2.565 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.982
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.736
DDF storm depth : 60.535 mm
Design storm depth : 43.789 mm
Peak rainfall [design] : 5.504 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 291.859
Cini flag : ReFH Design Standard
Cini value : 133.452
alpha_T flag : ReFH Design Standard
alpha_T value : 0.830
Maximum runoff : 52.9%
Minimum runoff : 38.0%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 1.379 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.115
Unit hydrograph kink abscissa : 2.757 hours
Unit hydrograph time base : 4.957 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 22.350
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.004
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.032
Maximum Baseflow : 0.143 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 0.895 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 0.981 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley4
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.006; Season set to WINTER
return period = 1000.0; ReFH not calibrated for events greater than 150 yr.

***** end of data read warnings *****

FILE=A5ED.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley4
****
Catchment Characteristics
****
Easting : 229600 Northing : 379700
Area : 0.570 km2
DPLBAR : 0.660 km
DPSBAR : 13.400 m/km
PROPWET : 0.450
BFIHOST : 0.385
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.006)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 1000.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 2.562 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.982
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.736
DDF storm depth : 108.395 mm
Design storm depth : 78.410 mm
Peak rainfall [design] : 9.855 mm
==========

Loss model
==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 291.859
Cini flag : ReFH Design Standard
Cini value : 133.452
alpha_T flag : ReFH Design Standard
alpha_T value : 0.700
Maximum runoff : 58.7%
Minimum runoff : 32.1%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 1.377 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.115
Unit hydrograph kink abscissa : 2.753 hours
Unit hydrograph time base : 4.951 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 22.323
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.004
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.032
Maximum Baseflow : 0.239 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 1.609 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 1.744 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley5
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.006; Season set to WINTER

***** end of data read warnings *****

FILE=D7D4.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley5
****
Catchment Characteristics
****
Easting : 229600 Northing : 379700
Area : 0.302 km2
DPLBAR : 0.660 km
DPSBAR : 13.400 m/km
PROPWET : 0.450
BFIHOST : 0.385
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.006)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 2.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 2.565 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.986
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.736
DDF storm depth : 20.785 mm
Design storm depth : 15.088 mm
Peak rainfall [design] : 1.896 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 291.859
Cini flag : ReFH Design Standard
Cini value : 133.452
alpha_T flag : ReFH Design Standard
alpha_T value : 1.000
Maximum runoff : 50.9%
Minimum runoff : 45.8%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 1.379 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.061
Unit hydrograph kink abscissa : 2.757 hours
Unit hydrograph time base : 4.957 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 22.350
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.004
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.017
Maximum Baseflow : 0.036 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 0.174 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 0.199 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley5
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.006; Season set to WINTER

***** end of data read warnings *****

FILE=259F.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley5
****
Catchment Characteristics
****
Easting : 229600 Northing : 379700
Area : 0.302 km2
DPLBAR : 0.660 km
DPSBAR : 13.400 m/km
PROPWET : 0.450
BFIHOST : 0.385
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.006)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 5.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 2.565 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.986
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.736
DDF storm depth : 27.672 mm
Design storm depth : 20.088 mm
Peak rainfall [design] : 2.525 mm
==========
Loss model

```
==========================================
Cmax flag                  : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                 :  291.859
Cini flag                  : ReFH Design Standard
Cini value                 :  133.452
alpha_T flag               : ReFH Design Standard
alpha_T value              :    1.000
Maximum runoff             :     52.6%
Minimum runoff             :     45.8%
==========================================
Routing model
==========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    1.379 hours
Up flag                    : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                    : ReFH Design Standard
Uk value used              :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    0.061
Unit hydrograph kink abscissa :    2.757 hours
Unit hydrograph time base    :    4.957 hours
==========================================
Baseflow model
==========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                   :   22.350
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                   :    1.004
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                  :    0.017
Maximum Baseflow           :    0.044 m3/s
==========================================
Output summary
==========================================
Direct runoff hydrograph peak :    0.236 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :    0.265 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Valley5
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.006; Season set to WINTER

***** end of data read warnings *****

FILE=C493.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley5
****
Catchment Characteristics
****
Easting : 229600 Northing : 379700
Area : 0.302 km2
DPLBAR : 0.660 km
DPSBAR : 13.400 m/km
PROPWET : 0.450
BFIHOST : 0.385
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.006)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 20.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 2.565 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.986
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.736
DDF storm depth : 40.111 mm
Design storm depth : 29.118 mm
Peak rainfall [design] : 3.660 mm
==========
Loss model

```
========================================
Cmax flag                : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value               :  291.859
Cini flag                : ReFH Design Standard
Cini value               :  133.452
alpha_T flag             : ReFH Design Standard
alpha_T value            :    0.940
Maximum runoff           :     52.9%
Minimum runoff           :     43.0%
========================================
Routing model
========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor   :    1.000
Instantaneous UH time to peak :    1.379 hours
Up flag                  : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                  : ReFH Design Standard
Uk value used            :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    0.061
Unit hydrograph kink abscissa :    2.757 hours
Unit hydrograph time base    :    4.957 hours
========================================
Baseflow model
========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor   :    1.000
BL value                 :   22.350
Baseflow recharge (BR) flag  : Catchment descriptors
BR donor correction factor   :    1.000
BR value                 :    1.004
Initial Baseflow (BF0) flag  : ReFH Design Standard
BF0 value                :    0.017
Maximum Baseflow         :    0.057 m3/s
========================================
Output summary
========================================
Direct runoff hydrograph peak :    0.333 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak   :    0.368 m3/s
Hydrograph scaling factor    :    1.000
Simulation results using     : Full hydrograph

************************************************************
```

Valley5
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.006; Season set to WINTER

***** end of data read warnings *****

FILE=C2BE.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley5
****
Catchment Characteristics
****
Easting : 229600 Northing : 379700
Area : 0.302 km2
DPLBAR : 0.660 km
DPSBAR : 13.400 m/km
PROPWET : 0.450
BFIHOST : 0.385
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.006)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 100.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 2.565 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.986
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.736
DDF storm depth : 60.535 mm
Design storm depth : 43.945 mm
Peak rainfall [design] : 5.523 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 291.859
Cini flag : ReFH Design Standard
Cini value : 133.452
alpha_T flag : ReFH Design Standard
alpha_T value : 0.830
Maximum runoff : 52.9%
Minimum runoff : 38.0%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 1.379 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.061
Unit hydrograph kink abscissa : 2.757 hours
Unit hydrograph time base : 4.957 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 22.350
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.004
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.017
Maximum Baseflow : 0.076 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 0.476 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 0.522 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley5
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.006; Season set to WINTER
return period = 1000.0; ReFH not calibrated for events greater than 150 yr.

***** end of data read warnings *****

FILE=AC16.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley5
****
Catchment Characteristics
****
Easting : 229600 Northing : 379700
Area : 0.302 km2
DPLBAR : 0.660 km
DPSBAR : 13.400 m/km
PROPWET : 0.450
BFIHOST : 0.385
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.006)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 1000.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 2.562 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.986
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.736
DDF storm depth : 108.395 mm
Design storm depth : 78.688 mm
Peak rainfall [design] : 9.890 mm
==========

Loss model
==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 291.859
Cini flag : ReFH Design Standard
Cini value : 133.452
alpha_T flag : ReFH Design Standard
alpha_T value : 0.700
Maximum runoff : 58.8%
Minimum runoff : 32.1%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 1.377 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.061
Unit hydrograph kink abscissa : 2.753 hours
Unit hydrograph time base : 4.951 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 22.323
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.004
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.017
Maximum Baseflow : 0.127 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 0.856 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 0.928 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley6
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.000; Season set to WINTER

***** end of data read warnings *****

FILE=5415.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley6
****
Catchment Characteristics
****
Easting : 230250 Northing : 379600
Area : 1.770 km2
DPLBAR : 1.560 km
DPSBAR : 19.800 m/km
PROPWET : 0.450
BFIHOST : 0.388
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.000)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 2.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 3.990 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.974
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.744
DDF storm depth : 20.981 mm
Design storm depth : 15.198 mm
Peak rainfall [design] : 1.910 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 294.019
Cini flag : ReFH Design Standard
Cini value : 133.690
alpha_T flag : ReFH Design Standard
alpha_T value : 1.000
Maximum runoff : 50.6%
Minimum runoff : 45.5%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.112 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.233
Unit hydrograph kink abscissa : 4.225 hours
Unit hydrograph time base : 7.596 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 27.361
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.012
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.102
Maximum Baseflow : 0.184 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 0.797 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 0.933 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley6
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.000; Season set to WINTER

***** end of data read warnings *****

FILE=A902.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley6
****
Catchment Characteristics
****
Easting : 230250 Northing : 379600
Area : 1.770 km2
DPLBAR : 1.560 km
DPSBAR : 19.800 m/km
PROPWET : 0.450
BFIHOST : 0.388
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.000)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 5.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 3.990 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.974
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.744
DDF storm depth : 27.936 mm
Design storm depth : 20.236 mm
Peak rainfall [design] : 2.543 mm
==========
Loss model

```
=========================================
Cmax flag                 : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                :  294.019
Cini flag                 : ReFH Design Standard
Cini value                :  133.690
alpha_T flag              : ReFH Design Standard
alpha_T value             :    1.000
Maximum runoff            :     52.3%
Minimum runoff            :     45.5%
=========================================
Routing model
=========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    2.112 hours
Up flag                   : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                   : ReFH Design Standard
Uk value used             :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    0.233
Unit hydrograph kink abscissa :    4.225 hours
Unit hydrograph time base    :    7.596 hours
=========================================
Baseflow model
=========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                  :   27.361
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                  :    1.012
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                 :    0.102
Maximum Baseflow          :    0.224 m3/s
=========================================
Output summary
=========================================
Direct runoff hydrograph peak :    1.079 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :    1.235 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Valley6
** beginning of data read warnings **

***** end of data read warnings *****

FILE=DF8D.dat ISIS VER= 6.7.0.110

****

ISIS

****

HYDROLOGICAL DATA

Catchment: Valley6

****

Catchment Characteristics

****

Easting : 230250 Northing : 379600
Area : 1.770 km2
DPLBAR : 1.560 km
DPSBAR : 19.800 m/km
PROPWET : 0.450
BFIHOST : 0.388

****

Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH software computational engine, v1.4.0005
ReFH © Wallingford HydroSolutions or CEH (NERC) 2007

****

Estimation of T-year flood

==========

Season : WINTER
(Seasonality determined by URBEXT = 0.000)

==========

Rainfall

==========

Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 20.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 3.990 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.974
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.744
DDF storm depth : 40.499 mm
Design storm depth : 29.336 mm
Peak rainfall [design] : 3.633 mm

==========

Loss model

==========

Cmax flag : Catchment descriptors

Cmax donor correction factor : 1.000
Cmax value : 294.167
Cini flag : ReFH Design Standard
Cini value : 133.758
alpha_T flag : ReFH Design Standard
alpha_T value : 0.936
Maximum runoff : 52.5%
Minimum runoff : 42.6%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.112 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.233
Unit hydrograph kink abscissa : 4.225 hours
Unit hydrograph time base : 7.596 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 27.361
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.012
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.102
Maximum Baseflow : 0.286 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 1.519 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 1.706 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley6
** beginning of data read warnings **

***** end of data read warnings *****

FILE=FBA5.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley6
****
Catchment Characteristics
****
Easting : 230250 Northing : 379600
Area : 1.770 km2
DPLBAR : 1.560 km
DPSBAR : 19.800 m/km
PROPWET : 0.450
BFIHOST : 0.388
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH software computational engine, v1.4.0005
ReFH © Wallingford HydroSolutions or CEH (NERC) 2007
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.000)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 100.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 3.990 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.974
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.744
DDF storm depth : 61.128 mm
Design storm depth : 44.279 mm
Peak rainfall [design] : 5.484 mm
==========
Loss model
==========
Cmax flag : Catchment descriptors

Cmax donor correction factor : 1.000
Cmax value : 294.167
Cini flag : ReFH Design Standard
Cini value : 133.758
alpha_T flag : ReFH Design Standard
alpha_T value : 0.832
Maximum runoff : 52.8%
Minimum runoff : 37.9%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.112 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.233
Unit hydrograph kink abscissa : 4.225 hours
Unit hydrograph time base : 7.596 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 27.361
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.012
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.102
Maximum Baseflow : 0.380 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 2.186 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 2.422 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley6
** beginning of data read warnings **

return period = 1000.0; ReFH not calibrated for events greater than 150 yr.

***** end of data read warnings *****

FILE=C654.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley6
****
Catchment Characteristics
****
Easting : 230250 Northing : 379600
Area : 1.770 km2
DPLBAR : 1.560 km
DPSBAR : 19.800 m/km
PROPWET : 0.450
BFIHOST : 0.388
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH software computational engine, v1.4.0005
ReFH © Wallingford HydroSolutions or CEH (NERC) 2007
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.000)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 1000.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 3.990 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.974
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.744
DDF storm depth : 109.477 mm
Design storm depth : 79.301 mm
Peak rainfall [design] : 9.822 mm
==========
Loss model
==========

Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 294.167
Cini flag : ReFH Design Standard
Cini value : 133.758
alpha_T flag : ReFH Design Standard
alpha_T value : 0.703
Maximum runoff : 58.8%
Minimum runoff : 32.1%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.112 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.233
Unit hydrograph kink abscissa : 4.225 hours
Unit hydrograph time base : 7.596 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 27.361
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.012
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.102
Maximum Baseflow : 0.624 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 3.944 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 4.289 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley7
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.008; Season set to WINTER

***** end of data read warnings *****

FILE=868C.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley7
****
Catchment Characteristics
****
Easting : 230900 Northing : 378550
Area : 4.460 km2
DPLBAR : 2.880 km
DPSBAR : 22.300 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.008)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 2.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 5.480 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.964
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.748
DDF storm depth : 21.063 mm
Design storm depth : 15.193 mm
Peak rainfall [design] : 1.910 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 1.000
Maximum runoff : 50.7%
Minimum runoff : 45.6%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.875 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.431
Unit hydrograph kink abscissa : 5.750 hours
Unit hydrograph time base : 10.339 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 30.355
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.260
Maximum Baseflow : 0.428 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 1.624 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 1.951 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley7
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.008; Season set to WINTER

***** end of data read warnings *****

FILE=3B19.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley7
****
Catchment Characteristics
****
Easting : 230900 Northing : 378550
Area : 4.460 km2
DPLBAR : 2.880 km
DPSBAR : 22.300 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.008)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 5.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 5.480 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.964
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.748
DDF storm depth : 28.035 mm
Design storm depth : 20.222 mm
Peak rainfall [design] : 2.542 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 1.000
Maximum runoff : 52.4%
Minimum runoff : 45.6%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.875 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.431
Unit hydrograph kink abscissa : 5.750 hours
Unit hydrograph time base : 10.339 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 30.355
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.260
Maximum Baseflow : 0.515 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 2.200 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 2.568 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley7
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.008; Season set to WINTER

***** end of data read warnings *****

FILE=35FA.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley7
****
Catchment Characteristics
****
Easting : 230900 Northing : 378550
Area : 4.460 km2
DPLBAR : 2.880 km
DPSBAR : 22.300 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.008)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 20.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 5.480 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.964
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.748
DDF storm depth : 40.626 mm
Design storm depth : 29.304 mm
Peak rainfall [design] : 3.683 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 0.940
Maximum runoff : 52.8%
Minimum runoff : 42.9%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.875 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.431
Unit hydrograph kink abscissa : 5.750 hours
Unit hydrograph time base : 10.339 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 30.355
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.260
Maximum Baseflow : 0.654 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 3.110 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 3.544 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley7
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.008; Season set to WINTER

***** end of data read warnings *****

FILE=2537.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley7
****
Catchment Characteristics
****
Easting : 230900 Northing : 378550
Area : 4.460 km2
DPLBAR : 2.880 km
DPSBAR : 22.300 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.008)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 100.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 5.480 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.964
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.748
DDF storm depth : 61.292 mm
Design storm depth : 44.211 mm
Peak rainfall [design] : 5.557 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 0.830
Maximum runoff : 52.8%
Minimum runoff : 37.9%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.875 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.431
Unit hydrograph kink abscissa : 5.750 hours
Unit hydrograph time base : 10.339 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 30.355
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.260
Maximum Baseflow : 0.858 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 4.448 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 4.982 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Valley7
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.008; Season set to WINTER
return period = 1000.0; ReFH not calibrated for events greater than 150 yr.

***** end of data read warnings *****

FILE=AD39.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Valley7
****
Catchment Characteristics
****
Easting : 230900 Northing : 378550
Area : 4.460 km2
DPLBAR : 2.880 km
DPSBAR : 22.300 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.008)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 1000.000 years
Data interval : 0.250 hours
Design storm duration : 5.250 hours
Critical storm duration : 5.480 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.964
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.748
DDF storm depth : 109.697 mm
Design storm depth : 79.127 mm
Peak rainfall [design] : 9.945 mm
==========

Loss model
==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 0.700
Maximum runoff : 58.7%
Minimum runoff : 32.0%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.875 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.431
Unit hydrograph kink abscissa : 5.750 hours
Unit hydrograph time base : 10.339 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 30.355
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.260
Maximum Baseflow : 1.395 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 7.996 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 8.765 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

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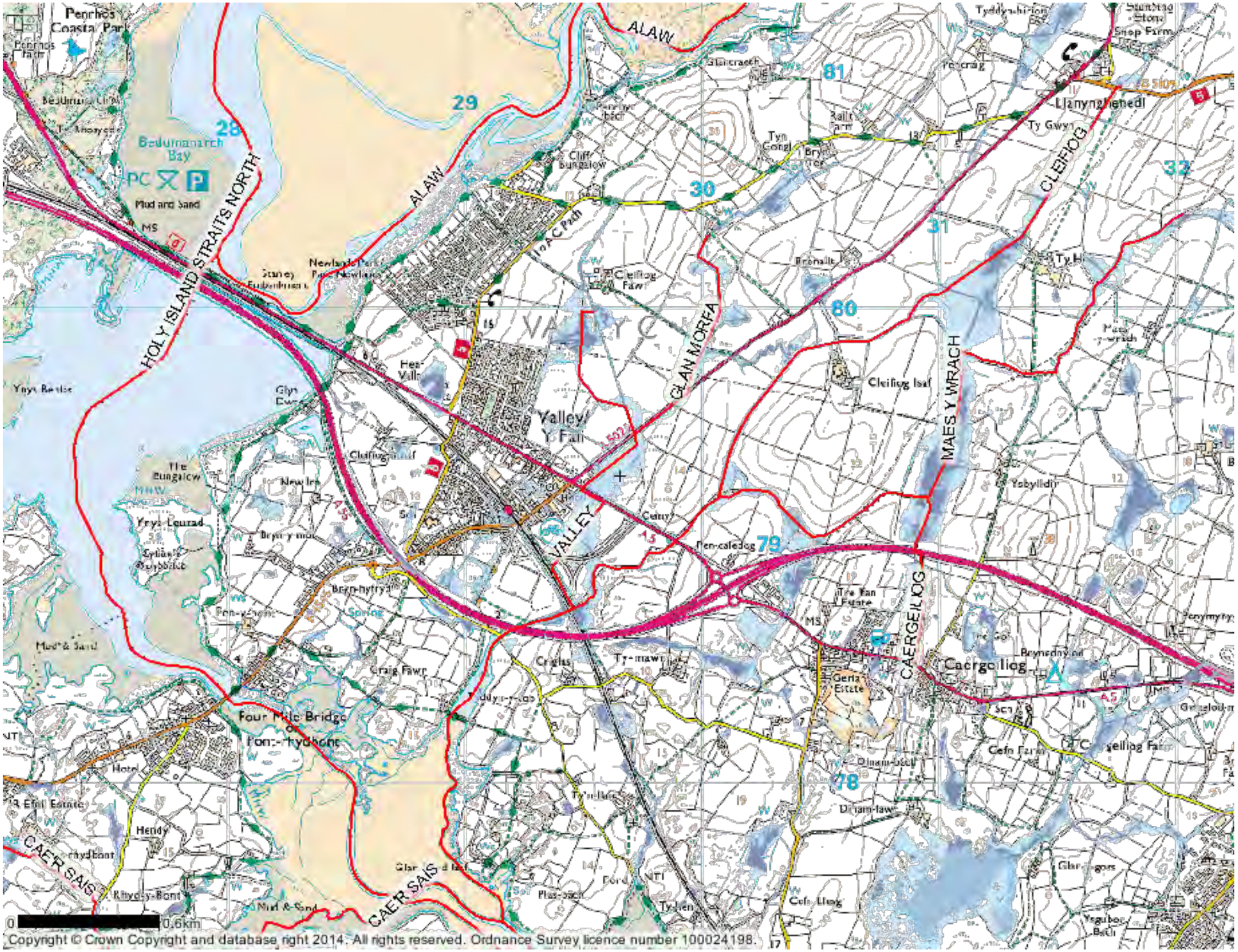
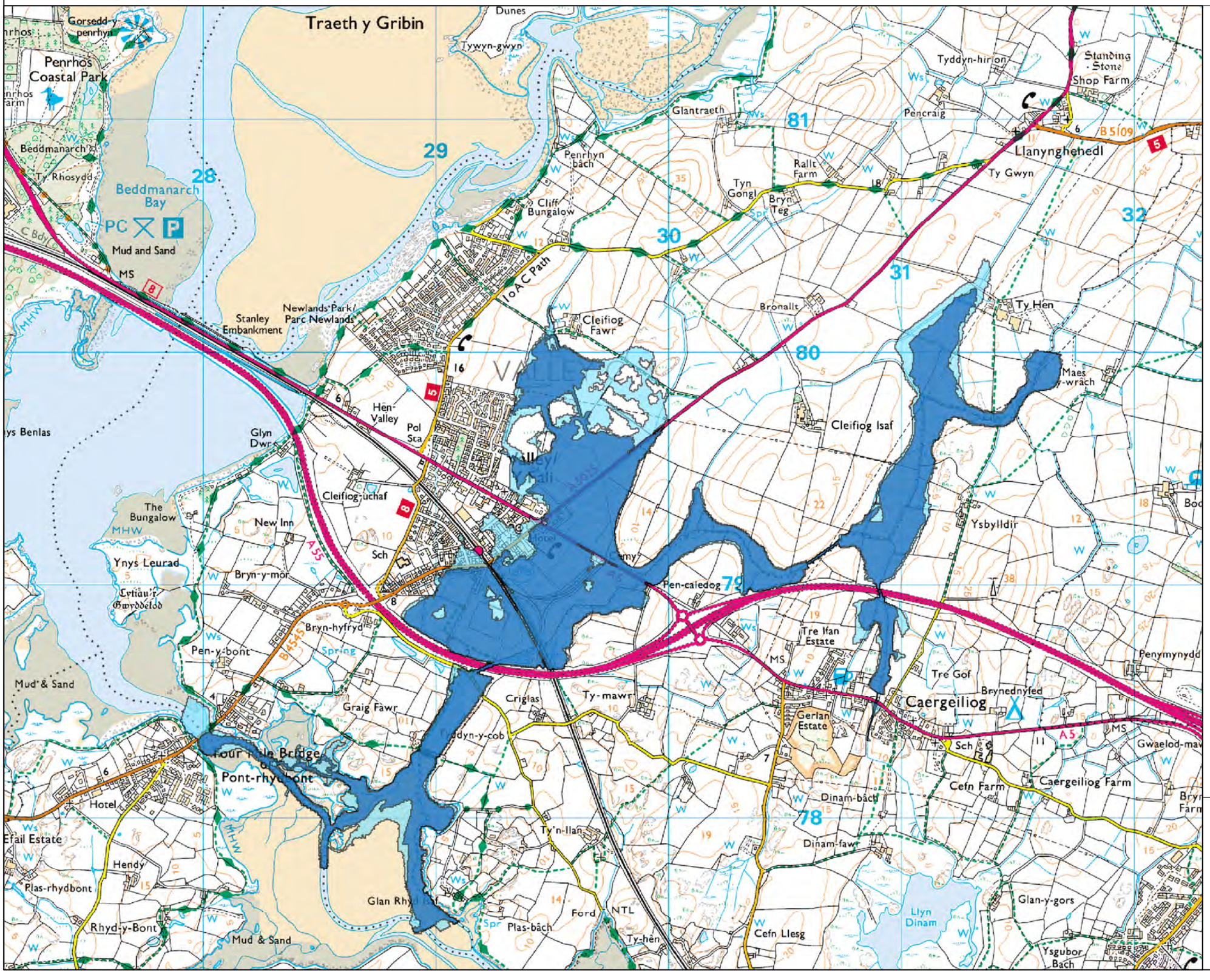
Appendix E
NRW Fluvial Flood Zones

Flood Map for Surface Water: 3.33%, 1% & 0.1% Annual Probability


Penrhos Coastal Park
Penrhos Farm
Beddmanarch Bay
Mud and Sand
HOLY ISLAND STRAITS NORTH
ALAW
Stanley Embankment
Newlands Park
Parc Newlands
Ynys Bardsey
Glyn Cwm
Hen-Valley
Valley
Y Fali
Cleifiog Saf
The Bungalow
MHW
New Inn
Bryn-y-mor
Pen-y-Graig
Spring
Mud & Sand
Craig Fawr
Four Mile Bridge
Pont-trychont
Hotel
Efail Estate
Hendy
Rhydy-Bont
Mud & Sand
CAER SAIS
Glan Morfa
Cleifiog Faw
Cleifiog Isaf
Tyn Cong
Bryn Teg
Cliff Bungalow
Stanleigh
Penrhos
Tyddyn-hirion
Stanleigh Stone
Shop Farm
Llanynghenedl
Ty Gwyn
CLEIFIOG
Rail Farm
Pencraig
Bronallt
Ty Hen
MAES Y WRACH
Ysbyllidir
Pen-caledog
Tre Fan Fawr
Caergeiliog
CAERGEILIOG
Gerlan Estate
Cefn Farm
Dinam-isaf
Dinam-law
Cefn Llwyd
Ty-mawr
Craglas
Ty-isaf
Plas-isaf
Ford
Ty-Isaf
Glan-gors
Penymynydd
Brynedyn
Ty-Isaf
Ty-Uchaf
Ty-Ucha
Ty-Isa
Ty-Isaf
Ty-Isaf
Ty-Isaf

Cyfoeth Naturiol Cymru
Natural Resources Wales

Fluvial Flood Zones at Valley



Legend

cäçç=wçåÉ=P=Ëñá îá-äÉ=åÇåÅ~íÉëíÜÉ=~ëÉ~=íÜ~í=Åçì äÇ=ÄÉ=ÑáçÇÉÇ=ï áÜ=~=NB =EN=åá=NMMF=çê=ÖëÉ~íÉê=ÅÜ~åÅÉ=çÑÜ~éëÉåáÖÉ~ÅÜ=óÉ~ëK

cäçç=wçåÉ=O=Ëñá îá-äÉ=åÇåÅ~íÉëíÜÉ=Éñí Éåí=çÑ~å=Éñíéëã É=ÑáçÇ=Ñáçã =~=êá ÉëK=qÜÉëÉ=~ëÉ~ë=~ëÉ=äáÉäáÉ=íç=ÄÉ=~ÑÑÉÅíÉÇ=Äó=~=ã ~àçê=ÑáçÇí=ï áÜ=i é=íç=~=MKNB =EN=åá=NMMF=ÅÜ~åÅÉ=çÑçÅÅì êëáÖÉ~ÅÜ=óÉ~ëK

cäçç=wçåÉë=Çç=åçí=éêçîáÇÉ=áÑÑçëã ~íáçå=çå=Ñáçç=Çáå=Ñáçã =Öêçì åÇï ~íÉê=çê=çíÜÉê=ëçì êÅÉëK

N

M MKO MKQ MKU háçã ÉíÉëë

oÉéêçÇ ÁÉÇ=Äó=éÉëã äëëçà=çÑ áÇà~âÁÉ=pì ã Éó=çå=ÄÉÜ~áÑçÑej pl K=
«= êçï å= çéóëáÜÜí=âÇÇ~í~Ä~ëÉ=ëáÜÜí=OMNPK=i áÇà~àÁÉ=pì ã Éó áÁÉ=âÁÉ=ài ã ÄÉë=NMMMNVTQNK

^ íÖóëÜóëÁÜí óÇŠ=ÁÜ~åà-íŠÇ~óê^ êçã Ö=i áÇà~âë=~êë-à=i áÑÑ~Éà=j ~í ëÜóÇK=« =e ~ï åë-áí=-Ü~ï ãë=i =Ëëçà=Ñ~ÇÇ~í~'êd çêçà=OMNPK
oÜëÑqëï óÇÇÉÇ~óê^ êçã Ö=i áÇà~âë=NMMMNVTQNK

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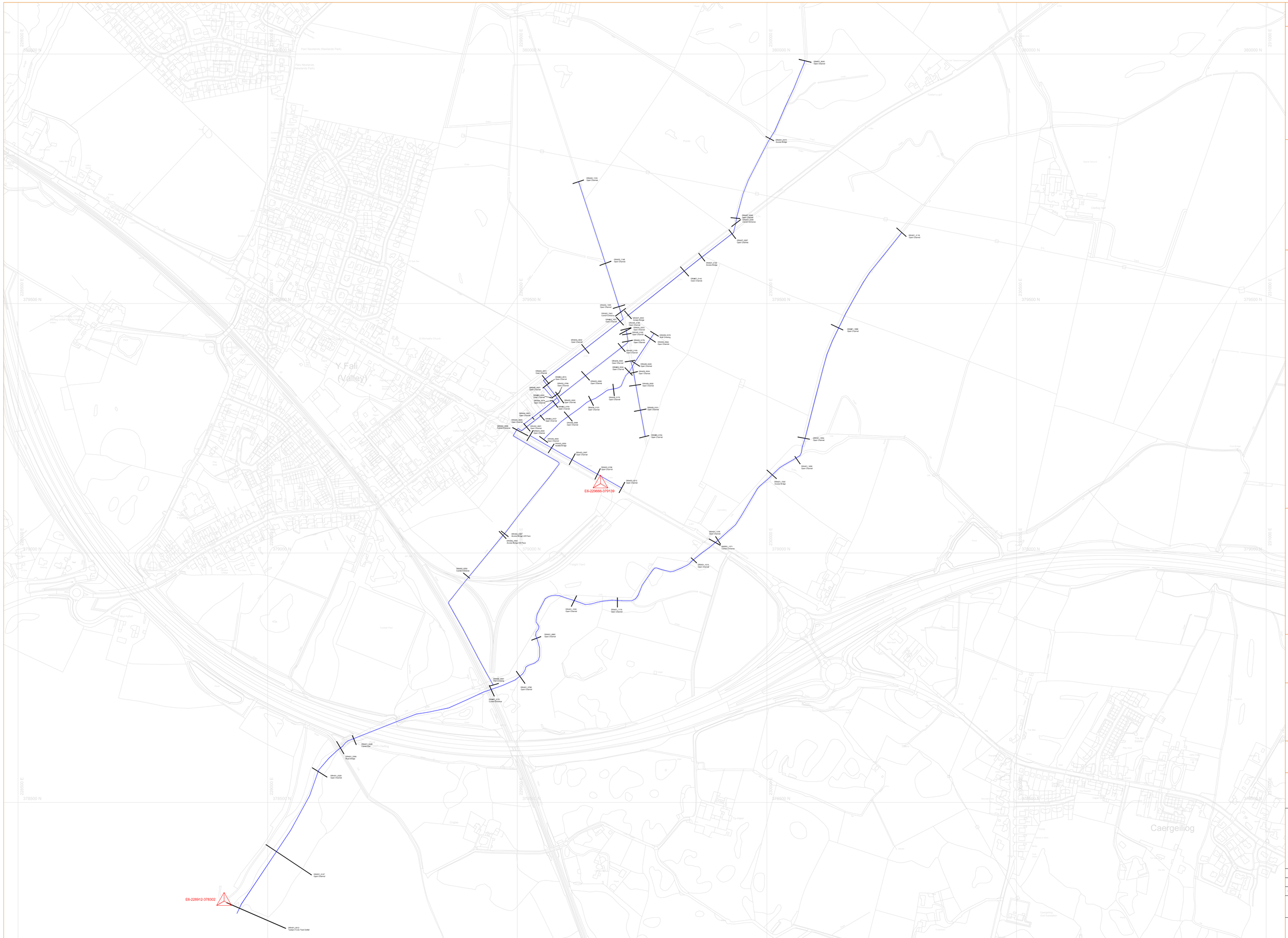
Appendix C
Structure Representation


E6-229666-379139
E6-228912-378302
Y Fali (Valley)
Caergeiliog
Parc Newydd (Newlands Park)
Tregele Road
Valley Road
Station Road
Cattle Grid
Level Crossing
Footbridge
Bridge
Pond
Quarry
Tank
Pylon
Mast
Church
Chapel
Graveyard
Cemetery
Pumping Station
Sewage Works
Telephone Kiosk
Post Box
Public House
Hotel
Shop
Post Office
Garage
Petrol Station
Car Parking Area
Caravan Park
Campsite
Golf Course
Sports Ground
Recreation Ground
Allotments
Orchard
Wood
Scrub
Marsh
Reeds
Rough Grass
Heath
Sand
Shingle
Rock
Cliff
Foreshore
Mean High Water
Mean Low Water
Tidal Limit
Sea Wall
Groyne
Jetty
Pier
Slipway
Boat Yard
Moorings
Lighthouse
Beacon
Buoy
Anchorage
Restricted Area
Danger Area
Firing Range
Airfield
Runway
Helipad
Control Tower
Hangar
Windsock
Radar
Weather Station
Meteorological Station
Seismic Station
Tide Gauge
Current Meter
Wave Rider
Sonar
Echo Sounder
Side Scan Sonar
Multibeam
Magnetometer
Gravimeter
Seismometer
Hydrophone
Underwater Camera
Underwater Vehicle
Diver
Submarine
Ship
Boat
Helicopter
Aeroplane
Satellite
Antenna
Transmitter
Receiver
Transceiver
Modem
Router
Switch
Hub
Server
Workstation
Laptop
Tablet
Smartphone
Printer
Plotter
Scanner
Camera
Video Camera
Microphone
Speaker
Headphones
Keyboard
Mouse
Trackball
Joystick
Touchscreen
Monitor
Projector
Screen
Whiteboard
Flipchart
Marker
Eraser
Pencil
Pen
Paper
Notebook
Folder
Binder
Clipboard
Calculator
Ruler
Protractor
Compass
Set Square
Scale
Level
Theodolite
Total Station
GPS
GNSS
Differential GPS
Real Time Kinematic
Base Station
Rover
Control Point
Benchmark
Trig Point
Spot Height
Contour
Hachure
Hill Shading
Relief
Terrain
Elevation
Depth
Bathymetry
Topography
Survey
Traverse
Triangulation
Trilateration
Resection
Intersection
Offset
Chainage
Baseline
Grid
Datum
Projection
Coordinate
Easting
Northing
Height
Level
Gradient
Slope
Aspect
Curvature
Volume
Area
Perimeter
Length
Width
Depth
Thickness
Density
Mass
Weight
Force
Pressure
Stress
Strain
Modulus
Poisson's Ratio
Young's Modulus
Shear Modulus
Bulk Modulus
Compressibility
Permeability
Porosity
Void Ratio
Moisture Content
Liquid Limit
Plastic Limit
Plasticity Index
Shrinkage Limit
Consistency
Density
Specific Gravity
Unit Weight
Dry Density
Wet Density
Saturated Density
Submerged Density
Relative Density
Compaction
Optimum Moisture Content
Maximum Dry Density
California Bearing Ratio
Shear Strength
Cohesion
Angle of Internal Friction
Undrained Shear Strength
Effective Stress
Total Stress
Pore Water Pressure
Hydrostatic Pressure
Seepage
Flow
Velocity
Discharge
Head
Gradient
Permeability
Transmissivity
Storativity
Specific Yield
Specific Storage
Hydraulic Conductivity
Darcy's Law
Flow Net
Equipotential
Streamline
Phreatic Surface
Capillary Rise
Suction
Infiltration
Evaporation
Transpiration
Evapotranspiration
Precipitation
Rainfall
Runoff
Catchment
Watershed
Drainage Basin
Stream
River
Creek
Gully
Ravine
Valley
Floodplain
Terrace
Delta
Estuary
Lagoon
Reef
Atoll
Island
Peninsula
Isthmus
Cape
Bay
Gulf
Strait
Channel
Ocean
Sea
Lake
Reservoir
Dam
Weir
Spillway
Culvert
Bridge
Tunnel
Viaduct
Aqueduct
Pipeline
Conduit
Duct
Cable
Wire
Fibre Optic
Coaxial
Twisted Pair
Ethernet
Wi-Fi
Bluetooth
Zigbee
Z-Wave
Thread
Matter
Thread
Matter
Zigbee
Z-Wave
Bluetooth
Wi-Fi
Ethernet
Coaxial
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Streamline
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Discharge
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Gradient
Permeability
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Density
Shrinkage Limit
Liquid Limit
Plastic Limit
Plasticity Index
Moisture Content
Void Ratio
Porosity
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Compressibility
Bulk Modulus
Young's Modulus
Shear Modulus
Poisson's Ratio
Modulus
Strain
Stress
Pressure
Force
Weight
Mass
Density
Thickness
Depth
Width
Length
Perimeter
Area
Volume
Curvature
Aspect
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Easting
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Projection
Datum
Grid
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Traverse
Triangulation
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Resection
Intersection
Offset
Chainage
Survey
Bathymetry
Topography
Elevation
Terrain
Hachure
Hill Shading
Relief
Contour
Spot Height
Benchmark
Control Point
Base Station
Rover
Real Time Kinematic
Differential GPS
GPS
GNSS
Total Station
Theodolite
Level
Scale
Ruler
Protractor
Compass
Set Square
Calculator
Pencil
Pen
Paper
Notebook
Folder
Binder
Clipboard
Whiteboard
Flipchart
Marker
Eraser
Keyboard
Mouse
Trackball
Joystick
Touchscreen
Monitor
Projector
Screen
Printer
Plotter
Scanner
Camera
Video Camera
Microphone
Speaker
Headphones
Laptop
Tablet
Smartphone
Server
Workstation
Router
Switch
Hub
Modem
Transmitter
Receiver
Transceiver
Antenna
Satellite
Aeroplane
Helicopter
Ship
Boat
Submarine
Diver
Underwater Vehicle
Underwater Camera
Sonar
Echo Sounder
Side Scan Sonar
Multibeam
Magnetometer
Gravimeter
Seismometer
Hydrophone
Current Meter
Wave Rider
Tide Gauge
Seismic Station
Meteorological Station
Weather Station
Radar
Control Tower
Hangar
Windsock
Airfield
Runway
Helipad
Firing Range
Danger Area
Restricted Area
Anchorage
Buoy
Beacon
Lighthouse
Moorings
Boat Yard
Slipway
Pier
Jetty
Groyne
Sea Wall
Foreshore
Cliff
Rock
Shingle
Sand
Heath
Rough Grass
Reeds
Marsh
Scrub
Wood
Orchard
Allotments
Recreation Ground
Sports Ground
Golf Course
Caravan Park
Campsite
Car Parking Area
Petrol Station
Garage
Post Office
Shop
Hotel
Public House
Post Box
Telephone Kiosk
Pumping Station
Sewage Works
Cemetery
Graveyard
Chapel
Church
Mast
Pylon
Tank
Quarry
Pond
Footbridge
Level Crossing
Cattle Grid
Bridge
Tunnel

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Structure 1			
Name of Structure	Double culverts under farmers track on Drain 01		
OS Grid Ref	230019 379148		
Survey reference	DRAI01_1550		
Included in Model?	Yes	**Model Label / reason for exclusion**	01_1550_c1 01_1550_c2
Model representation	Two orifice units based on survey section DRAI01_1550 (surveyed upstream face of culverts). O1: Orifice unit used, throat invert level 0.1mAOD, throat soffit level 1.00mAOD, bore area 0.636m^2, upstream sill level 0.1mAOD, downstream sill level 0.08mAOD. O2: Orifice unit used, throat invert level 0.14mAOD, throat soffit level 1.04mAOD, bore area 0.636m^2, upstream sill level 0.14mAOD, downstream sill level 0.12mAOD. Track deck 2.34-2.91 mAOD represented by a 1D spill unit (01_1550_su).		
Coefficients used	Orifice: discharge coefficients – 1.000; modular Limit – 0.700 Spill: weir coefficients – 1.200; modular Limit – 0.900		
Assumptions	The culvert length is short (<5m) so orifice units were used. This unlikely to significantly affect the results. .		
Photograph			
Structure 2			
Name of Structure	A5 road bridge over Drain 01		
OS Grid Ref	229906 379015		
Survey reference	DRAI01_1371		
Included in Model?	Yes	**Model Label / reason for exclusion**	01_1371_c

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Model representation	Bridge based on survey section DRAI01_1371 (surveyed upstream face of culverts). Rectangular conduit unit used, invert 0.62 mAOD. Width 3.93 m, height, 1.3 m. Track deck 3.40 mAOD represented in 2D domain. Culvert length 12.00 m. Downstream culvert face based on upstream face, invert raised by 0.05 m to adjust for slope. The culvert sits higher than the bed of the channel therefore an inline spill unit was used at the entrance and exit of the culvert to help with stability.		
Coefficients used	Manning's: 0.011 7 (Concrete: Culvert, straight and free of debris) Inlet: Conduit type B; K: 0.515; M: 0.667; C: 0.0375; Y: 0.79		
Assumptions	The two inline spill units added will account for inlet and outlet losses. The pipe crossing was not included as they are narrow and in line with flow and therefore not deemed to significantly influence the flow through the culvert. Although the pipe crossings pose a blockage risk no blockage assessment was undertaken as the culvert is on the Cleifiog upstream of the confluence with the Valley watercourses so a blockage here would not significantly affect water levels at the proposed bypass footprint.		
Photograph			
Structure 3			
Name of Structure	Railway triple culvert bridge over Drain 01		
OS Grid Ref	229453 378712		
Survey reference	DRAI01_0721		
Included in Model?	Yes	**Model Label / reason for exclusion**	01_0721_c1 01_0721_c2 01_0721_c3

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Model representation	Bridge based on survey section DRAI01_0721 (surveyed upstream face of culverts). C1: Sprung Arch conduit unit used, invert 0.32 mAOD. Width 1.89 m; Springing height, 0.90 m; Crown height 0.60 m C2: Sprung Arch conduit unit used, invert 0.22 mAOD. Width 1.82 m; Springing height, 0.99 m; Crown height 0.65 m C3: Sprung Arch conduit unit used, invert 0.29 mAOD. Width 1.78 m; Springing height, 0.93 m; Crown height 0.62 m Track deck 4.02 mAOD represented in 2D domain, no spill in 1D model. Culvert length 11.40 m. Downstream culvert face based on upstream face, invert unchanged as surveyed long section suggests no change to slope over culvert length.		
Coefficients used	Manning's: 0.025 Invert, 0.02 Walls/Arch: 7 (Concrete: Culvert, straight and free of debris) Inlet: Conduit type A; K: 0.0083; M: 2; C: 0.0379; Y: 0.69		
Assumptions	Walkway in front of culvert has not been represented as it shallow and in line with flow and therefore not deemed to significantly influence the flow through the culvert. The walkway could potentially pose a risk of blockage. This crossing is downstream of the confluence with the Valley watercourses. No blockage tests have been undertaken as the crossing is 600m downstream of the proposed bypass footprint and blockage at this location is unlikely to have significant impact on water levels at the proposed bypass footprint. However, given the flat nature of the system future modelling should consider modelling a blockage scenario.		
Photograph			
Structure 4			
Name of Structure	A55 road bridge over Drain 01		
OS Grid Ref	229177 378615		
Survey reference	DRAI01_0428		
Included in Model?	Yes	**Model Label / reason for exclusion**	DRAI01_0428u
Model representation	Bridge based on survey section DRAI01_0428 (surveyed upstream face of bridge). USBPR bridge unit used, Springing level 1.574m; soffit 7.08 mAOD. Start chainage 9.604m, finish chainage, 20.006m. Track deck represented in LiDAR in 2D domain. Bridge length 92.83 m.		
Coefficients used	Manning's: values based on channel roughness in DRAI01_0428.		
Assumptions	Given the irregular shape of eth structure it was not possible to represent it as a culvert. Therefore, a bridge was used (with the distance added to the downstream cross section). The USBPR was chosen over the Arch due to the large size of the opening.		

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Photograph			
Structure 5			
Name of Structure	Tidal barrage on Drain 01		
OS Grid Ref	229036 378247		
Survey reference	DRAI01_0012		
Included in Model?	Yes	**Model Label / reason for exclusion**	01_0000_c1 (culvert 1) 01_0000_c2 (culvert 2) 01_0000_c3 (culvert 3) 01_0000_c1d (orifice 1) 01_0000_c2d (orifice 2) 01_0000_c3d (orifice 3)

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Model representation	The tidal barrier is an embankment containing three parallel culverts each linked to a flapped outfall on the seaward side of the barrier. The representation has been based on survey section DRAI01_0012 (surveyed upstream face of culverts), and the 'as built' drawings provided by NRW (Drawing numbers: 2001, 2006, 2007, 2008, 2011 and 2099). C1: Sprung Arch conduit unit used, invert 0.00 mAOD. Width 2.55 m; Springing height 0.08 m; Crown height 1.27 m C2: Sprung Arch conduit unit used, invert 0.00 mAOD. Width 2.55 m; Springing height 0.08 m; Crown height 1.27 m C3: Rectangular conduit unit used, invert 0.14 mAOD. Width 1.68 m; height 1.28 m. O1: Flapped outfall orifice unit used, throat invert level 0.00mAOD, throat soffit level 1.00mAOD, bore area 1.5m^2, upstream sill level 0.00mAOD, downstream sill level 0.00mAOD. O2: Flapped outfall orifice unit used, throat invert level 0.00mAOD, throat soffit level 1.00mAOD, bore area 1.5m^2, upstream sill level 0.00mAOD, downstream sill level 0.00mAOD. O3: Flapped outfall orifice unit used, throat invert level 0.00mAOD, throat soffit level 1.00m, bore area 1.5m^2, upstream sill level 0.00mAOD, downstream sill level 0.00mAOD. Embankment crest level 4.02 mAOD represented in 2D domain, no spill in 1D model. Culvert length 11.70m. Downstream culvert face based on upstream face, invert unchanged as surveyed long section and design drawings suggest no change to slope over culvert length.
Coefficients used	Manning's: 0.02 Invert, 0.02 Walls/Arch: 7 (Concrete: Culvert, straight and free of debris) Inlet: Rectangular conduit type A; K: 0.005; M: 1.05; C: 0.04; Y: 0.48; Ki: 0.26 Inlet: Sprung Arch conduit type A; K: 0.0083; M: 2; C: 0.0379; Y: 0.69; Ki: 0.26
Assumptions	Orifice bore areas have been assumed based penstock dimensions detailed on 'as built' drawing 2008. Tidal flap was not surveyed, from photos and design drawings it is assumed the flaps cover and seal the outfall to prevent reverse flow, this has been represented as part of the orifice unit. Arch culvert height and width and invert have been assumed based on dimensions detailed on 'as built' drawing 2008. These were also consistent with new channel survey of culvert entrance undertaken for this project in 2015. Rectangular culvert dimensions were taken from section DRAI01_0012 of channel survey undertaken for this project in 2015. As this was representative of what was observed on site visit and consistent with the restrictive rectangular opening shown on 'as built' drawing 2008.

C7

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Photograph	

C8

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Photograph			
Structure 6			
Name of Structure	**Double culverts under A5025 on Drain 02**		
OS Grid Ref	**229717 379490**		
Survey reference	**DRAI02_1043**		
Included in Model?	Yes	**Model Label / reason for exclusion**	02_1043_c1 02_1043_c2

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Model representation	Two orifice units based on survey section DRAI02_1043 (surveyed upstream face of culverts). O1: Orifice unit used, throat invert level 1.1 mAOD, throat soffit level 1.55 mAOD, bore area 0.159m^2, upstream sill level 1.1 mAOD, downstream sill level 0.98 mAOD. O2: Orifice unit used, throat invert level 0.93 mAOD, throat soffit level 1.62 mAOD, bore area 0.374m^2, upstream sill level 0.93 mAOD, downstream sill level 0.81 mAOD. Track deck represented inline spill linked to dummy HT boundary to pass flow into the 2D domain as main A5025 carriageway represented by LiDAR.		
Coefficients used	Orifice: discharge coefficients – 1.000; modular Limit – 0.700		
Assumptions	An orifice unit was used to aid the stability of the model. The culvert was 12.580 m long. This length has been lost to the model.		
Photograph			
Structure 7			
Name of Structure	**Culvert under A5 on Drain 02**		
OS Grid Ref	**229521 379234**		
Survey reference	**DRAI02_0666**		
Included in Model?	Yes	**Model Label / reason for exclusion**	02_0666_c1
Model representation	Culvert based on survey section DRAI02_0666 (surveyed upstream face of culverts). C1: Rectangular conduit unit used, invert 0.62 mAOD. Width 0.77m, height 0.73m Track deck represented by LiDAR in 2D domain. Culvert length 12.580 m. Downstream culvert face based on upstream face, invert unchanged as surveyed long section suggests no change to slope over culvert length.		
Coefficients used	Manning's: Invert 0.03, Walls 0.025, Soffit 0.025 = 7 (Concrete: Culvert, straight and free of debris) Inlet: Conduit type B; K: 0.469; M: 0.696; C: 0.033; Y: 0.751; Ki: 0.26		

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Assumptions	The culvert is not perfectly rectangular. To be conservative the narrowest width was taken as the width of the culvert (0.77m from survey)		
Photograph			
Structure 8			
Name of Structure	**Culvert under farmers track on Drain 02**		
OS Grid Ref	**229482 379032**		
Survey reference	**DRAI02_0367** **DRAI02_0362**		
Included in Model?	Yes	**Model Label / reason for exclusion**	02_0367_cu
Model representation	An orifice unit based on survey section DRAI02_0362 (surveyed downstream face of culvert). The downstream poses more of a constriction to flow than the upstream section and therefore was deemed more representative. O1: Orifice unit used, throat invert level 0.17 mAOD, throat soffit level 1.07 mAOD, bore area 0.640m^2, upstream sill level 0.29 mAOD, downstream sill level 0.22 mAOD. Track deck of 1.50mAOD represented by spill unit.		
Coefficients used	Orifice: discharge coefficients – 1.000; modular Limit – 0.700 Spill: weir coefficients – 1.2; modular limit – 0.900		
Assumptions	An orifice unit was used to aid the stability of the model. The culvert was <5m long. Culvert surveyed upstream face and downstream face show culvert shape changes from rectangular to circular pipe at an unknown distance along the culvert length. The circular culvert has been represented in the 1D model for the entire length, as this is the more constricting element of the structure. The circular culvert is shown on the survey data to be partially filled with mud and stones from the channel bed. The sill levels have been adjusted to account for the silt.		

C11

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Photograph	
Structure 9	
Name of Structure	**Double culvert under railway on Drain 02**
OS Grid Ref	**229404 378949**

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Survey reference	**DRAI02_0253**		
Included in Model?	Yes	**Model Label / reason for exclusion**	02_0253_c1 02_0253_c2
Model representation	Double culvert based on survey section DRAI02_0367 (surveyed upstream face of culverts). C1: Sprung Arch conduit unit used, invert 0.46 mAOD. Width 1.201 m; Springing height 0.22 m; Crown height 0.60 m C2: Sprung Arch conduit unit used, invert 0.44 mAOD. Width 1.201 m; Springing height 0.22 m; Crown height 0.60 m Track deck represented by LiDAR in 2D domain. Culvert length 20.30 m. Downstream culvert face based on upstream face, invert unchanged as surveyed long section suggests no change to slope over culvert length.		
Coefficients used	Manning's: Invert 0.013, Walls 0.011, Soffit 0.011 = 7 (Concrete: Culvert, straight and free of debris) Inlet: Conduit type A; K: 0.0078; M: 2; C: 0.0292; Y: 0.74; Ki: 0.3		
Assumptions	Sprung arch shape was used due to siltation surveyed during survey. The original culverts were circular but siltation means it was more representative to use an arch shape. However, the inlet coefficients remain for a circular culvert, this is also due to there being no standard arch culvert inlet coefficients for a concrete pipe within the software.		
Photograph			
Structure 10			
Name of Structure	**Triple culverted wall over end of Drain 02**		
OS Grid Ref	**229462 3787738**		
Survey reference	**DRAI02_0001**		
Included in Model?	Yes	**Model Label / reason for exclusion**	02_0001_c1 02_0001_c2 02_0001_c3

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Model representation	Three orifice units based on survey section DRAI02_0001 (surveyed upstream face of culverts). O1: Orifice unit used, throat invert level 0.34mAOD, throat soffit level 0.95mAOD, bore area 0.689m^2, upstream sill level 0.34mAOD, downstream sill level 0.34mAOD. O2: Orifice unit used, throat invert level 0.36mAOD, throat soffit level 0.95mAOD, bore area 0.336m^2, upstream sill level 0.36mAOD, downstream sill level 0.36mAOD. O3: Orifice unit used, throat invert level 0.51mAOD, throat soffit level 0.83mAOD, bore area 0.166m^2, upstream sill level 0.51mAOD, downstream sill level 0.51mAOD. Track deck 2.13 to 2.55 mAOD represented in Spill Unit 02_0001_sd in 1D model.		
Coefficients used	Orifice: discharge coefficients – 1.000; modular Limit – 0.700 Spill: weir coefficients – 1.2; modular limit – 0.900		
Assumptions	An orifice unit was used to aid the stability of the model. The culvert was <1m long. All three were irregular openings hence orifice unit used. Orifice 1 and 2 inverts were the average. Orifice 3 invert the highest bed value was used to offset the irregular shape. All bore areas are commensurate with the survey drawings.		
Photograph			
Structure 11			
Name of Structure	**Culvert under farmers track on Drain 07**		
OS Grid Ref	**230013 379826**		
Survey reference	**DRAI07_0474**		
Included in Model?	Yes	**Model Label / reason for exclusion**	07_0474_c
Model representation	Orifice unit based on survey section DRAI07_0474 (surveyed upstream face of culvert). O1: Orifice unit used, throat invert level 1.05mAOD, throat soffit level 1.5mAOD, bore area 0.159m^2, upstream sill level 1.05mAOD, downstream sill level 1.00mAOD. Track deck 2.1mAOD represented by spill unit.		
Coefficients used	Orifice: discharge coefficients – 1.000; modular Limit – 0.700 Spill: weir coefficient – 1.200; modular Limit – 0.900		
Assumptions	An orifice unit was used to aid the stability of the model. The culvert was <5 m long.		

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Photograph			
Structure 12			
Name of Structure	**Culvert under A5025 on Drain 07**		
OS Grid Ref	**230013 379826**		
Survey reference	**DRAI07_0290**		
Included in Model?	Yes	**Model Label / reason for exclusion**	07_0290_cu
Model representation	Culvert based on survey section DRAI07_0290 (surveyed upstream face of culverts). C1: Circular conduit unit used, invert 0.95 mAOD. Diameter 0.69m. Track deck represented by LiDAR in 2D model domain. Culvert length 18.56 m Downstream culvert face based on upstream face, invert decreased by 0.04 m to adjust for slope.		
Coefficients used	Manning's: 0.011 = 7 (Concrete: Culvert, straight and free of debris) Inlet: Conduit type A; K: 0.0078; M: 2; C: 0.0292; Y: 0.74; Ki: 0.3		

C15

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Photograph			
Structure 13			
Name of Structure	**Culvert under farmers track off A5025 on Drain 07**		
OS Grid Ref	**229875 379584**		
Survey reference	**DRAI07_0190**		
Included in Model?	Yes	**Model Label / reason for exclusion**	07_0190_cu
Model representation	Orifice unit based on survey section DRAI07_0190 (surveyed upstream face of culvert). O1: Orifice unit used, throat invert level 0.89mAOD, throat soffit level 1.89mAOD, bore area 0.785m^2, upstream sill level 0.915mAOD, downstream sill level 0.88mAOD. Track deck 2.26-2.45mAOD represented by spill unit.		
Coefficients used	Orifice: discharge coefficients – 1.000; modular Limit – 0.700 Spill: weir coefficient – 1.200; modular Limit – 0.900		
Assumptions	An orifice unit was used to aid the stability of the model. The culvert was <5 m long. Culvert invert elevation changed to bed level of surveyed cross section on upstream face of culvert (DRAI07_0190), due to presence of mud/stones in culvert pipe.		

C16

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Photograph			
Structure 14			
Name of Structure	**Culvert under wooden bridge off A5025 on Drain 07**		
OS Grid Ref	**229728 379469**		
Survey reference	**DRAI07_0003**		
Included in Model?	Yes	**Model Label / reason for exclusion**	07_0003_cu
Model representation	Orifice unit based on survey section DRAI07_0003 (surveyed upstream face of culvert). O1: Orifice unit used, throat invert level 0.74mAOD, throat soffit level 1.45mAOD, bore area 0.602m^2, upstream sill level 0.74mAOD, downstream sill level 0.54mAOD. Track deck 1.74-1.77mAOD represented by spill unit		
Coefficients used	Orifice: discharge coefficients – 1.000; modular Limit – 0.700 Spill: weir coefficient – 1.200; modular Limit – 0.900		
Assumptions	An orifice unit was used to aid the stability of the model. The culvert was <5 m long.		
Photograph			

C17

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Structure 15			
Name of Structure	**Culvert under A5**		
OS Grid Ref	**229561 379221**		
Survey reference	**CULV01_0015**		
Included in Model?	Yes	**Model Label / reason for exclusion**	08_0000_cu
Model representation	Orifice unit based on survey section CULV01_0015 (surveyed upstream face of culvert). O1: Orifice unit used, throat invert level 0.71mAOD, throat soffit level 1.32mAOD, bore area 0.531m^2, upstream sill level 0.71mAOD, downstream sill level 0.66mAOD. Track deck represented in 2D model by LIDAR as the A5 is higher than peak water levels. The orifice was connected to an inline spill unit which is connected to the 2D TUFLOW model		
Coefficients used	Orifice: discharge coefficients – 1.000; modular Limit – 0.700		
Assumptions	An orifice unit was used to aid the stability of the model. To allow for the orifice to be linked to the 2D model it was necessary to set the upstream of the orifice to the junction with the Valley watercourse (Drain02) downstream of the A5 (results point 1 on Figure 4.1), the downstream was then set to a dummy QT boundary which linked via an sx line to the TUFLOW model to transfer the water in the floodplain under the A5 into the drain downstream.		
Photograph			

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Appendix D
Channel Roughness Representation

Manning's roughness values have been determined using definitions detailed in Chow (1959) referenced below. The roughness values chosen for each section of the Valley model are presented in this appendix.

- Chow, V.T., 1959. Open-channel hydraulics: New York, McGraw-Hill, 680 p.

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
Cleifiog	**2116**	left bank top	1.short grass	0.03		
		bank top				
		banks	1. scattered brush, heavy weeds	0.05		
		bed	g. sluggish reaches, weedy, deep pools	0.07	Very weeded section may suggest max variant, but adjusted to mid for winter storm event	
		right bank top	4. medium to dense brush, in winter	0.07		
Cleifiog	**1886**	left bank top	1. no crop	0.03	Established crops in photo, but adjusted to mid variant for winter scenario	
		all other	as 2116	as 2116	as 2116	
Cleifiog	**1654**	left bank top	4. medium to dense brush, in winter	0.05		

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
		all other	as 1886	as 1886	as 1886	
Cleifiog	**1609**	left bank top	2. high grass	0.035		
		all other	as 1654	as 1654	as 1654	
Cleifiog	**1550**	bed	g. sluggish reaches, weedy, deep pools	0.05	Weedy along a lot of reach, but min to represent the clearer section around the culvert	
		right bank top	4. medium to dense brush, in winter	0.05	Dense section, but less dense than upstream section.	

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
		all other	as 1609	as 1609	as 1609	
Cleifiog	**1378**	left bank top	4. medium to dense brush, in winter	0.07		
		banks	4. medium to dense brush, in winter	0.07		
		bed	g. sluggish reaches, weedy, deep pools	0.07		
		right bank top	4. medium to dense brush, in winter	0.07		
Cleifiog	**1371**	left bank top	2. light brush and trees, in winter	0.04	Brush lighter than upstream reach	
		banks	f. same as "d" with more stones	0.05		
		bed	f. same as "d" with more stones	0.05	Weedy, but less so than upstream reaches	

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
		right bank top	2. light brush and trees, in winter	0.04	Brush lighter than upstream reach	
Cleifiog	**13 15**	left bank top	2. light brush and trees, in winter	0.06	Denser than right bank	
		banks	e. same as above, lower stages, more ineffective	0.048	Less weeds than upstream section	
		bed	e. same as above, lower stages, more ineffective	0.048	Less weeds than upstream section	
		right bank top	2. light brush and trees, in winter	0.05	Less dense than left bank	
Cleifiog	**11 19**	left bank top	1. scattered brush, heavy weeds	0.04	Less dense than right bank	
		banks	g. sluggish reaches, weedy, deep pools	0.06	Less weedy than some upstream sections	
		bed	g. sluggish reaches, weedy, deep pools	0.06	Less weedy than some upstream sections	

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
		right bank top	2. light brush and trees, in winter	0.05		
Cleifiog	**10 30**	all	as 1119	as 1119	as 1119	
Cleifiog	**08 82**	left bank top	1. scattered brush, heavy weeds	0.05		
		bed	e. same as above, lower stages, more ineffective	0.048		
		banks	e. same as above, lower stages, more ineffective	0.048		

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
		right bank top	1. scattered brush, heavy weeds	0.05		
Cleifiog	**0785**	left bank top	1. scattered brush, heavy weeds	0.05		
		bed	d. same as above, but some weeds and stones	0.045		
		banks	d. same as above, but some weeds and stones	0.07		
		right bank top	1. scattered brush, heavy weeds	0.05		

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
Cleifiog	**0721**	all	as 0785	as 0785	as 0785	
Cleifiog	**0428**	left bank top	2. high grass	0.05	Also, section attributed with Manning's of 0.2, due to flat gravel footpath	
		bed	b. same as above, but more stones and weeds	0.035		
		banks	6. gunite, wavy section	0.025	Very distinct, short waves in Gunite design	
		right bank top	2. high grass	0.05		
Cleifiog	**0395**	left bank top	1. scattered brush, heavy weeds	0.05		
		bed	b. same as above, but more stones and weeds	0.035		
		banks	g. sluggish reaches, weedy, deep pools	0.07		

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
		right bank top	1. scattered brush, heavy weeds	0.05		
Cleifiog	**0329**	all	as 0395	as 0395	as 0395	

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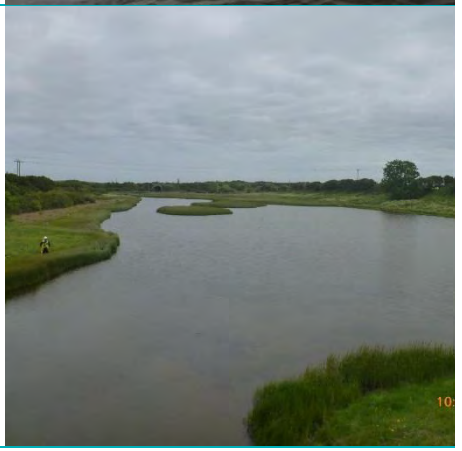
Watercourse		Section	Manning's category	Manning's n	Justification	Picture
Cleifiog	**0147**	all	as 0329	as 0329	as 0329	
Cleifiog	**0012**	all	as 0147	as 0147	as 0147	
Valley	**1318**	left bank top	4. medium to dense brush, in winter	0.07		
		bed	f. same as "d" with more stones	0.05		
		banks	f. same as "d" with more stones	0.05		

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
		right bank top	1.short grass	0.035	Short grass but also sporadic brush	
Valley	**1146**	right bank top	1. scattered brush, heavy weeds	0.05		
		all others	as 1318	as 1318	as 1318	
Valley	**1055**	bed	g. sluggish reaches, weedy, deep pools	0.06	Very weedy, but not as weedy as some Drain 1 sections	

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
		all others	as 1146	as 1146	as 1146	
Valley	**1043**	left bank top	3. light brush and trees, in summer	0.06		
		bed	e. same as above, lower stages, more ineffective	0.048		
		banks	1. scattered brush, heavy weeds	0.05		
		right bank top	3. light brush and trees, in summer	0.06		
Valley	**1021**	left bank top	1. scattered brush, heavy weeds	0.05		
		bed	f. same as "d" with more stones	0.05		
		banks	g. sluggish reaches, weedy, deep pools	0.07		

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
		right bank top	3. light brush and trees, in summer	0.06		
Valley	**0932**	all	as 1021	as 1021	as 1021	

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
Valley	**0831**	all	as 0932	as 0932	as 0932	
Valley	**0816**	left bank top	1. scattered brush, heavy weeds	0.05		
		bed	g. sluggish reaches, weedy, deep pools	0.07		
		banks	g. sluggish reaches, weedy, deep pools	0.07		
		right bank top	4. medium to dense brush, in winter	0.07		
Valley	**0789**	bed	g. sluggish reaches, weedy, deep pools	0.06		

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
		all others	as 0816	as 0816	as 0816	
Valley	**0765**	all	as 0789	as 0789	as 0789	

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
Valley	**0727**	all	as 0765	as 0765	as 0765	
Valley	**0691**	all	as 0727	as 0727	as 0727	
	0666	left bank top	4. medium to dense brush, in winter	0.07	Road section noted as smooth asphalt	
		bed	e. same as above, lower stages, more ineffective	0.048		
		banks	1. scattered brush, heavy weeds	0.05		
		right bank top	4. medium to dense brush, in winter	0.07	Road section noted as smooth asphalt	
Valley	**0367**	left bank top	2. high grass	0.035	Inclusion of some scattered weeds etc.	
		bed	g. sluggish reaches, weedy, deep pools	0.07		
		banks	2. light brush and trees, in winter	0.05		

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
		right bank top	1.short grass	0.035	Inclusion of some scattered weeds etc.	
Valley	**0362**	bed	d. same as above, but some weeds and stones	0.045		
		all other	as 0367	as 0367	as 0367	
Valley	**0253**	left bank top	2. high grass	0.035		
		bed	d. same as above, but some weeds and stones	0.045		
		banks	2. high grass	0.05	Inclusion of some weeds etc.	

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
		right bank top	2. high grass	0.035		
Valley	**0001**	left bank top	1. scattered brush, heavy weeds	0.05		
		bed	e. same as above, lower stages, more ineffective	0.048		
		banks	g. sluggish reaches, weedy, deep pools	0.07		
		right bank top	1. scattered brush, heavy weeds	0.05		
Glan Morfa	**0645**	left bank top	4. medium to dense brush, in winter	0.07		
		bed	g. sluggish reaches, weedy, deep pools	0.05	Not as weedy as some reaches, similar coverage to banks.	
		banks	1. scattered brush, heavy weeds	0.05		

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
		right bank top	1.short grass	0.03		
Glan Morfa	**04 74**	left bank top	1. scattered brush, heavy weeds	0.05		
		bed	d. same as above, but some weeds and stones	0.045		
		banks	2. high grass	0.045	Small amounts of brush also	
		right bank top	2. high grass	0.045	Small amounts of brush also	
Glan Morfa	**03 00**	left bank top	3. mature field crops	0.04		
		bed	b. same as above, but more stones and weeds	0.035		
		banks	1. scattered brush, heavy weeds	0.05		

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
		right bank top	3. mature field crops	0.04		
Glan Morfa	**02 90**	left bank top	smooth asphalt	0.013		
		bed	d. same as above, but some weeds and stones	0.045		
		banks	1. scattered brush, heavy weeds	0.05		
		right bank top	1.short grass	0.03		
Glan Morfa	**02 67**	left bank top	1.short grass	0.03		
		bed	g. sluggish reaches, weedy, deep pools	0.06	Not as weed filled as some reaches	
		banks	1. scattered brush, heavy weeds	0.05		

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
		right bank top	smooth asphalt	0.013		
Glan Morfa	**01 90**	left bank top	1.short grass	0.03		
		bed	g. sluggish reaches, weedy, deep pools	0.07		
		banks	g. sluggish reaches, weedy, deep pools	0.07		
		right bank top	smooth asphalt	0.013		
Glan Morfa	**01 45**	left bank top	high grass	0.035		
		bed	g. sluggish reaches, weedy, deep pools	0.06	Not as weed filled as some reaches	
		banks	1. scattered brush, heavy weeds	0.05		

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Watercourse		Section	Manning's category	Manning's n	Justification	Picture
		right bank top	4. medium to dense brush, in winter	0.07		
Glan Morfa	**0003**	all	as 0145	as 0145	as 0145	

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Appendix E Model Review Updates

The NRW model review (January 2017) concluded that:

The hydrology used has previously been agreed to be suitable for use in the modelling work. The main concern relates to the tidal doors and timings of high tides. To assist with the assumptions made with the dimensions of the doors I shall forward you 6 separate e-mails with 'as built drawings' for the Valley Tidal Doors improvements works carried out by our predecessors in 2010. It may be appropriate to confirm some aspects of the drawings with a site visit. With regards to timing of the inflows coinciding with the ebb tide this is not normal practice and timings should be altered to give the actual ''worse case" flood scenario for the site/area as a whole.

The table below contains the red and amber NRW comments as referenced above. Each comment has been addressed and the table documents the Amec Foster Wheeler response to resolve the issue, along with the specific action taken to facilitate the resolution.

NRW Review Comments	AmecFW Response	Action taken
An Automated Preissmann Slot has been activated with non-default parameters. Instead of a 1m deep slot, a 5m deep slot has effectively been added to the entire 1D network. The Preissmann Slot weighting factor (theta) has also been changed from the default. These settings have the potential to affect the model results by creating false storage volume in the channel network so should be justified. Preissmann slots are normally used to cover for stability issues at low flows but no mention of the slot and change of parameters is mentioned. Ideally these slot dimensions should be reduced or evidence supplied that it is not influencing the modelled river levels.	The adjustment of these values was necessary for the model to run without instability. We acknowledge these are not standard parameters, but they are not outside the realms of realism. However during this next round of model refinement we will investigate whether these values can be taken back to default.	Model has been stabilised so now default parameters are used except for: ▶ Automatic Preissmann Slot for River Sections (1m) ▶ Orifice linearization head (m): 0.1 ▶ Tidal 1:200 year AEP event was run with Theta of 0.85 to enable model to run.
However, the fact that the flapped outfall dimensions are assumed (rather than surveyed) will induce uncertainty in the model, especially as the key structures in the model. Therefore, clarification of the assumed outfall dimensions ought to be provided and agreed.	New drawings have now been provided by NRW of the tidal barrier and gates. The model will be updated to represent this new data.	Tidal structure representation was updated using new survey drawings provided by NRW. See structure section of technical note for further information.
The model inflows in the supplied model are timed to coincide with the ebb tide (at T=28.5 hours). At first sight this would seem unlikely to provide a suitably conservative assessment of the flood risk in the study area since design inflows would normally be timed to coincide with the peak (not ebb) of a tide cycle in an FCA. However, the report states "Tidal cycles set to peak at 47 hours to provide the 'worst-case' tide locking scenario" so it is possible that this does represent a 'worst-case' or 'suitably conservative' scenario. Therefore, evidence should be provided that the chosen configuration produces suitably conservative outputs.	During the Hydrology assessment some coarse 1D modelling was undertaken to determine which duration was the worst case for the site. To determine this each storm duration was run for tides in 1hr increments with the peak at 35-55hours to ensure that the worst case storm duration and peak tide combination was identified. The 47 hours was a result of that assessment.	Sensitivity test undertaken to test the impact of a coincident tidal peak - see Section 8.
Initial conditions enable the model to start reasonably but the model results could be sensitive to initial water levels in	The initial conditions have been set as far as possible to match the baseflow for the system as calculated by the hydrology assessment.	No Action required

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both in the channel and 2D domain so this should ideally be sensitivity tested because this is a known tide locking area.	It is acknowledged that the system could be sensitive to initial conditions. The fluvial event is deliberately very long so by the time the fluvial event has peaked there has already been a number of tide cycles in the model to account for the increased storage of water in the system due to tide locking. The joint probability of the system already being waterlogged then the design storm hitting is outside the remit of this assessment	
There are a few short periods of instability but none of these can be seen to have any adverse influence on the results. However, if more extreme scenarios including joint (fluvial/ tidal) probabilities are required from the model, instability may become more prevalent.	These periods of instability will be investigated and checked in the larger events. Much has already been done to stabilise the model to date, and the instabilities have been greatly reduced to a minimum. The instabilities remaining are small and not considered to effect results at the site.	The instabilities were arising from the attempt to represent the minor drains across the field containing the proposed bypass footprint in the 1D model. The drains have neem removed from the 1D and represented in the 2D by including the survey data as a series of topographic modifications.
One QT boundary (MAESYWRACH) is applied directly to a 2D channel in the west of the domain (see below). This inflow is not listed in the accompanying report and is not producing a realistic flow pattern, largely because narrow 2D channels cannot convey water as accurately as 1D channels, particularly when bridges are still evident in the model DTM. In reality, much of the 3.5m3/s inflow from this boundary could reach the lower catchment and contribute an additional ~35% volume to that which being directly input into the 1D drain system. Therefore, in the absence of survey data, one should have considered the more conservative approach of applying this point inflow directly into DRAI01. If the drain is to be modelled in 2D it needs to made more efficient (i.e. with GULLY lines and bridges removed from the DTM).	A detailed discussion was provided in the hydrology report as to the contribution of this easterly catchment to our study area. It was decided to not put the entire flow in to the 1D river directly as this would be overly conservative as there is significant storage in the neighbouring catchment. This drain enters the watercourse upstream of the A5. The A5 culvert is deemed to be a restriction to downstream flow and therefore adding this inflow direct to the 1D channel would likely have minimal effect on the levels at the confluence with the Valley watercourse and thus flood levels on site.	Continued to apply Maes-Y-Wrach inflow to 2D domain. The option of 'burning' in a channel and removing bridge decks using a THICK GULLY line in TuFLOW was adopted. The THICK GULLY line has been digitised to ensure a continuous flow path.
WLL lines are currently not defined. This means that the 1D results will not be mapped into the 2D output maps and this could be why no flooding is being reported close to the tidal barrier. Note that this is highlighted red since it may be the reason why the 2D output maps are not showing the expected extent of flooding near the downstream end of the model and not because it implies anything wrong with the model results.	The colouring is inconsistent with the previous two reviews which coloured this comment as orange. As stated this is a purely cosmetic issue, and has no bearing on the model results. As this modelling is for FCA only and not flood mapping it is not deemed necessary to include these at this time.	No Action Required
The 2D software used (2013-12-AC-iSP-w64) is a little out of date. The 2016 release of TUFLOW has been available for around one year and has some significant changes to the default settings. However, since these are largely in 1D (ESTRY) the use of 2013-12-AC-iSP-w64 is likely to be acceptable. However, further runs should ideally be carried out on the latest TUFLOW release.	Acknowledged the version used has now been superseded.	New runs have been run with latest version of TUFLOW.
Single precision TUFLOW was used. There is no great advantage in running single over double precision TUFLOW unless you after quick results so for fast,	The Valley model takes a significantly long time to run (days). It is not believed double precision will offer any significant benefits to this site over single precision, and using it will	No Action Required

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shallow flow double precision should be favoured but the low velocities in the Valley model probably do not need the benefit of double precision.	only make run times longer and unmanageable. Therefore, is not practicable given only minimal benefit.	
The MB2 map shows that locally high MBEs occur in association with the drain to which the MAESYWRACH inflow is attached. This lends further weight to the suggestion that this drain is not being modelled accurately because in addition to the over-simplified hydraulics, flow along this watercourse also causes stability issues that would be avoided with a 1D approach.	Acknowledged. As comment above a sensitivity test will be undertaken to look at the impact of adding the Maes-Y-Wrach flow direct to the 1D model. If this sensitivity test proves to be a better representation this will be carried forward and therefore the MB errors in this location will be resolved.	No Action Required. Continue to apply Maes-Y-Wrach inflow to 2D domain. Not impacting results at the proposed bypass footprint.
Calibration/evaluation against past flood history is an important part of model development. No mention is made of model calibration in the model report. NRW mentioned prior to the review that there was frequent flooding to the downstream extent of the model (which the reviewer assumes is related to tide locking at the outfalls) that does not seem to be predicted by the model. A number of reasons for this potential discrepancy have been encountered during this review and these are listed in the Recommendations section at the end of this review. The modellers should ideally consider these factors in conjunction with NRW to determine whether the model can be adjusted to match the observed risk or other factors (e.g. surface/ground water) could be the source of this observed flooding.	We searched for data but there is no data to calibrate the model to. We requested evidence of flooding from NRW and IACC. The areas of flooding predicted by the model (i.e. the fields) are consistent with photo graphs of recent flood events provided. As noted in this review the downstream extent of the model (just upstream of the barrier) is mostly contained within the 1D domain hence why no flood depths are seen in that area. But the water levels in the 1D model suggest the site does get wet. Other anecdotal flooding evidence is more synonymous with flooding from surface water as opposed to fluvial/tidal flooding.	The FCA will provide a commentary on historic flooding and the sources that it is attributable to.
Sensitivity test results have not been documented or supplied for review. The standard tests (roughness and flow) should ideally be undertaken to inform freeboard margins but relevant additional tests for this tide-locked area could include storm duration, tide level, initial water levels and climate change impacts.	Sensitivity tests are being undertaken as per the original agreed methodology statement these include: 1. Increasing and decreasing adopted Manning's roughness values both in the channel and bank top 2. Increasing and decreasing adopted structure coefficients 3. Failure of Tidal Gates In response to the above comments we will also test the impact of coinciding the peak tide.	Sensitivity tests detailed in method statement (and the new one listed above) will be undertaken and reported in the technical note.

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Appendix F
Compensatory Storage Design

F2

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Technical note:
Compensatory storage at Valley

1 Requirement for compensatory storage

The proposed A5025 bypass at Valley requires construction of a new roundabout on the A5 and the new bypass route to the north. The bypass cuts through an area of existing flooding and hence bank top storage will be lost, both where the bypass is proposed to be built and where a flow path to other areas of storage will be blocked. The combined areas of bank top storage loss are shown on Figure 1.1.

In order to assess compensatory storage requirements, the level and extent of ground raising associated with the bypass is required. The detailed extent of the bypass design was taken from *X-REF_DF5_OFL_02.dwg* and elevations of both the bypass and associated drainage were taken from *VALLEY_3DS_AMEC_02.dwg*. Both drawings were provided by AECOM.

The elevations provided in *VALLEY_3DS_AMEC_02.dwg* attributed a single elevation to a line along the length of the bypass and therefore the revised digital terrain model (DTM) used in the compensatory storage assessment will not accurately reflect the height of the bypass. However, as the 1:100 year AEP design event with an uplift in flows of 30% representing climate change floods up to an elevation of 2.33mAOD, proposed elevations above 3mAOD do not need to be accurately represented for the compensatory storage assessment.

The proposed bypass and the 1:100 year AEP event with an uplift in flows of 30% representing climate change is shown on Flood extent for the baseline 1:100 year AEP event with climate change and proposed bypass Figure 1.1.

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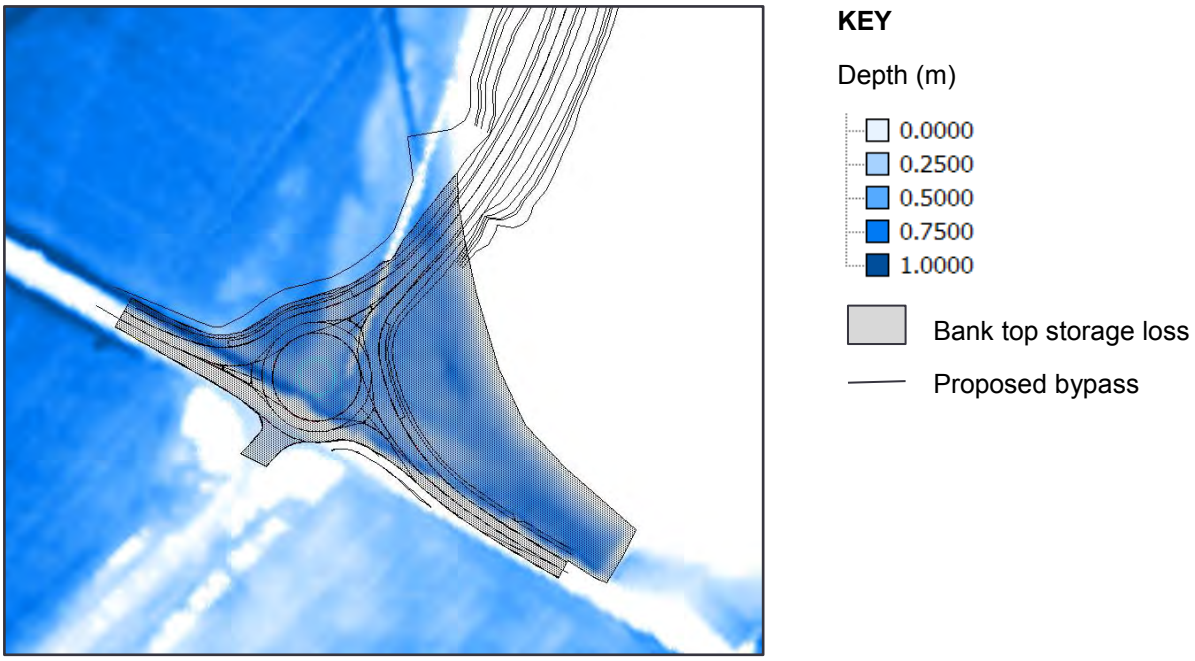
Figure 1.1 Flood extent for the baseline 1:100 year AEP event with climate change and proposed bypass route overlain



Without any flood relief culverts the proposed bypass will also prevent water from flowing south-east across the bypass during a flood event. Bank top storage of approximately 2,050m^3 will be lost as a result of the bypass during a 1:100 year AEP event with climate change. This was calculated by subtracting the DTM values from the peak water level grid (for the 1:00 year AEP event +CC) for the area within the footprint of the by-pass design, as indicated in Figure 1.1. The bypass also indirectly prevents water from reaching a further 1,650m^3 to the east of the proposed bypass. This was calculated by subtracting the DTM values from the peak water level grid (for the 1:00 year AEP event +CC) for the of bank top to the east of the bypass which will be disconnected from the bank top, as indicated in Figure 1.1. The proposed bypass has already been moved to try to minimise the amount of flood water being displaced and therefore compensatory storage is required to mitigate for 3,700m^3. The Flood Consequence Assessment (FCA) will provide further details on the alignment of the bypass. The distribution of displaced volume in 0.1m bands is provided in Table 1.1.

Table 1.1 Bank top storage loss volumes by level

Range	Volume (m^3)
Up to 1.6mAOD	23
1.6-1.7mAOD	36
1.7-1.8mAOD	148
1.8-1.9mAOD	362
1.9-2.0mAOD	583
2.0-2.1mAOD	706
2.1-2.2mAOD	769
2.2-2.33mAOD	1079

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Range	Volume (m^3)
TOTAL	3706

The hydraulic model represents flood water from the Cleifiog watercourse flowing north-west and merging with water flowing south-east from the Valley watercourse at the peak of the 1:100 year AEP event with climate change (see Figure 1.1). The predicted peak water depth is up to 0.2m. For most of the 1:100 year AEP event with climate change and all smaller events there is no interaction between flood extents associated with the Cleifiog and Valley watercourses at this location because of the topography.

Ground levels are slightly higher east of the high point located at the eastern extent of the area of bank top storage loss shown on Figure 1.1 (by up to 0.004m – which in modelling terms is essentially the same), meaning that there is negligible flow from the Cleifiog watercourse towards the Valley watercourse. As a result of the limited depth difference and duration of flow across the high point, it is not expected that the bypass would displace water from the Cleifiog and that the bank top storage loss between the bypass and the high point (predominantly from the Valley watercourse) are appropriate to consider for assessing compensatory storage.

2 Compensatory storage

2.1 Constraints on provision of storage

Ideally level for level storage would be provided. However, areas of higher ground that can be removed to create new areas of lower ground, and hence storage, are limited. This is further limited by the need for the new area to be hydraulically connected to the location of bank top loss, i.e. not upstream of a constraint like an embankment or culvert. The area chosen for compensation (Figure 2.1) is enclosed by the raised A5025 to the north-west, the raised A5 to the south-west and the new bypass to the east.

Further design constraints limit locations for compensatory storage:

- A 3m setback from the proposed bypass, including areas providing drainage for the proposed bypass, is required;
- A stable slope from the 3m setback to the new area at 1.6mAOD is required. This assessment assumed a 1:3 gradient; and
- Existing drains crossing the area cannot contribute to the new compensatory storage area.

These constraints mean that available area above 2.0mAOD is actually a fraction of what is actually required. There is sufficient area where flood storage volume can be created, however, it will not be level for level. Given that flow out of the area is constrained by culverts and topography, the total volume is likely to influence peak water level rather than the timing that storage volume is used. Therefore, it is considered that as long as sufficient volume for volume compensatory storage is created this is unlikely to result in a significant change in flood risk to receptors. This assumption will need to be tested through representing the proposed new topography of the compensatory storage area and proposed bypass in the hydraulic model.

2.2 Developing the initial proposed compensatory storage

The initial proposed compensatory storage area has been derived based on maximising the available area at higher ground level. Additional volume is provided at as high an elevation as possible, i.e. as close to the bank top storage loss elevation as possible. A comparison of approximately displaced area and available area is shown in Table 2.1.

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Table 2.1 Displaced and available areas by level

Elevation	Approximate Area displaced (m^2)	Available Area (m^2)	Percentage of required area
1.6mAOD	360	14890	4177%
1.7mAOD	1490	13720	924%
1.8mAOD	3620	10580	292%
1.9mAOD	5830	7150	123%
2.0mAOD	7060	3210	45%
2.1mAOD	7690	1630	21%
2.2mAOD	8300	910	11%

Based on the identified areas at each elevation, an approximate equivalent flood compensatory volume was calculated for comparison against the bank top storage loss and is provided in Table 2.2.

Table 2.2 Bank top storage loss volumes and approximate compensatory storage volumes by level

Range	Bank top storage loss volume (m^3)	Approximate compensatory storage volume (m^3)[1]
Up to 1.6mAOD	23	
1.6-1.7mAOD	36	1431
1.7-1.8mAOD	148	1215
1.8-1.9mAOD	362	887
1.9-2.0mAOD	583	518
2.0-2.1mAOD	706	242
2.1-2.2mAOD	769	127
2.2-2.33mAOD	1079	59
TOTAL	3706	4478

[1] Approximately volume based on average area and depth of band, this was not calculated using GIS and is therefore only indicative

The proposed area where material would be removed, to reduce the ground level for the extent of the storage area to 1.6mAOD is shown on Figure 2.1. It is split into a northern area and southern area by an existing drain. The ground in this area, which currently slopes up to an area of high ground, would be landscaped to remain at 1.6mAOD before rising to the edge of the proposed bypass at a slope of 1:3.

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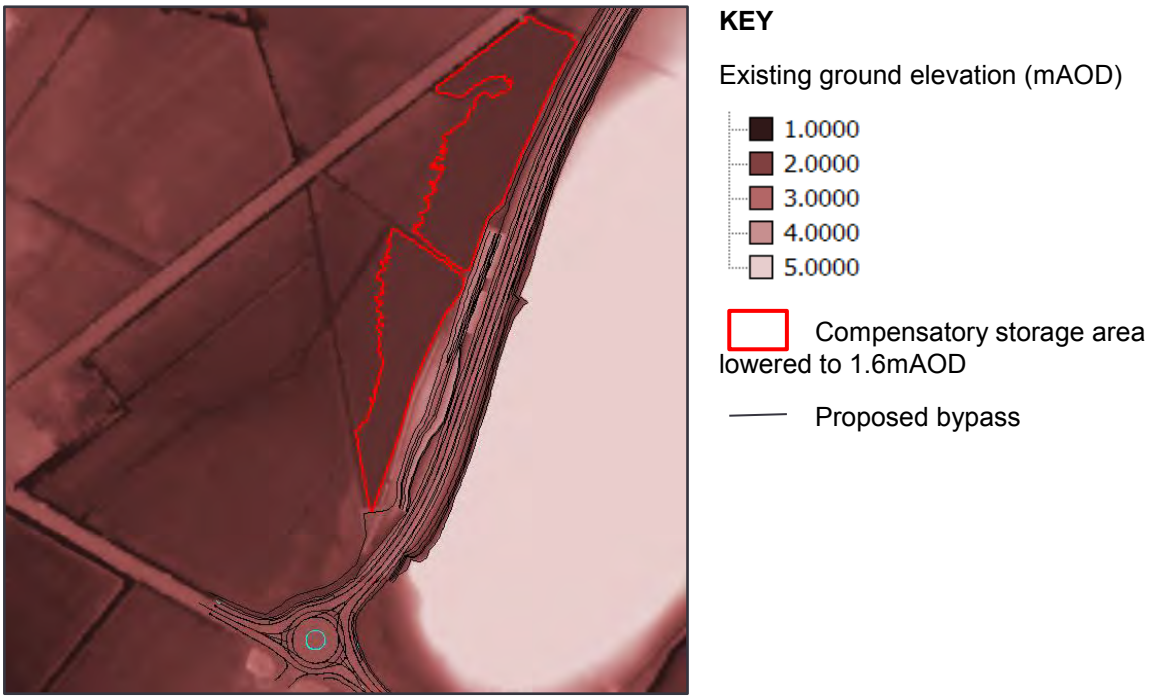
Figure 2.1 Proposed area of compensatory storage



As the proposed compensatory storage volume, available within the proposed compensatory storage area identified on Figure 2.1, will be located at a lower elevation than the current situation, the storage will be utilised earlier during the event than currently. Effectively water will pre-fill these areas and therefore it is not as efficient as providing new storage at the required level. To manage this, the proposed compensatory storage area was over-sized. Approximately 21% additional volume was incorporated in the initial proposed storage area (4,478m^3 compensatory storage volume compared with 3,706m^3 bank top storage loss.

2.3 Hydraulic connectivity

It is essential that the proposed compensatory storage area is hydraulically connected to the location of bank top loss and can thus fill in a similar time frame as currently. The area is crossed by a number of drains that that LiDAR data may not have identified the bed invert[9], but nonetheless are likely to convey water around the general area enabling the proposed compensatory storage area to fill. Although compensatory storage has been designed for the 1:100 AEP event with climate change it is important that the area is connected with the more frequent events as well. A flood inundation map showing the proposed compensatory storage area with the baseline1:5 year AEP event is presented on Figure 2.2. This shows the compensatory storage area has a good connection with the existing flood extent and therefore should not pose an issue in terms of starting to fill at an appropriate time during an event.

[9] Light can be reflected off vegetation in the channel or on the banks, as well as, water levels in the drain and therefore elevations are not a true representation of the existing drain bed invert.

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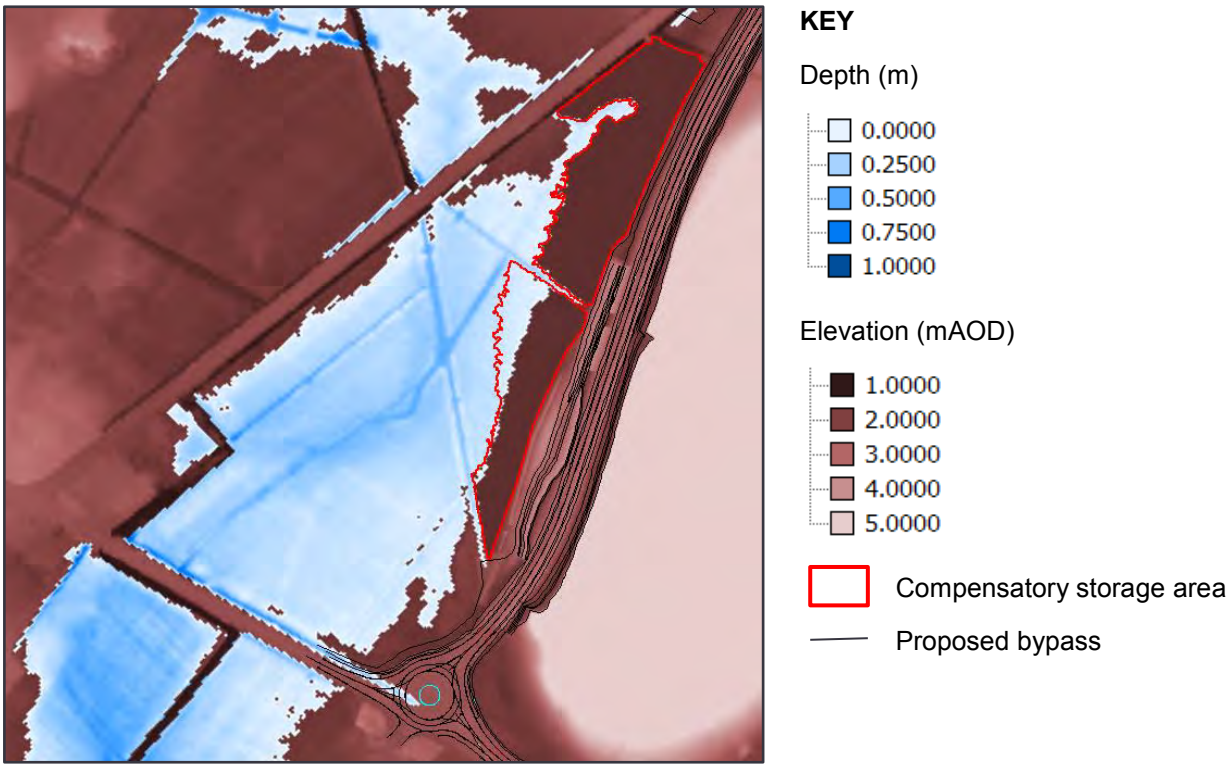
Figure 2.2 Proposed area of compensatory storage with existing 1:5 year AEP event



3 Compensatory design summary

The construction of the proposed bypass and subsequent blockage of an overland flow path to additional current storage results in bank top storage loss of approximately 3,700m^3 during a 1:100 year AEP event with an uplift of 30% representing climate change. There is insufficient ground at higher levels that could be removed to provide level for level compensatory storage. It has been proposed that ground levels are lowered to 1.6mAOD over an area of approximately 15,550m^2 to provide compensatory storage. This will tie into existing ground levels at the western edge of the proposed bypass at a slope of 1:3. This provides an additional 21% volume over the flood water being displaced in order to mitigate against the different timing of use of the bank top storage influencing flood risk to third party receptors.

This represents an initial proposed compensatory storage area, but the proposed new landform will need to be represented in the hydraulic model to determine the impact on water levels. The hydraulic model will be used to represent this initial compensatory storage proposal. If the flood risk is increased significantly for receptors, additional area may be required or alternative mitigation measures may need to be considered. If the flood risk is decreased significantly for receptors, the proposed area may be reduced to reduce spoil.

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Appendix G8-01.4 Section 3 flood modelling results

Horizon Nuclear Power

Wylfa Newydd Associated Development - A5025 Bypass, Llanfachraeth, Anglesey, NW Wales

Hydraulic and Hydrology Modelling Factual Report

January 2018

Amec Foster Wheeler

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Report for

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1. Introduction

1.1 Purpose of this report

This factual report has been produced for the purpose of describing the hydrological and hydraulic modelling undertaken to support the Wylfa Newydd DCO (Development Consent Order) Project, specifically for the proposed A5025 bypass at Llanfachraeth, Anglesey, NW Wales. This factual report does not present an assessment of the results. This factual report provides a detailed statement of the hydrological and hydraulic modelling methods applied, assumptions made and the limitations within the approaches. The report also details the data used together with the results of QA and validation checks.

This report is an Annex to the Flood Consequence Assessment (FCA) for this Offline A5025 bypass at Llanfachreath. The FCA presents a description of the proposal and wider flood risk context justifying the requirement for the hydraulic modelling reported in this document. The FCA presents the flood risk assessment conclusions drawn from the modelled results pertaining to the proposed development.

1.2 Purpose of modelling

1D-2D Modelling has been undertaken to support the assessment of the proposed A5025 bypass at Llanfachraeth, Anglesey, NW Wales, a location plan can be found in Figure 4.1. Modelling has determined the baseline (present day) fluvial and tidal flood risk to the bypass location and nearby receptors, and the future risk including climate change impacts, both with and without the proposed bypass. A range of design flood events have been modelled to establish the full extent of the baseline flood risk, which has then been used to inform the bypass development design. The modelling has also been used to determine the impact of the bypass design on fluvial and tidal flood risk elsewhere in the Llanfachraeth area. A summary of the model scenarios represented by the hydraulic model is shown in Table 1.1; hydrological assessment is required for the fluvial scenarios only. A full Joint Probability Analysis of Fluvial flows and Tidal levels has not been undertaken but a single pre-defined combined fluvial-tidal event has been assessed.

Table 1.1 Summary of model scenarios

Source	Hydrology method	Event	Season	Storm Duration	Epoch	Climate change
Fluvial	ReFH1 with FEH13 rainfall data to WINFAP 3.3.4 peak	QMED[1], 1:20, 1:100, 1:1,000 year AEP	Winter	10.75 hour	2017	n/a
		1:100 year AEP	Winter	10.75 hour	2080s (representing 2114)	30%
Tidal	n/a	1:200, 1:1,000 year AEP	n/a	n/a	2017	n/a
		1:1,000 year AEP	n/a	n/a	2080s (representing 2114)	Sea level rise

AEP = Annual exceedance probability
[1] QMED (median annual maximum flood) used to represent fluvial flow in combination with tidal flood modelling

1.3 Overview of modelling approach

To fulfil the requirements of the Flood Consequence Assessment (FCA) and Natural Resources Wales (NRW) it was necessary to construct a detailed 1D-2D flood model of the Llanfachraeth area to determine

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the impact of the proposed A5025 bypass. The requirements were to develop a robust baseline flood risk position against which the impacts of the propose bypass could be robustly compared. There were no existing models that could be used. The 1D-2D approach was adopted as it was known that a bridge was going to be built and that this bridge would potentially have an impact. The 1D-2D platform is deemed superior when it comes to defining those impacts in specific land parcels.

The 1D-2D hydraulic modelling software used was Flood Modeller - TUFLOW. These are industry standard software packages, widely used for flood modelling. he FCA required the 1:20, 1:100, 1:100+climate change and 1:1000 yr AEP fluvial events to be simulated, along with 1:200, 1:1000 and 1:1000 yr AEP plus climate change tidal events and a combined 1:100 fluvial and 1:200 tidal event. This report presents flood depths, peak water levels and flood extent associated with these return periods

1.4 Key assumptions

A channel topographic survey was conducted in October 2015 of the channels and associated structures. LiDAR data was used to represent the floodplain topography. The following key assumptions have been made:

- It was assumed that the modelled watercourses are not undergoing regular maintenance, and thus 'soft bed' channel survey readings have been utilised in the model build;
- Two lateral inflows are represented in the model; it has been assumed that the flow can be split equally between the nodes at which the flow is applied;
- LiDAR has been used to determine cross sections to extend the model downstream boundary for 1km beyond the surveyed extent. This has been carried out to improve tidal boundary stability;
- Flows from the Tan 'Rallt tributary catchment is represented in the model as a singular inflow;
- USBPR bridge units have the 'orifice flow' option applied if they become surcharged. They also have bypass spill units which ensure water exceeding the level of the bridge deck is transferred within the 1D model to downstream of the structure;
- A site visit undertaken in November 2014, and survey photographs, have suggested the Afon Alaw channel and Llywenan tributary is reasonably regular and consistent along its length, with few substantial changes in shape for width. This has informed survey cross sections spacing, and allowed for interpolate sections to be added to aid model conveyance and stability;
- Aerial photography and site visits have suggested banks are not heavily vegetated for the most part of the modelled channel reaches, and thus assumptions that 1m LiDAR resolution is satisfactory to pick out bank levels and channels between surveyed cross sections; and
- Model extents have been determined in order to prevent any model boundary influence on the focus area around the bypass site location. The model is not intended as a catchment-wide flood extent assessment.

The model is considered the best representation of the Afon Alaw and its tributary Afon Llywenan in the vicinity of Llanfachraeth. The use of the available data was appropriate for this study as the main purpose is to provide an estimate of flood extent across the site and determine the potential impact of the proposed developments. The model has been built for the purpose of flood risk mapping; therefore, it has been optimised for high flows.

1.5 Model review

In addition to internal model QA checks the model was reviewed externally on behalf of NRW (January 2017, by JBA Consulting). A full review of the 1D and 2D components was undertaken, including analysis of the various fluvial and tidal scenario outputs with and without climate change.

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A technical review certificate was produced, the key findings of which are tabulated in Appendix E. Appendix E also provides details on the action taken to address the respective review comment, with supporting information where applicable. The close out actions have also been agreed with the external peer review team.

The model details provided hereafter incorporate any review updates.

1.6 Document structure

The remainder of this report is structured as follows:

- Section 2 - Available data: Identifies data collated or commissioned to aid model build, catchment and structure representation. Discusses any lack of data where appropriate;
- Section 3 - Hydrology: Details the fluvial hydrology assessment;
- Section 4 - Model Overview: Details the representation of the modelled channels in the 1D model domain, and the 2D model domain, including any assumptions made for representations or stability;
- Section 5 - Model Runs: Lists the baseline model scenarios run, including file structures;
- Section 6 - Model Results: Summarises baseline model results, including flood extents and depths;
- Section 7 - Bypass Modelling: Details approach to bypass inclusion and summary of impact on flood levels; and
- Section 8 - Sensitivity Testing: Lists sensitivity runs carried out on the 1D-2D model, and discusses outputs.

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2. Data summary

The 1D-2D model was built following collation of a number of datasets to represent the Llanfachraeth catchment topography, floodplain, structures, channel and banks. Table 2.1 below details data sets collated, and provides a description of the contents of each data set.

Table 2.1 Data summary

Item	Comments
Cross-section survey	Maltby Land Surveys Ltd; October 2015 Surveyed channels: Afon Alaw, Tributary to Afon Alaw, Afon Llywenan Overall location plan: channel and structure locations Drain cross sections (channel shape): bed level (soft/hard); bank levels; water levels; location photos Structure surveys: culverts/bridges/obstructions/walls. The survey was undertaken according to NRW specification
Topography	LiDAR 1m resolution Digital Terrain Model. From Environment Agency (EA) Geomatics, obtained March 2015. The LiDAR data has a stated vertical accuracy of +/- 0.15m
Mapping data	Ordnance Survey (OS) MasterMap (supplied by URS, October 2014)
Gauging stations	No gauging stations.
Calibration / verification events	No calibration events identified due to no gauged data available
Flood history	Natural Resources Wales (NRW) and Isle of Anglesey County Council (IACC) currently have no readily available information on historic flooding.
Tidal Boundary Condition	Supplied by NRW (2015) in response to a standard data request.
Admiralty Tide Data	Provides the harmonics and mean high water spring levels to enable the derivation of the tidal curve. Purchased in 2015

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3. Hydrology assessment

This section summarises the process to derive the hydrology inputs for the hydraulic modelling. A detailed hydrology technical note is provided in Appendix B. The hydrology for Llanfachraeth was developed in early 2016 and issued to NRW for review. The review was completed and all required modifications incorporated into the hydrology assessment in 2016. In the intervening period industry standard hydrological methods and software have been updated. It was however agreed with NRW at a meeting on the 12/04/17 meeting that it was not necessary to update the Llanfachraeth hydrology in support of the August 2017 DCO application, but that this may need to be reviewed in future.

The fluvial hydrology inputs to the hydraulic model were hydrographs (flow/time) for a single critical storm duration, at the bypass location, and a range of events. The hydrology inputs have been calculated for the current baseline at Llanfachraeth.

3.1 Catchment overview

The Afon Alaw flows south-west from Llyn Alaw (reservoir), flowing into Holyhead Bay approximately 2.5km south-west of Llanfachraeth. The Llywenan tributary flows west from Llyn Llywenan (reservoir), flowing into the Afon Alaw at Llanfachraeth approximately 25m upstream of the existing A5025. The Tan 'Rallt tributary flows from Llanddeusant, flowing into the Afon Alaw estuary at Llanfachraeth approximately 500m west of where Afon Alaw flows into the estuary. A site location plan showing these watercourses and their associated FEH catchments is provided in Appendix B (Figure 1.1).

Hydrological assessment locations (HAL) were chosen to represent the inflow at the upper extent of the model (4 - Afon Alaw, 5 - Llywenan tributary, and 6 – Tan 'Rallt tributary) and to calculate intervening catchments on Afon Alaw (2 and 1) and Llywenan tributary(3), as shown in Appendix B (Figure 2.2).

3.2 Method of hydrograph calculation

Hydrological assessment was undertaken for Afon Alaw and the Llywenan and Tan 'Rallt tributaries to determine the fluvial inflow. Hydrographs were required to model the following fluvial events: 1:20 year, 1:100 year and 1:1,000 year AEP events. A further hydrograph was required for the QMED event (1:2 year AEP) in combination with tidal flood modelling.

Catchment boundary and catchment descriptors

The three watercourse catchments identified on the FEH CD-ROM 3 were compared to that derived using OS mapping and topographic data. This showed there was no significant difference in catchment extent apart from the Tan 'Rallt tributary, illustrated in Appendix B (Figure 2.1). The drainage path of an area approximately 3.8km^2 to the north-east of the catchment is dependent on the presence of a culvert under the A5025, which could not be found on site. A conservative approach was undertaken to include this area in the Tan 'Rallt tributary catchment. Flows for hydrological assessment location 6 (Tan 'Rallt tributary) have been calculated using the FEH catchment and then area-weighted to increase the peak flow and ensure that rainfall from all potential contributing areas is represented.

The key hydrological parameters for each location presented in Table 3.1.

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Table 3.1 Key hydrological parameters

Hydrological assessment location (HAL)	Watercourse	Location description	National Grid References (NGR)	Area (km^2)	SAAR* (mm/yr)	FARL*	BFIHOST*	URBEXT* 2000
1	Afon Alaw	Downstream of bypass	SH 31550 82150	56.75	1001	0.789	0.387	0.0042
2	Afon Alaw	Upstream of bypass and Llywenan tributary confluence	SH 31800 82250	47.74	1011	0.776	0.38	0.0037
3	Llywenan tributary	Upstream of bypass and Afon Alaw confluence	SH 31800 82200	8.81	951	0.862	0.418	0.0071
4	Afon Alaw	Upper catchment	SH 32950 82800	45.51	1016	0.767	0.377	0.0033
5	Llywenan tributary	Upper catchment	SH 33100 81400	6.99	960	0.829	0.418	0.00900
6	Tan 'Rallt tributary	Upper catchment	SH 31050 82350	25.04	See FEH Catchment 6			
	Tan 'Rallt tributary	FEH Catchment 6	SH 31050 82350	21.28	980	1.000	0.412	0.0023

Source: FEH CD-ROM 3. From 9 November 2015 FEH CD-ROM data have been available online, however, as this hydrological assessment was largely completed before the launch of the FEH Web Service (CEH, 2016) and it is understood that there is no significant difference to the catchment descriptor data, use of the FEH CD-ROM 3 catchment descriptor data are considered appropriate.
* SAAR = Average annual rainfall in the standard period (1961-1990), FARL = Flood Attenuation by Reservoirs and Lakes index), BFIHOST = Base Flow Index of catchment responsiveness derived using Hydrology Of Soil Type (HOST), URBEXT = Extent of urban and suburban land cover in 1999/2000 expressed as a fraction

Deriving hydrographs

Current guidance from Natural Resources Wales (NRW), in the form of Technical Guidance: Flood Estimation (NRW, 2016), identifies two recommended methods to estimate flow for events up to and including a 1:1,000 year AEP event:

- Flood Estimation Handbook (FEH) statistical method; and
- Revitalised Flood Hydrograph (ReFH) method.

NRW's preferred approach for estimating peak flows up to and including a 1:100 year AEP event is the FEH statistical method based on Technical Guidance: Flood Estimation (NRW, 2016). The FEH statistical method uses pooled annual maxima flow data from a group of hydrologically similar gauged catchments. The ReFH method (CEH, 2007) can be reliably used with small catchments and produces full hydrographs, as required by the hydraulic model.

The ReFH method was used with ReFH 1 software[1] and FEH99 rainfall to derive hydrograph shapes for the required events which were uplifted to the FEH statistical peak. WINFAP-FEH 3 software[2] was used to

[1] ReFH 1 was the current software at the start of the project, subsequently updated to ReFH 2.1 and 2.2. However, the changes associated with the recent software updates are not expected to significantly change the results as the hydrograph will be adjusted to the peak flow derived from the FEH statistical method.
[2] WINFAP-FEH v 3.3.4 was the current software at the start of the project, subsequently updated to v4 (May 2016), v4.1 (May 2016) and v5 (April 2017). However, the additional three water years of gauge data available with v5 is not expected to significantly change the growth curve.

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develop two growth curves for 1) the Afon Alaw assessment points (hydrological assessment locations 1, 2 and 4), and 2) the tributary assessment points (hydrological assessment locations 3, 5 and 6). The statistical method was applied using the most up to date WINFAP database (v3.4.4) at the time of undertaking the calculations. A value of QMED was derived using catchment descriptors, adjusted using the 102001 Cefni at Bodffordd and adjusted for urbanisation. Subsequent discussions with NRW has identified that the Cefni at Bodffordd gauge was not considered suitable for use as a donor, however, as the hydrology assessment and hydraulic modelling had already been completed and the approach represents an uplift of 12% which is conservative, no change was made to the hydrology.

ReFH 1 was used to derive the flow hydrograph shape for the required events, and then adjusted to fit the FEH statistical peak. To derive the FEH statistical 1:1,000 year AEP peak flow, the ratio method was applied based on the ReFH 1 peak flows.

Season profile

As the hydrograph was fit to the FEH statistical peak a winter profile, with greater volume in the hydrograph, represented a conservative approach. It was therefore considered reasonable to adopt the winter profile as the critical season.

Storm duration

As the catchment areas are relatively small, it is expected that the same event will occur across all the catchments simultaneously. The critical storm duration of 10.75 hours was taken for the bypass location, calculated from hydrological assessment location 1 catchment descriptors. The derived hydrograph was fit to the FEH statistical peak.

Climate change allowance

Climate change is applied by using a 30% uplift on the 1:100 year AEP event as per current guidance (Llywodraeth Cymru/Welsh Government, 2016). This is the central estimate for climate change allowance for the 2080s. Although this has been applied to the peak flows for this report, when representing in the model the entire hydrograph was scaled to this adjusted peak.

3.3 Hydrographs for fluvial scenarios

This section presents the hydrographs which were used in the Flood Modeller – TUFLOW hydraulic modelling, based on the approached presented in Section 3.2. The inflow hydrographs derived for the headwaters of each catchment (hydrological assessment locations 4, 5 and 6) were applied directly in the hydraulic model as point inflows to the upstream extent of the hydraulic model representation of Afon Alaw, the Llywenan tributary and the Tan ‘Rallt tributary, respectively.

Lateral inflow hydrographs for the Afon Alaw and the Llywenan tributary are determined through subtracting the upstream hydrograph from the downstream hydrograph. Lateral inflows were not applied between hydrological assessment points 2 and 1 on the Afon Alaw as the method returned a predominantly negative flow.

The derived hydrographs are shown on Figure 3-1, with the peaks listed in Table 3.2. It should be noted that flow values shown on the table for lateral flows for channel reaches 2-4 and 3-5 are for intervening areas between the respective HAL points and not the total values for the point itself.

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Figure 3-1 Final hydrographs to be modelled (1:100, 1:100+CC, 1:1,000 year AEP)

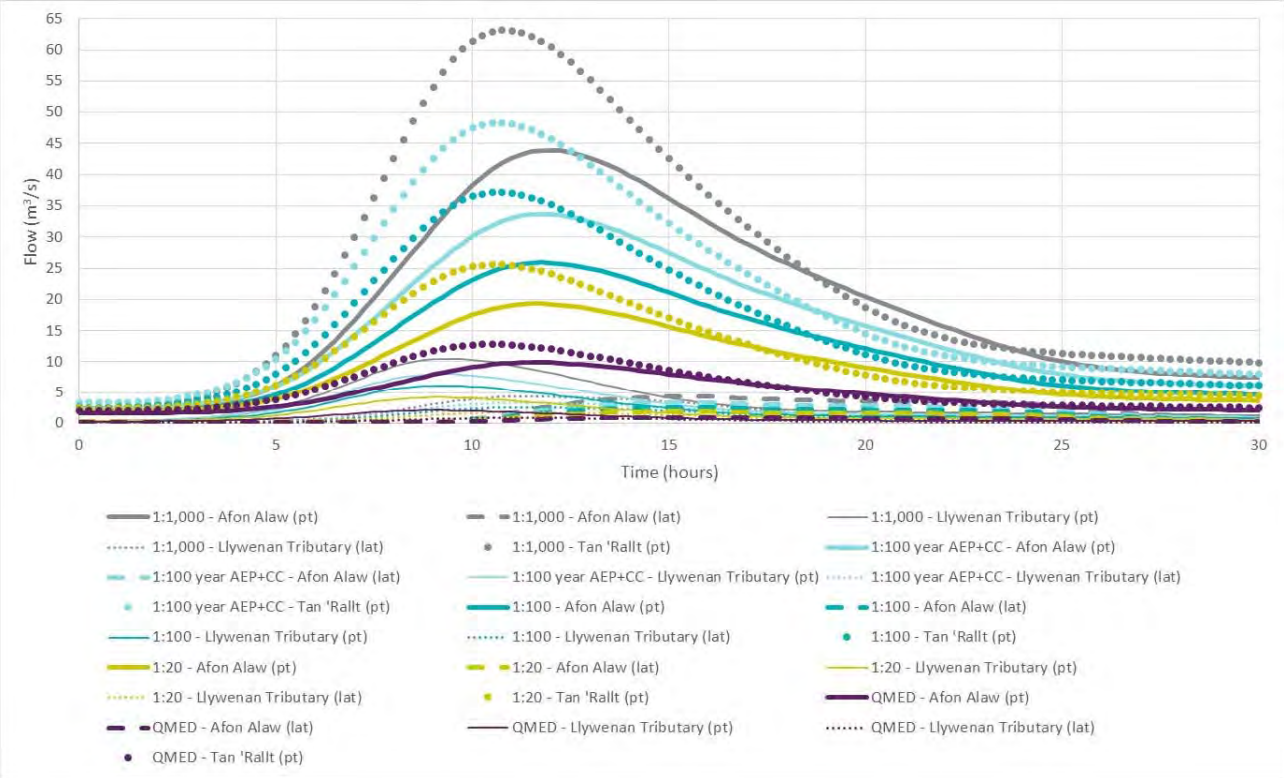

Table 3.2 Final hydrograph peak flows to be modelled in m^3/second

Event	Afon Alaw (HAL 2-HAL4)	Llywenan Tributary (HAL3-HAL5)	Afon Alaw (HAL4)	Llywenan Tributary (HAL5)	Tan 'Rallt Tributary (HAL6)
	Lateral inflow	Lateral inflow	Point inflow	Point inflow	Point inflow
QMED	1.0	0.9	9.9	2.1	12.8
1:20 year AEP	1.9	1.8	19.3	4.2	25.6
1:100 year AEP	2.6	2.6	25.9	6.2	37.1
1:100 year AEP+CC	3.4	3.4	33.7	8.0	48.3
1:1,000 year AEP	4.4	4.4	43.9	10.5	63.1

AEP = Annual exceedance probability
CC = Climate change
HAL = Hydrological assessment location

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4. Hydraulic modelling

4.1 Model overview

This section provides an overview of the 1D-2D integrated hydraulic models built to represent flood flow around the Llanfachraeth bypass development area. The software deployed is detailed in (Table 4.1). The model extent and model schematic are detailed in (Table 4.2 and Figure 4-1).

Table 4.1 Model approach and software

Item	Comments
Model Approach	1D 2D hydraulic modelling approach.
Model Software	1D Model: Flood Modeller v4.2 (previously known as ISIS) 2D Model: TUFLOW Build 2016-03-AE-w64 (single precision)

Table 4.2 Model extent

Watercourse	Channel representation	Floodplain representation	Upstream Limit	Downstream limit	Length/Area of Model
Entire model	Flood Modeller	TUFLOW	232976 382863	230010 381010	4.67 km^2
Afon Alaw	Flood Modeller	TUFLOW	232976 382863	230252 381417	3.75 km (2.82 km surveyed)
Afon Llywenan	Flood Modeller	TUFLOW	233071 381442	231691 382142	2.03 km

231000
232000
233000
383000
382000
381000
N
1
2
3
4
5
6
7
8
9
10
11
12
13

Key

Roughness Zones (Mannings n coefficient)

- 0.015 - Road
- 0.025 - Path, Roadside
- 0.035 - Inland Water
- 0.08 - Rough Grassland, Scrub, Trees
- 0.3 - Buildings, Glasshouse
- 0.04 - Grass, General surface

Model boundary

1D Model Domain

Results Point

Results Line

OS Mastermap

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
Hydraulic Modelling

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Figure 4.1
A5025 Llanfachraeth 1D-2D Hydraulic Model

file: H:\Projects\35989 Wylfa NNB Modelling\Design\Task05_A5025 Bypass\Modelling\Llanfachraeth\Baseline_Results_May_17\Maps

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4.2 1D model

The Llanfachraeth 1D model has been built in Flood Modeller Pro, and represents the Afon Alaw and Afon Llywenan tributary channel. The overview of the 1D baseline model set up is detailed in Table 4.3.

Table 4.3 1D base model overview

Item	Comments
Software & Version	Flood Modeller (previously ISIS) version 4.2 (Latest available release at model review stage).
1D Model Purpose	The 1D 'Flood Modeller' model represents only the channel geometry. Standard cross section units and structure units have been used to represent the watercourses being modelled.
Watercourse Survey	Detailed channel and structure survey was commissioned as part of the project. See Section 2 for summary of data received..
Initial Conditions	Initial conditions have been derived from running the model in unsteady model and then extracting conditions at the 3 hour time step, which is a standard approach using 'Flood Modeller'.
Upstream Boundary	Approximately 1 km upstream of the bypass location on both watercourses. Allows sufficient distance for boundary effects to dissipate upstream of area of interest. Ensures all potential upstream receptors are included in the model.

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Item	Comments
Inflow Boundaries	Model Node ALAW01_2816 (Point Inflow HAL 4 in Table 3.2) ▶ NGR: SH 32950 82800 ▶ No minimum flow ▶ Flow m^3/s, 31.00 hrs duration, last flow extended as a base flow continuation Model Node TRIB01_2027 (Point Inflow HAL 5 in Table 3.2) ▶ NGR: SH 33100 81400 ▶ No minimum flow ▶ Flow m^3/s, 31.00 hrs duration, last flow extended as a base flow continuation Model Node AL_1360_h (Lateral Inflow HAL2 in Table 3.2) ▶ Applied to nodes: Alaw_2277i, Alaw_2161, Alaw_1914, Alaw_1696d and Alaw_1360 (20% of the flow is applied at each of these five nodes within this river reach) ▶ NGR: SH 31800 82250 ▶ No minimum flow ▶ Flow m^3/s, 31.00 hrs duration, last flow extended as a base flow continuation Model Node TR_0428_lh (Lateral inflow HAL3 in Table 3.2) ▶ Applied to nodes: Trib_1552, Trib_1504, Trib_1327i, Trib_1150, Trib_0939, Trib_0819i, Trib_0699, Trib_0630, Trib_0630i, Trib_0482, Trib_0428i and TR_0080 ▶ NGR: SH 31800 82200 ▶ No minimum flow ▶ Flow m^3/s, 31.00 hrs duration, last flow extended as a base flow continuation Model Node AL_0386_l (Point Inflow HAL 6 in Table 3.2) ▶ Applied to nodes: Alaw_0386_i ▶ NGR: SH 31050 82350 ▶ No minimum flow ▶ Flow m^3/s, 31.00 hrs duration, last flow extended as a base flow continuation
Lateral Catchment Weighting	Hydrographs and associated peak flows for Sub-catchments 4 and 5 can be applied as derived since they represent the headwater catchments of their respective watercourses. Lateral inflow points 2 and 3 are intervening catchments and hydrological inputs were derived as adjusted to 'remove' the upstream inflow already represented in the model. . ▶ Lateral inflow 2 The inflow hydrograph has been adjusted to remove the inflow from assessment point 4 (headwater of Afon Alaw). ▶ Lateral inflow 3 The inflow hydrograph has been adjusted to remove the inflow from assessment point 5 (headwater of Tributary to Afon Alaw). Inflow 6 is a point inflow representing the Tan 'Rallt, an un-modelled tributary to the Afon Alaw. It has been entered into the model using a lateral inflow unit, but the entire hydrograph is applied to a single model node, to represent the contribution of the Tan 'Rallt catchment.

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Item	Comments
Downstream Boundary	Model Node ALAW01_-0935 ▶ NGR: SH 230252 381417 ▶ Head-Time boundary node ▶ Tidal boundary data has been derived using NRW data (provided January 2015), and is based on the following steps: ▶ Holyhead tide levels and Admiralty harmonics used in Flood Modeller tide module to create Holyhead tide curves. Source = Coastal flood boundary conditions for UK mainland and islands (report SC060064/TR2), Environment Agency, 2011) ▶ A unit surge curve has been obtained from NRW to represent surges at Holyhead. ▶ Unit surge has been scaled to extreme sea levels provided by NRW, for 1:200 year and 1:1,000 year AEP events, present day and 2114.

	Peak sea level (mAOD)		
Epoch	MHWS	1:200 year AEP	1:1000 year AEP
Present day (2014)	2.6	4.2	4.4
Future (2114) Using uplift factors defined by the 2080s epoch	3.6	5.2	5.5

▶ Scaled surge applied to Holyhead tide curves to produce downstream tidal boundaries for 1:200 year and 1:1,000 year AEP events present day and 2114.

▶ Note the values provided by NRW in 2015 were based on the 2011 climate change guidance, it is acknowledged that during the course of the project new guidance has been issued on sea level rise by the Welsh government (2016). The sea level rise when calculated for the period of 2014-2114 using the 2016 guidance is 1.0m (when rounded to 1dp) as such the future sea level values used in the model are still valid.

▶ MHWS level obtained from Admiralty tide data, the Flood Modeller derived tide curve was adjusted to this level

▶ Tidal cycles shifted back 25.5 hours to allow peak tide to coincide with peak fluvial outflow

▶ Tide levels dropping below 0.9mAOD were set to 0.9mAOD to prevent the lower reaches of the model producing a ‘dry’ flow, which caused the model to fail

▶ The end of the first, small, tide cycle was set to 0.9mAOD to prevent it interfering with initial conditions towards the lower reaches of the model, which caused the model to fail

▶ Total tidal data length 30 hours, to maintain tidal boundary for full length of fluvial hydrograph and model run time

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Item	Comments	
Backwater Length	This is a calculation to work out how far upstream you would expect the model downstream boundary to influence the model results upstream, The calculation ensures that the downstream boundary is far enough from the site of interest to not influence the fluvial results. Modelled backwater length: 1.87km (from downstream boundary to development location) Recommended backwater length (Samuels, 1989): ~ 0.78km *0.7 x (Depth/Slope)* *Max channel depth (bed to bank top) at downstream boundary: ~ 1.60mAOD* *Max bed height at model upstream boundary: ~ 6.903mAOD* *Min bed height at model downstream boundary: ~ 0.229mAOD* *Model length: ~3.75km (longest continuous channel)* *Slope: (6.903 - 0.229) / 3.75 = 1.43* Model downstream boundary taken as estuary of the Afon Alaw. Model extent cannot be taken any further. Recommended backwater length within actual modelled backwater length.	
Model Length (km)	Alaw 01: 3.75km (2.82km surveyed) Trib 01: 2.03km **Total: 5.78km** *See* Table 4.2 *for model channel and tributary grid references*	
Total Number of nodes and structures	**River Section (total)**	86
	River Section (surveyed)	34
	River Section (copied)	7
	River/Estuary Section (using LiDAR data)	4
	River Sections (interpolated using Flood Modeller Pro)	41
	Junctions	10
	Bridges	2
	Sluices	0
	Orifices	3
	Conduits (culverts upstream and downstream)	4
	Culvert Inlet (General Loss)	2
	Culvert Outlet	2
	Weirs (general purpose)	0
	Weirs (sharp crested)	0
	Inline Spills	4
	Lateral Spills	0
	Spills over structures	4
	Reservoirs	0
	QH CONTROL	0
	ReFHBDY	0
	QTBDY	5 (2 main, 3 lateral)
	HTDBDY	1 (tidal)

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Item	Comments
Interpolates and copy sections	Site visits have suggested the Afon Alaw channel and Llywenan tributary is reasonably regular and consistent along its length, with few substantial changes in shape or width. This has informed requested survey cross sections spacing, and allowed for interpolate sections to be added to aid model convergence and stability.
Labelling/ Numbering System	ALAW01_#### (for sections along Afon Alaw) TRIB01_#### (for sections along Tributary to Afon Alaw) Where #### represents chainage upstream from the downstream boundary Node names may be suffixed by the following: _u upstream copy of surveyed node _d downstream copy of surveyed node _ci culvert inlet _co culvert outlet _cu culvert unit upstream face _cd culvert unit downstream face _s spill unit _h lateral hydrological inflow unit _i interpolate river section Where labelling exceeds the permitted number of characters, the '01' prefix has been dropped from the node label.
Structure representation	See Appendix C - Structure representation
Structure coefficients	Structure coefficients have been determined following inspection of the structure survey drawings and photos. Standard values have been used, based on best practice guidance and modeller experience. Structure coefficients would usually be adjusted during a calibration process if sufficient data is available. For this project modelling, sensitivity testing has been undertaken instead as there was not sufficient calibration data.
Hydraulic roughness values	See Appendix D – Channel roughness representation. 1D roughness values taken from published descriptions of Manning's roughness values in Chow (1959) and Syme (2008)

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Item	Comments
Other information / alterations made to model	Bridges Due to instabilities during change of mode of flow through bridges, the option has been enabled to allow surcharged bridges to be modelled as orifice flow (Alaw01_1040; Al_2174bu). Weirs Due to instabilities in the model causing flow oscillations, the following weirs have instead been modelled as in-line spills, with the weir cross-sectional profile entered as the spill profile: Trib01_2027w; Alaw01_1696; Alaw01_1122; AL_1040uu. Culverts Due to instabilities in the model causing flow oscillations, the following culverts have instead been modelled as orifice units: Tr_1844_01; Tr_1844_02; Tr_0008_ou. The adoption of an orifice unit at Tr_0008_ou is applicable as the structure is a simple stone spanning the channel. There is limited length in the structure, thereby lending itself to an orifice unit rather than conduit/culvert as friction losses will not be significant. The use of and office unit at Tr_1844_01 and Tr_1844_02 is also appropriate. The Flood Modeller software supports the use of an orifice unit for an orifice and short culvert. Analysis of the long section model behaviour in the vicinity of the orifice locations shows no oscillation. Time series outputs for a variety of scenarios confirm smooth, convergent model behaviour. River units Additional river units have been added to the section of the 1D model downstream of the last surveyed river unit. This is to ensure the tidal curve boundary propagates through the downstream section of the model with less instabilities. The river unit cross-sectional profiles have been taken from LiDAR elevations, which were slightly adjusted to more realistically represent the channels long section slope in the downstream section. River units added are: Alaw01_-0235; Alaw01_-0500; Alaw01_-0700; Alaw01_-0935. River Cross Sections Due to instabilities in the model, some cross sections which had been surveyed very close to each other have been removed from the 1D network. This allows smoother convergence between the cross section nodes. The sections removed are: Alaw01_2503 and Alaw01_1122;. At Alaw01_1122 the surveyed cross sections were very close together resulting in a very small distance (<5m) between sections. The model was unstable in this area and removing this section solved the instability. Other options to resolve the instability were tried prior to this, but were not satisfactory. The most representative sections were chosen to be retained. In addition, it is the weir in this vicinity that controls the hydraulic behaviour.

See Appendix C for details of survey locations and structure representation.

See Appendix D for details of channel roughness.

4.3 2D model

The Llanfachraeth 2D model domain has been built in TUFLOW and represents the floodplain and wider catchment of the Afon Alaw and Afon Llywenan channels. The overview of the 2D baseline model set up is detailed in Table 4.4.

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Table 4.4 2D model overview

Item	Comments
Resolution of grid / 2D cell size	3 metres. The level of detail required to model floodplain requires a relatively detailed cell size. The LIDAR resolution in the area is 1m and it is best practice for the grid-size to be no smaller than twice the resolution of the LIDAR.
Orientation of grid	South West to North East (orientation of main floodplain flow direction)
Model extent	Bounded in the south by the Afon Alaw Estuary, leading into the Cymyran Strait, and the topographic catchment boundaries in the north, east and west. The northern extent of the model area is 1 km upstream of the proposed bypass site.
2D boundary conditions	Point source inflows are represented in 1D model – as detailed in Table 4.3. The 2D domain links to the 1D domain through links between cross-section nodes and the river banks in the 2D model in layer '1d_Llan_Base_Nodes_009'. The 2D downstream boundary is represented on the left and right bank adjacent to the final 1D cross section, at the Afon Alaw estuary. The south western boundary uses a tidal head-time (HT) boundary. There was no controlled boundary along the northern, eastern and western limits of the 2D domain (i.e. the edge of the 2D domain acts as a glass wall where topography does not naturally contain the flood extent). The eastern and western limits to the 2D domain are formed along the topographic boundary of the catchment. The northern boundary forms a glass wall at the top of the modelled area and forces the fluvial inflow to flow downstream. The active 2D area (2d_code_Llan_003) is sufficiently large enough so as not to artificially influence flood flows. This allows tidal inflow to the model domain when the tide level is higher than ground level, outflow will occur if the tide level in the boundary condition permits.
Ground Model	LIDAR DTM with 1m resolution purchased from Environment Agency Geomatics, October 2014. The initial LIDAR based DTM has been checked thoroughly for possible missing flow routes, such as road bridges, culverts beneath railway embankments etc., as well as null LIDAR areas.
Topographic modifications	2d_zsh_Llan_Base_002: Raises LiDAR elevation on right bank of cross section ALAW01_2161 to correct low point which survey data and photography did not give any evidence for. Topography raised to 6.867 mAOD. Possible topography error caused here by vegetation and trees presence. 2d_z___Llan_Base_002: Raises LiDAR elevation on both banks of cross section TRIB01_2027 to represent the sides of narrow channelized section either side of the weir. Topography raised to 13.135 mAOD. 2d_zln_Llan_Base_002: Raises LiDAR elevation at the two bridges along the Afon Alaw (ALAW01_2487 and ALAW_1040) to more accurately represent the elevation of the bridge deck as per survey data.
Representation of buildings	Buildings have been represented at ground level with an increased roughness of n=0.3 (Syme, 2008). This approach allows for impedance to flow given by the buildings and for flood volume to be dissipated within the area of the buildings.
Representation of river banks	LiDAR has been used to represent river bank tops as surveyed bank tops between cross sections is not available. The LIDAR is assumed to be representative of the bank heights observed on site. Checks have been carried out between the bank levels in the surveyed cross section data and the LIDAR to ensure they are acceptably consistent. Aerial photography and site visits have suggested banks are not heavily vegetated for the most part of the modelled channel reaches, and thus assumptions that 1m LiDAR resolution is satisfactory to pick out bank levels and channels between surveyed cross sections.
1D-2D Link	The 1D-2D link has been digitised along the top of bank (2d_bc_Llan_Base_016). The 'Flood Modeller' cross sections are a width consistent with the 1D-2D link and deactivated area in the 2D TUFLOW model. Slight alterations of locations of banks were occasionally made in the 1D-2D link to ensure the 1D banks matched the 2D LiDAR bank locations, however bank levels were generally in agreement when located correctly.

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Item	Comments	
Initial conditions	Aside from a specific area of initial water level added for tidal boundary stability (2d_iwl_Llan_Base_001), the model will start as a 'dry' model with no previous flooding in the floodplain. However, the simulation covers 30 hours - a long enough period to ensure the flood zoning is representative of the maximum flood extent. Initial water levels of 0.9mAOD have been applied downstream of cross section Alaw01_0000 (the surveyed channel extent of the Afon Alaw). This has been applied to stabilise the tidal boundary application across the Afon Alaw estuary, and does not take up floodplain storage across the 2D model domain surrounding the surveyed channel extents or proposed bypass site.	
Inflows	Inflows are represented in the 1D model only.	
Delineation of roughness areas	OS Mastermap and publicly available aerial photography was used to determine roughness of the 2D zone surface types in the floodplain (2d_mat_Llan_Base_002 and 2d_mat_stability_Llan_Base_002).	
Hydraulic roughness values	**2D Surface**	**Roughness Value** (Chow, 1959; Syme, 2008)
	Land/Grass/general surface	0.04
	Buildings/glasshouses/structures	0.3
	Rough grassland/ scrub / Trees	0.08
	Inland Water	0.035
	Path/Roadside/Rail	0.025
	Road	0.015
	Stability	0.1

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5. Model runs

The 1D-2D Llanfachraeth model build described in Section 4 has been run for baseline fluvial and tidal flood events, for a range of annual exceedance probabilities. The model was then run with bypass design development scenarios. The following section lists the document structures and naming conventions for the model run files (Table 5.1), along with details of each baseline model run completed (Table 5.2).

Table 5.1 Model folder structure and file names

Folder	File	Description
Flood Modeller		
dat (Flood Modeller model data file)	Llan_Base_035.dat Llan_Base_035_n+50.dat Llan_Base_035_n-50.dat Llan_Base_035_s+20.dat Llan_Base_035_s-20.dat	Baseline model 1D network. Sensitivity scenario models 1D network. n+50 denotes Manning's roughness coefficient being increased by 50% for the given baseline simulation. n-50 denotes Manning's roughness coefficient being decreased by 50% for the given baseline simulation. s+20 denotes structural coefficients being increased by 20% for the given baseline simulation. s-20 denotes structural coefficients being decreased by 20% for the given baseline simulation.
ied (Flood Modeller event data file)	Llan_Base_20yr_002.ied Llan_Base_100yr_003.IED Llan_Base_100yr+cc_003.IED Llan_Base_1000yr_002.IED Llan_Base_QMED_002.IED Llan_Base_QMEDcc_003.IED Llan_MWHS(2114)_001.IED Llan_MWHS_002.IED Llan_T200(2014)_001.IED Llan_T200(2114)_001.IED Llan_T1000(2014)_001.IED Llan_T1000(2114)_001.IED	Baseline event file for fluvial events. Baseline event file for tidal events.
lef (Flood Modeller run data file)	Llan_Base_1D035_2D023_F20.ief Llan_Base_1D035_2D023_F100.ief Llan_Base_1D035_2D023_F100CC.ief Llan_Base_1D035_2D023_F1000.ief Llan_Base_1D035_2D023_F100ccT200cc.ief Llan_Base_1D035_2D023_T200.ief Llan_Base_1D035_2D023_T1000.ief Llan_Base_1D035_2D023_T1000cc.ief Llan_Base_1D035_2D023_F100_n+50.ief Llan_Base_1D035_2D023_F100_n-50.ief Llan_Base_1D035_2D023_F100_s+20.ief Llan_Base_1D035_2D023_F100_s-20.ief Llan_Base_1D035_2D023_T200_n+50.ief Llan_Base_1D035_2D023_T200_n-50.ief Llan_Base_1D035_2D023_T200_s+20.ief Llan_Base_1D035_2D023_T200_s-20.ief Llan_Base_1D035_2D023_F100_dp.ief	Baseline simulation file for 1D2D model, where 1D035 refers to the 1D dat file used in the simulation, and 2D023 refers to the 2D bc file. F and T denotes if the results represent a Fluvial or Tidal event. 'cc' denotes where the results have been run for an event which includes climate change impacts. Simulation file for sensitivity runs 1D2D model.

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Folder	File	Description
▶ **Iic (Flood Modeller Initial Conditions file)**	LLAN_BASE_1D035_2D023_F1000_3hr.iic	Baseline initial conditions for 1D model.
▶ **Results**		
▶ **Baseline**	Llan_Base_1D035_2D023_F20 Llan_Base_1D035_2D023_F100 Llan_Base_1D035_2D023_F100CC Llan_Base_1D035_2D023_F1000 Llan_Base_1D035_2D023_F100ccT200cc Llan_Base_1D035_2D023_T200 Llan_Base_1D035_2D023_T1000 Llan_Base_1D035_2D023_T1000cc	Standard Flood Modeller 1D results files for each baseline run including: .exy, .uic, .zzd, .zzl, .zzn, .zzu, .zzx
▶ **Sensitivity**	Llan_Base_1D035_2D023_F100_n+50 Llan_Base_1D035_2D023_F100_n-50 Llan_Base_1D035_2D023_F100_s+20 Llan_Base_1D035_2D023_F100_s-20 Llan_Base_1D035_2D023_T200_n+50 Llan_Base_1D035_2D023_T200_n-50 Llan_Base_1D035_2D023_T200_s+20 Llan_Base_1D035_2D023_T200_s-20 Llan_Base_1D035_2D023_F100_dp	Standard Flood Modeller 1D results files for each sensitivity run including: .exy, .uic, .zzd, .zzl, .zzn, .zzu, .zzx
▶ **TUFLOW**		
▶ **Bcdbase (TUFLOW boundary conditions database file)**	bc_dbase_Llan_001_MHWS(2014).csv bc_dbase_Llan_001_MHWS(2114).csv bc_dbase_Llan_001_T200(2014) .csv bc_dbase_Llan_001_T200(2114) .csv bc_dbase_Llan_001_T1000(2014) .csv bc_dbase_Llan_001_T1000(2114) .csv Llan_MHWS(2014)_001.csv Llan_MHWS(2014)_002.csv Llan_MHWS(2114)_001.csv Llan_MHWS(2114)_002.csv Llan_T200(2014)_001.csv Llan_T200(2014)_002.csv Llan_T200(2114)_001.csv Llan_T200(2114)_002.csv Llan_T1000(2014)_001.csv Llan_T1000(2014)_002.csv Llan_T1000(2114)_001.csv Llan_T1000(2114)_002.csv	bcdbase holds the boundary condition links for the 2D domain. For Llanfachraeth, this holds the link to the tidal boundary. 2014 / 2114 refers to the epoch for the scenario (present or future). The bcdbase links to two further csv files which hold the relevant calculated tidal time series.
▶ **Checks (TUFLOW check file)**	Llan_Base_023_F20_MHWS(2014) Llan_Base_023_F100_MHWS(2014) Llan_Base_023_F1000_MHWS(2014) Llan_Base_023_F100CC_MHWS(2114) Llan_Base_023_QMED_T200(2014) Llan_Base_023_QMED_T1000(2014) Llan_Base_023_QMEDcc_T1000(2114) Llan_Base_023_F100cc_T200(2114)	Standard TUFLOW check files in MID/MIF MapInfo format, including: 1d_to_2d_check; grd_check; bcc_check; zpt_check. F and T denotes if the results represent a Fluvial or Tidal event. 'cc' denotes where the results have been run for an event which includes climate change impacts. 2014 / 2114 refers to the epoch for the scenario (present or future).

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Folder	File	Description
▶ **Run (TUFLOW run file)**	LLAN_Base_023_F20_MHWS(2014).tcf LLAN_Base_023_F100_MHWS(2014).tcf LLAN_Base_023_F1000_MHWS(2014).tcf LLAN_Base_023_F100CC_MHWS(2114).tcf LLAN_Base_023_QMED_T200(2014).tcf LLAN_Base_023_QMED_T1000(2014).tcf LLAN_Base_023_QMEDcc_T1000(2114).tcf LLAN_Base_023_F100cc_T200(2114).tcf LLAN_Base_023_F100_MHWS(2014)_n+50.tcf LLAN_Base_023_F100_MHWS(2014)_n-50.tcf LLAN_Base_023_F100_MHWS(2014)_s+20.tcf LLAN_Base_023_F100_MHWS(2014)_s-20.tcf LLAN_Base_023_QMED_T200(2014)_n+50.tcf LLAN_Base_023_QMED_T200(2014)_n-50.tcf LLAN_Base_023_QMED_T200(2014)_s+20.tcf LLAN_Base_023_QMED_T200(2014)_s-20.tcf LLAN_Base_023_F100_MHWS(2014)_dp.tcf	Standard TUFLOW run files. Base denotes the baseline scenario model is being run. Sensitivity run files. n±50 denotes Manning's 1D roughness coefficient increased/decreased by 50% and 2D increased/decreased to reasonable upper and lower limits for respective land cover type. s±20 denotes 1D structural coefficients increased/decreased by 20%. 'dp' denotes double precision run (all other runs use single precision).
▶ **Model (TUFLOW model file)**	Llan_Base_018.tbc Llan_Base_022.tgc Llan_02.tmf Llan_02_n+50.tmf Llan_02_n-50.tmf	Standard TUFLOW model files: tbc – details the boundary conditions tgc – details the geometry files tmf – details the material layer and roughness values Base denotes the baseline scenario model is being run. n±50 denote the percentage increase or decrease in manning's n for the sensitivity runs.
▶ **Results**		
▶ **Baseline**	LLAN_Base_023_F20_MHWS(2014) LLAN_Base_023_F100_MHWS(2014) LLAN_Base_023_F1000_MHWS(2014) LLAN_Base_023_F100CC_MHWS(2114) LLAN_Base_023_QMED_T200(2014) LLAN_Base_023_QMED_T1000(2014) LLAN_Base_023_QMEDcc_T1000(2114) LLAN_Base_023_F100cc_T200(2114)	Standard TuFLOW 2D results files for each baseline run including: .2dm, .ALL, .hV, .mat, _d.dat, _h.dat, _MB.csv, _MB1.dat, _MB2.dat, _MB2D.csv, _PO.csv, _POMM.csv, _q.dat, _Times.dat, _TS.mid/mif, _v.dat.zzx, and _ZUK0.dat.
▶ **Sensitivity**	LLAN_Base_023_F100_MHWS(2014)_n+50 LLAN_Base_023_F100_MHWS(2014)_n-50 LLAN_Base_023_F100_MHWS(2014)_s+20 LLAN_Base_023_F100_MHWS(2014)_s-20 LLAN_Base_023_QMED_T200(2014)_n+50 LLAN_Base_023_QMED_T200(2014)_n-50 LLAN_Base_023_QMED_T200(2014)_s+20 LLAN_Base_023_QMED_T200(2014)_s-20 LLAN_Base_023_F100_MHWS(2014)_dp	Standard TuFLOW 2D results files for each baseline run including: .2dm, .ALL, .hV, .mat, _d.dat, _h.dat, _MB.csv, _MB1.dat, _MB2.dat, _MB2D.csv, _PO.csv, _POMM.csv, _q.dat, _Times.dat, _TS.mid/mif, _v.dat.zzx, and _ZUK0.dat. n represents sensitivity tests on Manning's roughness s represents sensitivity tests on structure coefficients dp represents test on precision.

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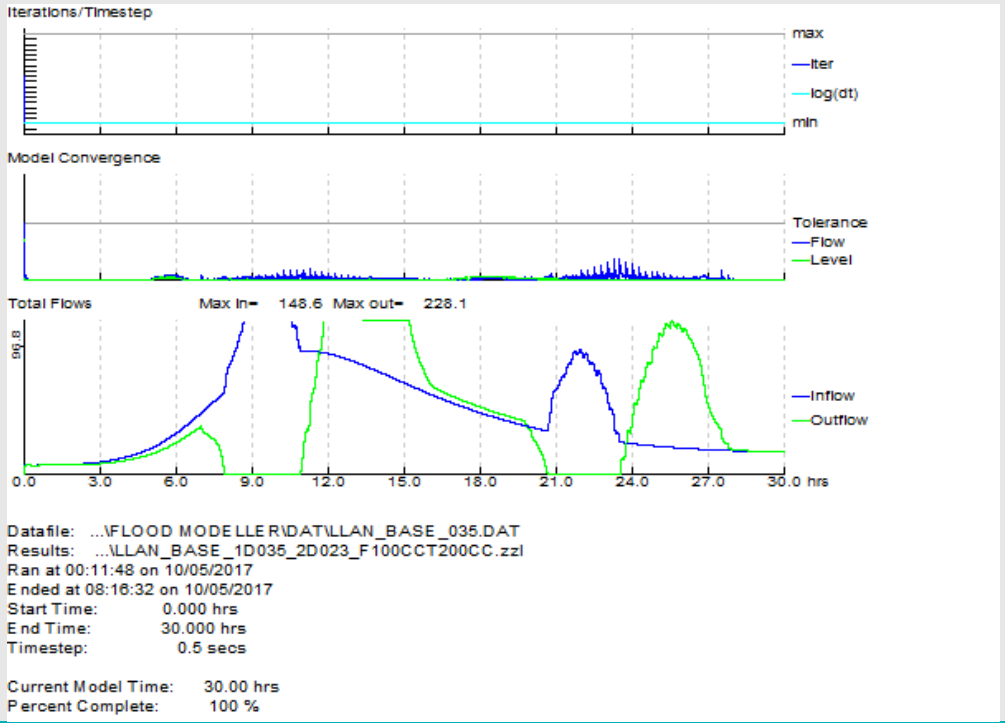
Table 5.2 Design runs

Baseline design event[3]	F20	F100	F1000	F100cc	T200	T1000	T1000cc	F100cc T200cc
1D run model files (.ief)	*Llan_Base_1D035_2D023_F20.ief*	*Llan_Base_1D035_2D023_F100.ief*	*Llan_Base_1D035_2D023_F1000.ief*	*Llan_Base_1D035_2D023_F100CC.ief*	*Llan_Base_1D035_2D023_T200.ief*	*Llan_Base_1D035_2D023_T1000.ief*	*Llan_Base_1D035_2D023_T1000cc.ief*	*Llan_Base_1D035_2D023_F100ccT200cc.ief*
2D model files (.tcf)	*LLAN_base_023_F20_MHWS(2014).tcf*	*LLAN_base_023_F100_MHWS(2014).tcf*	*LLAN_base_023_F1000_MHWS(2014).tcf*	*LLAN_base_023_F100CC_MHWS(2114).tcf*	*LLAN_base_023_QMED_T200(2014).tcf*	*LLAN_base_023_QMED_T1000(2014).tcf*	*LLAN_base_023_QMEDcc_T1000(2114).tcf*	*LLAN_base_023_F100cc_T200(2114).tcf*
Model run parameters and settings	Default parameters were used for all settings except those listed below: dflood: 10 maxitr: 19 Orifice linearization head (m): 0.1 These parameters were increased slightly from the default to improve model convergence, the values remain within an acceptable range.							
1D model stability	Flow and Stage graphs for 1D long section and cross sections do not highlight any oscillations or instabilities. 1D convergence .bmp files (e.g. plot below) indicate no non-convergence in models, which would be visible as a red line which is not present. Influence of tidal signature noted in bmp file.							



[3] Where F denotes fluvial and T denotes tidal. For fluvial runs a MHWS downstream boundary was applied. For tidal runs a QMED flow was applied to the watercourse. The number refers to the AEP event e.g. 20 = 1:20 year AEP event. CC denotes climate change, this has been determined as a 30% increase for fluvial flows with tide levels increased in line with NRW projected extreme sea level data for 2114.

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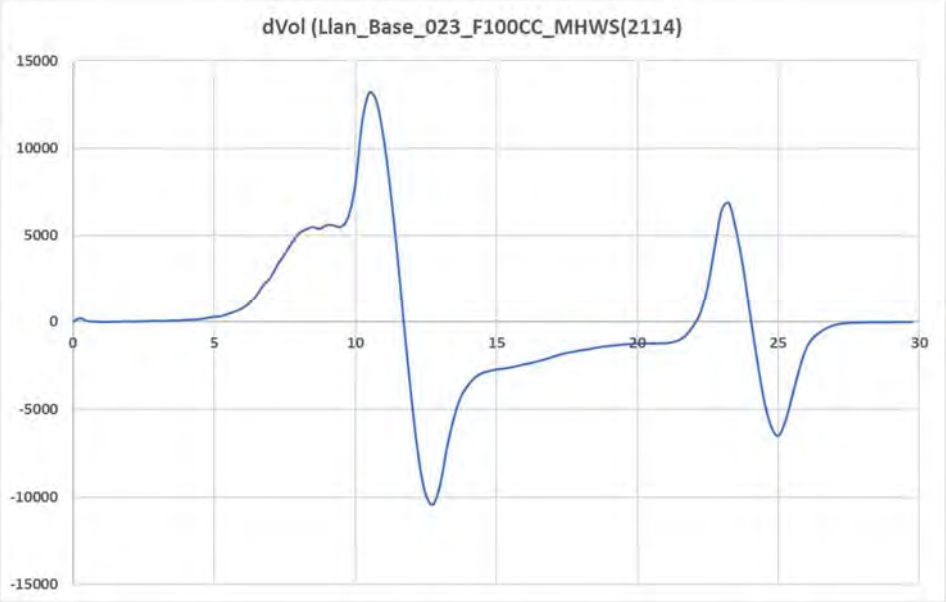
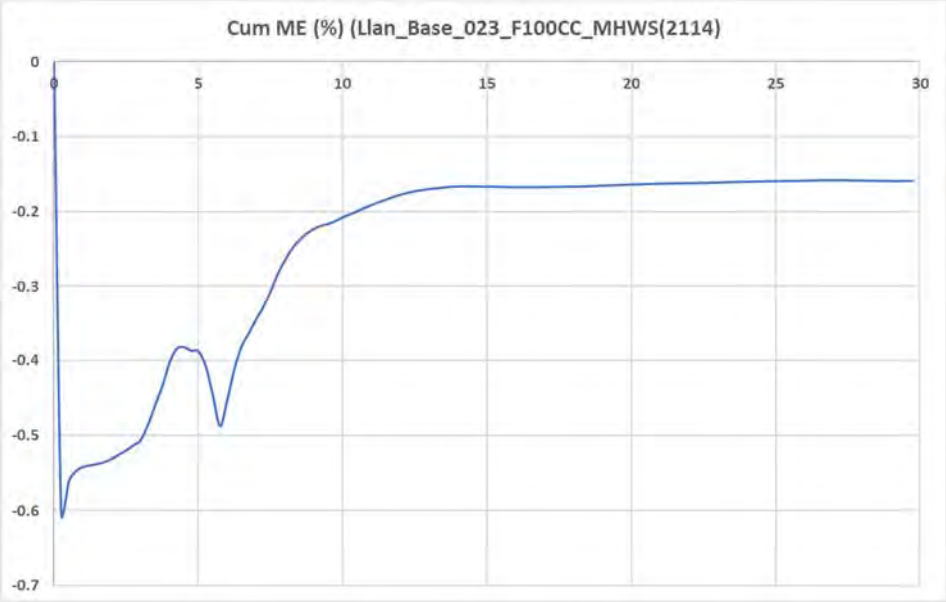
2D model stability	dVol and Mass Balance plots are stable and show no oscillations or instabilities.  
Model warnings	No model warnings (1D/2D) other than standard warnings for culverts and orifice's becoming surcharged

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6. Baseline model results

Analysis of the flood mechanism is discussed in Section 6.1 and a summary of the results obtained from the baseline hydraulic modelling are discussed in Section 6.2. These results present the current day and future flood risk (with climate change) to the study area in the baseline condition. Results are presented as water levels extracted from 1D nodes immediately upstream of the proposed bypass location and via maps illustrating the fluvial and tidal flood extents. Appendix A contains the following flood depth and extent maps which depict the baseline flood estimates:

Figure 6-1 A5025 Llanfachraeth baseline peak fluvial flood extents.

Figure 6-2 A5025 Llanfachraeth baseline peak fluvial depth 1:20 year AEP present day.

Figure 6-3 A5025 Llanfachraeth baseline peak fluvial depth 1:100 year AEP present day.

Figure 6-4 A5025 Llanfachraeth baseline peak fluvial depth 1:1000 year AEP present day.

Figure 6-5 A5025 Llanfachraeth baseline peak fluvial depth 1:100 year AEP climate change (30%).

Figure 6-6 A5025 Llanfachraeth baseline peak tidal flood extents.

Figure 6-7 A5025 Llanfachraeth baseline peak tidal depth 1:200 year AEP present day.

Figure 6-8 A5025 Llanfachraeth baseline peak tidal depth 1:1000 year AEP present day.

Figure 6-9 A5025 Llanfachraeth baseline peak tidal depth 1:1000 year AEP climate change (2114).

Figure 6-10 A5025 Llanfachraeth baseline peak combined fluvial depth 1:100 year AEP climate change (30%) and peak tidal depth 1:200 year AEP climate change (2114).

6.1 Flooding mechanisms

The mechanisms of flood propagation vary with each of the different baseline model simulations (listed in Table 5.1) . Flood propagation mechanisms varies depending if the event being simulated is a fluvial dominated or tidally dominated event. For completeness, the 1:100 year AEP fluvial event and the 1:200 year AEP tidal events are described below.

Fluvial 1:100 year AEP event

Analysis of the flood propagation shows that flooding starts on the Afon Alaw upstream of the A5025 road bridge and in the upper and mid reaches of the Llywenan tributary. As the event progresses the flooding in these areas extends further and flooding also starts in the upstream reaches of the Afon Alaw and around the area of Neuadd-Wen as a result of the tidal level and estuary flood mechanism. By the peak of the event (peak here refers to the time of the peak of the hydrograph) flooding is seen on both banks along the majority of the Afon Alaw and Llywenan tributary, within the study area. The A5025 road bridge is a clear hydraulic control on the flood behaviour. In the 1:100 year AEP event there is a 0.3m headloss through the A5025 road bridge. Flood propagation of the 1:100 year AEP fluvial event is shown on Figure 6-11.

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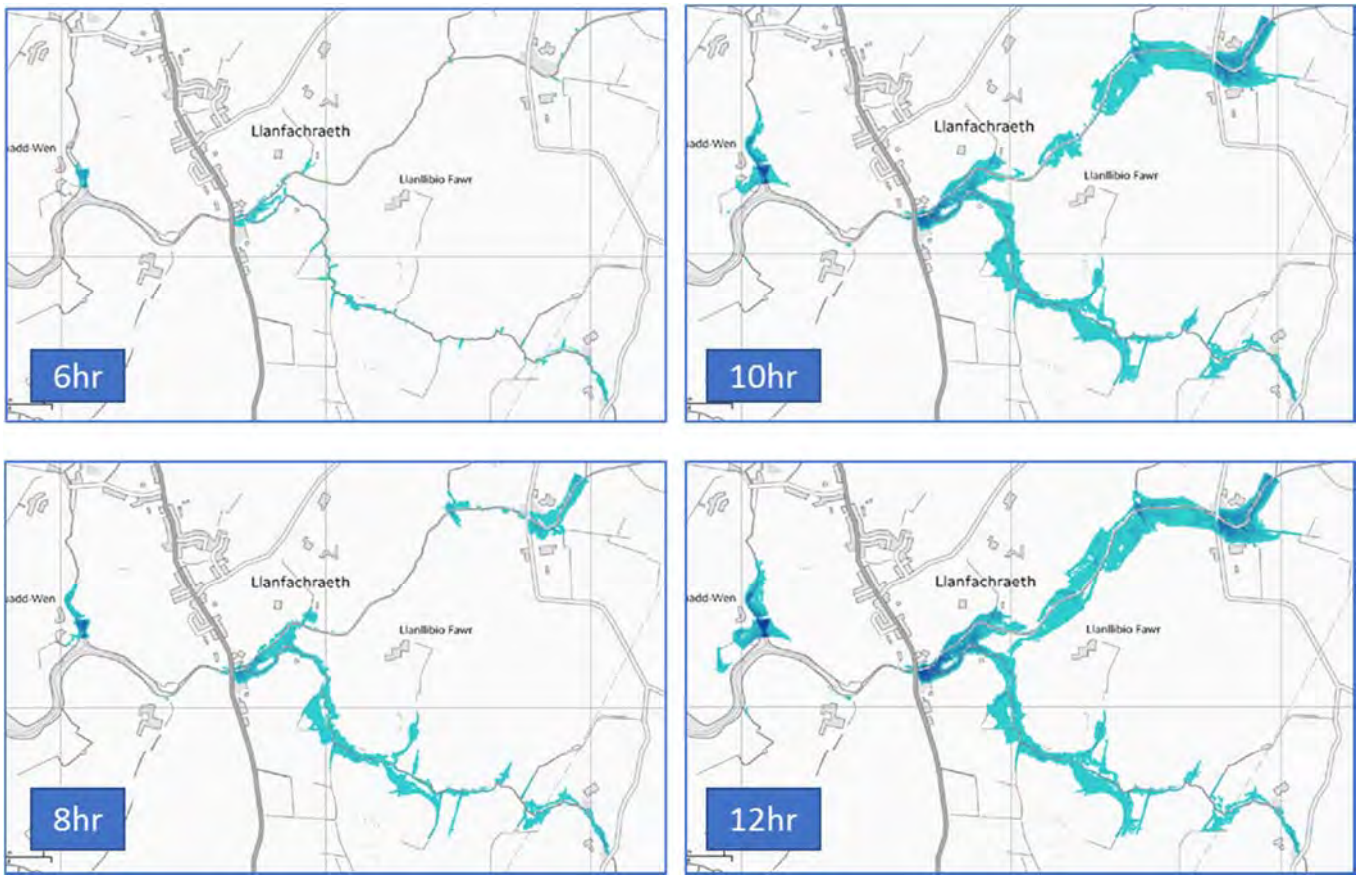
Figure 6-11 Fluvial 1:100 year AEP event – flood propagation



Note: times denote time since the start of the flood event (time zero on the inflow hydrograph)

Tidal 1:200 year AEP event

Analysis of the flood propagation shows that flooding starts on the right bank of the Afon Alaw estuary and around the area of Neuadd-Wen as a result of the tidal level and estuary flood mechanism. There is limited flooding upstream of the A5025 road bridge on the Afon Alaw. As the event progresses the estuary flooding extends on the right bank and commences on the left bank. By the peak of the event the majority of the flooding is via the estuary, downstream of the A5025 road bridge. In the upstream area of the A5025 road bridge, the flooding extends to the confluence of the two watercourses. Flood propagation of the 1:200 year AEP tidal event is shown on Figure 6-12.

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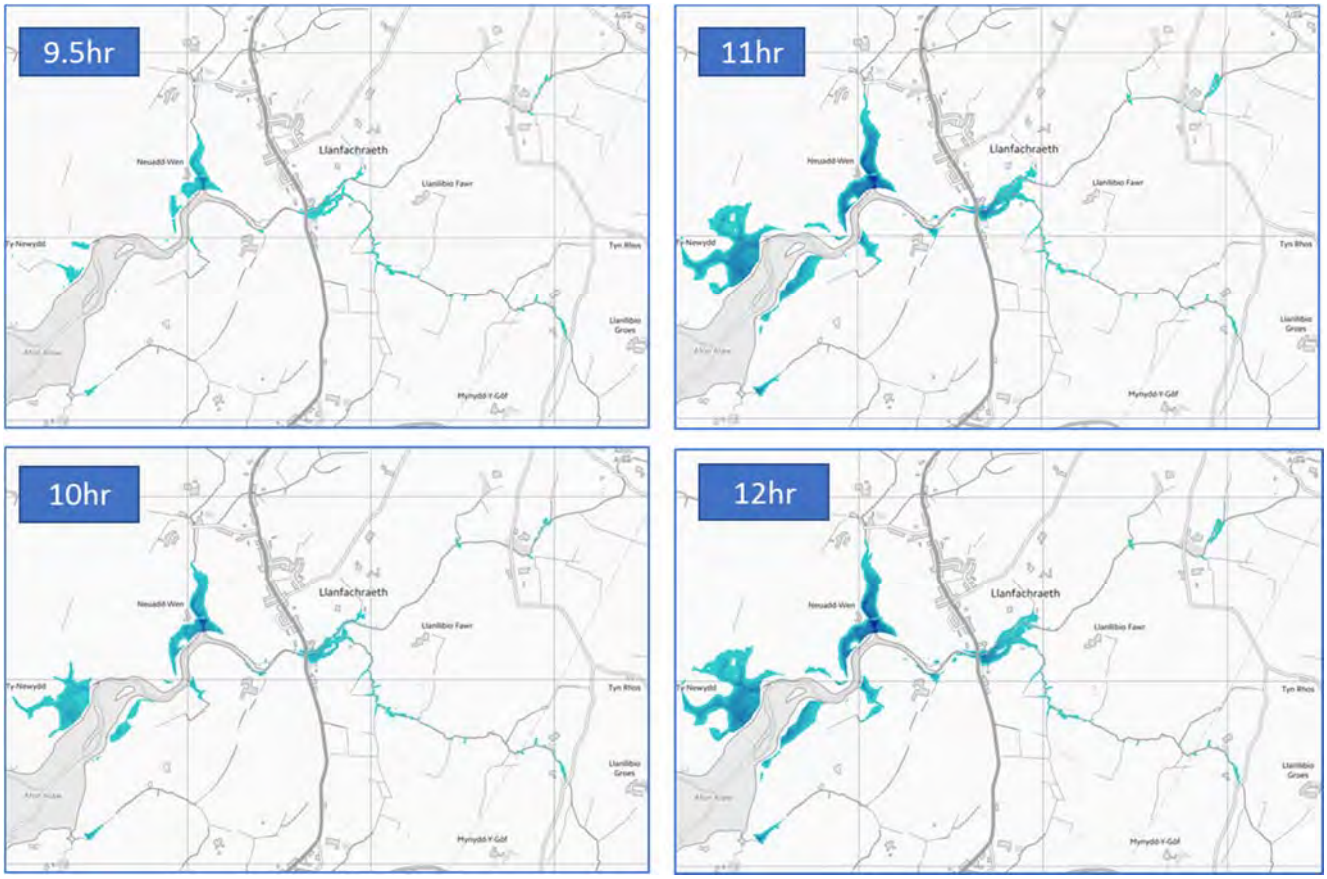
Figure 6-12 Tidal 1:200 year AEP event – flood propagation



Note: times denote time since the start of the flood event (time zero on the inflow hydrograph)

Other events

The local topography generally constrains the flood extent upstream of the A5025 road bridge, with little difference seen between flood extents for different modelled annual exceedance probabilities (for both fluvial and tidal events, respectively) around the location of the proposed bypass (shown in red on Figure 6-13). Further upstream on the Afon Alaw the difference between extents is more apparent, although the Llywenan tributary remains topographically constrained until its most upper reaches. Pathways for the fluvial flood extents are, as expected, sourced from the two main modelled channels, however at the location where the 1D results are extracted (Figure 6-13) the conveyance pathways from the two channels merge and no individual pathway from either channel can be distinguished. A similar pathway characteristic is noted for the tidal events, with the main source the Afon Alaw estuary.

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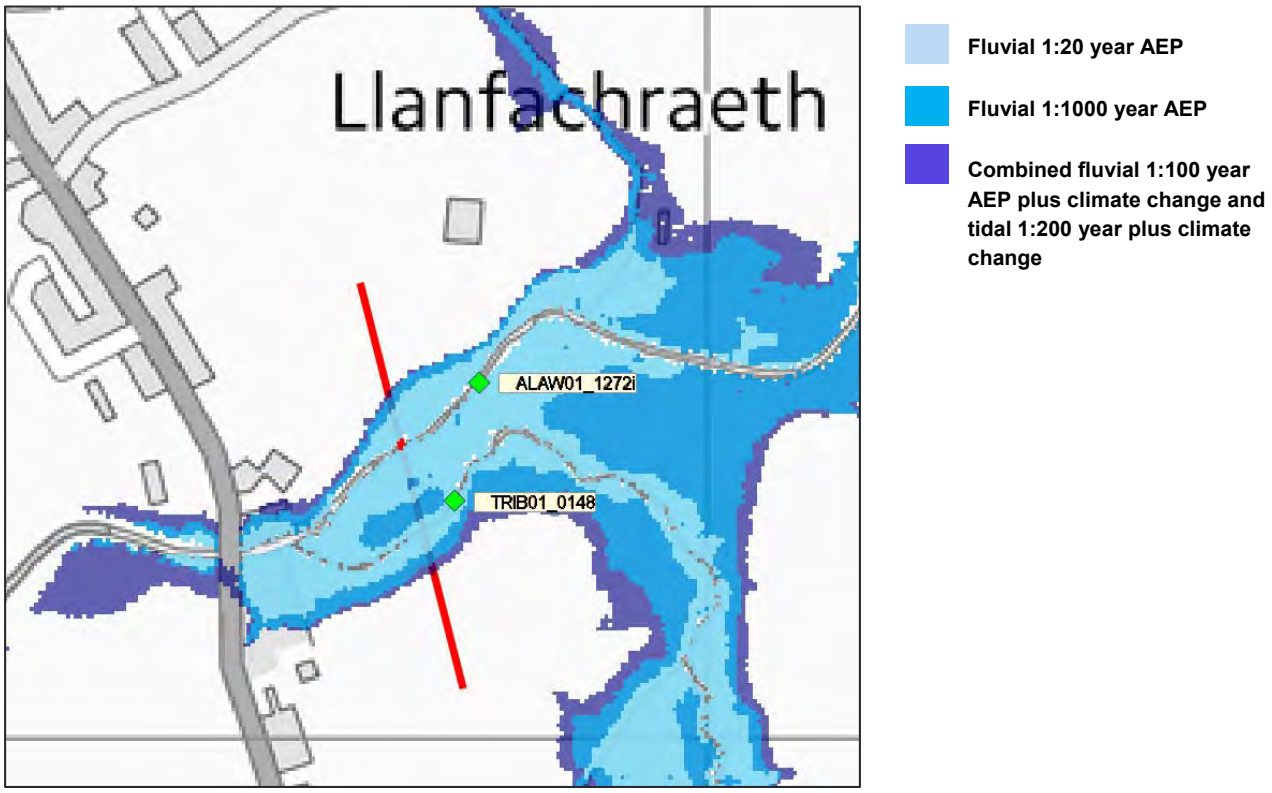
Figure 6-13 Baseline Flood extent at proposed by-pass location



The peak water levels have been extracted from the 1D model (Table 6.1) on the Afon Alaw and Llywenan Tributary immediately upstream of the proposed bypass development site, at the two nodes detailed on Figure 6-13. The baseline peak water levels are shown to reach similar levels in both the Afon Alaw and Afon Llywenan, ranging between 4.04 mAOD and 5.66 mAOD across all the events. The maximum peak is noted in the combined fluvial 1:100 year AEP plus climate change and tidal 1:200 year plus climate change event, with water levels peaking at 5.66mAOD in the Afon Alaw.

Figure 6-1 to Figure 6-5 (fluvial events) and Figure 6-6 to Figure 6-10 (tidal events) in Appendix A illustrate the baseline flood extent across the 2D domain.

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Table 6.1 Baseline peak water levels at 1D nodes immediately upstream of development location

Scenario		Maximum water level at node (mAOD)	
		ALAW01_1271i (1D)	TRIB01_0148 (1D)
Baseline	F20	4.26	4.04
	F100	4.48	4.33
	F1000	5.20	5.16
	F100cc	4.81	4.74
	T200	4.31	4.29
	T1000	4.49	4.47
	T1000cc	5.59	5.59
	F100ccT200cc	5.66	5.65

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7. Bypass modelling

Analysis of the impact of the bypass structure on the flood risk and the changes to the flood mechanism is discussed in this Section. Background to the structure inclusion within the model and summary of the results obtained from the hydraulic modelling are discussed. Results are presented as water levels extracted from 1D nodes immediately upstream of the proposed bypass location and in difference depth grids illustrating the impact spatially across the Llanfachraeth area.

Appendix A contains the following flood depth and extent maps which describe the bypass flood hazard:

Figure 7-1 A5025 Llanfachraeth 'with bypass' peak fluvial depth 1:20 year AEP present day.

Figure 7-2 A5025 Llanfachraeth 'with bypass' peak fluvial depth 1:100 year AEP present day.

Figure 7-3 A5025 Llanfachraeth 'with bypass' peak fluvial depth 1:1000 year AEP present day.

Figure 7-4 A5025 Llanfachraeth 'with bypass' peak fluvial depth 1:100 year AEP climate change (30%).

Figure 7-5 A5025 Llanfachraeth 'with bypass' peak tidal depth 1:200 year AEP present day.

Figure 7-6 A5025 Llanfachraeth 'with bypass' peak tidal depth 1:1000 year AEP present day.

Figure 7-7 A5025 Llanfachraeth 'with bypass' peak tidal depth 1:1000 year AEP climate change (2114).

Figure 7-8 A5025 Llanfachraeth 'with bypass' peak combined fluvial depth 1:100 year AEP climate change (30%) and peak tidal depth 1:200 year AEP climate change (2114).

Figure 7-9 A5025 Llanfachraeth peak fluvial depth difference - 1:20 year AEP present day.

Figure 7-10 A5025 Llanfachraeth peak fluvial depth difference - 1:100 year AEP present day.

Figure 7-11 A5025 Llanfachraeth peak fluvial depth difference - 1:1000 year AEP present day.

Figure 7-12 A5025 Llanfachraeth peak fluvial depth difference - 1:100 year AEP climate change (30%).

Figure 7-13 A5025 Llanfachraeth peak tidal depth difference - 1:200 year AEP present day.

Figure 7-14 A5025 Llanfachraeth peak tidal depth difference - 1:1000 year AEP present day.

Figure 7-15 A5025 Llanfachraeth peak tidal depth difference - 1:1000 year AEP climate change (2114).

Figure 7-16 A5025 Llanfachraeth peak tidal depth difference combined fluvial 1:100 year AEP climate change (30%) and Tidal 1:200 year AEP climate change (2114).

7.1 Modelling approach

The 'with bypass' modelling encompassed three key changes to the baseline topography:

- New DTM (*rev_viaduct_topo.asc*) to incorporate the bypass embankment levels. This inherently included the ground local to the piers immediately adjacent to the embankments.
- Flow constriction layer (*2d_fcsh_llan_bypass_001.mif*) to represent the impact of the three floodplain piers on the flow of water.
- New roughness layer (*2d_mat_Llan_bypass_001.mif*) to represent the change in roughness due to the bypass structure.

The drawings *WN02.05-ACM-SCH-018.pdf* and *Revised Viaduct Design (OS Coordinates).dwg* were used to inform the pier locations and design. Three piers are located across the floodplain and the respective grid cells impacted by each pier were reproduced in the flow constriction layer and the percentage blockage per cell populated.

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In addition the .tgc file was updated to include reference to the new DTM, flow constriction layer and roughness layer (*Llan_Base_022_bypass.tgc*).

The revised roughness considered three key land types to represent the road, pathway and embankment based on the drawing layers in drawing '*Revised Viaduct Design (OS Coordinates).dwg'*. The piers are not included explicitly in the new roughness layer as the flow constriction layer already restricts flow due to the piers and therefore inclusion in the roughness layer would double count the impact on flow.

The *'_input_layers.mif'* file was used to check that the layers being read in the 'with bypass' model were correct. In addition, the *'_fcsh_uvpt_check_point.mif'* file was used to ensure that the pier blockage was being used to modify the uv points accordingly. Visual checks on the results confirmed that the model was detecting the presence of the embankment and impact of the blockage ratio at the pier locations.

7.2 Flood mechanism

Analysis of the 'with bypass' flood mechanism similar behaviour as the baseline flood mechanism. Analysis of the flood propagation shows that flooding starts on the Afon Alaw upstream of the A5025 road bridge and in the upper and mid reaches of the Afon Llywenan. As the event progresses the flooding in these areas extends further and flooding also starts in the upstream reaches of the Afon Alaw and around the area of Neuadd-Wen because of the tidal level and estuary flood mechanism. By the peak of the event, flooding is seen on both banks along the majority of the Afon Alaw and Afon Llywenan, within the study area. The existing A5025 road bridge remains a clear hydraulic control on the flood behaviour.

Review of the modelling results indicates that there is flooding in present day conditions from the 1:20 year AEP event. Inclusion of the bypass does impact the resultant water levels. The impact on the resultant flood depth is analysed in Section 7.3.

7.3 Flood depths

The impact of the bypass on water levels and therefore flood depths is described in two ways:

1) By means of change in depth of flooding at the two previously analysed 1D model cross section nodes: one on the Afon Alaw and one on the Afon Llywenan, both immediately upstream of the bypass location; and

2) By mapping the difference in flood depths across the 2D domain for each scenario assessed.

1D flood depths

The impact of the bypass on water levels in the Afon Alaw and Afon Llywenan is shown in Table 7.1. Water levels in the Afon Alaw are impacted more than the Afon Llywenan, with a maximum increase across all events analysed of 0.09m (fluvial 1:100 year AEP event), as opposed to 0.02m on the Afon Llywenan.

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Table 7.1 Bypass peak water levels at 1D nodes immediately upstream of development location

Scenario		Bypass maximum water level at node (mAOD) and difference (m) to maximum baseline water level			
		ALAW01_1271i (1D)	*Difference*	**TRIB01_0148 (1D)**	*Difference*
With bypass	**F20**	**4.31**	*+0.05*	**4.06**	*+0.02*
	F100	**4.57**	*+0.09*	**4.35**	*+0.02*
	F1000	**5.27**	*+0.07*	**5.18**	*+0.02*
	F100cc	**4.89**	*+0.08*	**4.75**	*+0.01*
	T200	**4.33**	*+0.02*	**4.29**	*0.00*
	T1000	**4.50**	*+0.01*	**4.48**	*+0.01*
	T1000cc	**5.59**	*0.00*	**5.59**	*0.00*
	F100ccT200cc	**5.68**	*+0.02*	**5.66**	*+0.01*

Notes: where difference values are +ve this implies that the bypass is increasing water levels

2D flood depths

The impact of the bypass on water levels across the floodplain is shown for each annual exceedance probability in Figure 7-17 (below) and Table 7.2 details the range of impact for each scenario. Analyses of the results show that the maximum increase in water levels is experienced on the upstream face of the northerly embankment, where floodwater conveyance is constrained causing attenuation. Reduction in water level is observed downstream of the bypass structure for all fluvial events compared to in baseline conditions.

It is evident that the impact of the bypass on flood extent is greater as the magnitude of the fluvial event increases. The impact of the bypass on the flood extent is also greater in the 1:1,000 yr than the 1:200 yr AEP tidal event. There is generally no observable difference between the baseline 1:1,000 yr AEP plus climate change event and the with bypass 1:1,000yr AEP plus climate change event. Analysis of the T1000cc event shows the difference between the baseline and with bypass is within the negligible impact range of 'no change' (-0.005m to +0.005m). Only isolated changes in peak water levels are observed at the embankment faces and local to the piers.

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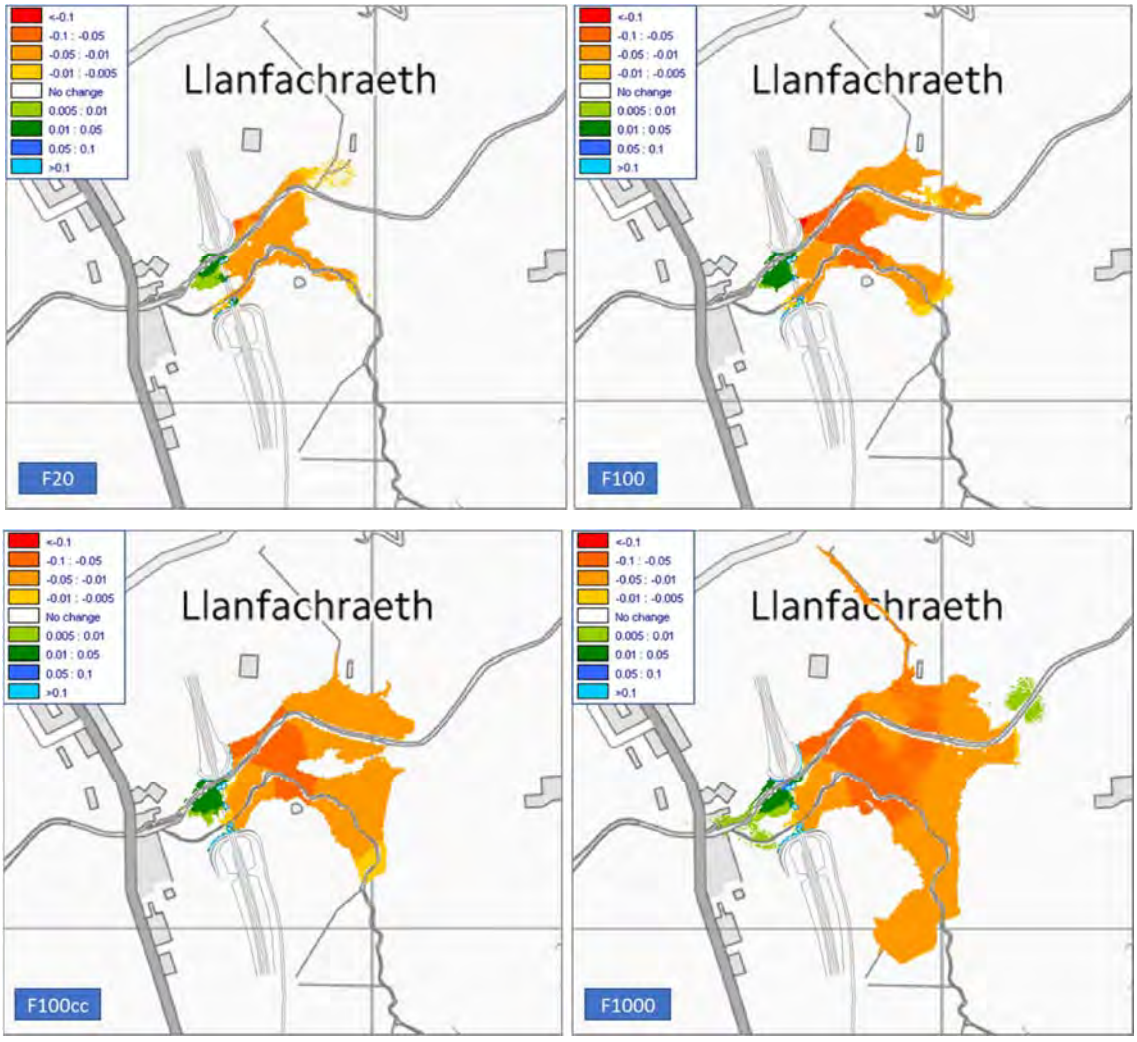
Table 7.2 Range of impact from bypass on water levels in the 2D Domain

Scenario		Range of impact (m): Negative shows adverse impact to water levels; positive shows benefit to water levels	
With bypass	F20	-0.078	0.552
	F100	-0.113	0.865
	F1000	-0.083	1.471
	F100cc	-0.092	1.252
	T200	-0.052	0.881
	T1000	-0.053	1.045
	T1000cc	-0.080	1.887
	F100ccT200cc	-0.031	1.925

Figure 7-17 Difference depth grids (m)



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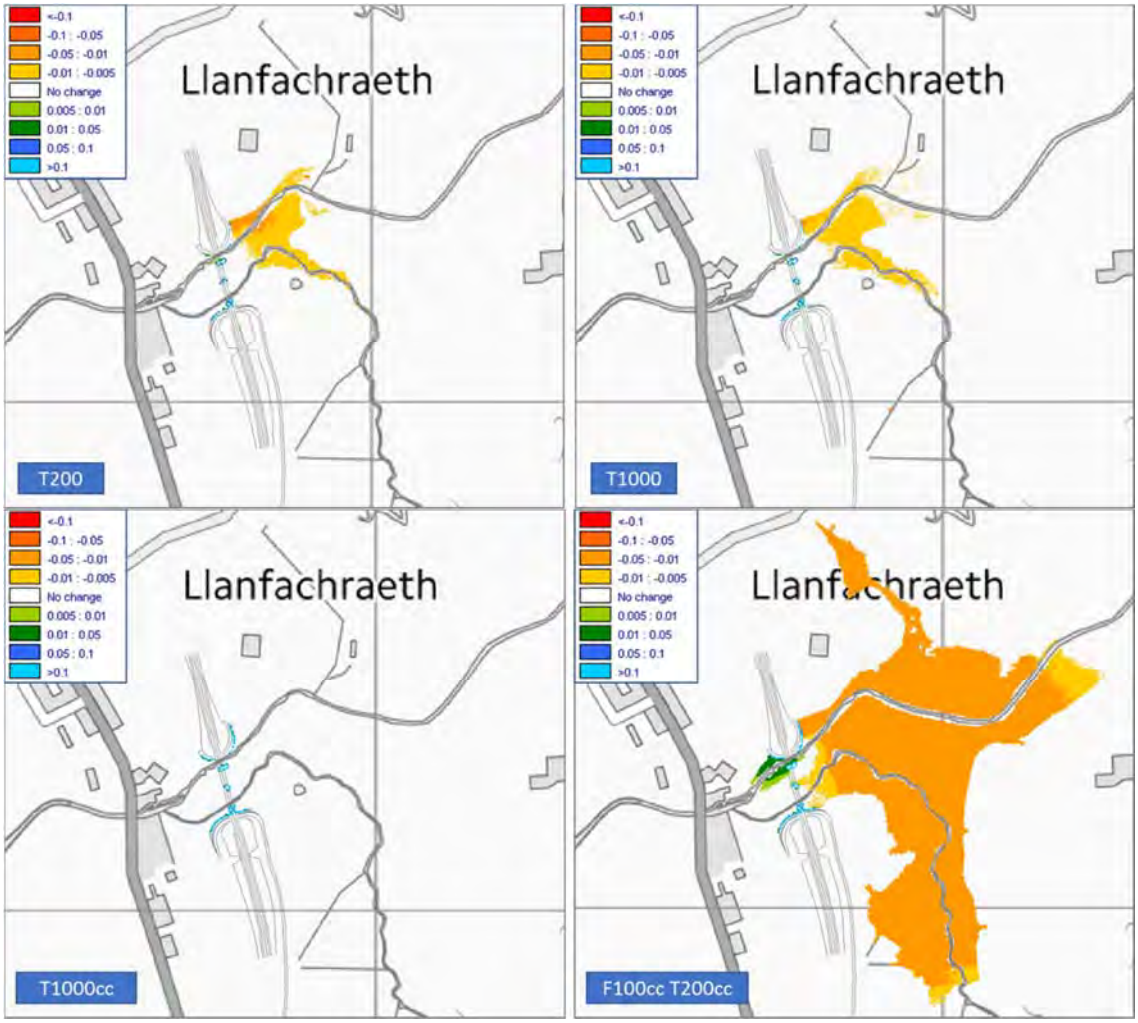

7.4 Summary of bypass impact

- The inclusion of the bypass has a maximum impact of 0.11m increase on water levels (fluvial 1:100 year AEP event), observed on the upstream face of the bypass northern embankment.
- The water level immediately upstream of the bypass is increased in the Afon Alaw and Afon Llywenan by 0.09m and 0.02m respectively.
- The bypass reduces fluvial flood levels immediately downstream of the bypass structure and local to the structure itself.

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8. Sensitivity testing

The purpose of sensitivity testing is to test the validity of the underlying assumptions in the model, and ensure the model is behaving as expected under various underlying uncertainties. Sensitivity testing provides a means of assessing how sensitive the predicted depths are to changes in the model parameters and assumptions. It is clear that if a parameter is changed then the resultant flood depth could change. The objective of the sensitivity testing is to highlight the potential range of change associated with adjusted parameters so as to provide confidence in the value selected.

Section 8.1 details the sensitivity tests undertaken, and their application in the 1D and 2D model domains. A discussion on the results then follows in Section 8.2, with conclusions in Section 8.3. Additional scenarios used to further test the robustness of the model and its performance are then presented, including a test on the downstream tidal boundary is Section 8.3, a comparison of the results produced when changing the 2D model precision in Section 8.5, and finally a comparison between hydrographs produced by different hydrological methods in Section 8.6.

8.1 Sensitivity test method

Sensitivity to model parameters and hydrology have been tested for the Llanfachraeth 1D-2D model. Table 8.1 below details the application of the tests in the 1D and 2D model domains.

Table 8.1 Sensitivity test methods

Test	Description
Test 1	a) Manning's (n) roughness increase b) Manning's (n) roughness decrease
1D application	All cross section Manning's n roughness values increased and decreased by 50%, including bridges and structures where relevant (i.e. conduit friction)
2D application	For the 2D domain the absolute values are increased and decreased to reflect the realistic upper and lower limits of each landuse class. Land/Grass/general surface – baseline 0.04; test 0.05 / 0.03 (max/min, rough grass) Buildings/glasshouses/structures – baseline 0.30; test 0.5 / 0.01 (max/min, building) Rough grassland/ scrub/Trees – baseline 0.08; test 0.11 / 0.06 (max/min, mixed vegetation) Inland Water/Tidal Water – baseline 0.035; test 0.045 / 0.025 (max/min, inland water) Path/Roadside – baseline 0.025; test 0.03 / 0.02 (max/min, pavement) Road – baseline 0.015; test 0.017 / 0.013 (max/min, road) Stability – baseline 0.10; remains as 0.10 for model stability.
Test 2	a) Structure coefficient + 20% b) Structure coefficient - 20%
1D application	The following structure coefficients increased and decreased by 20% from default value: Culvert Inflow – K; M; C; Y; Ki Orifice – Weir Flow; Surcharged Flow Bridge – Orifice discharge coefficient (where applied) Spill units – Weir coefficient.
2D application	No change in 2D domain
Test 3	Orifice flow not applied at upstream bridge
1D application	Change to bridge unit AL_2174bu so that orifice flow is not applied when the bridge surcharges.
2D application	No change in 2D domain

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Test 4	Simulation parameters. Changes to the advanced parameters detailed in the.ief file: a) 'dflood' set to default (reduced from 10m to 3m) b) 'maxitr' set to default (reduced from 19 to 11)
1D application	No change
2D application	No change in 2D domain
Test 5	Additional 1D roughness change
1D application	The 1D roughness (Manning's n) was increased globally to 0.07 for all channel sections
2D application	No change in 2D domain
Test 6	Storm duration Additional storm durations were tested for the 1:100 year AEP fluvial event, to test sensitivity to storm duration
1D application	The hydrological boundary conditions were adjusted to match the hydrograph produced by each storm duration
2D application	No change

8.2 Sensitivity test summary results

The following sensitivity test sections**Error! Reference source not found.** detail the differences in water levels from the baseline and the sensitivity runs. **Error! Reference source not found.**Differences in water level are sampled from 1D nodes on the Afon Alaw and Afon Llywenan tributary, immediate upstream of the proposed bypass development location. Water levels are also extracted from a plot observation results line (PO line) in the 2D domain – as depicted on Figure 4.1.

Test 1: Manning's (n) roughness (+/- 50%)

Modelled water levels for Manning's roughness sensitivity tests are shown to be within 0.3m difference from the water levels of the same baseline 1:100 year AEP fluvial event (Table 8.2). Water level differences are also shown to be of a similar range in both the 1D and 2D nodes (i.e. in the river channel, and across the floodplain). Differences in water levels are high but within the range that would be expected for a Manning's roughness sensitivity test, where 'n' values are varied as much as 50%. 50% represents a significant change in channel condition a decrease would represent a more maintained channel, and the increase represents a less maintained heavily vegetated channel. Results also show that time to peak is also slightly longer where Manning's roughness values are increased, as expected.

Modelled water levels for the 1:200 year AEP tidal event (Table 8.2**Error! Reference source not found.**) are less sensitive, with a maximum difference of 0.06m. This shows that the tidal level is less influential than the fluvial flow at the locations analysed, as a consequence of a tidal flood event being a level driven flood event as opposed to a flow driven flood event. Water level differences are also shown to be of a similar range in both the 1D and 2D nodes (i.e. in the river channel, and across the floodplain).

A further test on the model sensitivity to roughness is assessed in Test 5.

Table 8.2 Roughness sensitivity tests 1a and 1b summary results

Node	Maximum water level 1:100 year AEP fluvial event (mAOD)					Maximum water level 1:200 year AEP tidal event (mAOD)				
	Baseline	Test 1a (+50%)	Difference (m)	Test 1b (-50%)	Difference (m)	Baseline	Test 1a (+50%)	Difference (m)	Test 1b (-50%)	Difference (m)
ALAW01_1272i (1D)	4.48	4.72	0.24	4.26	-0.22	4.31	4.37	0.06	4.28	-0.03

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TRIB01_0148 (1D)	4.33	4.63	0.30	4.08	-0.25	4.29	4.34	0.05	4.25	-0.04
PO Line (2D)	4.30	4.58	0.28	4.08	-0.22	4.28	4.32	0.04	4.25	-0.03

Test 2: Structure coefficient (+/- 20%)

Sensitivity tests on structure coefficients show modelled water levels to be within 0.09m difference from the water levels of the same baseline 1:100 year AEP fluvial event (Table 8.3). Water level differences are also shown to be of a similar range in both the 1D and 2D nodes (i.e. in the river channel, and across the floodplain). The model is more sensitive to decreasing the structure coefficients, with the difference in water levels being approximately double those estimated when the structure coefficients were increased. A lower spill coefficient results in more resistance to flow and therefore a higher water level. The differences in water levels are minimal and within the range that would be expected for a structure coefficient sensitivity test of +/- 20%.

Modelled water levels for the 1:200 year AEP tidal event (Table 8.3) are less sensitive, with a maximum difference of 0.02m. This shows that the tidal level is less influential than the fluvial flow at the locations analysed. Water level differences are also shown to be of a similar range in both the 1D and 2D zones (i.e. in the river channel, and across the floodplain).

Table 8.3 Structure coefficient sensitivity tests 2a and 2b summary results

Node	**Maximum water level 1:100 year AEP fluvial event (mAOD)**					**Maximum water level 1:200 year AEP tidal event (mAOD**				
	Baseline	**Test 2a (+20%)**	**Difference (m)**	**Test 2b (-20%)**	**Difference (m)**	**Baseline**	**Test 2a (+20%)**	**Difference (m)**	**Test 2b (-20%)**	**Difference (m)**
ALAW01_1272i (1D)	4.48	4.45	-0.03	4.53	0.05	4.31	4.31	0.00	4.33	0.02
TRIB01_0148 (1D)	4.33	4.30	-0.03	4.40	0.07	4.29	4.28	-0.01	4.30	0.01
PO Line (2D)	4.30	4.26	-0.04	4.39	0.09	4.28	4.27	-0.01	4.29	0.01

Test 3: Orifice flow at upstream bridge not applied

The orifice flow function for the bridge (AL_2174bu) was switched off to determine the model's sensitivity to the difference in flow calculation when the bridge is surcharging. The sensitivity test, where flow is always calculated using the bridge flow equation through a bridge even if the flow is surcharging, reports negligible difference in peak depths at the Site (Table 8.4). A 1cm decrease in depth is reported at 1D node ALAW01_1272i (814m downstream of the bridge) with no difference in peak depths reported at 1D node TRIB01_0148 or the 2D PO Line. This test confirms that the model is not sensitive to the calculation method of surcharging flow at the bridge AL_2174bu.

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Table 8.4 Orifice flow parameter sensitivity test 3

Node	Maximum water level 1:100 year AEP fluvial event (mAOD)		
	Baseline	Test 3	Difference (m)
ALAW01_1272i (1D)	4.48	4.47	-0.01
TRIB01_0148 (1D)	4.33	4.33	0.00
PO Line (2D)	4.30	4.30	0.00

Test 4: Simulation parameters

Test 4a, where the 'dflood' parameter (height of vertical walls added to the highest point on each river cross section to allow for flooding) was reduced from 10m to the default 3m, shows no difference in peak depths at the Site locations (Table 8.5). Test 4b, where the 'maxitr' parameter (maximum number of iterations performed at each time step) was reduced from 19 to 11, also shows no difference at peak depths compared to the Baseline (Table 8.5). These test results confirm that the model is not sensitive to changes in the simulation parameters used.

Table 8.5 Simulation parameters sensitivity tests 4a and 4b

Node	Maximum water level 1:100 year AEP fluvial event (mAOD)				
	Baseline	Test 4a (dflood)	Difference (m)	Test 4b (maxitr)	Difference (m)
ALAW01_1272i (1D)	4.48	4.48	0.00	4.48	0.00
TRIB01_0148 (1D)	4.33	4.33	0.00	4.33	0.00
PO Line (2D)	4.30	4.30	0.00	4.30	0.00

Test 5: 1D roughness (n) value increased to 0.07

The 1D roughness (Manning's n) value was increased across the model to 0.07 for all channel sections, to reflect the roughness recommended in the literature (Chow, 1959) for a scenario where the channel sections had become heavily vegetated. The increase in roughness, as expected, has caused an increase in peak depths (Table 8.6). The increase at the sample locations is up to 35cm (0.35m), with an increase of 27cm reported at 1D node ALAW01_1272i. For some channel sections, the increase to 0.07 is a 75% increase in roughness and an increase in peak depths reported is in keeping with the change to 1D roughness. These test results confirm the model is behaving as expected to the 1D roughness sensitivity test, further evidenced by the results of Test 1.

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Table 8.6 1D roughness sensitivity test 5

Node	Maximum water level 1:100 year AEP fluvial event (mAOD)		
	Baseline	Test 5	Difference (m)
ALAW01_1272i (1D)	4.48	4.75	0.27
TRIB01_0148 (1D)	4.33	4.68	0.35
PO Line (2D)	4.30	4.65	0.35

Test 6: Storm duration sensitivity test (1:100 year AEP)

Test 6 investigated the hydraulic model sensitivity to changes to storm duration. For the baseline model the critical storm duration at the bypass location was taken to be 10.75 hours, derived from hydrological assessment location 1 catchment descriptors, as described in Section 3.2. This sensitivity test employed the latest hydrological method ReFH2.2 to derive the hydrographs, and applied the same ratio used in the baseline modelling to scale the hydrographs to the FEH statistical peak. This ensured a useful comparison against the baseline modelling results, enabling the analysis of model sensitivity to storm duration and to updated hydrological methods. 1D-only modelling indicated that the critical duration may be longer than that chosen in the baseline modelling, but did not capture the floodplain interaction and hence the "glass-walling" model returned significantly higher peak water levels than are realistic, providing no useful information regarding the sensitivity to storm duration. As such, four longer durations were run through the 1D-2D model: 12, 13, 14 and 16 hours, as shown in Table 8.7. The model demonstrates an insensitivity to storm duration, with the greatest variation in peak water levels at both 1D nodes only 0.01 m from the value reported in the baseline modelling.

Table 8.7 Test 7 - Sensitivity to storm duration

Node	Maximum water level 1:100 year AEP fluvial event (mAOD)					
	Baseline (10.75 hours)	12 hour	13 hour	14 hour	16 hour	Max difference
ALAW01_1272i (1D)	4.48	4.48	4.48	4.49	4.49	0.01
TRIB01_0148 (1D)	4.33	4.33	4.33	4.34	4.34	0.01

8.3 Sensitivity test conclusions

Summary results for the Manning's roughness (Test 1) and structure coefficient (Test 2) indicate the model is responding appropriately and as expected to the sensitivity tests, with water level differences proportionate to the existing hazard, thus not causing a significant impact on flood results in the study area. It is therefore concluded that the roughness values taken as typical for the channel vegetation condition and surrounding area, and the structure coefficient values adopted for the hydraulic model are appropriate.

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Test 3 demonstrates that the method applied to calculate flow through bridge AL_2174bu when surcharged results in only a 1 cm change to peak water levels, and the model is therefore not sensitive to this change in calculation.

Summary results for Test 4 indicate no changes to peak water levels as a result of changing the simulation parameters dflood and maxitr.

The increase in roughness applied to the 1D model network in Test 5, produced an appropriate increase in peak water levels at the nodes upstream of the bypass. The model can therefore be said to be performing as expected.

Test 6 demonstrates that the catchment is insensitive to storm duration, and thus that the duration adopted for the baseline modelling is appropriate.

8.4 Downstream boundary test

The model sensitivity to changes in the downstream tidal boundary was assessed by applying two additional tests. The fluvial 1:20 year AEP (1st test) and 1:100 year AEP (2nd test) events were combined with the tidal 1:200 year AEP event, and compared against the baseline results which used a mean high water spring (MHWS) tidal boundary. As expected, the increase in the tidal levels caused an increase in peak depths in both tests (Table 8.8). The greatest increase is seen when combining the 1:200 year AEP tidal event with the 1:20 year AEP fluvial event, where the peak depth increased by 0.49m at the 2D PO line. The greatest depth encountered in both tests, and baselines, remains at the 1D node at ALAW01_1272i, where a peak depth of 4.73m is reported in the second test. These results indicate the model is behaving appropriately as a result of the increase in tidal depth.

Table 8.8 Downstream tidal boundary sensitivity tests

Node	Maximum water level 1:20 year AEP fluvial event (mAOD)			Maximum water level 1:100 year AEP fluvial event (mAOD)		
	Baseline (MHWS)	1st test (1:200 year AEP tidal)	Difference (m)	Baseline	2nd test (1:200 year AEP tidal)	Difference (m)
ALAW01_1272i (1D)	4.26	4.53	0.27	4.48	4.73	0.25
TRIB01_0148 (1D)	4.04	4.48	0.44	4.33	4.68	0.35
PO Line (2D)	3.98	4.47	0.49	4.30	4.66	0.19

8.5 Double precision test

In addition to assessing the sensitivity to key parameters (as detailed above), the sensitivity of the model performance to the choice of TUFLOW precision was assessed. All model runs documented were run with a single precision version of TUFLOW (TUFLOW Build 2016-03-AE-w64 (single precision)). Sensitivity was tested by applying the double precision version of TUFLOW (TUFLOW Build 2016-03-AE-w64 (double precision)) for the 1:100 AEP fluvial flood event with MHWS tidal boundary.

Analysis of the results shows no difference in water levels between the single and double precision version of the software at the three key locations analysed (ALAW01_1272i, TRIB01_0148 and the 2D PO line). Analysis of the mass balance showed the same cumulative mass error for both versions, -0.18%. These results support the use of the single precision version of the software which has been applied to all runs.

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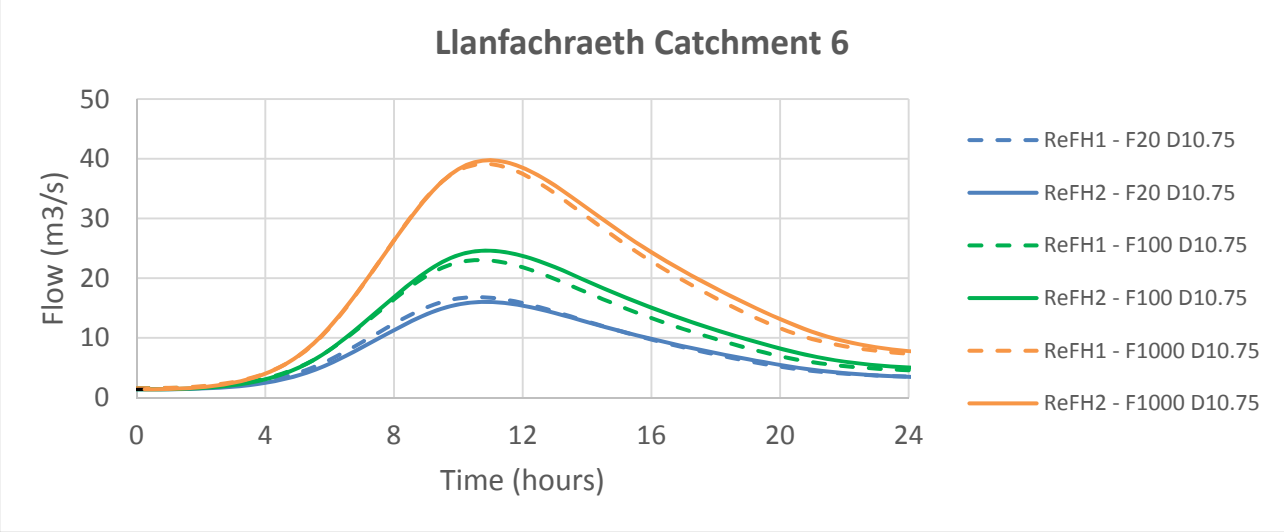
8.6 Comparison of ReFH1 and ReFH2 inflow hydrographs

The current hydrology software at the time of the baseline modelling, ReFH1, was used to derive the hydrographs. Hydrographs for Llanfachraeth Catchment 6 for the 1:20, 1:100 and 1:1000 year AEPs, generated using ReFH1 with FEH 99 data were compared to those generated using ReFH2 with FEH 13 data, to improve confidence in the hydrographs and reduce any uncertainty associated with using the previous method.

Figure 8-1 below compares the hydrographs for the three events, all of which applied a winter seasonal profile and a 10.75 hour storm duration.

Figure 8-1 Comparison of hydrographs generated by ReFH1 and ReFH2



The updated hydrographs produced by the ReFH2 method are very similar in both shape and in terms of the peak flows produced by ReFH1.

Table 8.9 Comparison of ReFH1 and ReFH2 derived peak flows

Scenario	ReFH1 peak flow (m3/s)	ReFH2 peak flow (m3/s)	Difference %
1:20 year AEP	16.83	16.01	-4.82
1:100 year AEP	23.05	24.60	+6.74
1:1000 year AEP	39.15	39.76	+1.57

The maximum percentage difference of 6.74% shown in Table 8.9 for the 1:100 year AEP event further demonstrates the small change brought about for this catchment by updating the hydrological method, increasing confidence in the hydrological boundary conditions generated for the baseline model.

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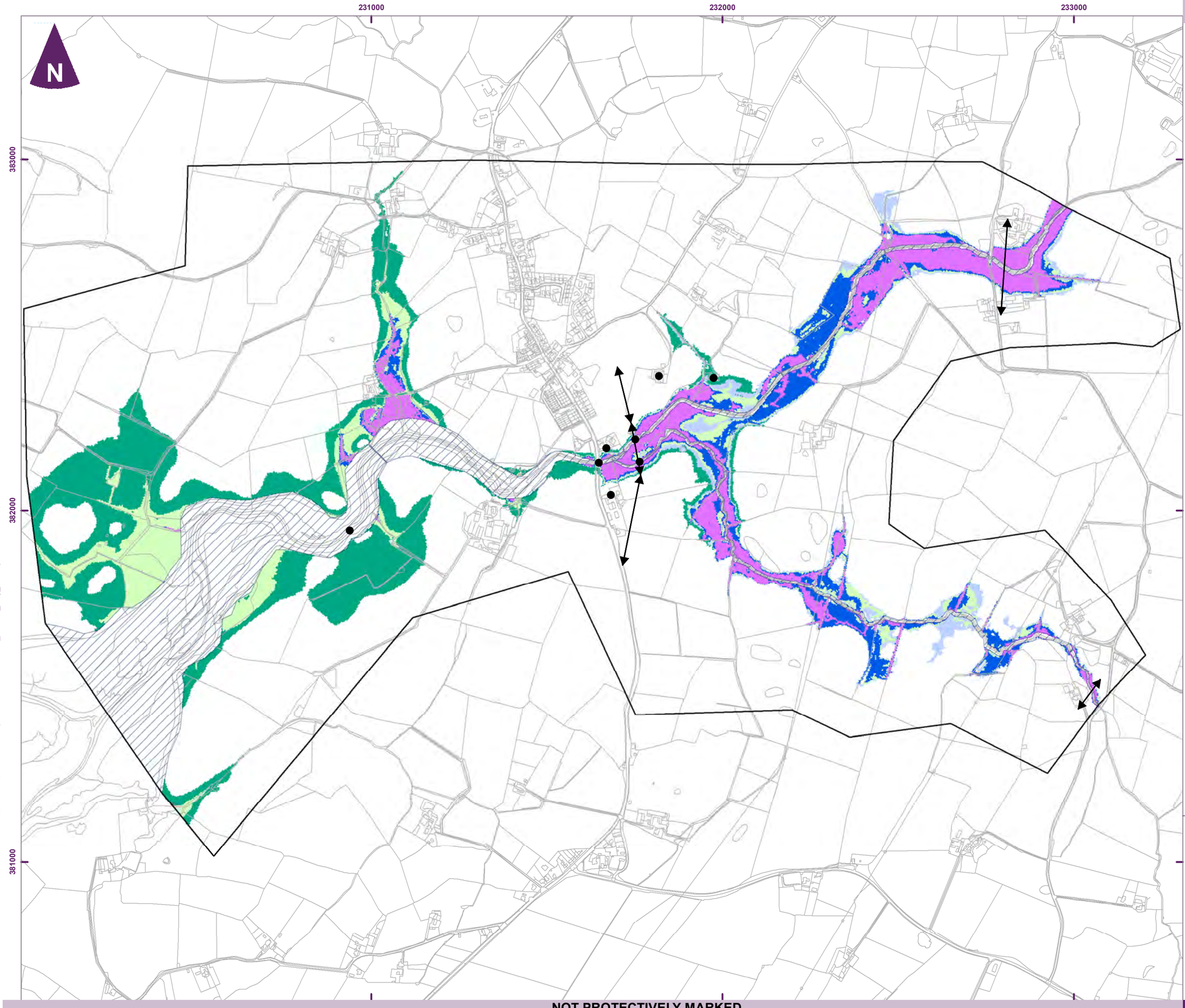
Appendix A
Supporting A3 Figures



Key

Baseline fluvial
Peak flood extents

- 1:20 year AEP
- 1:100 year AEP
- 1:100 year AEP - plus 30% climate change
- 1:1000 year AEP
- 1:100 year AEP plus 30% climate change with future 2115 1:200 year AEP Tide
- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 05/05/2017

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
Hydraulic Modelling

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Figure 6.1
A5025 Llanfachraeth baseline peak fluvial flood extents

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231000
232000
233000
383000
382000
381000
N

Key

Peak flood depth (m)
Baseline
1 : 20 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 05/05/2017
Corresponding data:
35989-C1349i1_A5025_Llan_Base_F20.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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Figure 6.2
A5025 Llanfachraeth baseline peak fluvial depth 1:20 year AEP present day

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231000
232000
233000
383000
382000
381000
N

Key

Peak flood depth (m)
Baseline
1 : 100 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 05/05/2017
Corresponding data:
35989-C1350i1_A5025_Llan_Base_F100.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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Figure 6.3
A5025 Llanfachraeth baseline peak fluvial depth 1:100 year AEP present day

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231000
232000
233000
383000
382000
381000
N

Key

Peak flood depth (m)
Baseline
1 : 1000 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

Model boundary
1D Model Domain
Results Point
Results Line
OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 05/05/2017
Corresponding data:
35989-C1351i1_A5025_Llan_Base_F1000.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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Figure 6.4
A5025 Llanfachraeth baseline peak fluvial depth 1:1000 year AEP present day

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231000
232000
233000
383000
382000
381000
N

Key

Peak flood depth (m)
Baseline
1 : 100 year AEP fluvial
Climate Change (30%)

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

Model boundary
1D Model Domain
Results Point
Results Line
OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 05/05/2017
Corresponding data:
35989-C1352i1_A5025_Llan_Base_F100cc.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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Figure 6.5
A5025 Llanfachraeth baseline peak fluvial depth 1:100 year AEP Climate Change (30%)

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231000
232000
233000
383000
382000
381000
N

Key

Baseline tidal
Peak flood extents

- 1:200 year AEP
- 1:1000 year AEP
- 1:1000 year AEP - plus climate change (2115)
- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 05/05/2017

Meters
0 100 200 300 400 500
Scale at A3

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Figure 6.6
A5025 Llanfachraeth baseline peak tidal flood extents

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231000
232000
233000
383000
382000
381000
N

Key

Peak flood depth (m)
Baseline
1 : 200 year AEP tidal
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 05/05/2017
Corresponding data:
35989-C1353i1_A5025_Llan_Base_T200.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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A5025 - Llanfachraeth
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Figure 6.7
A5025 Llanfachraeth baseline peak tidal depth 1:200 year AEP Present day

May 2017 35989-Lon484 beltl

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231000
232000
233000
383000
382000
381000
N

Key

Peak flood depth (m)
Baseline
1 : 1000 year AEP tidal
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

Model boundary
1D Model Domain
Results Point
Results Line
OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 05/05/2017
Corresponding data:
35989-C1354i1_A5025_Llan_Base_T1000.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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A5025 - Llanfachraeth
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Figure 6.8
A5025 Llanfachraeth baseline peak tidal depth 1:1000 year AEP Present day

May 2017 35989-Lon485 beltl

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231000
232000
233000
383000
382000
381000
N

Key

Peak flood depth (m)
Baseline
1 : 1000 year AEP tidal
Climate Change (2115)

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

Model boundary
1D Model Domain
Results Point
Results Line
OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 05/05/2017
Corresponding data:
35989-C1355i1_A5025_Llan_Base_T1000cc.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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A5025 - Llanfachraeth
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Figure 6.9
A5025 Llanfachraeth baseline peak tidal depth 1:1000 year AEP Climate Change (2115)

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231000
232000
233000
383000
382000
381000
N

Key

Peak flood depth (m)
Baseline
Combined fluvial and tidal
Climate Change

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

Model boundary
1D Model Domain
Results Point
Results Line
OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 05/05/2017
Corresponding data:
35989-C1356i1_A5025_Llan_Base_F100cc T200cc.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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A5025 - Llanfachraeth
Hydraulic Modelling

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Figure 6.10
A5025 Llanfachraeth baseline peak combined fluvial depth 1:100 year AEP Climate Change (30%) and peak tidal depth 1:200 year AEP Climate Change (2115)

May 2017 35989-Lon487 beltl

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231000
232000
233000
383000
382000
381000
N

Key

Peak flood depth (m)
With bypass
1 : 20 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap
- Bypass embankment location

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 30/05/2017
Corresponding data:
35989-C1395i1_A5025_Llan_Bypass_F20.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
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Figure 7.1
A5025 Llanfachraeth 'with bypass' peak fluvial depth 1:20 year AEP present day

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231000
232000
233000
383000
382000
381000
N

Key

Peak flood depth (m)
With bypass
1 : 100 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap
- Bypass embankment location

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 30/05/2017
Corresponding data:
35989-C1396i1_A5025_Llan_Bypass_F100.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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A5025 - Llanfachraeth
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Figure 7.2
A5025 Llanfachraeth 'with bypass' peak fluvial depth 1:100 year AEP present day

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231000
232000
233000
383000
382000
381000
N

Key

Peak flood depth (m)
With bypass
1 : 1000 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap
- Bypass embankment location

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 30/05/2017
Corresponding data:
35989-C1397i1_A5025_Llan_Bypass_F1000.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
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Figure 7.3
A5025 Llanfachraeth 'with bypass' peak fluvial depth 1:1000 year AEP present day

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231000
232000
233000
383000
382000
381000
N

Key

Peak flood depth (m)
With bypass
1 : 100 year AEP fluvial
Climate change (30%)

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap
- Bypass embankment location

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 30/05/2017
Corresponding data:
35989-C1398i1_A5025_Llan_Bypass_F100cc.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
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Figure 7.4
A5025 Llanfachraeth 'with bypass' peak fluvial depth 1:100 year AEP climate change (30%)

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231000
232000
233000
383000
382000
381000
N

Key

Peak flood depth (m)
With bypass
1 : 200 year AEP tidal
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

Model boundary
1D Model Domain
Results Point
Results Line
OS Mastermap
Bypass embankment location

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 30/05/2017
Corresponding data:
35989-C1399i1_A5025_Llan_Bypass_T200.xlsx

Meters
0 100 200 300 400 500
Scale at A3

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A5025 - Llanfachraeth
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Figure 7.5
A5025 Llanfachraeth 'with bypass' peak tidal depth 1:200 year AEP present day

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231000
232000
233000
383000
382000
381000
N

Key

Peak flood depth (m)
With bypass
1 : 1000 year AEP tidal
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap
- Bypass embankment location

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 30/05/2017
Corresponding data:
35989-C1400i1_A5025_Llan_Bypass_T1000.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
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Figure 7.6
A5025 Llanfachraeth 'with bypass' peak tidal depth 1:1000 year AEP present day

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231000
232000
233000
383000
382000
381000
N

Key

Peak flood depth (m)
With bypass
1 : 1000 year AEP tidal
Climate change (2115)

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap
- Bypass embankment location

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 30/05/2017
Corresponding data:
35989-C1401i1_A5025_Llan_Bypass_T1000cc.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
Hydraulic Modelling

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Figure 7.7
A5025 Llanfachraeth 'with bypass' peak tidal depth 1:1000 year AEP climate change (2115)

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231000
232000
233000
383000
382000
381000
N

Key

Peak flood depth (m)
With bypass
1 : 100 year AEP fluvial
Climate change (30%) and
1 : 200 year AEP tidal
Climate change (2115)

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00

Model boundary
1D Model Domain
Results Point
Results Line
OS Mastermap
Bypass embankment location

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 30/05/2017
Corresponding data:
35989-C1402i1_A5025_Llan_Bypass_F100ccT200cc.xlsx

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
Hydraulic Modelling

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Figure 7.8
A5025 Llanfachraeth 'with bypass' combined peak fluvial depth 1:100 year AEP climate change (30%) and peak tidal depth 1:200 year AEP

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232000

382000

N

Key

Peak flood depth difference (m)
1 : 20 year AEP fluvial
Present day

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap
- Bypass embankment location

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 50 100 150
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
Hydraulic Modelling

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Figure 7.9
A5025 Llanfachraeth peak fluvial depth difference - 1:20 year AEP present day

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232000

382000

N

Key

Peak flood depth difference (m)
1 : 100 year AEP fluvial
Present day

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap
- Bypass embankment location

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 50 100 150
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
Hydraulic Modelling

amec foster wheeler

Figure 7.10
A5025 Llanfachraeth peak fluvial depth difference - 1:100 year AEP present day

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232000

382000

N

Key

Peak flood depth difference (m)
1 : 1000 year AEP fluvial
Present day

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap
- Bypass embankment location

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 50 100 150
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
Hydraulic Modelling

amec foster wheeler

Figure 7.11
A5025 Llanfachraeth peak fluvial depth difference - 1:1000 year AEP present day

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232000

382000

N

Key

Peak flood depth difference (m)
1 : 100 year AEP fluvial
Climate change (30%)

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1

- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap
- Bypass embankment location

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 50 100 150
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
Hydraulic Modelling

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Figure 7.12
A5025 Llanfachraeth peak fluvial depth difference - 1:100 year AEP climate change (30%)

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232000

382000

N

Key

Peak flood depth difference (m)
1 : 200 year AEP tidal
Present day

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap
- Bypass embankment location

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 50 100 150
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
Hydraulic Modelling

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Figure 7.13
A5025 Llanfachraeth peak tidal depth difference - 1:200 year AEP Present Day

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232000

382000

N

Key

Peak flood depth difference (m)
1 : 1000 year AEP tidal
Present day

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap
- Bypass embankment location

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 50 100 150
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
Hydraulic Modelling

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Figure 7.14
A5025 Llanfachraeth peak tidal depth difference - 1:1000 year AEP Present Day

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232000

382000

N

Key

Peak flood depth difference (m)
1 : 1000 year AEP tidal
Climate change (2115)

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap
- Bypass embankment location

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 50 100 150
Scale at A3

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A5025 - Llanfachraeth
Hydraulic Modelling

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Figure 7.15
A5025 Llanfachraeth peak tidal depth difference - 1:1000 year AEP climate change (2115)

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232000

382000

N

Key

Peak flood depth difference (m)
1 : 100 year AEP fluvial
Climate change (30%) and
1 : 200 year AEP tidal
Climate change (2115)

- > 0.1
- 0.05 to 0.1
- 0.01 to 0.05
- 0.005 to 0.01
- No Change
- -0.005 to -0.01
- -0.01 to -0.05
- -0.05 to -0.1
- < -0.1
- Model boundary
- 1D Model Domain
- Results Point
- Results Line
- OS Mastermap
- Bypass embankment location

Notes:
The depths compared use the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Where positive values represent an increase in peak flood depth, and negative values represent a decrease in peak flood depth, as a consequence of the proposed bypass.

Meters
0 50 100 150
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
Hydraulic Modelling

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Figure 7.16
A5025 Llanfachraeth peak tidal depth difference combined fluvial 1:100 year AEP climate change (30%) and Tidal 1:200 year AEP climate change

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Appendix B
Detailed Hydrology Report

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A5025 Bypass – Llanfachraeth Hydrology Assessment

1. Introduction

As part of the Wylfa Newydd project, several highway enhancement projects have been identified, one of which is the Llanfachraeth A5025 bypass, which is the subject of this technical note. The proposed bypass route passes through agricultural land to the east of the village where it will cross the Afon Alaw and an unnamed tributary, shown on Figure 1.1.

1D-2D Modelling will be undertaken to support the assessment of the proposed A5025 bypass at Llanfachraeth, Anglesey, NW Wales. Modelling will determine the baseline (present day) fluvial and tidal flood risk to the bypass location and nearby receptors, and the future risk including climate change impacts.

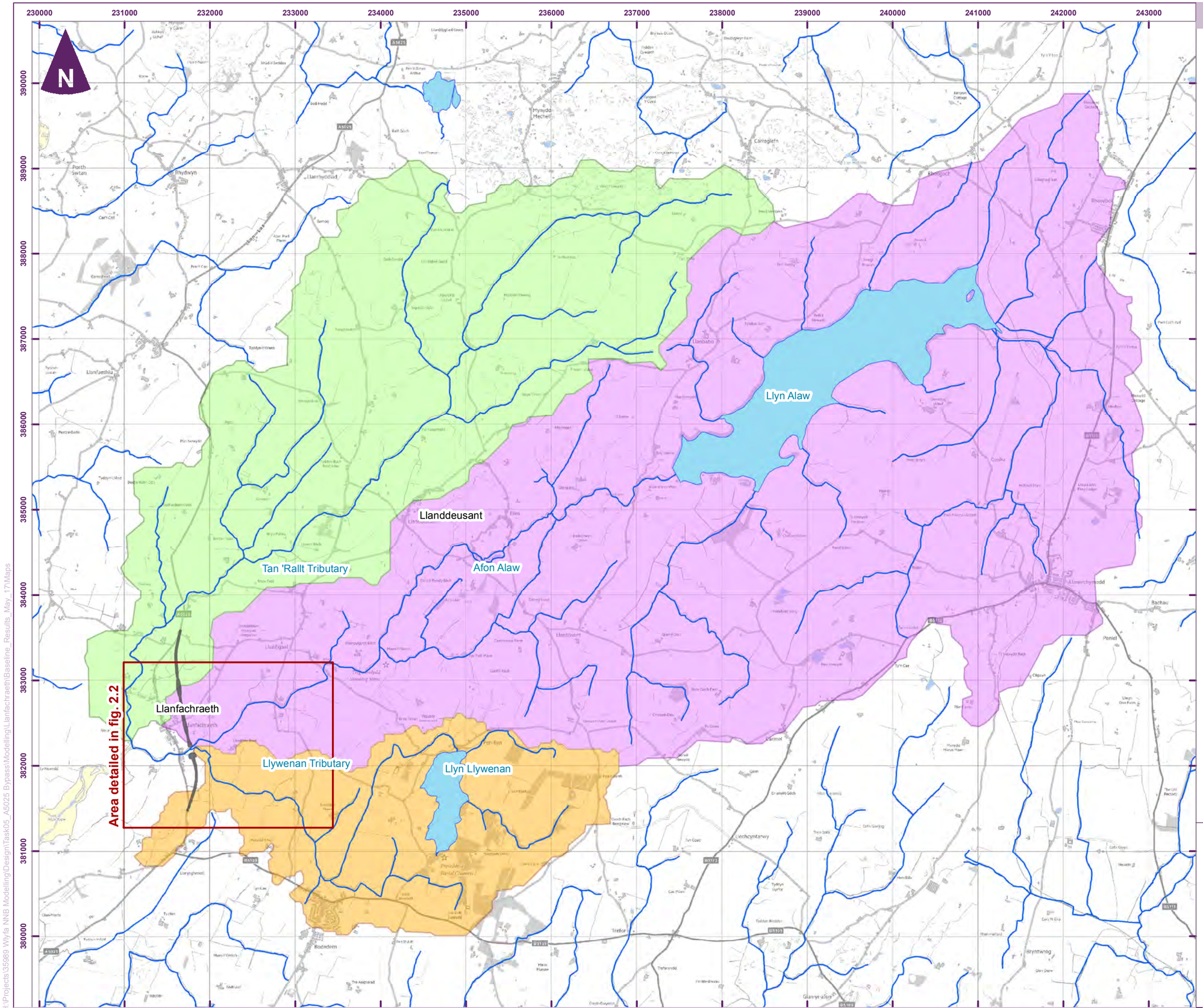
Hydrological assessment has determined the inflows which will be represented in the hydraulic model. NRW guidance[1] states that a FCA must consider the 1% (1 in 100) annual probability of occurrence and 0.1% (1 in 1,000) annual probability of occurrence events, including climate change on fluvial flows up to and including the 1% annual probability of occurrence. A 50% (1 in 2) annual probability of occurrence event is required to test the tidal flood risk. In addition, to provide a range of flood events the 20% (1 in 5) and 5% (1 in 20) annual probability of occurrence events have been determined to represent in the hydraulic modelling study.

The purpose of this hydrological assessment is to determine appropriate inflows, required as input to the hydraulic model of the proposed A5025 bypass at Llanfachraeth. This report defines the hydrological catchments which will be represented in the Llanfachraeth model and the flows which have been derived using two industry standard methods: the Flood Estimation Handbook (FEH) (Institute of Hydrology (IOH), 1999) statistical method and the revitalised flood hydrograph method described in Supplementary Report 1 to the FEH (Centre for Ecology & Hydrology (CEH), 2007)[2]. The results of the hydrological assessment and the flows to be represented in the hydraulic model are presented in this technical note.

This technical note has the following sections:

- Section 2: Catchment definition;
- Section 3: Derivation of flows using FEH statistical method;
- Section 4: Derivation of flows using ReFH1 method;
- Section 5: Final peak flows;
- Section 6: How flows are applied in the model; and
- Section 7: References.

[1] Natural Resources Wales, 2015. Good Practice Guide: Producing flood risk hydraulic models and flood consequence assessments for development planning purposes. GPG 101.
[2] ReFH1 was the current methodology at the start of the project. Although the methodology was subsequently updated to ReFH 2.2 (May 2016), the hydrology has not been updated as the modelling had already been completed.



Key

- FEH Catchment: Afon Alaw (2)
- FEH Catchment: Llywenan (3)
- FEH Catchment: Tan 'Rallt (6)
- Lakes
- Watercourse (1:50k river)
- A5025 Llanfachraeth Proposed Bypass

Meters
0 500 1,000 1,500 2,000
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
Hydrology

Figure 1.1
Llanfachraeth Site Location

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2. Catchment Definition

2.1 Overview

The Afon Alaw flows south-west from Llyn Alaw (reservoir), flowing into the Afon Alaw estuary at Llanfachraeth and Holyhead Bay approximately 2.5km south-west of Llanfachraeth. The Llywenan tributary flows west from Llyn Llywenan (reservoir), flowing into the Afon Alaw at Llanfachraeth approximately 25m upstream of the existing A5025. The Tan 'Rallt tributary flows from Llanddeusant, flowing into the Afon Alaw estuary at Llanfachraeth approximately 500m west of where Afon Alaw flows into the estuary. A site location plan showing these watercourses and their associated FEH catchments is provided in Figure 1.1.

The proposed bypass crosses both the Afon Alaw and Llywenan tributary immediately upstream of their confluence. The extent of any influence from the proposed A5025 bypass on flood extent cannot be estimated without a hydraulic model as there are no significant topographic features that would limit it. Therefore, a hydraulic model will be developed in order to assess the extent of this influence.

2.2 Hydrological Assessment

Hydrological assessment has been undertaken for the locations identified on Figure 2.1 for the Afon Alaw and tributaries. Hydrological assessment locations were chosen to represent the inflow at the upper extent of the model (4 - Afon Alaw, 5 - Llywenan tributary, and 6 – Tan 'Rallt tributary) and intervening catchments on Afon Alaw (2 and 1) and Llywenan tributary (3).

A comparison of OS mapping with the Afon Alaw, Llywenan tributary, and Tan 'Rallt tributary catchments identified on the FEH CD-ROM 3 showed there was no significant difference in catchment extent apart from the Tan 'Rallt tributary, Figure 2.1. An additional area in the headwaters is identified on the OS map as draining west across the A5025 to Llyn Garreg-lwyd, away from Tan 'Rallt. However, the culvert under the A5025 could not be found on site. It is therefore possible that this 3.8km^2 area drains to the Tan 'Rallt and therefore a conservative approach has been undertaken to represent this in the hydrology. Flows for hydrological assessment location 6 have been calculated using the FEH catchment, but then area-weighted to increase the peak flow and ensure that rainfall from all potential contributing areas is represented.

It was considered appropriate to use the catchment data directly from FEH. All catchment descriptor data exported from FEH CD-ROM 3[3] for each of the six hydrological assessment locations is provided in Appendix B, with key hydrological parameters for each location presented in Table 2.1. Key hydrological parameters include:

- Catchment area (AREA);
- Standard annual average rainfall (SAAR) for the period 1960-1990;
- The degree of flood peak attenuation within the catchment from reservoirs and lakes indicated by the FARL value (with a value of 1 indicating no attenuation), and
- A measure of catchment responsiveness indicated by the base flow index (BFIHOST).

[3] From 9 November 2015 FEH CD-ROM data have been available from FEH Web Service, however, as this hydrological assessment was largely completed before the launch of the FEH Web Service and it is understood that there is no significant difference to the catchment descriptor data, use of the FEH CD-ROM 3 catchment descriptor data are considered appropriate.

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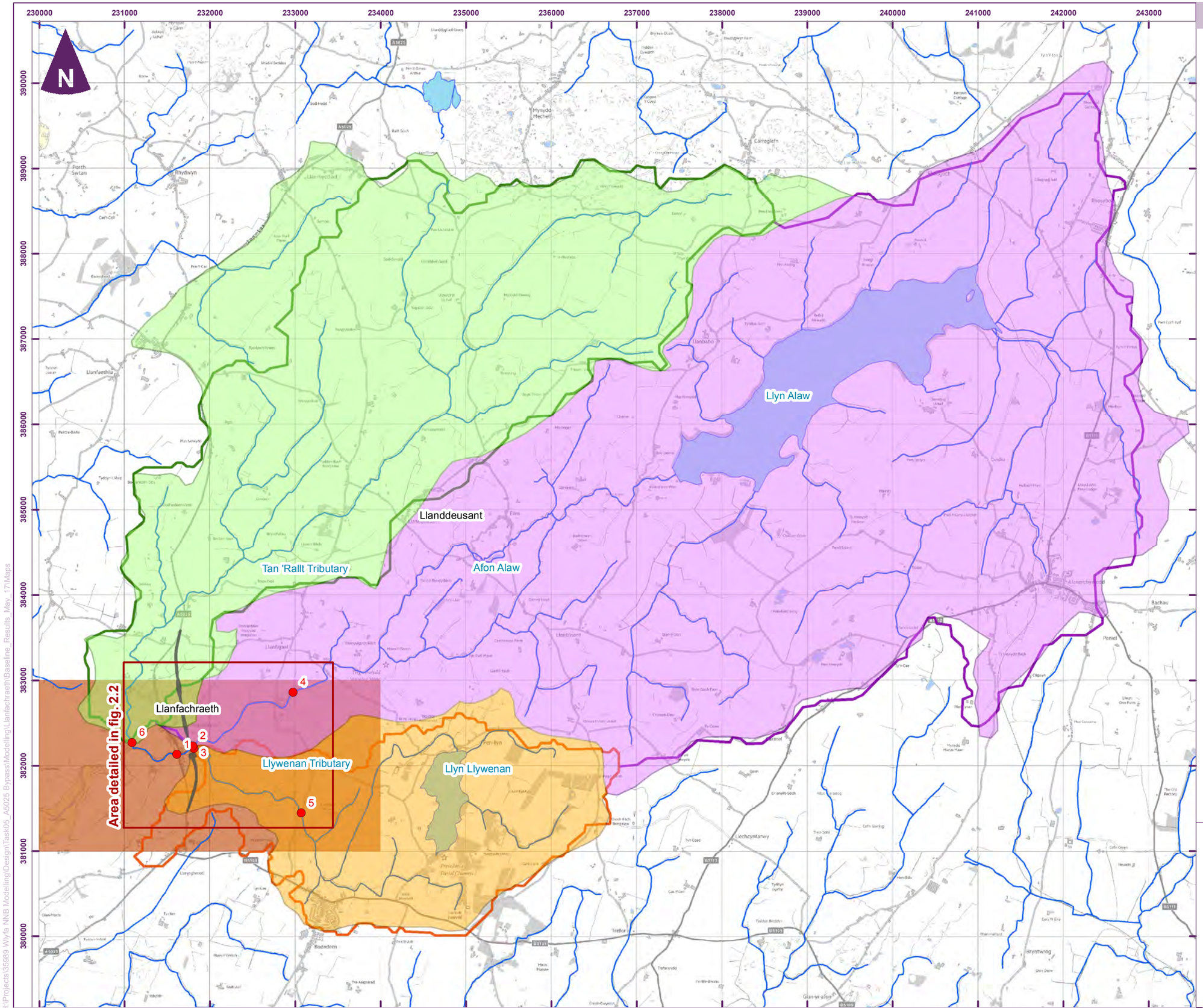
Table 2.1 Key Hydrological Parameters

Hydrological assessment location	Watercourse	Location description	National Grid Reference (NGR)	AREA (km^2)	SAAR (mm/yr)	FARL	BFIHOST	URBEXT 2000
1	Afon Alaw	Downstream of bypass	SH 31550 82150	56.75	1001	0.789	0.387	0.0042
2	Afon Alaw	Upstream of bypass and Llywenan tributary confluence	SH 31800 82250	47.74	1011	0.776	0.38	0.0037
3	Llywenan tributary	Upstream of bypass and Afon Alaw confluence	SH 31800 82200	8.81	951	0.862	0.418	0.0071
4	Afon Alaw	Upper catchment	SH 32950 82800	45.51	1016	0.767	0.377	0.0033
5	Llywenan tributary	Upper catchment	SH 33100 81400	6.99	960	0.829	0.418	0.00900
6	Tan 'Rallt tributary	Upper catchment	SH 31050 82350	25.04	See FEH Catchment 6[a]			
	Tan 'Rallt tributary	FEH Catchment 6	SH 31050 82350	21.28	980	1.000	0.412	0.0023

Note: (a) Hydrological assessment location 6 on the FEH CD-ROM (21.28km^2) would miss flows from the additional 3.76km^2 in hydrological assessment location 6 and therefore the hydrological assessment was undertaken for the FEH Catchment 6 (21.28km^2) and the results were scaled on and area-weighted basis for hydrological assessment location 6 (25.04km^2).

Inflow hydrographs identified for hydrological assessment locations 4, 5 and 6 will be represented as point inflows in the model, and the inflow hydrographs for hydrological assessment locations 1, 2 and 3 will be used as lateral inflows within the model. Greater detail on how inflows will be applied is provided in Section 6.



Key

- Topographic Catchment: Afon Alaw (2)
- Topographic Catchment: Llywenan (3)
- Topographic Catchment: Tan 'Rallt (6)
- FEH Catchment: Afon Alaw (2)
- FEH Catchment: Llywenan (3)
- FEH Catchment: Tan 'Rallt (6)
- Lakes
- A5025 Llanfachraeth Proposed Bypass
- Watercourse (1:50k river)
- Hydrological Assessment Location

LIDAR Elevations (mAOD)

High : 3.403

Low : 1.175

Meters
0 500 1,000 1,500 2,000
Scale at A3

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A5025 - Llanfachraeth
Hydrology

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Figure 2.1
Llanfachraeth Catchment Review

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231000
232000
233000
383000
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381000
N
Bungalow
Llanfigael
Afon Alaw
Tan 'Rallt Tributary
Afon Alaw
Llanfachraeth
Neuadd-Wen
Llanllibio Fawr
Newydd
Tyn Rho
Llywenan Tributary
Llanllibio Groes
Afon Alaw
Mynydd-Y-Gôf
B5109
Llanynghenedl
1
2
3
4
5
6

Key

- FEH Catchment: Afon Alaw (2)
- FEH Catchment: Llywenan (3)
- FEH Catchment: Tan 'Rallt (6)
- Lakes
- Llanfachraeth Hydraulic Model Extent
- Watercourse (1:50k river)
- A5025 Llanfachraeth Proposed Bypass
- Hydrological Assessment Location

LiDAR Elevations

High : 3.403

Low : 1.175

Meters
0 100 200 300 400 500
Scale at A3

Wylfa Newydd
A5025 - Llanfachraeth
Hydrology

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Figure 2.2
Llanfachraeth Hydrological Assessment Locations

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3. Derivation of Peak Flows using FEH Statistical Method

Flows were derived using the statistical method set out in the FEH, using WINFAP-FEH 3 software. The method derives a pooling group of catchments for which there are reliable gauged annual maxima (or peak over threshold) flows and which are hydrologically similar to the subject site. Gauged sites suitable for pooling are included in the HiFlows-UK database now hosted on the National River Flow Archive (NRFA) website (CEH, 2015). A growth curve is derived from the gauged data and applied to the median of annual maximum flood (QMED) for the subject site.

The median flood is derived theoretically for ungauged sites, i.e. the subject sites, but refined using data from an appropriate gauged donor site, if available. A further urban adjustment is applied to account for the urban extent within the catchment.

The hydrological assessment locations on Afon Alaw and the Llywenan tributary are influenced by reservoirs in the headwaters. The FEH statistical method has been used to account for these reservoirs using the catchment descriptor FARL. In general, pooling groups will tend to feature sites with some influence from lakes and reservoirs. Environment Agency (EA) Flood Estimation Guidelines (EA, 2015) states that "you should not rely on the QMED equation when FARL is below around 0.9 due to impounding reservoirs, unless they are kept permanently full and thus act like natural lakes". FARL values for both the Afon Alaw and Llywenan tributary are 0.79 and 0.86, respectively. EA Flood Estimation Guidelines (EA, 2015) recommends using observed events to derive hydrographs, however, there is no gauged data from either catchment that could be used. As the reservoir provides drinking water, specific releases of water into the Afon Alaw are not expected and therefore outflow from the reservoir to the Afon Alaw can be considered to be generally similar to a natural lake. No further adjustment to QMED was considered to be required.

3.1 Median Flood – Based on Catchment Descriptors

A median flood estimate (QMED) has been identified using the catchment descriptor equation given in the EA Flood Estimation Guidelines (EA, 2015), at page 43:

$$QMED = 8.3062 \times AREA^{0.8510} \times 0.1536^{1000/SAAR} \times FARL^{3.4451} \times 0.0460^{BFIHOST^2}$$

where, AREA, SAAR, FARL and BFIHOST are the FEH catchment descriptors area, rainfall, flow attenuation by reservoirs or lakes, and baseflow index described by soil class, respectively (see Appendix B for all FEH catchment descriptors).

The unadjusted median flood estimates based on catchment descriptors are shown in Table 3.3.3.

3.2 Adjusting the Median Flood – Donor Catchments

Where flows are derived using the FEH statistical approach with no gauged data at the subject site, an adjustment to the median flood should always be considered with data from a donor site (or sites) where possible and appropriate. The latest method for determining donor sites (in WINFAP-FEH 3), chooses a donor based solely on distance from the subject catchment, and the influence of the donor catchment falls off as the distance between the donor catchment centroid and the subject site catchment centroid increases. Proposed donor sites with centroids further than 10km have only a small influence on the median flood estimate. The EA Flood Estimation Guidelines (EA, 2015) confirms that hydrological similarity should also be considered when choosing a donor catchment.

Donor catchments have been considered based on data from the NRFA website (CEH, 2015). There are no HiFlows-UK sites on Anglesey which identify QMED values, which means there are no suitable HiFlows-UK donor sites within a reasonable distance of the catchments of interest. A wider search of the NRFA website found other gauges which were considered as potential donor stations and summarised in terms of suitability in Table 3.1. Although no HiFlows-UK data was available for the Cefni at Bodffordd, it was the closest gauge, being the only one of the gauges listed which is on Anglesey. Flow data provided by NRW for the Cefni at Bodffordd was used to determine an annual maximum (AMAX) series for fourteen full water years and thus identify QMED for the gauge.

Table 3.1 Potential Donor Stations

Station	Centroid Distance (km)	Consideration	Considered as a donor
102001: Cefni at Bodffordd	7	QMED determined from 15-min flow data	Yes
65006: Seiont at Peblig Mill	31	Suitable for QMED according to HiFlows-UK	Yes
65004: Gwyrfai at Bontnewydd	33	Suitable for QMED according to HiFlows-UK	Yes
65015: Llyfni at Pont Y Cim	35	No QMED value available	No
65008: Peris at Nant Peris	36	No QMED value available	No
65014: Colwyn at Hafod Wydr	39	No QMED value available	No
65001: Glaslyn at Beddgelert	41	Suitable for QMED according to HiFlows-UK	Yes

Note: Sites are listed based on approximate direct-line distance from Afon Alaw, from closest to furthest away.

Gauge stations 102001, 65006, 65004 and 65001 were identified as potential donor sites, based on relevant catchment characteristics, particularly FARL and BFIHOST, and also AREA and SAAR. These HiFlows-UK sites were identified on HiFlows-UK as suitable for deriving QMED. Adjustment factors were derived using a ratio with the weighting factor applied, as per the EA Flood Estimation Guidelines (EA, 2015):

$$QMEDs, adj = QMEDs, cds \times (QMEDg, obs / QMEDg, cds)^{a}$$

$$a = 0.4598 \times \exp(-0.02 \times d_{ij}) + (1 - 0.4598) \times \exp(-0.4785 \times d_{ij}).$$

where, QMEDs, adj is the median flood at the subject site, adjusted with the donor sites (m^3/s);

QMEDs, cds is the median flood at the subject site using catchment descriptors (m^3/s);

QMEDg, obs is the gauged median flood at the donor site (m^3/s);

QMEDg, cds is the median flood at the gauged site using catchment descriptors (m^3/s), and

d_{ij} is the distance between centroids of the subject and donor catchments (km).

The four donor catchments have similar hydrological parameters to the Afon Alaw (hydrological assessment location 1). In particular, the Llanfachraeth catchments, with the exception of the Tan 'Rallt tributary, have FARL (attenuation) values less than 1.0 because of the existence of reservoirs upstream. Donor catchments were chosen to reflect amounts of attenuation similar to the Afon Alaw catchment. Catchment details and adjustment factors are presented in Table 3.2.

Table 3.2 Donor Sites to Refine Median Flood (QMED)

	Afon Alaw	Cefni at Bodffordd	Seiont at Peblig Mill	Gwyrfai at Bontnewydd	Beddgelert at Glaslyn
NRFA Ref	-	102001	65006	65004	65001
AREA (km^2)	56.75	21.01	74.4	47.9	68.6
SAAR (mm)	1001	1061	2278	2147	2791
FARL	0.789	0.964	0.85	0.862	0.896

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	Afon Alaw	Cefni at Bodffordd	Seiont at Peblig Mill	Gwyrfai at Bontnewydd	Beddgelert at Glaslyn
BFIHOST	0.387	0.448	0.499	0.412	0.406
URBEXT	0.4%	0.1%	1.0%	0.2%	0.0%
Centroid X	237777	242964	257840	255036	261419
Centroid Y	384610	380648	360311	356471	351174
Distance between centroids (km)	-	6.32-10.45	28.54	30.07	45.99
QMEDcds (m^3/s)	11.08	9.01	37.92	33.21	63.95
QMEDobs (m^3/s)	-	11.85	46.22	20.35	90.39
QMEDobs/cds	-	1.315	1.219	0.613	1.413
Record length	-	14	36	32	45
Suitable for QMED (as stated on HiFlows-UK)	-	-	yes	yes	yes
Factors affecting runoff (from NRFA HiFlows-UK site)	-	Weir susceptible to blockage	contains two large ribbon lakes; runoff affected by regulation for hydroelectric power	runoff affected by reservoirs and public water supply abstraction	runoff affected by reservoirs and regulation for hydroelectric power
Adjustment factor as a % (QMEDs,adj / QMEDcds)	-	112%	105%	89%	107%

Note: Afon Alaw data presented for hydrological assessment location 1, however, the data is very similar for the other catchments.

For Llanfachraeth, the Cefni at Bodffordd is significantly closer than the other sites and has similar catchment characteristics - it has therefore been used as a single donor to adjust the subject site median flood for all Llanfachraeth hydrological assessment locations.

3.3 Adjusting the Median Flood – Urbanisation

The median flood values determined using catchment descriptors assume a rural catchment. The flow values were adjusted for urbanisation using the PRUAF method (Kjeldsen, 2010) in line with the EA Flood Estimation Guidelines (EA, 2015). This method is incorporated in WINFAP-FEH 3 (although referred to in WINFAP-FEH 3 as dating from 2009, the paper was issued in 2010), but for this work, it was calculated separately. The urban adjustment factor (UAF) is given by:

$UAF = (1+URBEXT_{2000})^{0.37} \times PRUAF^{2.16}$
$PRUAF = 1+0.47URBEXT_{2000} \times (BFIHOST/ (1-BFIHOST))$.

where, PRUAF = percent runoff urban adjustment factor, and URBEXT and BFIHOST are standard FEH catchment descriptors (see Appendix B).

3.4 Summary of Median Flood Estimate and Adjustment

The initial estimate of the median flood from catchment descriptors, adjustment factors from donor sites and for urbanisation, and the final adjusted median flood values are given in Table 3.3.3. The final adjusted median flood values are taken forward for developing the flood frequency values, in the next section.

Table 3.3.3 Derivation of Median Flood Estimate

	Hydrological assessment location					
	1	**2**	**3**	**4**	**5**	**6**
Initial median flood Q_{MED} (m^3/s) using catchment descriptors	12.5	10.6	2.9	9.9	2.1	12.8
Adjustment factor from donor sites	1.12	1.13	1.11	1.13	1.12	1.11
Urban adjustment factor	1.00	1.00	1.01	1.00	1.01	1.00
Final adjusted median flood Q_{MED} (m^3/s)	11.12	9.38	2.60	8.79	1.91	9.85

Note: Adjusted median flood values have been calculated using urban adjustment factors with four decimal places and therefore the values reported for the adjusted median flood values may be slightly different than those calculated based on the reported values.

3.5 Peak Flood Flow Estimates Using FEH Statistical Method

Pooling groups were derived for each catchment using WINFAP-FEH 3. HiFlows-UK Version 3.3.4, dating from August 2014, is the latest version of peak flow data (as at 22/06/2015)[4] available from the CEH website. These peak flow data were used with the WINFAP-FEH 3 software for this analysis. When choosing hydrologically similar catchments for the pooling group, the filepath in the software was set to choose files from the subset identified as suitable for pooling.

The WINFAP-FEH 3 software was used to derive a pooling group of hydrologically similar catchments for each subject site. This was then used to derive a growth curve for flood frequency estimation. A review of the initial pooling groups for each site identified significant differences between the pooling groups derived for Afon Alaw and tributaries, but minor differences within each of these two groups. Therefore, growth curves were derived for hydrological assessment location 1 and applied to all Afon Alaw assessment locations (hydrological assessment locations 1, 2, 4); growth curves were derived for hydrological assessment location 3 and applied to all tributary assessment locations (hydrological assessment locations 3, 5 and 6). Hydrological assessment locations are shown on Figures 2.1 and 2.2. The pooling group for hydrological assessment location 1 and 3 was reviewed and amended where necessary as described below. The final pooling group data is provided in Appendix C. Flow results are given in Table 3.6.

[4] WINFAP-FEH gauge data version 4 and 4.1 were released in May 2016, but as the hydrological assessment had already been undertaken it was not re-calculated with the updated dataset. The hydrological assessment undertaken for the Cefn Coch (which was undertaken in May 2016) was reviewed and determined that peak flows derived using v3.3.4 and were slightly higher compared to those derived using v4.1. It is expected that this would also apply to the Llanfachraeth catchment.

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Hydrological Assessment Location 1 – (Applied to Afon Alaw Hydrological Assessment Locations)

Fifteen gauged stations with records suitable for pooling group construction were selected by the software. These had a combined record length of 515 station-years, greater than the 500 station-years, a minimum recommended for estimating the 100 year flow.

Catchment parameter SPRHOST was found to be less than 20%, indicating a permeable catchment, for four sites (42007 Alre at Drove Lane Alresford, 42009 Candover Stream at Borough Bridge, 33054 Babingley at Castle Rising and 39042 Leach at Priory Mill Lechlade). The annual maxima were reviewed and none, two, two and one water year(s), respectively, were considered to be non-flood years (AMAX<QMED/2). Non-flood AMAX data were removed from these gauges, leaving a record length of 511 years.

A heterogeneity parameter H2 of 3.473 indicated that the pooling group was heterogeneous and a review of the pooling group was desirable. Review of the sites showed that:

- The pooled sites had rainfall ranging from 575mm/year to 1,292mm/year compared to the subject site (1,001mm/year), but as these are between 57% and 129% of the subject site rainfall it was not considered appropriate to remove any sites on this basis;
- FARL is lower at the subject site (0.789) than all of the pooled sites (0.839 – 1.000), but there are limited alternative sites that could be used as very few sites with low FARL are included within the national distribution of available HiFlows-UK sites (as shown by the graphs in WINFAP-FEH). It was therefore not appropriate to remove stations on this basis since replacement sites would likely be less similar overall;
- BFIHOST varies considerably across the pooling group (0.276 – 0.964), with four sites having significantly higher BFIHOST than the subject site (0.387). It was not appropriate to remove all these sites, since replacement catchments would be less similar overall (BFIHOST is no longer used by WINFAP-FEH 3 to identify catchment similarity);
- The URBEXT2000 is low for the subject site (0.0042) and for all the pooled sites (0 - 0.026). Sites for the pooling group should all be rural, with urban adjustment applied separately if required. From EA Flood Estimation Guidelines (EA, 2015), URBEXT2000 ≤0.125 indicates essentially rural; therefore all pooled sites were rural and it was not necessary to remove sites on this basis;
- Sites 11 (19008 South Esk) and 6 (42009 Candover Stream) had a slightly higher growth curve than the other sites, but none of the catchment descriptors for these sites were significantly different to the subject site. South Esk had two AMAX values much higher than the rest of the record, but there was no indication from the station comments that these were erroneous. Therefore, it was not considered appropriate to remove these sites or any specific AMAX values;
- None of the sites was identified as discordant (a measure identifying individual stations that are strongly different from the group-average); and
- The Generalised Logistic (GL), General Extreme Value (GEV) and Pearson Type 3 (PT3) distributions all gave an acceptable fit to the data, adding confidence to the suitability of the pooled data themselves. The best fit distribution was the GEV with a Z value of -0.5305 compared to the limit of (absolute value) 1.64 for acceptable fit.

As a result of the pooling group review, no stations were removed or added to the group. The GEV distribution is recommended since it gave the best fit to the data.

Hydrological Assessment Location 3 – (Applied to Tributary Hydrological Assessment Locations)

Seventeen gauged stations with records suitable for pooling group construction were selected by the software. These had a combined record length of 542 years, greater than the 500 years minimum recommended for estimating the 100 year flow. However, one station had a short record (49006 Camel at Camelford; 6 years) and was removed from the group as the record was shorter than eight years, leaving 536 pooled years of data.

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SPRHOST is less than 20%, indicating a permeable catchment, for three sites (27073 Brompton Beck at Snainton Ings, 26802 Gypsey Race at Kirby Grindalythe and 44008 South Winterbourne at Winterbourne). The annual maxima were reviewed and two, one and six water year(s), respectively, were considered to be non-flood years (AMAX<QMED/2). Non-flood years had already been removed from the 27073 Brompton Beck and 26802 Gypsey Race gauge data. Non-flood AMAX data were removed from the 44008 South Winterbourne gauge, leaving a record length of 530 years.

A heterogeneity parameter H2 of 3.9655 indicated that the pooling group was heterogeneous and a review of the pooling group was desirable. Review of the sites showed that:

- The pooled sites had rainfall ranging from 616mm/year to 1,904 mm/year compared to the subject site (951mm/year). These are between 76% and 200% of the subject site rainfall. The higher value is twice that of the subject site and this station (25003 Trout Beck at Moor House) could have been considered to have too high to be included. However, in this case, the similarity rankings of alternative sites needed to make up the required record length would be worse (the pooled sites had a similarity distance of 2.0 or lower and alternative sites would have higher values) an even less like the subject site in general. Therefore it was decided to make no changes to the pooling group based on rainfall;
- FARL is lower at the subject site (0.862) than all of the pooled sites (0.942 – 1.000), but there are limited alternative sites that could be used as very few sites with low FARL are included within the national distribution of available HiFlows-UK sites (as shown by the graphs in WINFAP-FEH 3). It was therefore not appropriate to remove stations on this basis since replacement sites would be likely to be less similar overall;
- BFIHOST varies considerably across pooling group (0.227 - 0.959), with six sites having significantly higher BFIHOST than the subject site (0.418). It was not appropriate to remove all these sites, since replacement catchments would be less similar overall (BFIHOST is no longer used by WINFAP-FEH 3 to identify catchment similarity);
- The URBEXT2000 is low for the subject site (0.0071) and for all the pooled sites (0 - 0.014). Sites for the pooling group should all be rural, with urban adjustment applied separately if required. From EA guidelines URBEXT2000 ≤0.125 indicates essentially rural; therefore, all pooled sites were rural and it was not necessary to remove sites on this basis;
- Catchment 4 (45816 Haddeo at Upton), Catchment 6 (25019 Leven at Easby) and Catchment 13 (44008 Winterbourne at Winterbourne) had a slightly higher growth curve than the other sites, but none of the catchment descriptors for this site were significantly different to the subject site. Therefore it was not considered appropriate to remove these sites;
- None of the sites was indicated as discordant, with the highest discordancy value of 2.36 at 20002 West Peffer Burn at Luffness in the final pooling group compared to a value of 3.00 (for a pooling group of 15 or more stations) which would indicate a discordant site. Therefore, it was not considered appropriate to remove this site; and
- The GL and GEV distributions gave an acceptable fit to the data, adding confidence to the suitability of the pooled data themselves. The best fit distribution was the GL with a Z value of -0.4862 compared to the limit of (absolute value) 1.64 for acceptable fit.

The GL distribution is recommended because it gives the best fit to the data.

Adjusting the Growth Curve for Urbansiaton

It is recommended that the growth curve (which represents a rural catchment) should be adjusted where URBEXT2000 is equal to, or exceeds 0.03 (EA, 2006). All of the Llanfachraeth catchments associated with hydrological assessment locations are ‘essentially rural’ with URBEXT2000 less than 0.03 so no adjustment was necessary.

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Adjusting the Growth Curve for Permeable Catchment

It is acknowledged that the final pooling group data used to derive the growth curves for HALs 1 and 3 contained permeable catchments as indicated by catchment descriptors. To test the sensitivity of the growth factors to permeable catchment adjustments. The non-flood years for the permeable catchments were identified to obtain a new permeable-adjusted growth curve, as described in the FEH Handbook Volume 3 Ch 19. The final pooling groups are presented in Appendix C, with Table 3.4 and Table 3.5 below showing the change in the growth factors after the adjustment.

Table 3.4 HAL1 Sensitivity to permeable catchment adjustment

Return Period, Years	Growth Factor (before adjustment)	Growth Factor (after adjustment)	Change in growth factor
2	1.000	1.000	0.0%
5	1.398	1.349	-3.5%
10	1.676	1.610	-3.9%
20	1.952	1.896	- 2.8%
50	2.327	2.336	+0.4%
100	2.620	2.729	+4.2%
200	2.923	3.186	+9.0%
500	3.341	3.908	+17.0%

Table 3.5 HAL3 Sensitivity to permeable catchment adjustment

Return Period, Years	Growth Factor (before adjustment)	Growth Factor (after adjustment)	Change in growth factor
2	1.000	1.000	0.00%
5	1.389	1.380	-0.63%
10	1.677	1.668	-0.51%
20	1.990	1.988	-0.10%
50	2.468	2.484	+0.66%
100	2.891	2.932	+1.43%
200	3.379	3.458	+2.33%
500	4.146	4.297	+3.65%

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The results show that there are very small changes to the flood growth curves as a result of the permeable catchment adjustment. The increase in the growth factors are higher for high return period values. The increments are not significant, and do not warrant any reconsideration of flood peak values from the pooled statistical analysis.

Peak Flow Estimates

The appropriate growth curve derived for hydrological assessment locations 1 (Afon Alaw) and 3 (tributary) were applied to the median flood estimate for each corresponding hydrological assessment location to give peak flows, which are shown in Table 3.6. Results for the acceptable pooled growth curve distributions for each site were reviewed, and the preferred distribution identified. For hydrological assessment locations on the Afon Alaw (1, 2 and 4), the GL, GEV and PT3 distributions gave an acceptable fit and for hydrological assessment locations on tributaries (3, 5 and 6), the GL and GEV distributions gave an acceptable fit. The recommended distributions are described in the preceding sections and identified in Table 3.6.

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Table 3.6 Peak Flood Flow Estimates from Statistical Method – Llanfachraeth (Afon Alaw) (m^3/s)

	Assessment Location 1			Assessment Location 2			Assessment Location 3			Assessment Location 4			Assessment Location 5			Assessment Location 6		
Return Period (yrs)	**GL**	**GEV**	**PT3**	**GL**	**GEV**	**PT3**	**GL**	**GEV**	**PT3**	**GL**	**GEV**	**PT3**	**GL**	**GEV**	**PT3**	**GL**	**GEV**	**PT3**
2	12.5	12.5	12.5	10.6	10.6	10.6	2.9	2.9	-	9.9	9.9	9.9	2.1	2.1	-	12.8	12.8	-
5	17.0	17.5	17.8	14.4	14.8	15.0	4.0	4.1	-	13.5	13.8	14.1	3.0	3.0	-	17.8	18.3	-
10	20.3	21.0	21.3	17.2	17.7	18.0	4.9	5.0	-	16.1	16.6	16.8	3.6	3.7	-	21.5	22.2	-
20	23.9	24.4	24.6	20.2	20.6	20.7	5.8	5.9	-	18.9	19.3	19.4	4.2	4.3	-	25.6	26.1	-
50	29.3	29.1	28.7	24.8	24.6	24.2	7.2	7.1	-	23.2	23.0	22.7	5.3	5.2	-	31.7	31.5	-
100	34.1	32.8	31.7	28.8	27.7	26.8	8.4	8.1	-	27.0	25.9	25.1	6.2	5.9	-	37.1	35.8	-
200	39.5	36.6	34.7	33.3	30.9	29.3	9.8	9.1	-	31.3	28.9	27.4	7.2	6.7	-	43.4	40.2	-
500	47.9	41.8	38.5	40.5	35.3	32.5	12.0	10.5	-	37.9	33.1	30.5	8.8	7.7	-	53.3	46.5	-
1000	55.5	45.9	41.4	46.8	38.8	34.9	14.0	11.6	-	43.9	36.3	32.7	10.3	8.5	-	62.1	51.5	-
Recommended fitting (best fit)		GEV			GEV		GL				GEV		GL			GL		

4. Derivation of Peak Flows Using Revitalised Flood Hydrograph Method

The Revitalised Flood Estimation Handbook rainfall runoff method (ReFH) was used in the ISIS v3.7 software[5] to derive flow hydrographs for the required events. As the catchment areas are relatively small, it is expected that the same event will occur across all the catchments simultaneously. Consequently, the critical storm duration was chosen for all hydrological assessment locations to be the same duration as hydrological assessment location 1 (see Figure 2.2 for hydrological assessment locations). Although this may slightly underestimate peak flows on the tributaries, and to a lesser degree in the headwaters of the Afon Alaw, if the shorter storm duration were to be applied it would underestimate peak flows on Afon Alaw to a greater degree. Optimising the storm duration for the bypass location ensures that an appropriate, but worst case scenario has been represented. Relevant parameters for hydrological assessment location 1 are shown in Table 4.1.

Table 4.1 Storm Duration and Timestep Parameters for all Assessment Locations

	Parameter
Critical storm duration (hr)	10.8
Storm duration used (hr)	10.75
Timestep (hr)	0.25

Note: there must be an odd integer number of timesteps in the storm duration to derive the design storm profile

FEH catchment 6 was factored by catchment area to ensure all rainfall draining to Tan 'Rallt is represented in hydrological assessment location 6 as discussed in Section 3.

Catchment area (FEH catchment 6) = 21.3km^2;

Llanfachraeth hydrological assessment location 6 area = 25.0km^2.

ReFH1 generated peak flows for all hydrological assessment locations are shown in Table 4.2. Summary ReFH1 reports from ISIS are included as Appendix D.

Table 4.2 ReFH1 Peak Flows (m^3/s)

Return Period	**Hydrological assessment location**					
	1	**2**	**3**	**4**	**5**	**6**
20	34.5	29.1	6.5	29.3	5.7	16.8
100	47.1	39.7	8.9	40.0	7.9	23.0
1000	79.5	67.1	15.2	67.7	13.5	39.1

5. Final FEH Statistical Peak Flows

The FEH statistical and ReFH1 results for 20 year, 100 year and 1000 year events are repeated, for ease of comparison, in Table 5.1.

[5] ReFH 1 was the current software at the start of the project, subsequently updated to ReFH 2.2. However, the changes associated with this most recent software update are not expected to change the results significantly.

Table 5.1 Peak Flows (m^3/s)

Return Period	Method	Hydrological assessment location					
		1	2	3	4	5	6
20	FEH statistical	24.4	20.6	5.8	19.3	4.2	25.6
	ReFH1	34.5	29.1	6.5	29.3	5.7	16.8
100	FEH statistical	32.8	27.7	8.4	25.9	6.2	37.1
	ReFH1	47.1	39.7	8.9	40.0	7.9	23.0
1000	FEH statistical	45.9	38.8	14.0	36.3	10.3	62.1
	ReFH1	79.5	67.1	15.2	67.7	13.5	39.1

It is noted from results presented in Table 5.1 that the FEH statistical method flows are significantly lower than the ReFH1 values for all hydrological assessment locations for the 20 year, 100 year and 1000 year events, except hydrological assessment location 6 (the Tan 'Rallt tributary downstream of the bypass) for which the statistical values are higher for all three events. For example, for hydrological assessment location 1, the 20 year peak flow from the FEH statistical method is 24.4m^3/s compared to 34.5m^3/s from the ReFH1 method, while for the 1,000 year event values are 45.9m^3/s and 79.5m^3/s, respectively. Furthermore, for the smaller catchments (hydrological assessment locations 3, 5 and 6) the ReFH1 method uses a storm duration that is not the critical storm duration for that catchment.

Following advice on page 100 and 101 of the EA Flood Estimation Guidelines (EA, 2015) the following approach was adopted here:

- Peak flow results from the FEH statistical method have been used for more frequent events – up to and including the 100 year event;
- The ratio of the 1000 year to 100 year flows are determined from the ReFH1 results. The ratio was then applied to the 100 year event FEH statistical method peak flow value to determine an equivalent 1000 year flow; and
- The hydrographs from the ReFH1 method have been factored to the identified peak flows.

Based on peak flow data provided in Table 5.1, the 1,000/100 year ReFH1 ratio and resulting 1,000 year peak flows were determined and are provided in Table 5.2.

Table 5.2 Revised 1000 Year Flow Estimates Using Ratio Method

Return Period	Hydrological assessment location					
	1	2	3	4	5	6
ReFH1 1000/100 year flow ratio	1.69	1.69	1.70	1.69	1.71	1.70
Revised 1000 year event	55.4m^3/s	46.8m^3/s	14.3m^3/s	43.9m^3/s	10.5m^3/s	63.1m^3/s

Note: Ratio method flow values have been calculated using initial peak flows and ratios with four decimal places and therefore the values reported for the ratio method 1000 year event may be slightly different than those calculated based on the reported values.

Final peak flows using the FEH statistical and ratio methods are given in Table 5.3 and the hydrograph with peak flow is shown on Figure 5.1. Climate change is applied by using a 30% uplift on the 100 year events as per current guidance (Welsh Government, 2011). Although this has been applied to the peak flow for this report, when representing in the model the entire hydrograph will be scaled to this adjusted peak.

Table 5.3 Final Peak Flows to be Modelled (m^3/s)

Return Period	Method	Hydrological assessment location					
		1	2	3	4	5	6
QMED	Adjusted catchment descriptors	12.5	10.6	2.9	9.9	2.1	12.8
5	FEH statistical	17.5	14.8	4.0	13.8	3.0	17.8
20	FEH statistical	24.4	20.6	5.8	19.3	4.2	25.6
100	FEH statistical	32.8	27.7	8.4	25.9	6.2	37.1
100 + climate change	FEH statistical + 30%	42.6	36.0	10.9	33.7	8.0	48.3
1000	Ratio	55.4	46.8	14.3	43.9	10.5	63.1

5.1 Uncertainty

This hydrological assessment has presented an appropriate consideration of hydrology for the catchments influencing the study area. However, it is recognised that there are still limitations in the methods applied. Assumptions made include the following:

- The 1,000 year growth factors are best estimated from rainfall-runoff methods and a ratio applied to statistical method estimates from the 100 year event;
- The FEH catchment 6 produces a hydrograph that is proportionate to area and that it is appropriate to area-weight the hydrograph; and
- The influence of reservoirs is similar to that of natural lakes.

Limitations:

- Historic flood events were not identified, as data were not available.

The assessment of QMED from catchment descriptors is one of the more uncertain aspects of the assessment. Confidence limits have been calculated based on EA Flood Estimation Guidelines (EA, 2015) and presented in Table 5.4. The 95% confidence limit is between half and twice the central estimate.

Derivation of growth factors is also uncertain, being based on a diverse set of catchment descriptors. There is no simple method to derive confidence intervals for pooled growth curves.

Table 5.4 Confidence Limits in QMED

	Hydrological assessment location					
	1	**2**	**3**	**4**	**5**	**6**
QMED (m^3/s)	12.5	10.6	2.9	9.9	2.1	12.8
68% confidence limit (lower)	8.8	7.4	2.0	6.9	1.5	9.0
68% confidence limit (upper)	17.9	15.1	4.1	14.2	3.0	18.4
95% confidence limit (lower)	6.1	5.2	1.4	4.8	1.0	6.3
95% confidence limit (upper)	25.5	21.5	5.9	20.2	4.3	26.2

Confidence intervals for the pooled growth curves is not currently available for the statistical method, however, a qualitative assessment has been undertaken and is presented in Table 5.5.

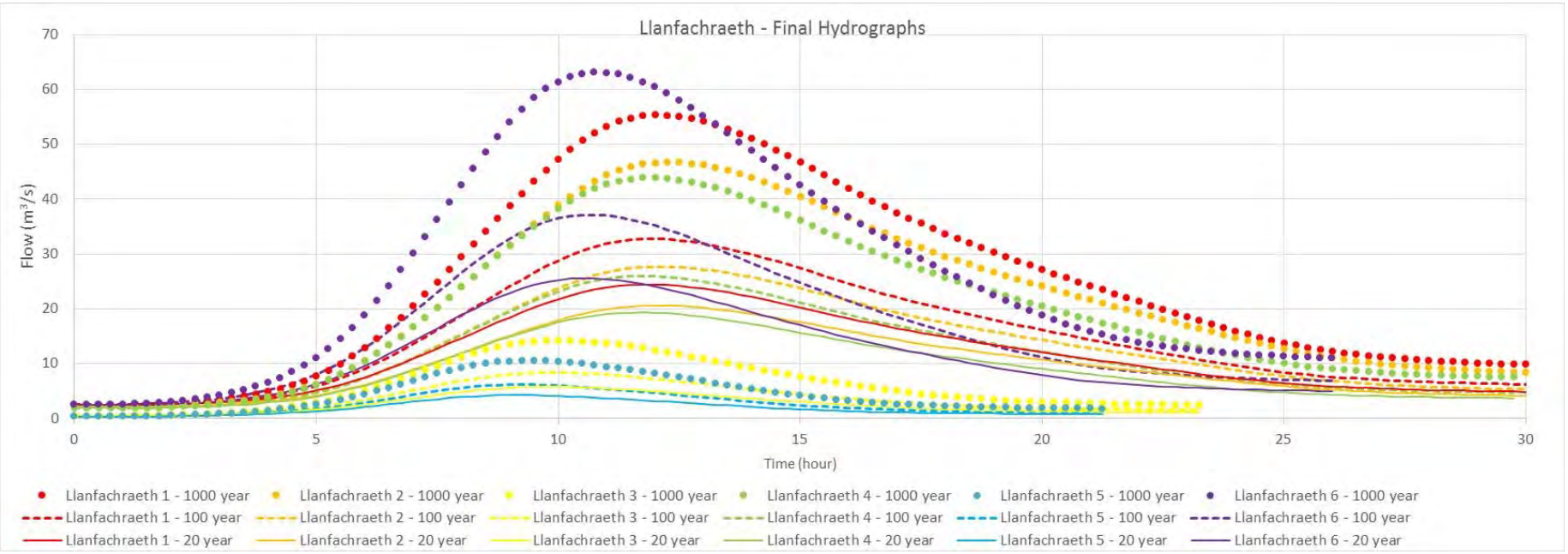
Table 5.5 Uncertainty in the Pooling Group

Parameter	Comments	Certainty
Length of flood peak record	Pooling groups reflected 511 and 530 years of pooled record to determine 100 year event maximum at hydrological assessment locations 1 and 3, respectively.	High
Choice of pooling group	Similarity of all gauges (distance) was less than 2.0 for all sites in the pooling group for all hydrological assessment locations.	High
Choice of distribution	Goodness-of-fit test for both hydrological assessment locations was approximately 0.5 which indicates a good fit.	High

The uncertainty in both QMED and the growth curve will combine to produce a combined uncertainty.

Again, it is considered that the hydrological assessment has produced the best estimate (central estimate), however, it is acknowledged that there is an uncertainty in many of the components that are used to determine this estimate. It is recommended that the modelling undertake sensitivity runs based on the above confidence limits, however, the specific limits will be separately described as part of the hydraulic modelling study.

Figure 5.1 Final Peak Flows Hydrographs



6. Representation of Flows in the Hydraulic Model

The final peak flows represent the total flow at each hydrological assessment location and, for locations within the same catchment, would over-estimate flows if applied directly in the hydraulic model. Hydrographs and associated peak flows for hydrological assessment locations 4, 5 and 6 can be applied as derived since they represent the headwater catchments of Afon Alaw, the Llywenan tributary and the Tan 'Rallt tributary.

Lateral inflow hydrographs for the Afon Alaw and the Llywenan tributary to be applied within the model were determined through consideration of hydrographs for hydrological assessment locations 2, 3, 4 and 5. Hydrological assessment locations 2 and 3 include the headwater inflows and hydrographs were adjusted to 'remove' the upstream inflow already represented in point inflows.

- **Llywenan tributary (lateral inflow between hydrological assessment locations 5 and 3)** - The inflow hydrograph was derived by subtracting the hydrographs for hydrological assessment location 5 from the hydrographs for hydrological assessment location 3. Hydrological assessment location 5 represents the headwater catchment for the Llywenan tributary;
- **Afon Alaw (lateral inflow between hydrological assessment locations 4 and 2)** - The inflow hydrograph was derived by subtracting the hydrographs for hydrological assessment location 4 from the hydrographs for hydrological assessment location 2. Hydrological assessment location 4 represents the headwater catchment for Afon Alaw.

Hydrological assessment location 1, downstream of the bypass, was originally intended for determining lateral inflow between hydrological assessment locations 2 and 1. However, the calculation returned a predominantly negative flow, indicating that the inflow contributing to this short section was already represented in the upstream inflows, so location 1 was not used. The method of determining intervening catchment flow can sometimes return anomalous results like this. However, the lack of lateral inflow to the short section at the downstream reach of the model, having been representing upstream, will not significantly influence the model results near the bypass.

7. References

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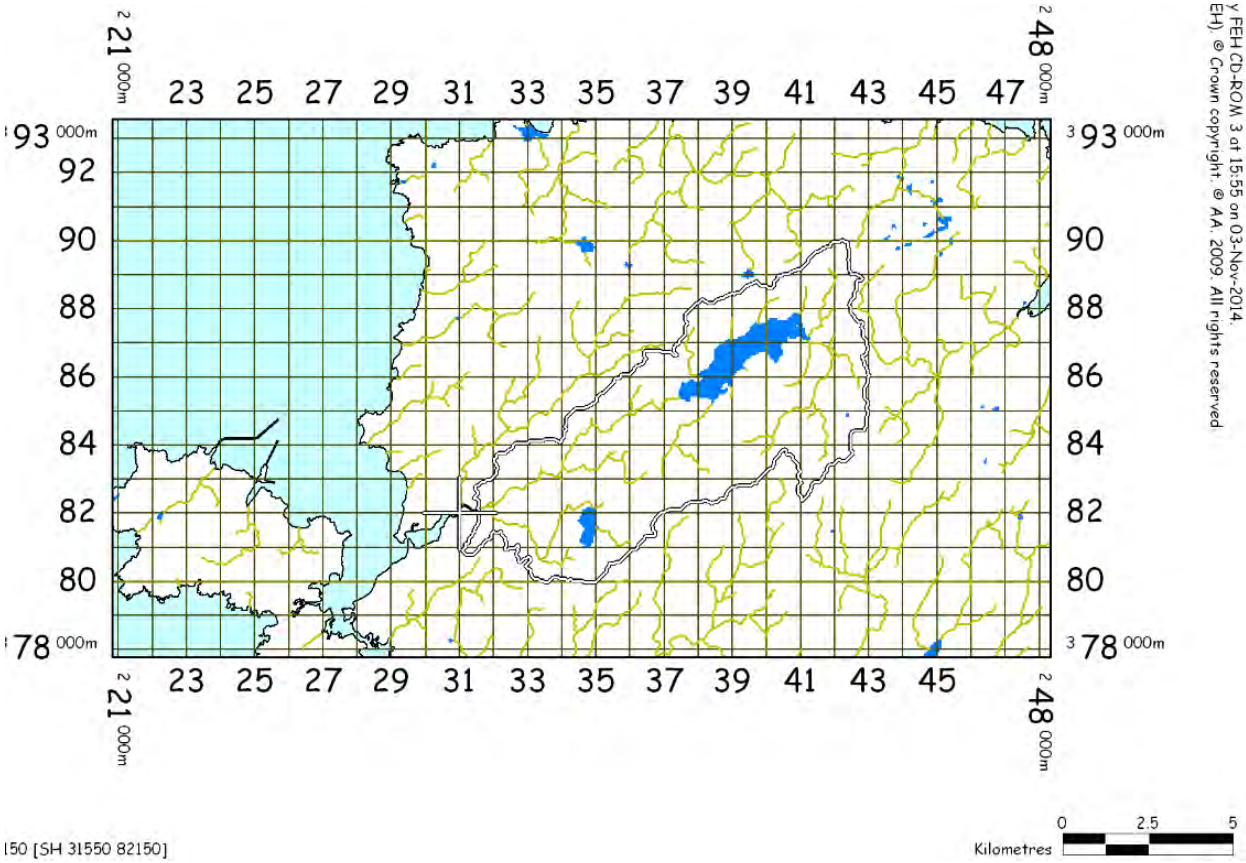
Kjeldsen, T. *Modelling the impact of urbanisation on flood frequency relationships in the UK*, Hydrology Research, 2010.

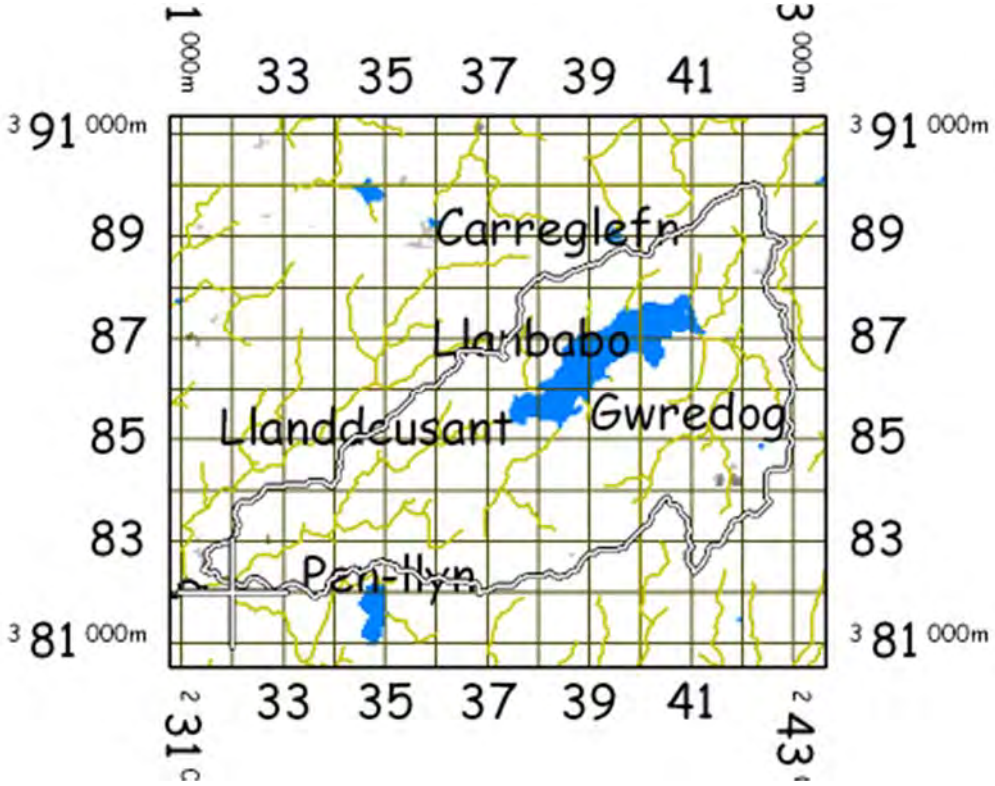
Welsh Government. *Adapting to Climate change: Guidance for Flood and Coastal Erosion Risk Management Authorities in Wales*, Welsh Government, 2011.

Appendix A
FEH Catchments

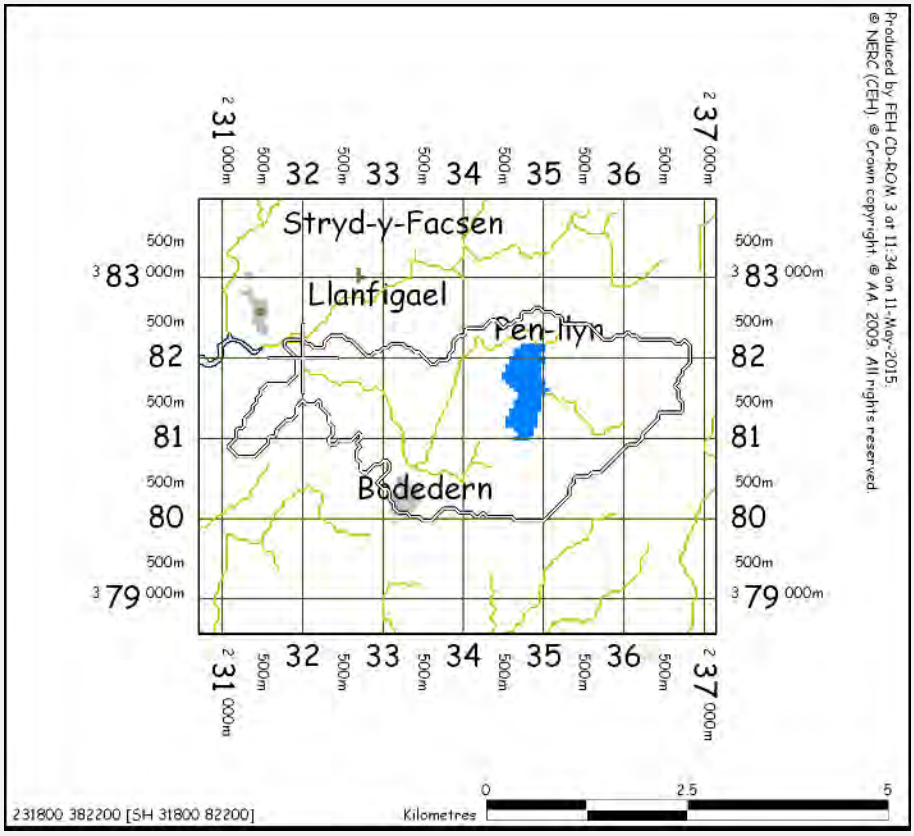
Hydrological assessment location 1



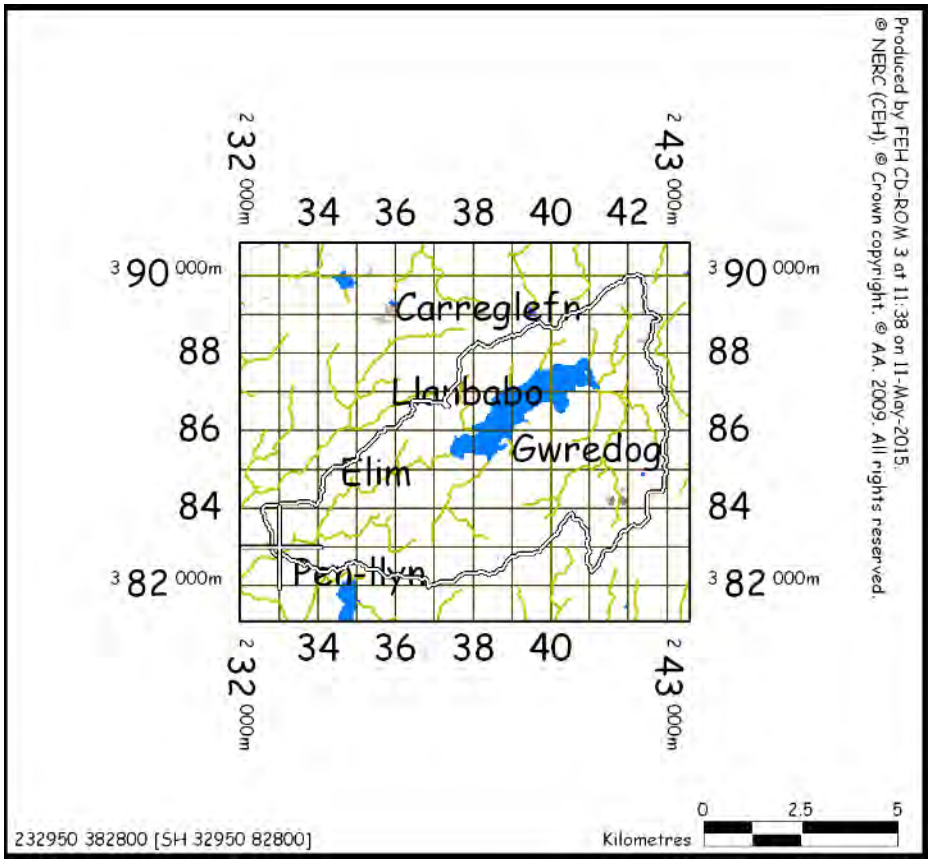
Hydrological assessment location 2



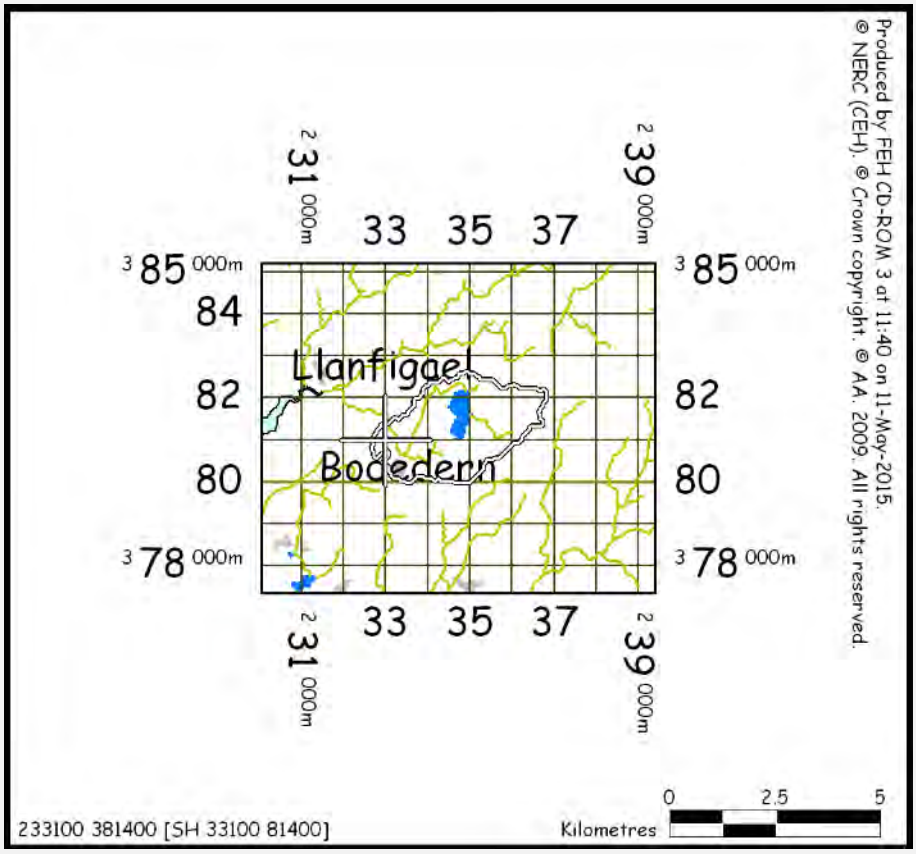
Hydrological assessment location 3



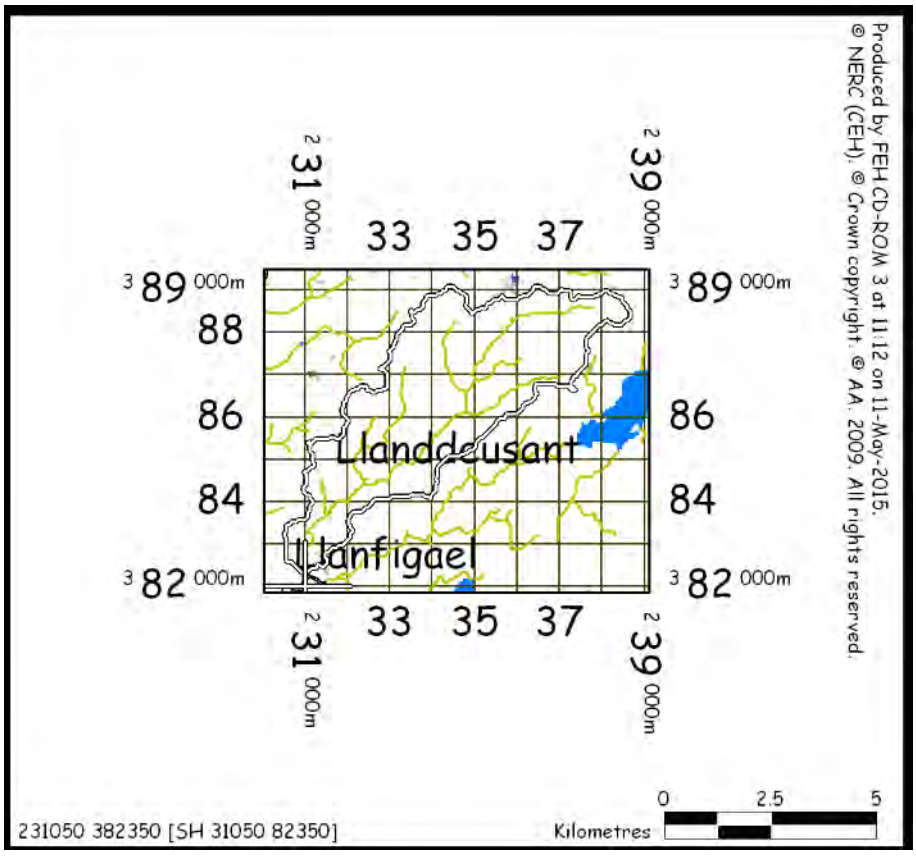
Hydrological assessment location 4



Hydrological assessment location 5



Hydrological assessment location 6



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Appendix B
FEH Catchment Descriptors

VERSION	FEH CD-R Version	3	exported at	11:45:29	GMT	Mon	11-May-15
CATCHMENT 1	GB	231550	382150	SH 31550 82150			
CENTROID	GB	237777	384610	SH 37777 84610			
AREA	56.75						
ALTBAR	51						
ASPBAR	278						
ASPVAR	0.19						
BFIHOST	0.387						
DPLBAR	10.44						
DPSBAR	39						
FARL	0.789						
FPEXT	0.0973						
FPDBAR	0.985						
FPLOC	0.837						
LDP	20.3						
PROPWET	0.45						
RMED-1H	10.5						
RMED-1D	36.6						
RMED-2D	46.4						
SAAR	1001						
SAAR4170	974						
SPRHOST	39.86						
URBCONC1990	-999999						
URBEXT1990	0.0026						
URBLOC1990	-999999						
URBCONC2000	-999999						
URBEXT2000	0.0042						
URBLOC2000	-999999						
C	-0.0304						
D1	0.40762						
D2	0.38682						
D3	0.35291						
E	0.3006						
F	2.336						
C(1 km)	-0.031						
D1(1 km)	0.393						
D2(1 km)	0.37						
D3(1 km)	0.353						
E(1 km)	0.305						
F(1 km)	2.301						

VERSION	FEH CD-R Version	3	exported at	10:15:23	GMT	Mon	11-May-15
CATCHMENT 2	GB	231800	382250	SH 31800 82250			
CENTROID	GB	238456	385225	SH 38456 85225			
AREA	47.74						
ALTBAR	54						
ASPBAR	269						
ASPVAR	0.16						
BFIHOST	0.38						
DPLBAR	11.22						
DPSBAR	40.4						
FARL	0.776						
FPEXT	0.0911						
FPDBAR	1						
FPLOC	0.879						
LDP	20.01						
PROPWET	0.45						
RMED-1H	10.5						
RMED-1D	36.9						
RMED-2D	47						
SAAR	1011						
SAAR4170	978						
SPRHOST	39.92						
URBCONC1990	-999999						
URBEXT1990	0.0017						
URBLOC1990	-999999						
URBCONC2000	-999999						
URBEXT2000	0.0037						
URBLOC2000	-999999						
C	-0.0303						
D1	0.40916						
D2	0.3892						
D3	0.35298						
E	0.29996						
F	2.3402						
C(1 km)	-0.031						
D1(1 km)	0.393						
D2(1 km)	0.37						
D3(1 km)	0.353						
E(1 km)	0.305						
F(1 km)	2.301						

VERSION	FEH CD-R Version	3	exported at	10:34:04	GMT	Mon	########
CATCHMENT 3	GB	231800	382200	SH 31800 82200			
CENTROID	GB	234234	381333	SH 34234 81333			
AREA	8.81						
ALTBAR	35						
ASPBAR	296						
ASPVAR	0.42						
BFIHOST	0.418						
DPLBAR	4.58						
DPSBAR	31.7						
FARL	0.862						
FPEXT	0.1271						
FPDBAR	0.868						
FPLOC	0.739						
LDP	9.15						
PROPWET	0.45						
RMED-1H	10.3						
RMED-1D	35						
RMED-2D	43.6						
SAAR	951						
SAAR4170	958						
SPRHOST	39.5						
URBCONC1990	0.667						
URBEXT1990	0.0071						
URBLOC1990	0.694						
URBCONC2000	0.851						
URBEXT2000	0.0071						
URBLOC2000	0.71						
C	-0.03088						
D1	0.39971						
D2	0.37439						
D3	0.35248						
E	0.30394						
F	2.3142						
C(1 km)	-0.031						
D1(1 km)	0.393						
D2(1 km)	0.37						
D3(1 km)	0.353						
E(1 km)	0.305						
F(1 km)	2.301						

LLANFRACHNAETH CATCHMENTS

VERSION	FEH CD-R Version	3	exported at	11:46:11	GMT	Mon	########
CATCHMENT 4	GB	232950	382800	SH 32950 82800			
CENTROID	GB	238743	385348	SH 38743 85348			
AREA	45.51						
ALTBAR	56						
ASPBAR	273						
ASPVAR	0.16						
BFIHOST	0.377						
DPLBAR	10.1						
DPSBAR	40.8						
FARL	0.767						
FPEXT	0.088						
FPDBAR	0.993						
FPLOC	0.894						
LDP	18.44						
PROPWET	0.45						
RMED-1H	10.5						
RMED-1D	37						
RMED-2D	47.2						
SAAR	1016						
SAAR4170	981						
SPRHOST	39.91						
URBCONC1990	-999999						
URBEXT1990	0.0017						
URBLOC1990	-999999						
URBCONC2000	-999999						
URBEXT2000	0.0033						
URBLOC2000	-999999						
C	-0.03026						
D1	0.40968						
D2	0.39007						
D3	0.35289						
E	0.29968						
F	2.34263						
C(1 km)	-0.031						
D1(1 km)	0.4						
D2(1 km)	0.37						
D3(1 km)	0.357						
E(1 km)	0.306						
F(1 km)	2.289						

VERSION	FEH CD-R Version	3	exported at	11:47:00	GMT	Mon	11-May-15
CATCHMENT 5	GB	233100	381400	SH 33100 81400			
CENTROID	GB	234711	381260	SH 34711 81260			
AREA	6.99						
ALTBAR	42						
ASPBAR	293						
ASPVAR	0.48						
BFIHOST	0.418						
DPLBAR	3.46						
DPSBAR	32.1						
FARL	0.829						
FPEXT	0.0952						
FPDBAR	0.745						
FPLOC	0.851						
LDP	7.21						
PROPWET	0.45						
RMED-1H	10.3						
RMED-1D	35.3						
RMED-2D	44.1						
SAAR	960						
SAAR4170	969						
SPRHOST	39.26						
URBCONC1990	0.679						
URBEXT1990	0.0085						
URBLOC1990	0.385						
URBCONC2000	0.851						
URBEXT2000	0.009						
URBLOC2000	0.374						
C	-0.03085						
D1	0.40115						
D2	0.37575						
D3	0.35217						
E	0.30374						
F	2.31777						
C(1 km)	-0.031						
D1(1 km)	0.398						
D2(1 km)	0.366						
D3(1 km)	0.352						
E(1 km)	0.304						
F(1 km)	2.298						

VERSION	FEH CD-R Version	3	exported at	11:47:33	GMT	Mon	########
CATCHMENT 6	GB	231050	382350	SH 31050 82350			
CENTROID	GB	234224	386376	SH 34224 86376			
AREA	21.28						
ALTBAR	46						
ASPBAR	205						
ASPVAR	0.21						
BFIHOST	0.412						
DPLBAR	6.97						
DPSBAR	42						
FARL	1						
FPEXT	0.0747						
FPDBAR	0.621						
FPLOC	0.793						
LDP	12.79						
PROPWET	0.45						
RMED-1H	10.3						
RMED-1D	35.7						
RMED-2D	45.1						
SAAR	980						
SAAR4170	938						
SPRHOST	39.55						
URBCONC1990	-999999						
URBEXT1990	0.0012						
URBLOC1990	-999999						
URBCONC2000	-999999						
URBEXT2000	0.0023						
URBLOC2000	-999999						
C	-0.03086						
D1	0.4084						
D2	0.38665						
D3	0.35752						
E	0.30389						
F	2.30221						
C(1 km)	-0.031						
D1(1 km)	0.389						
D2(1 km)	0.371						
D3(1 km)	0.353						
E(1 km)	0.305						
F(1 km)	2.299						

LLANFRACHNAETH CATCHMENTS

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Appendix C
Final Pooling Groups

Table C.7.1 Final Pooling Group – Hydrological Assessment Location 1

Station	Years	Discord	AREA	SAAR	FARL	URBEXT	BFIHOST	SPRHOST
42007 (Alre @ Drove Lane Alresford)	43	0.551	57.45	857	0.864	0.016	0.964	4.85
205005 (Ravernet @ Ravernet)	40	0.784	73.53	947	0.934	0	0.422	44.88
41022 (Lod @ Halfway Bridge)	39	1.551	52.44	857	0.951	0.009	0.48	38.72
6008 (Enrick @ Mill of Tore)	27	0.084	105.98	1292	0.839	0	0.43	43.62
37013 (Sandon Brook @ Sandon Bridge)	46	1.466	74.95	575	0.855	0.026	0.276	46.64
42009 (Candover Stream @ Borough Bridge)	41	1.228	72.07	819	0.93	0.011	0.951	6.06
33054 (Babingley @ Castle Rising)	36	0.482	48.51	686	0.944	0.005	0.906	9.73
96003 (Strathy @ Strathy Bridge)	21	0.216	120.87	1090	0.895	0	0.289	55.12
48012 (Fal @ Trenowth)	15	2.753	67.87	1243	0.979	0.019	0.523	35.4
53004 (Chew @ Compton Dando)	53	0.333	128.9	987	0.842	0.009	0.591	28.88
19008 (South Esk @ Prestonholm)	26	2.142	113.44	859	0.888	0.004	0.592	31
203043 (Oonawater @ Shanmoy)	25	1.318	88.59	1003	0.974	0.002	0.4	36.05
76019 (Roe Beck @ Stockdalewath)	13	0.717	62.99	984	1	0	0.429	38.24
52004 (Isle @ Ashford Mill)	50	0.833	87.41	891	0.979	0.026	0.499	39.76
39042 (Leach @ Priory Mill Lechlade)	40	0.541	77.57	736	0.971	0.003	0.865	12.21

Discord=Discordancy

Four gauges were identified as being permeable (SPRHOST<20%). These were investigated to identify influence of non-flood years in the dataset, i.e. annual maximums less than QMED/2, which were then removed from the dataset:

42007 (Alre @ Drove Lane Alresford)	no non-flood years (chance of flood year 1.00)
42009 (Candover Stream @ Borough Bridge)	two non-flood years (chance of flood year 0.95)
33054 (Babingley @ Castle Rising)	four non-flood years (chance of flood year 0.89)
39042 (Leach @ Priory Mill Lechlade)	one non-flood year (chance of flood year 0.98)

Table C.7.2 Final Pooling Group – Hydrological Assessment Location 3

Station	Years	Discord	AREA	SAAR	FARL	URBEXT	BFIHOST	SPRHOST
27051 (Crimple @ Burn Bridge)	40	0.553	8.15	855	1	0.006	0.309	40.77
47022 (Tory Brook @ Newnham Park)	19	0.821	13.45	1403	0.942	0.014	0.431	44.18
27073 (Brompton Beck @ Snainton Ings)	32	0.915	8.06	721	1	0.008	0.89	17.77
45816 (Haddeo @ Upton)	19	0.87	6.81	1210	1	0.005	0.590	31.27
26802 (Gypsey Race @ Kirby Grindalythe)	13	0.344	15.85	757	1	0	0.959	5.67
25019 (Leven @ Easby)	34	0.999	15.07	830	1	0.004	0.525	38.58
203046 (Rathmore Burn @ Rathmore Bridge)	30	1.282	22.51	1043	1	0	0.43	36.88
28033 (Dove @ Hollinsclough)	33	0.814	7.93	1346	1	0	0.403	42.49
25011 (Langdon Beck @ Langdon)	26	1.528	12.79	1463	1	0.001	0.237	58.21
206006 (Annalong @ Recorder)	48	1.959	13.66	1720	0.98	0	0.336	51.75
27010 (Hodge Beck @ Bransdale Weir)	41	0.359	18.84	987	1	0.001	0.227	50.56
44008 (South Winterbourne @ Winterbourne Steepleton)	33	1.779	20.17	1012	1	0.004	0.811	19.55
72014 (Conder @ Galgate)	45	0.764	28.99	1183	0.975	0.006	0.443	35.96
20002 (West Peffer Burn @ Luffness)	41	1.582	26.31	616	0.996	0.002	0.471	32.18
49003 (de Lank @ de Lank)	46	0.351	21.61	1628	0.998	0	0.379	47.75

Discord=Discordancy

Three gauges were identified as being permeable (SPRHOST<20%). These were investigated to identify influence of non-flood years in the dataset, i.e. annual maximums less than QMED/2, which were then removed from the dataset:

27073 (Brompton Beck @ Snainton Ings)	two non-flood years (chance of flood year 0.94)
26802 (Gypsey Race @ Kirby Grindalythe)	one non-flood year (chance of flood year 0.92)
44008 (South Winterbourne @ Winterbourne Steepleton)	six non-flood years (chance of flood year 0.82)

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Appendix D
ISIS Summary Report of ReFH Hydrograph Generation

Llanfr1
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.003; Season set to WINTER

***** end of data read warnings *****

FILE=7751.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llanfr1
****
Catchment Characteristics
****
Easting : 231550 Northing : 382150
Area : 56.750 km2
DPLBAR : 10.440 km
DPSBAR : 39.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.003)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 2.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 10.829 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.936
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.790
DDF storm depth : 29.600 mm
Design storm depth : 21.889 mm
Peak rainfall [design] : 1.368 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 1.000
Maximum runoff : 53.0%
Minimum runoff : 45.6%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 5.412 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 2.913
Unit hydrograph kink abscissa : 10.823 hours
Unit hydrograph time base : 19.461 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 40.370
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 3.611
Maximum Baseflow : 5.445 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 15.853 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 20.161 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Llanfr1
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.003; Season set to WINTER

***** end of data read warnings *****

FILE=6932.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llanfr1
****
Catchment Characteristics
****
Easting : 231550 Northing : 382150
Area : 56.750 km2
DPLBAR : 10.440 km
DPSBAR : 39.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.003)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 20.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 10.829 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.936
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.790
DDF storm depth : 53.649 mm
Design storm depth : 39.672 mm
Peak rainfall [design] : 2.479 mm
==========
Loss model

```
========================================
Cmax flag                 : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                :  293.299
Cini flag                 : ReFH Design Standard
Cini value                :  133.612
alpha_T flag              : ReFH Design Standard
alpha_T value             :    0.940
Maximum runoff            :     56.3%
Minimum runoff            :     42.9%
========================================
Routing model
========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    5.412 hours
Up flag                   : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                   : ReFH Design Standard
Uk value used             :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    2.913
Unit hydrograph kink abscissa  :   10.823 hours
Unit hydrograph time base     :   19.461 hours
========================================
Baseflow model
========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                  :   40.370
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                  :    1.009
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                 :    3.611
Maximum Baseflow          :    8.111 m3/s
========================================
Output summary
========================================
Direct runoff hydrograph peak  :   28.920 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :   34.542 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Llanfr1
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.003; Season set to WINTER

***** end of data read warnings *****

FILE=B7C3.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llanfr1
****
Catchment Characteristics
****
Easting : 231550 Northing : 382150
Area : 56.750 km2
DPLBAR : 10.440 km
DPSBAR : 39.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.003)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 100.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 10.843 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.936
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.790
DDF storm depth : 77.847 mm
Design storm depth : 57.567 mm
Peak rainfall [design] : 3.598 mm
==========
Loss model

```
========================================
Cmax flag                 : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                :  293.299
Cini flag                 : ReFH Design Standard
Cini value                :  133.612
alpha_T flag              : ReFH Design Standard
alpha_T value             :    0.830
Maximum runoff            :     57.4%
Minimum runoff            :     37.9%
========================================
Routing model
========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    5.419 hours
Up flag                   : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                   : ReFH Design Standard
Uk value used             :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    2.909
Unit hydrograph kink abscissa :   10.838 hours
Unit hydrograph time base    :   19.487 hours
========================================
Baseflow model
========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                  :   40.419
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                  :    1.009
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                 :    3.611
Maximum Baseflow          :   10.440 m3/s
========================================
Output summary
========================================
Direct runoff hydrograph peak :   40.285 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :   47.063 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Llanfr1
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.003; Season set to WINTER
return period = 1000.0; ReFH not calibrated for events greater than 150 yr.

***** end of data read warnings *****

FILE=F5A7.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llanfr1
****
Catchment Characteristics
****
Easting : 231550 Northing : 382150
Area : 56.750 km2
DPLBAR : 10.440 km
DPSBAR : 39.000 m/km
PROPWET : 0.450
BFIHOST : 0.387
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.003)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 1000.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 10.829 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.936
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.790
DDF storm depth : 131.855 mm
Design storm depth : 97.504 mm
Peak rainfall [design] : 6.094 mm
==========

Loss model
==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 293.299
Cini flag : ReFH Design Standard
Cini value : 133.612
alpha_T flag : ReFH Design Standard
alpha_T value : 0.700
Maximum runoff : 65.1%
Minimum runoff : 32.0%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 5.412 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 2.913
Unit hydrograph kink abscissa : 10.823 hours
Unit hydrograph time base : 19.461 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 40.370
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.009
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 3.611
Maximum Baseflow : 16.475 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 69.807 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 79.513 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Llan2
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.002; Season set to WINTER

***** end of data read warnings *****

FILE=6BDD.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan2
****
Catchment Characteristics
****
Easting : 231800 Northing : 382250
Area : 47.740 km2
DPLBAR : 11.220 km
DPSBAR : 40.400 m/km
PROPWET : 0.450
BFIHOST : 0.380
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.002)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 2.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 11.290 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.940
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.792
DDF storm depth : 29.829 mm
Design storm depth : 22.208 mm
Peak rainfall [design] : 1.388 mm
==========
Loss model

```
========================================
Cmax flag                 : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                :  288.257
Cini flag                 : ReFH Design Standard
Cini value                :  133.030
alpha_T flag              : ReFH Design Standard
alpha_T value             :    1.000
Maximum runoff            :     53.8%
Minimum runoff            :     46.2%
========================================
Routing model
========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    5.614 hours
Up flag                   : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                   : ReFH Design Standard
Uk value used             :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    2.362
Unit hydrograph kink abscissa  :   11.228 hours
Unit hydrograph time base     :   20.189 hours
========================================
Baseflow model
========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                  :   40.758
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                  :    0.990
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                 :    3.047
Maximum Baseflow          :    4.560 m3/s
========================================
Output summary
========================================
Direct runoff hydrograph peak  :   13.365 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :   16.981 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Llan2
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.002; Season set to WINTER

***** end of data read warnings *****

FILE=D899.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan2
****
Catchment Characteristics
****
Easting : 231800 Northing : 382250
Area : 47.740 km2
DPLBAR : 11.220 km
DPSBAR : 40.400 m/km
PROPWET : 0.450
BFIHOST : 0.380
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.002)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 20.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 11.290 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.940
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.792
DDF storm depth : 54.007 mm
Design storm depth : 40.209 mm
Peak rainfall [design] : 2.513 mm
==========
Loss model

```
==========================================
Cmax flag                 : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                :  288.257
Cini flag                 : ReFH Design Standard
Cini value                :  133.030
alpha_T flag              : ReFH Design Standard
alpha_T value             :    0.940
Maximum runoff            :     57.3%
Minimum runoff            :     43.4%
==========================================
Routing model
==========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    5.614 hours
Up flag                   : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                   : ReFH Design Standard
Uk value used             :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    2.362
Unit hydrograph kink abscissa :   11.228 hours
Unit hydrograph time base    :   20.189 hours
==========================================
Baseflow model
==========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                  :   40.758
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                  :    0.990
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                 :    3.047
Maximum Baseflow          :    6.791 m3/s
==========================================
Output summary
==========================================
Direct runoff hydrograph peak :   24.386 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :   29.101 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Llan2
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.002; Season set to WINTER

***** end of data read warnings *****

FILE=CBD0.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan2
****
Catchment Characteristics
****
Easting : 231800 Northing : 382250
Area : 47.740 km2
DPLBAR : 11.220 km
DPSBAR : 40.400 m/km
PROPWET : 0.450
BFIHOST : 0.380
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.002)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 100.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 11.301 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.940
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.792
DDF storm depth : 78.316 mm
Design storm depth : 58.307 mm
Peak rainfall [design] : 3.644 mm
==========
Loss model

```
=========================================
Cmax flag                 : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                :  288.257
Cini flag                 : ReFH Design Standard
Cini value                :  133.030
alpha_T flag              : ReFH Design Standard
alpha_T value             :    0.830
Maximum runoff            :     58.5%
Minimum runoff            :     38.4%
=========================================
Routing model
=========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    5.620 hours
Up flag                   : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                   : ReFH Design Standard
Uk value used             :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    2.360
Unit hydrograph kink abscissa :   11.239 hours
Unit hydrograph time base    :   20.209 hours
=========================================
Baseflow model
=========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                  :   40.795
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                  :    0.990
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                 :    3.047
Maximum Baseflow          :    8.744 m3/s
=========================================
Output summary
=========================================
Direct runoff hydrograph peak :   34.002 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :   39.663 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Llan2
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.002; Season set to WINTER
return period = 1000.0; ReFH not calibrated for events greater than 150 yr.

***** end of data read warnings *****

FILE=2D2C.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan2
****
Catchment Characteristics
****
Easting : 231800 Northing : 382250
Area : 47.740 km2
DPLBAR : 11.220 km
DPSBAR : 40.400 m/km
PROPWET : 0.450
BFIHOST : 0.380
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.002)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 1000.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 11.290 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.940
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.792
DDF storm depth : 132.526 mm
Design storm depth : 98.667 mm
Peak rainfall [design] : 6.166 mm
==========

Loss model
==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 288.257
Cini flag : ReFH Design Standard
Cini value : 133.030
alpha_T flag : ReFH Design Standard
alpha_T value : 0.700
Maximum runoff : 66.5%
Minimum runoff : 32.4%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 5.614 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 2.362
Unit hydrograph kink abscissa : 11.228 hours
Unit hydrograph time base : 20.189 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 40.758
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 0.990
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 3.047
Maximum Baseflow : 13.808 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 58.944 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 67.088 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Llan3
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.007; Season set to WINTER

***** end of data read warnings *****

FILE=60B.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan3
****
Catchment Characteristics
****
Easting : 231800 Northing : 382200
Area : 8.810 km2
DPLBAR : 4.580 km
DPSBAR : 31.700 m/km
PROPWET : 0.450
BFIHOST : 0.418
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.007)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 2.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 6.735 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.966
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.778
DDF storm depth : 28.446 mm
Design storm depth : 21.372 mm
Peak rainfall [design] : 1.336 mm
==========
Loss model

```
=========================================
Cmax flag                 : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                :  315.575
Cini flag                 : ReFH Design Standard
Cini value                :  135.445
alpha_T flag              : ReFH Design Standard
alpha_T value             :    1.000
Maximum runoff            :     49.7%
Minimum runoff            :     42.9%
=========================================
Routing model
=========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    3.452 hours
Up flag                   : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                   : ReFH Design Standard
Uk value used             :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    0.709
Unit hydrograph kink abscissa :    6.904 hours
Unit hydrograph time base    :   12.414 hours
=========================================
Baseflow model
=========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                  :   34.789
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                  :    1.097
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                 :    0.547
Maximum Baseflow          :    0.957 m3/s
=========================================
Output summary
=========================================
Direct runoff hydrograph peak :    3.021 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :    3.745 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Llan3
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.007; Season set to WINTER

***** end of data read warnings *****

FILE=56BF.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan3
****
Catchment Characteristics
****
Easting : 231800 Northing : 382200
Area : 8.810 km2
DPLBAR : 4.580 km
DPSBAR : 31.700 m/km
PROPWET : 0.450
BFIHOST : 0.418
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.007)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 20.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 6.735 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.966
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.778
DDF storm depth : 51.853 mm
Design storm depth : 38.959 mm
Peak rainfall [design] : 2.435 mm
==========
Loss model

```
========================================
Cmax flag                 : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                :  315.575
Cini flag                 : ReFH Design Standard
Cini value                :  135.445
alpha_T flag              : ReFH Design Standard
alpha_T value             :    0.940
Maximum runoff            :     52.7%
Minimum runoff            :     40.4%
========================================
Routing model
========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    3.452 hours
Up flag                   : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                   : ReFH Design Standard
Uk value used             :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    0.709
Unit hydrograph kink abscissa :    6.904 hours
Unit hydrograph time base    :   12.414 hours
========================================
Baseflow model
========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                  :   34.789
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                  :    1.097
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                 :    0.547
Maximum Baseflow          :    1.463 m3/s
========================================
Output summary
========================================
Direct runoff hydrograph peak :    5.533 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :    6.514 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Llan3
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.007; Season set to WINTER

***** end of data read warnings *****

FILE=E00E.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan3
****
Catchment Characteristics
****
Easting : 231800 Northing : 382200
Area : 8.810 km2
DPLBAR : 4.580 km
DPSBAR : 31.700 m/km
PROPWET : 0.450
BFIHOST : 0.418
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.007)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 100.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 6.732 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.966
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.778
DDF storm depth : 75.511 mm
Design storm depth : 56.735 mm
Peak rainfall [design] : 3.546 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 315.575
Cini flag : ReFH Design Standard
Cini value : 135.445
alpha_T flag : ReFH Design Standard
alpha_T value : 0.830
Maximum runoff : 53.6%
Minimum runoff : 35.7%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 3.451 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.709
Unit hydrograph kink abscissa : 6.902 hours
Unit hydrograph time base : 12.410 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 34.779
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.097
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.547
Maximum Baseflow : 1.907 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 7.730 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 8.936 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Llan3
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.007; Season set to WINTER
return period = 1000.0; ReFH not calibrated for events greater than 150 yr.

***** end of data read warnings *****

FILE=CB51.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan3
****
Catchment Characteristics
****
Easting : 231800 Northing : 382200
Area : 8.810 km2
DPLBAR : 4.580 km
DPSBAR : 31.700 m/km
PROPWET : 0.450
BFIHOST : 0.418
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.007)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 1000.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 6.735 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.966
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.778
DDF storm depth : 128.549 mm
Design storm depth : 96.585 mm
Peak rainfall [design] : 6.036 mm
==========

Loss model
==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 315.575
Cini flag : ReFH Design Standard
Cini value : 135.445
alpha_T flag : ReFH Design Standard
alpha_T value : 0.700
Maximum runoff : 60.6%
Minimum runoff : 30.1%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 3.452 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.709
Unit hydrograph kink abscissa : 6.904 hours
Unit hydrograph time base : 12.414 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 34.789
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.097
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.547
Maximum Baseflow : 3.050 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 13.430 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 15.213 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Llan4
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.002; Season set to WINTER

***** end of data read warnings *****

FILE=A24A.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan4
****
Catchment Characteristics
****
Easting : 232950 Northing : 382800
Area : 45.510 km2
DPLBAR : 10.100 km
DPSBAR : 40.800 m/km
PROPWET : 0.450
BFIHOST : 0.377
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.002)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 2.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 10.596 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.941
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.793
DDF storm depth : 29.937 mm
Design storm depth : 22.343 mm
Peak rainfall [design] : 1.396 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 286.094
Cini flag : ReFH Design Standard
Cini value : 132.762
alpha_T flag : ReFH Design Standard
alpha_T value : 1.000
Maximum runoff : 54.2%
Minimum runoff : 46.4%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 5.256 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 2.405
Unit hydrograph kink abscissa : 10.512 hours
Unit hydrograph time base : 18.902 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 39.719
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 0.981
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 2.909
Maximum Baseflow : 4.457 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 13.524 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 17.030 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Llan4
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.002; Season set to WINTER

***** end of data read warnings *****

FILE=C6A3.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan4
****
Catchment Characteristics
****
Easting : 232950 Northing : 382800
Area : 45.510 km2
DPLBAR : 10.100 km
DPSBAR : 40.800 m/km
PROPWET : 0.450
BFIHOST : 0.377
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.002)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 20.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 10.596 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.941
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.793
DDF storm depth : 54.176 mm
Design storm depth : 40.434 mm
Peak rainfall [design] : 2.527 mm
==========
Loss model

```
==========================================
Cmax flag                 : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                :  286.094
Cini flag                 : ReFH Design Standard
Cini value                :  132.762
alpha_T flag              : ReFH Design Standard
alpha_T value             :    0.940
Maximum runoff            :     57.7%
Minimum runoff            :     43.7%
==========================================
Routing model
==========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    5.256 hours
Up flag                   : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                   : ReFH Design Standard
Uk value used             :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    2.405
Unit hydrograph kink abscissa :   10.512 hours
Unit hydrograph time base    :   18.902 hours
==========================================
Baseflow model
==========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                  :   39.719
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                  :    0.981
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                 :    2.909
Maximum Baseflow          :    6.664 m3/s
==========================================
Output summary
==========================================
Direct runoff hydrograph peak :   24.658 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :   29.264 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Llan4
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.002; Season set to WINTER
return period = 1000.0; ReFH not calibrated for events greater than 150 yr.

***** end of data read warnings *****

FILE=84B2.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan4
****
Catchment Characteristics
****
Easting : 232950 Northing : 382800
Area : 45.510 km2
DPLBAR : 10.100 km
DPSBAR : 40.800 m/km
PROPWET : 0.450
BFIHOST : 0.377
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.002)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 1000.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 10.596 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.941
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.793
DDF storm depth : 132.842 mm
Design storm depth : 99.146 mm
Peak rainfall [design] : 6.196 mm
==========

Loss model
==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 286.094
Cini flag : ReFH Design Standard
Cini value : 132.762
alpha_T flag : ReFH Design Standard
alpha_T value : 0.700
Maximum runoff : 67.1%
Minimum runoff : 32.6%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 5.256 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 2.405
Unit hydrograph kink abscissa : 10.512 hours
Unit hydrograph time base : 18.902 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 39.719
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 0.981
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 2.909
Maximum Baseflow : 13.608 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 59.670 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 67.687 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Llan5
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.009; Season set to WINTER

***** end of data read warnings *****

FILE=102A.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan5
****
Catchment Characteristics
****
Easting : 233100 Northing : 381400
Area : 6.990 km2
DPLBAR : 3.460 km
DPSBAR : 32.100 m/km
PROPWET : 0.450
BFIHOST : 0.418
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.009)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 2.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 5.660 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.968
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.780
DDF storm depth : 28.644 mm
Design storm depth : 21.639 mm
Peak rainfall [design] : 1.352 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 315.575
Cini flag : ReFH Design Standard
Cini value : 135.445
alpha_T flag : ReFH Design Standard
alpha_T value : 1.000
Maximum runoff : 49.8%
Minimum runoff : 42.9%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.888 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.672
Unit hydrograph kink abscissa : 5.776 hours
Unit hydrograph time base : 10.385 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 32.604
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.097
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.437
Maximum Baseflow : 0.808 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 2.681 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 3.286 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Llan5
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.009; Season set to WINTER

***** end of data read warnings *****

FILE=DF3.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan5
****
Catchment Characteristics
****
Easting : 233100 Northing : 381400
Area : 6.990 km2
DPLBAR : 3.460 km
DPSBAR : 32.100 m/km
PROPWET : 0.450
BFIHOST : 0.418
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.009)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 20.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 5.660 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.968
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.780
DDF storm depth : 52.197 mm
Design storm depth : 39.432 mm
Peak rainfall [design] : 2.464 mm
==========
Loss model

```
========================================
Cmax flag                 : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                :  315.575
Cini flag                 : ReFH Design Standard
Cini value                :  135.445
alpha_T flag              : ReFH Design Standard
alpha_T value             :    0.940
Maximum runoff            :     52.8%
Minimum runoff            :     40.4%
========================================
Routing model
========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    2.888 hours
Up flag                   : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                   : ReFH Design Standard
Uk value used             :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    0.672
Unit hydrograph kink abscissa :    5.776 hours
Unit hydrograph time base    :   10.385 hours
========================================
Baseflow model
========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                  :   32.604
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                  :    1.097
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                 :    0.437
Maximum Baseflow          :    1.247 m3/s
========================================
Output summary
========================================
Direct runoff hydrograph peak :    4.913 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :    5.739 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Llan5
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.009; Season set to WINTER

***** end of data read warnings *****

FILE=53D9.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan5
****
Catchment Characteristics
****
Easting : 233100 Northing : 381400
Area : 6.990 km2
DPLBAR : 3.460 km
DPSBAR : 32.100 m/km
PROPWET : 0.450
BFIHOST : 0.418
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.009)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 100.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 5.670 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.968
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.780
DDF storm depth : 75.996 mm
Design storm depth : 57.411 mm
Peak rainfall [design] : 3.588 mm
==========
Loss model

```
==========================================
Cmax flag                 : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                :  315.575
Cini flag                 : ReFH Design Standard
Cini value                :  135.445
alpha_T flag              : ReFH Design Standard
alpha_T value             :    0.830
Maximum runoff            :     53.8%
Minimum runoff            :     35.7%
==========================================
Routing model
==========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    2.893 hours
Up flag                   : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                   : ReFH Design Standard
Uk value used             :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    0.671
Unit hydrograph kink abscissa :    5.785 hours
Unit hydrograph time base    :   10.403 hours
==========================================
Baseflow model
==========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                  :   32.653
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                  :    1.097
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                 :    0.437
Maximum Baseflow          :    1.630 m3/s
==========================================
Output summary
==========================================
Direct runoff hydrograph peak :    6.866 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :    7.889 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Llan5
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.009; Season set to WINTER
return period = 1000.0; ReFH not calibrated for events greater than 150 yr.

***** end of data read warnings *****

FILE=E341.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan5
****
Catchment Characteristics
****
Easting : 233100 Northing : 381400
Area : 6.990 km2
DPLBAR : 3.460 km
DPSBAR : 32.100 m/km
PROPWET : 0.450
BFIHOST : 0.418
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.009)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 1000.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 5.660 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.968
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.780
DDF storm depth : 129.336 mm
Design storm depth : 97.707 mm
Peak rainfall [design] : 6.106 mm
==========

Loss model
==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 315.575
Cini flag : ReFH Design Standard
Cini value : 135.445
alpha_T flag : ReFH Design Standard
alpha_T value : 0.700
Maximum runoff : 60.9%
Minimum runoff : 30.1%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 2.888 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 0.672
Unit hydrograph kink abscissa : 5.776 hours
Unit hydrograph time base : 10.385 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 32.604
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.097
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 0.437
Maximum Baseflow : 2.627 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 11.938 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 13.466 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

Llan6
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.001; Season set to WINTER

***** end of data read warnings *****

FILE=AE1E.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan6
****
Catchment Characteristics
****
Easting : 231050 Northing : 382350
Area : 25.040 km2
DPLBAR : 6.970 km
DPSBAR : 42.000 m/km
PROPWET : 0.450
BFIHOST : 0.412
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.001)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 2.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 8.291 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.952
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.785
DDF storm depth : 28.693 mm
Design storm depth : 21.433 mm
Peak rainfall [design] : 1.339 mm
==========
Loss model

==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 311.270
Cini flag : ReFH Design Standard
Cini value : 135.185
alpha_T flag : ReFH Design Standard
alpha_T value : 1.000
Maximum runoff : 50.3%
Minimum runoff : 43.4%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 4.187 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 1.661
Unit hydrograph kink abscissa : 8.375 hours
Unit hydrograph time base : 15.058 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 38.424
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.080
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 1.589
Maximum Baseflow : 2.561 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 7.746 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 9.735 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

```
Llan6
 ** beginning of data read warnings **

 ReFH dll is not being used - calculations are performed using the published
report.
 Calculations may therefore not be the latest recognised standard.
 URBEXT = 0.001; Season set to WINTER

 ***** end of data read warnings *****

                                          FILE=1D51.dat           ISIS VER=
6.7.0.110
 ************************************************************
 ISIS
 ************************************************************

 HYDROLOGICAL DATA

 Catchment: Llan6
 ************************************************************
 Catchment Characteristics
 ************************************************************
 Easting        :    231050 Northing       :    382350
 Area           :    25.040 km2
 DPLBAR         :     6.970 km
 DPSBAR         :    42.000 m/km
 PROPWET        :     0.450
 BFIHOST        :     0.412

*******************************************************************************
 Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
 Calculations from ReFH published report (2005)

*******************************************************************************
 Estimation of T-year flood
 ==========================
 Season                          :    WINTER
 (Seasonality determined by URBEXT = 0.001)
 ========================================
 Rainfall
 ========================================
 Event rainfall flag             :    DESIGN
 Rainfall profile flag           :    DESIGN
 Flood return period             :    20.000 years
 Data interval                   :     0.250 hours
 Design storm duration           :    10.750 hours
 Critical storm duration         :     8.291 hours
 ARF flag                        : ReFH Design Standard
 Areal reduction factor (ARF)    :     0.952
 SCF flag                        : ReFH Design Standard
 Seasonal correction factor      :     0.785
 DDF storm depth                 :    52.303 mm
 Design storm depth              :    39.069 mm
 Peak rainfall [design]          :     2.442 mm
 ========================================
 Loss model
 ========================================
 Cmax flag                       : Catchment descriptors
 Cmax donor correction factor    :     1.000
 Cmax value                      :   311.270
 Cini flag                       : ReFH Design Standard
 Cini value                      :   135.185
 alpha_T flag                    : ReFH Design Standard
 alpha_T value                   :     0.940
 Maximum runoff                  :      53.3%
 Minimum runoff                  :      40.9%
 ========================================
```

Routing model

Time-to-peak (Tp) flag	:	Catchment descriptors
Tp donor correction factor	:	1.000
Instantaneous UH time to peak	:	4.187 hours
Up flag	:	ReFH Design Standard
Dimensionless UH peak	:	0.650
Uk flag	:	ReFH Design Standard
Uk value used	:	0.800
Dimensionless UH kink ordinate	:	0.270
UH ordinate multiplier	:	1.661
Unit hydrograph kink abscissa	:	8.375 hours
Unit hydrograph time base	:	15.058 hours

Baseflow model

Baseflow lag (BL) flag	:	Catchment descriptors
BL donor correction factor	:	1.000
BL value	:	38.424
Baseflow recharge (BR) flag	:	Catchment descriptors
BR donor correction factor	:	1.000
BR value	:	1.080
Initial Baseflow (BF0) flag	:	ReFH Design Standard
BF0 value	:	1.589
Maximum Baseflow	:	3.851 m3/s

Output summary

Direct runoff hydrograph peak	:	14.192 m3/s
Minimum allowable flow	:	0.000 m3/s
Total flow hydrograph peak	:	16.826 m3/s
Hydrograph scaling factor	:	1.000
Simulation results using	:	Full hydrograph

****

Llan6
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.001; Season set to WINTER

***** end of data read warnings *****

FILE=A324.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan6
****
Catchment Characteristics
****
Easting : 231050 Northing : 382350
Area : 25.040 km2
DPLBAR : 6.970 km
DPSBAR : 42.000 m/km
PROPWET : 0.450
BFIHOST : 0.412
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.001)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 100.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 8.291 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.952
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.785
DDF storm depth : 76.166 mm
Design storm depth : 56.895 mm
Peak rainfall [design] : 3.556 mm
==========
Loss model

```
========================================
Cmax flag                 : Catchment descriptors
Cmax donor correction factor  :    1.000
Cmax value                :  311.270
Cini flag                 : ReFH Design Standard
Cini value                :  135.185
alpha_T flag              : ReFH Design Standard
alpha_T value             :    0.830
Maximum runoff            :     54.3%
Minimum runoff            :     36.1%
========================================
Routing model
========================================
Time-to-peak (Tp) flag       : Catchment descriptors
Tp donor correction factor    :    1.000
Instantaneous UH time to peak :    4.187 hours
Up flag                   : ReFH Design Standard
Dimensionless UH peak        :    0.650
Uk flag                   : ReFH Design Standard
Uk value used             :    0.800
Dimensionless UH kink ordinate :    0.270
UH ordinate multiplier       :    1.661
Unit hydrograph kink abscissa :    8.375 hours
Unit hydrograph time base    :   15.058 hours
========================================
Baseflow model
========================================
Baseflow lag (BL) flag       : Catchment descriptors
BL donor correction factor    :    1.000
BL value                  :   38.424
Baseflow recharge (BR) flag   : Catchment descriptors
BR donor correction factor    :    1.000
BR value                  :    1.080
Initial Baseflow (BF0) flag   : ReFH Design Standard
BF0 value                 :    1.589
Maximum Baseflow          :    4.983 m3/s
========================================
Output summary
========================================
Direct runoff hydrograph peak :   19.838 m3/s
Minimum allowable flow       :    0.000 m3/s
Total flow hydrograph peak    :   23.046 m3/s
Hydrograph scaling factor     :    1.000
Simulation results using      : Full hydrograph

************************************************************
```

Llan6
** beginning of data read warnings **

ReFH dll is not being used - calculations are performed using the published report.
Calculations may therefore not be the latest recognised standard.
URBEXT = 0.001; Season set to WINTER
return period = 1000.0; ReFH not calibrated for events greater than 150 yr.

***** end of data read warnings *****

FILE=1AA4.dat ISIS VER= 6.7.0.110
****
ISIS
****

HYDROLOGICAL DATA

Catchment: Llan6
****
Catchment Characteristics
****
Easting : 231050 Northing : 382350
Area : 25.040 km2
DPLBAR : 6.970 km
DPSBAR : 42.000 m/km
PROPWET : 0.450
BFIHOST : 0.412
****
Summary of estimate using Revitalised Flood Hydrograph rainfall-runoff model
Calculations from ReFH published report (2005)
****
Estimation of T-year flood
==========
Season : WINTER
(Seasonality determined by URBEXT = 0.001)
==========
Rainfall
==========
Event rainfall flag : DESIGN
Rainfall profile flag : DESIGN
Flood return period : 1000.000 years
Data interval : 0.250 hours
Design storm duration : 10.750 hours
Critical storm duration : 8.291 hours
ARF flag : ReFH Design Standard
Areal reduction factor (ARF) : 0.952
SCF flag : ReFH Design Standard
Seasonal correction factor : 0.785
DDF storm depth : 129.663 mm
Design storm depth : 96.857 mm
Peak rainfall [design] : 6.053 mm
==========

Loss model
==========
Cmax flag : Catchment descriptors
Cmax donor correction factor : 1.000
Cmax value : 311.270
Cini flag : ReFH Design Standard
Cini value : 135.185
alpha_T flag : ReFH Design Standard
alpha_T value : 0.700
Maximum runoff : 61.4%
Minimum runoff : 30.5%
==========
Routing model
==========
Time-to-peak (Tp) flag : Catchment descriptors
Tp donor correction factor : 1.000
Instantaneous UH time to peak : 4.187 hours
Up flag : ReFH Design Standard
Dimensionless UH peak : 0.650
Uk flag : ReFH Design Standard
Uk value used : 0.800
Dimensionless UH kink ordinate : 0.270
UH ordinate multiplier : 1.661
Unit hydrograph kink abscissa : 8.375 hours
Unit hydrograph time base : 15.058 hours
==========
Baseflow model
==========
Baseflow lag (BL) flag : Catchment descriptors
BL donor correction factor : 1.000
BL value : 38.424
Baseflow recharge (BR) flag : Catchment descriptors
BR donor correction factor : 1.000
BR value : 1.080
Initial Baseflow (BF0) flag : ReFH Design Standard
BF0 value : 1.589
Maximum Baseflow : 7.905 m3/s
==========
Output summary
==========
Direct runoff hydrograph peak : 34.493 m3/s
Minimum allowable flow : 0.000 m3/s
Total flow hydrograph peak : 39.147 m3/s
Hydrograph scaling factor : 1.000
Simulation results using : Full hydrograph

****

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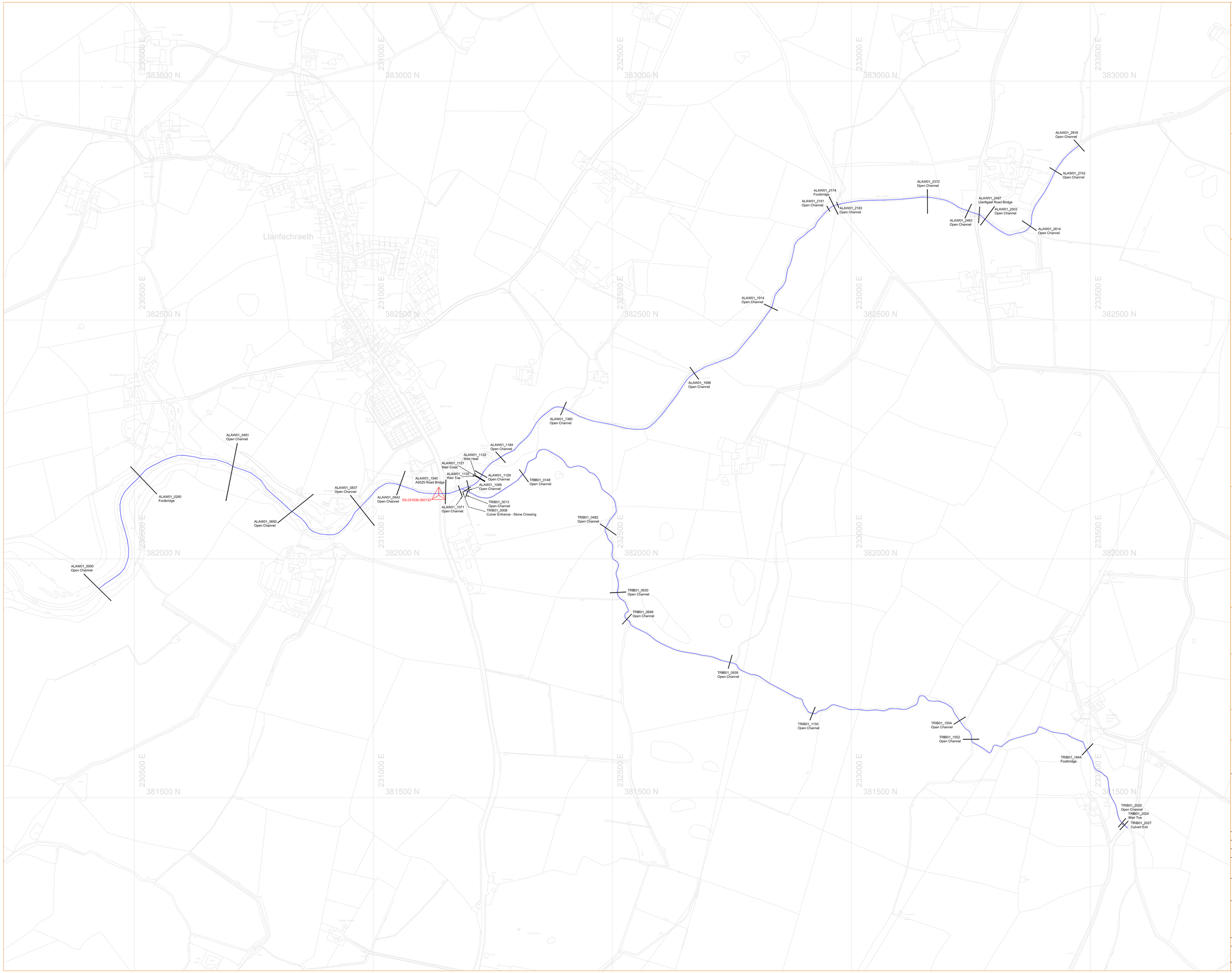
Appendix C
Structure representation



KEY TO SECTIONS:

- WATER LEVEL
- VISIBLE BED (TOP OF SILT) AND GROUND
- HARD BED (DETERMINED BY PROBING)
- C — BANK CREST

KEY TO LONGITUDINAL SECTION ONLY:

- LEFT BANK CREST
- RIGHT BANK CREST

VIEWED LOOKING DOWNSTREAM. POINTS INDICATED BY 'C' ON CROSS SECTIONS AND ADDITIONAL POINTS BETWEEN SECTIONS

SURVEY LEGEND

AB	AIR BRICK	FH	FIRE HYDRANT	PMF	POST & MESH FENCE
B	BOLLARD	FM	FLOOD LEVEL MARKER	PO	POLLARD TREE
B	BOLLARD	FL	FLOOR LEVEL	RE	RODDING EYE
BB	BELISHA BEACON	FP	FENCE POST	RSJ	ROLLED STEEL JOIST
BH	BOREHOLE	FW	FOUL WATER MANHOLE	RWP	RAINWATER PIPE
BH	BOREHOLE	G	GULLY	RWP	RAINWATER PIPE
BL	BED LEVEL	GB	GRADEBOARD	SC	STOP COCK
BOR	BOREHOLE	GF	GROUND LEVEL	SF	SLEEPER FENCE
BS	BUS STOP	GP	GATE POST	SI	SIGNBOARD
BW	BENCH MARK	GM	GAS MARKER	SL	SLOPE LEVEL
BW	BENCH MARK	GV	GAS VALVE	SMH	SURFACE WATER MANHOLE
BWF	BARBED WIRE FENCE	IC	INSPECTION CHAMBER	SMP	SHEET METAL PILING
CBF	CLOSE BOARDED FENCE	IL	INVERT LEVEL	SP	SIGN POST
CF	CHAIN LINK MESH FENCE	IP	IRON PEGGED	STN	STONE
CL	COVER LEVEL	IR	INTERMEDIATE RISER	SV	SLUICE VALVE
CLF	CONCRETE FENCE	KF	KERB FACE (FULL)	SWF	SHEEP WIRE FENCE
CONC	CONCRETE	KFC	KERB FACE (CHAMFER)	SWP	SHEEP WIRE PATH
CP	CONCRETE POST	LB	LETTER BOX	TBM	TEMPORARY BENCH MARK
CPF	CONCRETE POST & WIRE FENCE	LP	LAMP POST	TCB	TELEPHONE CABLE BOX/POST
CR	CHILD RAIL	LP	LAMP POST	TC	TELLOW CABINET
CV	CABLE TV MANHOLE	M	MOORING BOLLARD	TL	TELEGRAPH LINE
CVT	CULVERT	MF	MISCELLANEOUS FENCING	TM	TELEGRAPH LINE
DI	DROP KERB	MH	MANHOLE	TL	TRAFFIC LIGHT
DI	DROP KERB	MH	MANHOLE	TP	TELEPHONE POST
DP	DOWNPIPE	MP	MOORING POLE	TP	TELEGRAPH POLE
DPC	DAMP PROOF COURSE	MPF	METAL PAILING FENCE	TRS	TIMBER RUBBING STRIP
DW	DOORWAY	MW	MANHOLE	TS	TRAFFIC SIGN
DWB	DOG WASTE BIN	NB	NOTICE BOARD	TSR	TUBULAR STEEL RAILING
EA	ENVIRONMENT AGENCY	NRA	NATIONAL RIVERS AUTHORITY	UC	UPSTREAM
EB	ELECTRIC BOX	OB	OBSERVATION BOX	UP	UTILITY POLE SURVEY
ECF	ELECTRIC CABLE FENCE	OS	ORDNANCE SURVEY	WL	WATER LEVEL/WATER LINE
EDP	ELECTRICITY CABLE PIT	OTR	OPEN STEEL RAILINGS	WM	WATER METER
EM	ELECTRICITY MANHOLE	P	POST	WPF	WOODEN POST & WIRE FENCE
EP	ELECTRICITY POLE	PB	PILLAR BOX	WP	WOODEN POST
ER	EARTHING ROD	PM	PARKING METER	WPR	WOODEN POST & RAIL FENCE
ETL	ELECTRIC LINE/TRANSMISSION LINE	PO	POLLARD	WT	WATER TANK
FB	FLOWER BED	PRF	POST & RAIL FENCE	YC	YARD GULLY
FBR	FOOTBRIDGE	PTM	PARKING TICKET MACHINE		

Location Plan Orientation

GRID N

REV.	NOTES	DWN	DATE

ISO 9001 REGISTERED FIRM — Certificate Number: GB 6562

MEMBERS OF THE SURVEY ASSOCIATION

ISO 14001 REGISTERED FIRM — Certificate Number: GB 11414

Notes:

GRID AND LEVELS RELATE TO OS ACTIVE NETWORK
A REPORT HAS BEEN PRODUCED FOR THIS SURVEY

Control Used:
E6-231636-382132 SH 3163 8213 5.411m

LAND AND ENGINEERING SURVEYORS

MALTBY LAND SURVEYS LTD
2 QUEENS ROAD
HAYWARDS HEATH
WEST SUSSEX
RH16 1EB
Tel: 01444 416 246
Fax: 01444 417 697
E-Mail: mail@maltbysurveys.com
WebSite: http://www.maltbysurveys.com

SURVEYED	DW	AMEC
DRAWN	DW	
CHECKED	RAM	SCALE 1:2500

ANGLESEY WATERCOURSE SURVEY

LLANFACHRAETH, ANGLESEY
OVERALL LOCATION PLAN

Job No	Rev	Drawing Number
14_390		14_390_29

Date : OCTOBER 2015

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Structure 1			
Name of Structure	Double culvert under road crossing (from St Bugail's Church) on Afon Alaw.		
OS Grid Ref	230019 379148		
Survey reference	ALAW01_2487		
Included in Model?	Yes	**Model Label/reason for exclusion**	AL_2487_c1 AL_2487_c2
Model representation	Double culvert based on survey section ALAW01_2487 (surveyed upstream face of culverts). Circular conduit units used, inverts 5.45 mAOD. Surveyed 1.85 m diameter. No spill unit – because the 1000yr event does not exceed the bridge parapet level. Culvert length 10.30 mAOD. Downstream culvert face based on upstream face. Top Slot Settings: distance of slot below soffit 0.037m; height of top slot 1.850m No bottom slot		
Coefficients used	Manning's n roughness: 0.011 (Concrete: Culvert, straight and free of debris) Inlet: Conduit type A; K: 0.0045; M: 2; C: 0.0317; Y: 0.69; Ki 0.3		
Assumptions	Double culvert has two pipes running across face of culverts. These have not been included in the model, as they are narrow pipes, high on the culvert face, and thus not considered constricting to normal flow conditions. Location of the culverts is well above A5025 development site, and thus any backwater effects that would have been caused by these pipes would not affect the focus site of the model.		

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Photograph			
Structure 2			
Name of Structure	Foot bridge over Afon Alaw		
OS Grid Ref	229906 379015		
Survey reference	ALAW01_2174		
Included in Model?	Yes	**Model Label/reason for exclusion**	AL_2174bu
Model representation	Bridge based on survey section ALAW01_2174 (surveyed upstream face of culverts). USBPR bridge unit used, Soffit level 6.81 mAOD. Width 4.373 m Track deck max height 7.19 mAOD represented as spill unit in 1D domain.		

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Coefficients used	Modelled surcharged bridge as an orifice flow: Lower transition distance 0.1, upper transition distance 0.1, orifice discharge coefficient 1.0. Calibration coefficient 1.0.
Assumptions	n/a
Photograph	

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Structure 3			
Name of Structure	Collapsed bridge on Alaw 01		
OS Grid Ref	229453 378712		
Survey reference	ALAW01_1696		
Included in Model?	Yes	**Model Label/reason for exclusion**	ALAW01_1696
Model representation	Remaining parapets of collapsed bridge based on survey section ALAW01_1696, and represented in 1D model as in-line spill unit. Width of channel between parapets 2.886m, height of parapets 5.52 mAOD, channel bed 2.907 mAOD.		
Coefficients used	Weir coefficient 1.5; modular limit 0.9		
Assumptions	n/a		
Photograph			

C6 © Amec Foster Wheeler

Structure 4			
Name of Structure	Weir with sluice gate on Alaw01		
OS Grid Ref	229177 378615		
Survey reference	ALAW01_1122		
Included in Model?	Yes	**Model Label/reason for exclusion**	ALAW01_1129
Model representation	Weir height 2.492 mAOD, width 1.2 m, weir drop to downstream section 0.352 m. Weir based on survey section ALAW01_1122, and represented by in-line spill unit in 1D domain. Spill unit profile taken from ALAW01_1122 surveyed section, but with sluice gate gap filled in. Downstream section represented as surveyed section ALAW01_1120.		
Coefficients used	Weir coefficient 1.2; modular limit 0.9		
Assumptions	Sluice gate to mill stream is closed to give a conservative scenario. This is conservative because by closing the sluice (which would otherwise act to divert flows from the main watercourse) we are retaining maximum flow in the main river. The structure is close to the bypass location, but it is downstream of the bypass crossing. The fence crossing the channel is not included, as not considered to pose a significant constriction to flow.		

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Photograph			
Structure 5			
Name of Structure	Weir upstream of bridge on Alaw01		
OS Grid Ref	229036 378247		
Survey reference	ALAW_1040		
Included in Model?	Yes	**Model Label/reason for exclusion**	AL_1040uu
Model representation	Weir based on photographic evidence and site visit observations at section ALAW01_1040. Weir itself has not formed part of the cross sectional survey. Weir represented as in-line spill section in 1D domain. Spill profile taken from downstream section AL_1040, with bed elevation raised 0.2 m to reflect weir height. Weir height 1.847 mAOD. Downstream cross section bed height 1.628 mAOD.		
Coefficients used	Weir coefficient 1.2; modular limit 0.9		
Assumptions	Weir height of 0.2m based on site photography. No survey data available.		

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Photograph			
Structure 6			
Name of Structure	**Road Bridge over Alaw01**		
OS Grid Ref	**229717 379490**		
Survey reference	**ALAW01_1040**		
Included in Model?	Yes	**Model Label/reason for exclusion**	ALAW01_1040
Model representation	Road bridge based on survey section ALAW01_1040 (Surveyed upstream section of bridge). USBPR bridge unit used in 1D domain. Bridge soffit level 4.870 mAOD, springing level 4.870 m, and width 7.141 m. No 1D spill unit. 2D domain has Z-Shape to correct bridge track heights and bridge wall heights to surveyed levels. This is justifiable because the water level does not reach the top of the parapet		
Coefficients used	Modelled surcharged bridge as an orifice flow: Lower transition distance 0.5, upper transition distance 0.5, orifice discharge coefficient 1.0. Calibration coefficient 1.0.		

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Assumptions	n/a		
Photograph			
Structure 7			
Name of Structure	**Footbridge and walkway over Alaw01**		
OS Grid Ref	**229521 379234**		
Survey reference	**ALAW01_0280**		
Included in Model?	Yes	**Model Label/reason for exclusion**	ALAW_0280bu
Model representation	Road bridge based on survey section ALAW01_1040 (Surveyed upstream section of bridge). ARCH bridge unit used in 1D domain. Bridge soffit level 5.220 mAOD, springing level 3.890 m, and width 33.165 m. Spill unit included.		
Coefficients used	Calibration coefficient 1.0.		

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Assumptions	Walkway across floodplain is stilted, and thus provided minimal restriction. F100 baseline simulation flood levels do not extend over entire floodplain, so restriction to flow in this case without a 1D spill unit in model thought to be minimal.
Photograph	

C11 © Amec Foster Wheeler

Structure 8			
Name of Structure	**Channelised weir on Trib 01**		
OS Grid Ref	**229482 379032**		
Survey reference	**TRIB01_2024**		
Included in Model?	Yes	**Model Label/reason for exclusion**	TRIB01_2027w
Model representation	Weir based on surveyed section TRIB01_2024. Represented in 1D domain as in-line spill unit. Spill profile taken from surveyed section TRIB01_2024. Weir height 11.536 mAOD. Downstream cross section bed height 10.910 mAOD.		
Coefficients used	Weir coefficient 1.2; modular limit 0.9		
Assumptions	Model starts at the downstream face of the box culvert. Therefore culvert not included in model.		

C12

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Photograph	

 © Amec Foster Wheeler

Structure 9			
Name of Structure	**Double stone brick culvert on Trib 01**		
OS Grid Ref	**229404 378949**		
Survey reference	**TRIB01_1844**		
Included in Model?	Yes	**Model Label/reason for exclusion**	TR_1844_o1 TR_1844_o2
Model representation	Double culvert based on survey section TRIB01_1844 (surveyed upstream face of culverts). Both culvert sections represented in 2D domain as orifice units. O1: invert 9.12 mAOD, soffit level 10.33m AOD, bore area 1.889 m2; upstream sill level 9.117 mAOD, downstream sill level 9.117 mAOD. O2: invert 9.16 mAOD, soffit level 10.37m AOD, bore area 0.776 m2; upstream sill level 9.117 mAOD, downstream sill level 9.117 mAOD. Culvert track deck represented by spill unit, with profile taken from surveyed cross section.		
Coefficients used	Weir flow (over sill) 1.00, Surcharged flow 1.00, modular limit 0.70.		
Assumptions	Modelled as orifice units to aid model stability during surcharged flow, and to allow representation of irregular culvert area.		

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Photograph			
Structure 10			
Name of Structure	**Culverted wall over Trib01 at confluence with Alaw01**		
OS Grid Ref	**229462 3787738**		
Survey reference	**Trib01_0008**		
Included in Model?	Yes	**Model Label/reason for exclusion**	Trib01_0008ou
Model representation	Culvert based on survey section Trib01_0008 (surveyed upstream face of culverts). Culvert represented as 1D orifice unit. O1: invert 1.83 mAOD, soffit level 2.38 m AOD, bore area 0.589 m2; upstream sill level 1.807 mAOD, downstream sill level 1.55 mAOD. Culvert track deck represented by spill unit, with profile taken from surveyed cross section.		
Coefficients used	Weir flow (over sill) 1.00, Surcharged flow 1.00, modular limit 0.70.		
Assumptions	Modelled as orifice units to aid model stability during surcharged flow, and to allow representation of irregular culvert area.		

C15

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Photograph	

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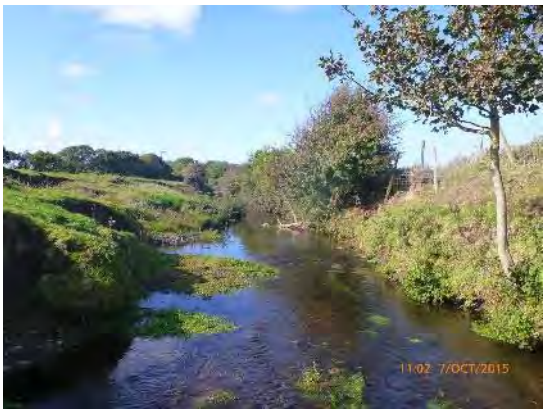
Appendix D
Channel roughness representation

Manning's roughness values have been determined using definitions detailed in Chow (1959) referenced below. The roughness values chosen for each section of the Llanfachraeth model are presented in this appendix.

- Chow, V.T., 1959, Open-channel hydraulics: New York, McGraw-Hill, 680 p.

D2 © Amec Foster Wheeler

Watercourse/ Reach		Range Manning's Roughness, n (watercourse bed – watercourse bank)	Picture
Afon Alaw	**2816**	0.050 – 0.070	
Afon Alaw	**2742**	0.045 – 0.060	
Afon Alaw	**2614**	0.045 – 0.060	

Watercourse/ Reach		Range Manning's Roughness, n (watercourse bed – watercourse bank)	Picture
Afon Alaw	**2487**	0.045 – 0.060	
Afon Alaw	**2463**	0.045 – 0.050	
Afon Alaw	**2372**	0.045 – 0.050	

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Watercourse/ Reach		Range Manning's Roughness, n (watercourse bed – watercourse bank)	Picture
Afon Alaw	**2183**	0.045 – 0.060	
Afon Alaw	**2161**	0.045 – 0.060	
Afon Alaw	**1914**	0.045 – 0.050	

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Watercourse/ Reach		Range Manning's Roughness, n (watercourse bed – watercourse bank)	Picture
Afon Alaw	**1696**	0.040 – 0.050	
Afon Alaw	**1360**	0.040 – 0.050	
Afon Alaw	**1184**	0.040 – 0.050	

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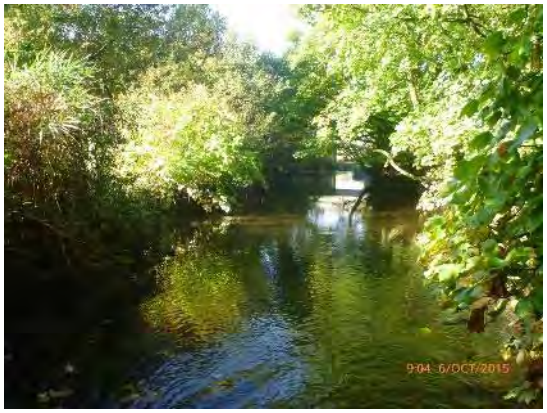
Watercourse/ Reach		Range Manning's Roughness, n (watercourse bed – watercourse bank)	Picture
Afon Alaw	**1129**	0.040 – 0.060	
Afon Alaw	**1120**	0.040 – 0.060	
Afon Alaw	**1089**	0.040 – 0.060	

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Watercourse/ Reach		Range Manning's Roughness, n (watercourse bed – watercourse bank)	Picture
Afon Alaw	**1071**	0.040 – 0.060	
Afon Alaw	**1040**	0.035 – 0.060	
Afon Alaw	**0942**	0.045 – 0.050	

Watercourse/ Reach		Range Manning's Roughness, n (watercourse bed – watercourse bank)	Picture
Afon Alaw	**0837**	0.030 – 0.050	
Afon Alaw	**0650**	0.030 – 0.050	
Afon Alaw	**0491**	0.030 – 0.045	

Watercourse/ Reach		Range Manning's Roughness, n (watercourse bed – watercourse bank)	Picture
Afon Alaw	**0280**	0.030 – 0.035	
Afon Alaw	**0000**	0.030 – 0.060	
Afon Alaw	**-0235**	0.030 – 0.060	No photo
Afon Alaw	**-0500**	0.030 – 0.060	No photo
Afon Alaw	**-0700**	0.030 – 0.060	No photo
Afon Alaw	**-0935**	0.030 – 0.060	No photo
Llywenan tributary	**2027**	0.045 – 0.025	
Llywenan tributary	**2020**	0.060 – 0.070	No photo

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Watercourse/ Reach		Range Manning's Roughness, n (watercourse bed – watercourse bank)	Picture
Llywenan tributary	**1844**	0.050 – 0.070	
Llywenan tributary	**1552**	0.035 – 0.070	
Llywenan tributary	**1504**	0.035 – 0.070	

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Watercourse/ Reach		Range Manning's Roughness, n (watercourse bed – watercourse bank)	Picture
Llywenan tributary	**1150**	0.060 – 0.070	
Llywenan tributary	**0939**	0.060 – 0.070	
Llywenan tributary	**0699**	0.050 – 0.060	

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Watercourse/ Reach		Range Manning's Roughness, n (watercourse bed – watercourse bank)	Picture
Llywenan tributary	**0630**	0.030 – 0.060	
Llywenan tributary	**0482**	0.030 – 0.045	
Llywenan tributary	**0148**	0.045 – 0.070	

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Watercourse/ Reach		Range Manning's Roughness, n (watercourse bed – watercourse bank)	Picture
Llywenan tributary	**0013**	0.045 – 0.070	

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Appendix E
Model review updates

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The NRW model review (January 2017) concluded that: '…*most aspects of the Llanfachraeth model configuration are sound and that results seem realistic. It is considered that there is only one (stability) issue (highlighted in red) that should be addressed to ensure that design levels are fit for purpose. Other issues (highlighted in amber) are considered unlikely to significantly change the results so any further modifications to the model based on the review should be seen as optional. There are also a number of minor/cosmetic issues (green) which the modeller might like to address to make the model more technically correct'.*

The table below contains the red and amber NRW comments as referenced above. Each comment has been addressed and the table documents the Amec Foster Wheeler response to resolve the issue, along with the specific action taken to facilitate the resolution.

NRW Review Comments	AmecFW Response	Action taken
The model documentation is generally fit for purpose, although a few inconsistencies with the model itself have been noted. The Technical Note should be reviewed to check all the information is up-to-date, particularly the final section about roughness values, which appears to be from a different model.	Technical Note will be reviewed and updated to ensure it is consistent with latest version of the model.	Technical Note updated accordingly. Updates to cell size, structure type, etc. updated to reflect model. Appendix B rewritten. In addition, full report updated to reference any new 1D-2D model files created during review updates.
Three surveyed cross sections have been removed from the model to allow smoother convergence between cross section nodes. However, including these surveyed sections would have resulted in a more accurate representation of the channel and should therefore ideally have been included, especially as ALAW01_1122 is close to the proposed location of the bypass. If the model was less stable with these sections in place, the initial action should have been to improve the stability with the sections in place rather than removing the sections.	These sections were very close together resulting in very small distance (<5m) between sections. The model was unstable in this area, and removing them solved the instability. Other options to resolve the instability were tried, and failed, in advance of taking the decision to remove these sections. The most representative sections were chosen to be retained. In addition, it is the weir in this vicinity that controls the hydraulic behaviour.	Technical Note updated accordingly.
The bed and bank roughness have been modelled via Manning's roughness values. However, these cannot be checked against photographs, as the 1D roughness values and photographs specified in the Technical Note do not seem to correspond to this particular model. This should be updated for the Llanfachraeth model, and roughness values should be justified.	Technical Note will be reviewed and updated to ensure it is consistent with latest version of the model.	Technical Note updated accordingly. Appendix B rewritten.
A number of structures have been simplified as ORIFICE rather than CULVERT units due to stability problems. The culverts at the upstream of the tributary can be justified as they are unlikely to influence the area of interest, although the orifice unit at the downstream of the tributary at its confluence with the Afon Alaw is much closer to the area of interest. However, the photograph suggests that this structure is quite simple and an orifice unit may be acceptable. Even so, justification that representation of this structure does not impact water levels in the vicinity of the proposed bypass should be provided.	Further justification for the use of and Orifice at the downstream of the tributary at its confluence with the Afon Alaw will be added to the technical note. The adoption of an orifice unit is applicable as the structure is a simple stone spanning the channel. There is limited length in the structure, thereby lending itself to an orifice unit rather than conduit/culvert. The Flood Modeller software supports the use of an orifice unit for an orifice and short culvert.	Technical Note updated accordingly.

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NRW Review Comments	AmecFW Response	Action taken
	Analysis of the long section model behaviour in the vicinity of the orifice location shows no oscillation. Time series outputs for a variety of scenarios confirm smooth, convergent model behaviour.	
During the baseline extreme 0.1% plus climate change tidal event, the 1D long section animation shows signs of instability at sections ALAW01_1089d and ALAW01_1071, at the confluence of the Afon Alaw and its tributary during the peak of the event, where the water level drops unrealistically (see Figure below). There is also some localised instability evident within the 2D results where levels are locally raised by 0.5m. This issue is only highlighted in red because it is assumed to lie in the vicinity of the proposed by-pass. This should be addressed by either ensuing that any reporting of peak levels from node ALAW01_1089d takes this instability into account (i.e. avoid reporting rogue levels) or by stabilising the model further (probably via a local 2D roughness patch).	This area of instability will be investigated and rectified for the final base model.	Model updated. A small number of stability patches were added to the model. 2d_mat_stability_Llan_Base_001.mif was replaced with 2d_mat_stability_Llan_Base_002.mif In addition, the 2d_bc layer was modified in a small number of locations to improve the 1D-2D link location. 2d_bc_Llan_Base_015.MIF replaced with 2d_bc_Llan_Base_016.MIF. The above updates resolved the unrealistic drop in water level at the peak of the 0.1% cc event thereby further stabilising the model.
A 2D HT boundary, with the same information as the 1D HT boundary, has been applied at the downstream extent of the 2D domain, which is appropriate since the downstream extent is open to the tides. The 2D boundary and section of active 2D domain contribute nothing to the model and will lead to wet cells at all time steps so should probably have been avoided (Note that since there is no boundary between 1D and 2D at the downstream end of the model, the tidal velocity vectors run perpendicular to the expected flow direction).	Agreed it probably would have been better to coincide the end of the 1D domain with the edge of the 2D domain. This is not affecting results. No Action Required. But if time allows we will move the 2D boundary so it coincides with the 1D boundary.	Model updated. 2d_bc layer updated to align 2D downstream boundary with 1D model downstream boundary. Boundary line applied to left and right of main channel. 2d_bc_Llan_Base_015.MIF replaced with 2d_bc_Llan_Base_016.MIF. Consequently, code layer updated to snap to new 2d_bc layer. Layer 2d_code_Llan_002.MIF replaced with 2d_code_Llan_003.MIF. .tbc and .tgc layers also updated: Llan_Base_017.tbc to Llan_Base_018.tbc Llan_Base_021.tgc to Llan_Base_022.tgc
The 2D software used (2013-12-AC-iSP-w64) is a little out of date. The 2016 release of TUFLOW has been available for around one year and has some significant changes to the default settings. However, since these are largely in 1D (ESTRY) the use of 2013-12-AC-iSP-w64 is likely to be acceptable. However, further runs should ideally be carried out on the latest TUFLOW release.	Acknowledged the version used has now been superseded. New runs will be run with latest version of TUFLOW.	Latest version of TUFLOW applied: TUFLOW Build 2016-03-AE-w64 (single precision). A sensitivity to double precision was also undertaken for completeness (results documented in main body of report) and found that there was no difference in the results from two precisions.
Both 1D and 2D flows and levels generally seem to vary smoothly, although there appears to be quite a bit of oscillation in the 1D-2D flux (zzx file), particularly during tidal events. This occurs mainly at nodes at the downstream of the Afon Alaw that are subject to tidal influence, but oscillation is also observed for all events at	This area of oscillation will be investigated and rectified for the final base model.	Model updated. A small number of stability patches were added to the model. 2d_mat_stability_Llan_Base_001.mif was replaced with 2d_mat_stability_Llan_Base_002.mif

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NRW Review Comments	AmecFW Response	Action taken
TR_1844i (probably linked to the 1D instability mentioned earlier) and TRIB01_0630. This should ideally be investigated and justification should be provided that this does not influence model results.		In addition, the 2d_bc layer was modified in a small number of locations to improve the 1D-2D link location. 2d_bc_Llan_Base_015.MIF replaced with 2d_bc_Llan_Base_016.MIF. The above updates significantly improved the 1D-2D flux (.zzx) and oscillation, thereby improving the interaction of water levels at the confluence of the main channel and tributary and further stabilising the model.

Appendix G8-01.5 Section 7 flood modelling results

NOT PROTECTIVELY MARKED

Horizon Nuclear Power

Wylfa Newydd DCO Project - Offline A5025 Bypass, Cefn Coch, Anglesey

Hydraulic and Hydrology Modelling Factual Report

January 2018

Amec Foster UK Limited

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1. Introduction

1.1 Purpose of this report

This factual report has been produced for the purpose of describing the hydrological and hydraulic modelling undertaken to support the proposed Offline A5025 bypass at Cefn Coch, Anglesey, NW Wales. This factual report does not present an assessment of the significance of the results. This factual report provides a detailed statement of the hydrological and hydraulic modelling methods applied, assumptions made and the limitations within the approaches. The report also details the data used together with the results of QA and validation checks.

This report is an Annex to the Flood Consequence Assessment (FCA) for this Offline A5025 bypass at Cefn Coch. The FCA presents a description of the proposal and wider flood risk context justifying the requirement for the hydraulic modelling reported in this document. The FCA presents the flood risk assessment conclusions drawn from the modelled results pertaining to the proposed development.

1.2 Purpose of modelling

1D-2D Modelling has been undertaken to support the design and application for the proposed A5025 bypass at Cefn Coch, Anglesey, NW Wales (NGR: SH 339900). Modelling has determined the baseline (present day) fluvial flood risk to the bypass location and nearby receptors, and the future risk including climate change impacts. The modelling does not include predictions of impacts of the proposed crossing as the proposed crossing design will free span the floodplain at the crossing location with appropriate headroom under the soffit. The reader is directed to the accompanying Flood Consequence Assessment (FCA) for further details. A range of design flood events (see Section 5) have been modelled to establish the full extent of the baseline flood risk. A summary of the model scenarios represented by the hydraulic model is shown in Table 1.1.

Table 1.1 Summary of model scenarios

Source	Hydrology method	Event	Season	Storm Duration	Epoch	Climate change increase in river flows*
Fluvial	ReFH2.1 with FEH13 rainfall data to WINFAP 3.3.4 peak	1:20, 1:100, 1:1,000 year AEP	Winter	3.0 hour	2017	n/a
		1:100 year AEP	Winter	3.0 hour	2080s	30%

AEP = Annual exceedance probability
* The guidance adopted in the modelling is drawn from the Welsh Government Guidance (published 23-08-16) in which the values for the 2020s, 2050s and 2080s are provided and in a footnote to Table 1 - the guidance states the FCAs should apply the 2080s value.

1.3 Overview of modelling approach

To fulfil the requirements of the Flood Consequence Assessment (FCA) it was necessary to construct a detailed 1D-2D model of the Cefn Coch area to determine the impact of the A5025 bypass. The requirements were to develop a robust baseline flood risk position to inform the design of the crossing so as to ensure no increase in flood risk post development. No pre-existing hydraulic models were available to inform the study, as such a new model based on new topographic survey information needed to be developed to meet this requirement. The 1D-2D modelling approach was adopted as it provides a more comprehensive understanding of the flooding mechanisms and the behaviour of water in the floodplain. The

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later was important to this modelling task as the definition of the floodplain would ultimately inform the bypass crossing at this location.

The 1D-2D hydraulic modelling software used was coupled Flood Modeller - TUFLOW. These are industry standard software packages, widely used for flood modelling. The FCA required the 1:20, 1:100, 1:100+climate change and 1:1,000 year AEP fluvial events to be simulated. This report presents flood depths, peak water levels and flood extent associated with these return periods.

1.4 Key assumptions

A detailed channel survey was conducted in April 2016 of the channels and associated structures. LiDAR data was used to represent the floodplain topography. The following key assumptions have been made:

- It was assumed that the modelled watercourses are not undergoing regular maintenance therefore:
  - A 90% blockage at survey section CAFN01_1172 of debris accumulated where a wire fence crosses the watercourse has therefore been included in the model representation. See Appendix C for details.
  - A 90% blockage at survey section CAFN01_0854 where the right culvert barrel is partially collapsed and blocked with debris has therefore been included in the model representation. See Appendix C for details.
  - 'Soft bed' channel survey readings have been utilised in the model build.
- One lateral inflow has been represented in the model, it has been assumed reasonable to distributed the inflow along the reaches where tributaries are shown to join the Afon Cafnan. With the split of the lateral inflow weighted according to the length of the watercourse between inflow locations as a proxy of their catchment size;
- Survey photographs, have suggested the Afon Cafnan channel and associated Llyn Llygeirian tributary is reasonably regular and consistent along its length, with few substantial changes in shape for width. This has informed requested survey cross sections spacing, and allowed for interpolate sections to be added to aid model convergence and stability; and
- Model extents have been determined in order to prevent any model boundary influence on the focus area around the bypass site location. The model is not intended as a catchment-wide flood extent assessment.

The assimilation of the available data detailed above into the flood model, is considered appropriate for this study as the main purpose is to provide an estimate of flood extent across the site and determine the potential impact of the proposed developments. The model has been built for the purpose of flood risk mapping; therefore, it has been optimised for high flows.

1.5 Model review

In addition to internal model QA checks the model was reviewed externally on behalf of NRW (December 2016). A full review of both the 1D and 2D components was undertaken, including analysis of the various fluvial scenario outputs with and without climate change.

A technical review certificate was produced, the key findings of which are tabulated in Appendix E. Appendix E also provides details on the action taken to address the respective review comment, with supporting information where applicable.

The model details provided hereafter incorporate any review updates.

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1.6 Document structure

The remainder of this report is structured as follows:

- Section 2 - Available data: Identifies data collated or commissioned to aid model build, catchment and structure representation. Discusses any lack of data where appropriate;
- Section 3 - Hydrology: Details the fluvial hydrology assessment;
- Section 4 - Model Overview: Details the representation of the modelled channels in the 1D model domain, and the 2D model domain, including any assumptions made for representations or stability;
- Section 5 - Model Runs: Lists the baseline model scenarios run, including file structures;
- Section 6 - Model Results: Summarises the baseline model results, including flood extents and depths; and
- Section 7 - Sensitivity Testing: Lists sensitivity runs carried out on the 1D-2D model, and discusses outputs.

A location plan for the proposed highway works can be found in Figure 4.1 in Section 4 and the hydrological catchments can be viewed in Figures 1.1 and 2.1 in Appendix B.

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2. Data summary

The 1D-2D model was built following collation of a number of datasets to represent the Cefn Coch catchment topography, floodplain, structures, channel and banks. Table 2.1 below details the datasets collated, and provides a description of the contents of each data set.

Table 2.1 Data summary

Item	Comments
Cross-section survey	Storm Geomatics; April 2016 Surveyed channels: Afon Cafnan, Unknown Tributary to Afon Cafnan. Overall location plan: channel and structure locations (See Appendix C). Channel cross sections (shape and width): bed level (soft/hard); bank levels; water levels; location photos. Structure surveys: culverts/bridges/obstructions/walls with road/deck levels. Survey undertaken in line with NRW specifications
Topography	LiDAR 1m resolution Digital Terrain Model. LiDAR Composite Dataset; downloaded from http://lle.wales.gov.uk/GridProducts#data=LidarCompositeDataset on 21/04/2016. The stated vertical accuracy of the data set from NRW is a vertical accuracy of +/-0.15m
Mapping data	Ordnance Survey (OS) MasterMap (supplied by URS, October 2014)
Gauging stations	No gauging stations in the catchment.
Calibration / verification events	No calibration events identified due to no gauged data available
Flood history	Natural Resources Wales (NRW) and Isle of Anglesey County Council (IACC) currently have no readily available information on historic flooding

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3. Hydrology assessment

This section summarises the process to derive the hydrology inputs for the hydraulic modelling. A detailed hydrology technical note is provided in Appendix B. The hydrology for Cefn Coch was developed over a number of months, completing in May 2016 and the report issued to NRW for review in June 2016 (Document Number: 203025-0000-AA40-RPT-0012). The review was completed and all required modifications incorporated into the hydrology assessment in 2016. In the intervening period industry standard hydrological methods and software have been updated. At a meeting on the 12/04/2017, NRW did not object to it not being necessary to update the Cefn Coch hydrology in support of the August 2017 DCO application, but that this may need to be reviewed in future, if there is any requirement to revisit the hydrology estimates as part of the detailed design phase. The need for this cannot be commented on at this stage.

The fluvial hydrology inputs to the hydraulic model were hydrographs (flow/time) for a single critical storm duration, at the bypass location, and a range of events. The hydrology inputs have been calculated for the current baseline at Cefn Coch.

3.1 Catchment overview

The Afon Cafnan flows north from Bod-Hedd, flowing into the sea near Cafnan approximately 2.5km north of Cefn Coch. The Llygeirian tributary flows west from Llyn Llygeirian, flowing into the Afon Cafnan 500m west of Llyn Llygeirian approximately 100m downstream of the existing A5025 (NGR: SH 339900). A site location plan showing these watercourses and their associated FEH catchments is provided in Appendix B (Figure 1.1).

Hydrological assessment locations (HAL) were chosen to represent the inflow at the upper extent of the model (HAL 1 - Afon Cafnan, and HAL 3 – Llygeirian tributary) and intervening catchment on Afon Cafnan (between HAL 2 – and HALs 1 and 3) as shown in Appendix B (Figure 2.1). HAL 2 has been used as total catchment to derive growth factors which is applied to each of the hydrographs derived at HAL 1 and HAL 3. The hydrograph peaks are scaled to match with the statistical peak floods. For the intervening area downstream of HALs 1 and 3, the hydrographs are derived by subtracting directly from the total hydrograph at HAL 2. It is assumed that the approach is a conservative and does not impart any significant changes in the total inflows. Furthermore, this lateral flow hydrograph will be distributed along the reach over a number cross sections which is deemed to have negligible effect on the relative timing.

3.2 Method of hydrograph calculation

Hydrological assessment was undertaken for Afon Cafnan and the Llygeirian tributary to determine the fluvial inflow. Design flow hydrographs were required to model the following fluvial events: 1:20 year, 1:100 and 1:1,000 year AEP events.

3.3 Catchment boundary and catchment descriptors

The catchments identified on the FEH CD-ROM 3 were compared to that derived using OS mapping and topographic data and the discrepancy was found to be less than 3% overall. This showed there was no significant difference in catchment extent, illustrated in Appendix B (Figure 2.1).

The key hydrological parameters for each location are presented in Table 3.1.

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Table 3.1 Key hydrological parameters

Hydrological assessment location (HAL)	Watercourse	Location description	National Grid References (NGR)	Area (km^2)	SAAR (mm/yr)	FARL	BFIHOST	URBEXT 2000
1	Afon Cafnan	Upstream of confluence with Llygeirian tributary	SH 33900 90050	1.12	978	1	0.477	0.0056
2	Afon Cafnan	Downstream of bypass and Llygeirian tributary confluence	SH 34150 91400	4.34	987	0.882	0.466	0.0029
3	Llygeirian tributary	Upstream of confluence with Afon Cafnan	SH 34000 90000	2.10	996	0.772	0.491	0.003

Source: FEH CD-ROM 3. From 9 November 2015 FEH CD-ROM data have been available online, however, as this hydrological assessment was largely completed before the launch of the FEH Web Service (CEH, 2016) and it is understood that there is no significant difference to the catchment descriptor data, use of the FEH CD-ROM 3 catchment descriptor data are considered appropriate.

3.4 Deriving hydrographs

Current guidance from Natural Resources Wales (NRW), in the form of Technical Guidance: Flood Estimation (NRW, 2016), identifies two recommended methods to estimate flow for events up to and including a 1:1,000 year AEP event:

- Flood Estimation Handbook (FEH) statistical method; and
- Revitalised Flood Hydrograph (ReFH) method.

NRW's preferred approach for estimating peak flows up to and including a 1:100 year AEP event is the FEH statistical method based on Technical Guidance: Flood Estimation (NRW, 2016). The FEH statistical method uses pooled annual maxima flow data from a group of hydrologically similar gauged catchments. The ReFH method (CEH, 2007) can be reliably used with small catchments and produces full hydrographs, as required by the hydraulic model.

The ReFH method was used with ReFH 2.1 software[1] and FEH13 rainfall to derive hydrograph shapes for the required events which were scaled to the FEH statistical peak. WINFAP-FEH 3 software[2] was used to develop a growth curve for the Afon Cafnan (hydrological assessment location 2), which was applied to all hydrological assessment locations. A value of QMED was derived using catchment descriptors, adjusted using the 102001 Cefni at Bodffordd and adjusted for urbanisation. Subsequent discussions with NRW has identified that the Cefni at Bodffordd gauge was not considered suitable for use as a donor. This decision can be supported by FEH making better use of local data in flood frequency estimation. The average uplift of 10% to peak flood values was considered to be conservative and changes to the hydrology assessment were deemed appropriate. Although the previous hydrology review had identified the 10% uplift was not necessary, it was retained here to be on conservative side to make the best use of local data and address uncertainty at the same time

[1] ReFH 2.1 was the current software at the start of the project, subsequently updated to ReFH 2.2 (25 May 2016). However, the changes associated with the recent software update was not expected to significantly change the results as the hydrograph was adjusted to the peak flow derived from the FEH statistical method.
[2] WINFAP-FEH v 3.3.4 was the current software at the start of the project, subsequently updated to v4 (12 May 2016), v4.1 (26 May 2016) and v5 (28 April 2017). However, the additional three water years of gauge data available with v5 is not expected to significantly change the growth curve.

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ReFH 2.1 was used to derive the flow hydrograph shape for the required events, and then adjusted to fit the FEH statistical peak. To derive the FEH statistical 1:1,000 year AEP peak flow, the ratio method was applied based on the ReFH 2.1 peak flows.

3.5 Season profile

As the study catchment was classified as rural catchment because of the low urbanisation index value (URBEXT2000<0.025), winter profile was chosen as it gave higher ReFH flood peak values than summer profile. As the hydrographs derived using winter profile were scaled to the FEH statistical peak, (representing greater flow and volume than a summer profile) this represented a conservative approach. It was therefore considered reasonable to adopt the winter profile as the critical season.

3.6 Storm duration

As the catchment areas are relatively small, it is expected that the same event will occur across all the catchments simultaneously. A critical storm duration of 3.0 hours was taken for the bypass location, calculated from catchment descriptors. The bypass location chosen for the critical storm duration lies approximately 100m downstream of HALs 1 and 3. The description of the location is given in section 4 of Appendix B. The derived hydrograph was fit to the FEH statistical peak. Additional sensitivity tests have been carried out to add confidence to the adopted storm duration and to quantify the uncertainties associated with the storm duration reported. The detail of the tests are presented in Section Test 4: Storm durations 0.

3.7 Climate change allowance

Climate change is applied by using a 30% uplift on the 1:100 year AEP event as per current guidance (Llywodraeth Cymru/Welsh Government, 2016). This is the central estimate for climate change allowance for the 2080s. Although this has been applied to the peak flows for this report, when representing in the model the entire hydrograph was scaled to this adjusted peak.

3.8 Hydrographs for fluvial scenarios

This section presents the hydrographs which were used in the Flood Modeller – TUFLOW hydraulic modelling, based on the approached presented in Section 3.2. The inflow hydrographs derived for the headwaters of each catchment (hydrological assessment locations 1 and 3) were applied directly in the hydraulic model as point inflows to the upstream extent of the hydraulic model representation of Afon Cafnan and the Llygeirian tributary, respectively.

Lateral inflow hydrographs for the Afon Cafnan are determined through subtracting the upstream hydrographs from the downstream hydrograph. The lateral flow hydrograph is distributed along the reach over several cross sections. The hydrographs generated for intervening areas is based on the subtraction of hydrographs at hydrologic assessment locations (HALs), this assumes that the catchment lag will have negligible impact on the result and it adds a conservatism to the peak flow value and total flow volume. A sensitivity test investigating the sensitivity of the flood extent predictions to the hydrograph generation method (subtraction vs disaggregation) has been carried out. This test, reported in Section 7.6, adds confidence that the subtraction method detailed in this section is appropriate.

The derived hydrographs applied to the hydraulic model are shown on Figure 3.1, with the peaks listed in Table 3.2. It is worth noting that the values in Table 3.2 are different from those derived using FEH statistical method (see Table 5.3 in Appendix B) in which the peak flood value for entire catchment is not the sum of its constituent sub-catchment peak values. This is because the statistical method does not take timing and volumetric flows into account.

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Figure 3.1 Final hydrographs to be modelled (1:20, 1:100, 1:100+CC, 1:1,000 year AEP)

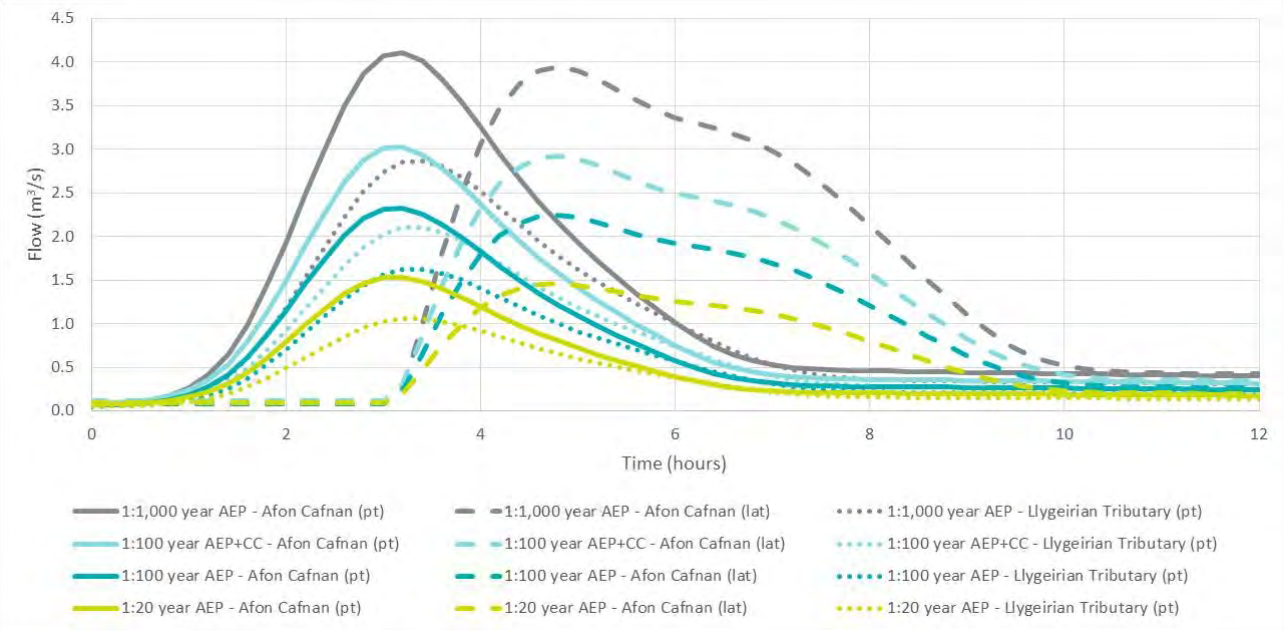

Table 3.2 Final hydrograph peak flows to be modelled

Event	Afon Cafnan (HAL 1)	Afon Cafnan (HAL2-HAL1-HAL3)	Llygeirian Tributary (HAL3)
	Point inflow (m^3/s)	**Lateral inflow (m^3/s)**	**Point inflow (m^3/s)**
1:20 year AEP	1.5	1.5	1.1
1:100 year AEP	2.3	2.2	1.6
1:100 year AEP+CC	3.0	2.9	2.1
1:1,000 year AEP	4.1	3.9	2.9

Note: AEP = Annual exceedance probability; CC = Climate change; HAL = Hydrological assessment location

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4. Hydraulic modelling

4.1 Model overview

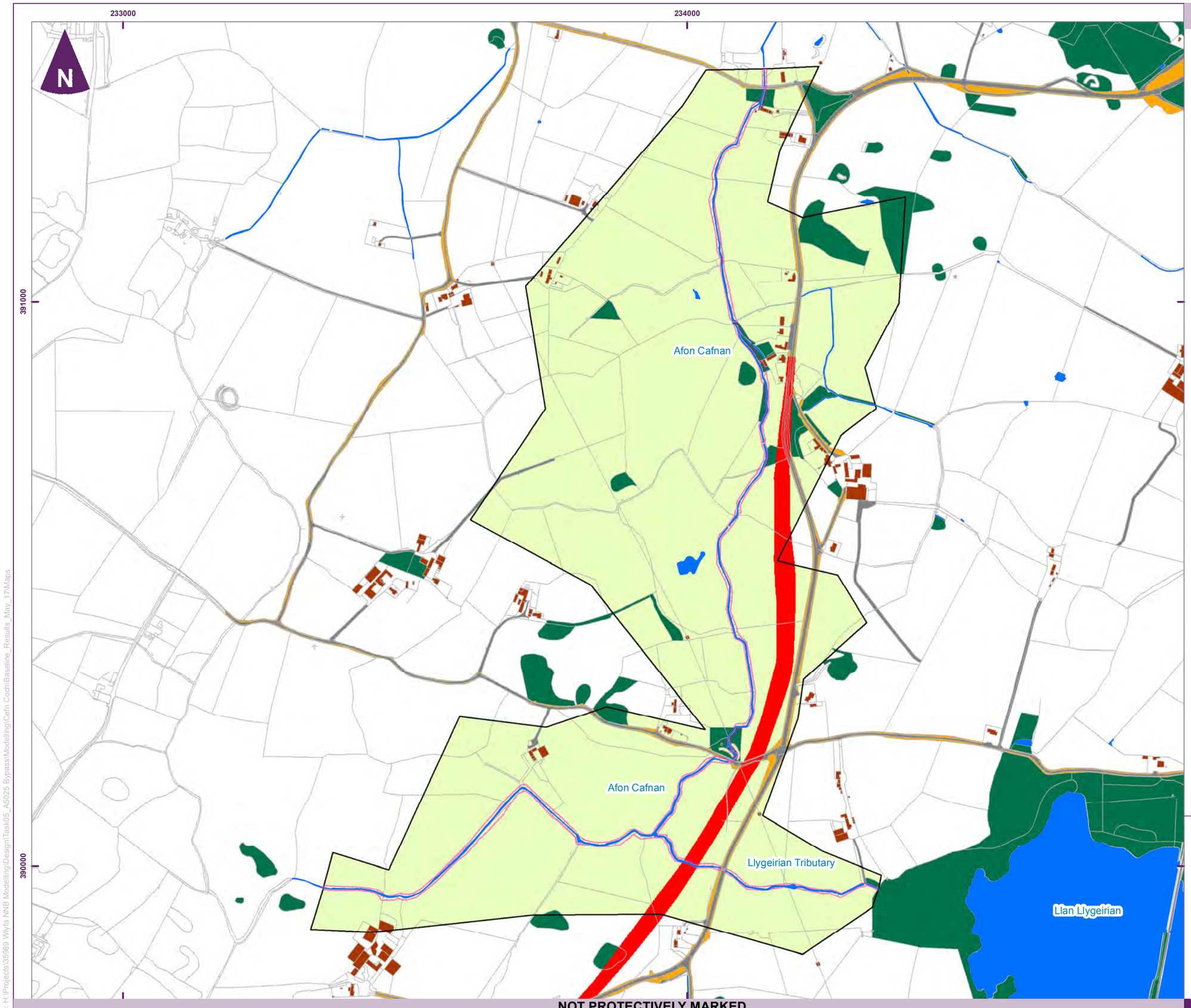
This section provides an overview of the 1D and 2D integrated hydraulic models built to represent flood flow around the Cefn Coch bypass development area. The software chosen (Table 4.1), model extents determined (Table 4.2 and Figure 4.1), are all detailed below and explanations and justifications provided in Table 4.3 and Table 4.4.

Table 4.1 Model approach and software

Item	Comments
Model Approach	1D-2D hydraulic modelling approach.
Model Software	1D Model: Flood Modeller v4.2 (previously known as ISIS) 2D Model: TUFLOW Build 2016-03-AE-w64 (single precision)

Table 4.2 Model extent

Watercourse	Channel representation	Floodplain representation	Upstream Limit	Downstream limit	Length/Area of Model
Entire model	Flood Modeller	TUFLOW	233239 389911	234118 391378	7.95 km^2
Afon Cafnan	Flood Modeller	TUFLOW	233239 389911	234118 391378	2.25 km
Llyn Llygeirian tributary	Flood Modeller	TUFLOW	234338 389960	233942 390052	0.45 km



Key

Roughness Zones (Mannings n coefficient)

- 0.015 - Road
- 0.025 - Path, Roadside
- 0.035 - Inland Water
- 0.08 - Rough Grassland, Scrub, Trees
- 0.3 - Buildings, Glasshouse
- 0.04 - Grass, General surface
- Model boundary
- 1D Model Domain
- OS Mastermap
- Proposed Bypass Route

Meters
0 100 200 300 400
Scale at A3

Wylfa Newydd
A5025 - Cefn Coch
Hydraulic Modelling

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Figure 4.1
A5025 Cefn Coch 1D-2D Hydraulic Model

NOT PROTECTIVELY MARKED

file: H:\Projects\35989 Wylfa NNB Modelling\Design\Task\05_A5025 Bypass\Modelling\Cefn Coch\Baseline_Results_May_17\Maps

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4.2 1D model

The Cefn Coch 1D model component has been built in Flood Modeller Pro, and represents the Afon Cafnan and Llyn Llygeirian tributary channel. The overview of the 1D baseline model set up is detailed in Table 4.3.

Table 4.3 1D base model overview

Item	Comments
Software & version	Flood Modeller (previously ISIS) version 4.2 (Latest available release at model review stage).
1D model purpose	The 1D 'Flood Modeller' model represents only the channel geometry. Standard cross section units and structure units have been used to represent the watercourses being modelled.
Watercourse survey	Detailed channel and structure survey was commissioned as part of the project. See Section 2 for summary of data received.
Initial conditions	Initial conditions have been derived as standard using 'Flood Modeller'.
Upstream boundary	Approximately 0.7km upstream of the bypass location on the Afon Cafnan and 0.3km on Llyn Llygeirian tributary. Allows sufficient distance for boundary effects to dissipate upstream of area of interest. Ensures all potential upstream receptors are included in the model.
Inflow boundaries	Model Node CAFN01_2251 (Point Inflow HAL1 in Table 3.2) ▶ NGR 233239 389911. ▶ No minimum flow. ▶ Flow m^3/s, 7.00 hrs duration, last flow extended as a base flow continuation. Model Node UNKN01_0448c (Point Inflow HAL3 in Table 3.2) ▶ NGR 234338 389960. ▶ No minimum flow. ▶ Flow m^3/s, 7.00 hrs duration, last flow extended as a base flow continuation. Model Node CAF_1526-00 (Lateral Inflow between the confluence and hydrological assessment location 2 , Inflow HAL2-HAL1-HAL3 in Table 3.2) ▶ Applied to nodes: CAFN01_1526, CAFN01_1297c, CAFN01_0764, CH0000000019 and CAFN_0336c. ▶ No minimum flow. ▶ Flow m^3/s, 7.00 hrs duration, last flow extended as a base flow continuation.
Lateral catchment weighting	Hydrographs and associated peak flows for inflows CAFN01_2251 and UNKN01_0448c has been applied as it was derived since they represent the headwater catchments of their respective watercourses. The lateral inflow CAF_1526-00 is applied laterally to an intervening catchment and hydrological inputs were derived as adjusted to 'remove' the upstream inflow already represented in the model. The lateral inflow was distributed among the cross sections where tributaries are shown to join the Afon Cafnan on the OS Explorer Map (scale 1:25,000, as accessed on www.bing.com/maps in June 2016). The inflows were weighted according to the length of the watercourse between inflow locations as a proxy of their catchment size.

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Item	Comments
Downstream boundary	CAFN01_-018c ▶ NGR 234118 391378. ▶ Normal depth downstream boundary node. ▶ Bed slope of normal depth boundary calculated in flood modeller from the difference in lowest bed elevations between CAFN01_-008c and CAFN01_-018c.
Backwater length	Recommended backwater length (Samuels, 1989): ~ 1km. Backwater equation: 0.7 x (Depth/Slope). Average depth of channel (bank to bed): ~ 1.43m. Surveyed slope in downstream section of Afon Cafnan (between section CAFN01_0162 and CAFN01_0000): (22.917 – 20.076) / 161.92 = 0.02. Backwater length = 0.7 x (1.43m / 0.02) = **50.05m.** This is a calculation to work out how far upstream you would expect the model downstream boundary to influence the model results upstream. The calculation ensures that the downstream boundary is far enough from the site of interest to not influence the fluvial results.
Model length (km)	Cafnan 01: 2.251km Unkn 01: 0.449km **Total: 2.7km** *See* Table 4.2 *for modelled channel and tributary grid references*
Total number of nodes and structures	**River Section (total)**: 45 **River Section (surveyed)**: 29 **River Section (copied)**: 18 **River Section (using LiDAR data)**: 3 replicates to represent the steep cascade feature at CAFN01_1282r, CAFN01_1267r and CAFN01_1252r informed by level change and slope in LiDAR in this area. **River Sections (interpolated using Flood Modeller Pro)**: 59 **Junctions**: 17 **Bridges**: 1 **Conduits (culverts upstream and downstream)**: 18 **Culvert Inlet (General Loss)**: 12 **Culvert Outlet**: 10 **Inline Spills**: 2 **Spills over structures**: 7 **QTBDY**: 3 (2 point inflow, 1 lateral inflow)
Interpolates and copy sections	Survey photos suggested the Afon Cafnan channel and Llyn Llygeirian tributary are reasonably regular and consistent along their length, with few substantial changes in shape or width. This has informed requested survey cross sections spacing, and allowed for interpolate sections to be added to aid model convergence and stability.

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Item	Comments
Labelling/ numbering system	CAFN01_#### (for sections along Afon Cafnan) UNKN01_#### (for sections along Unknown Tributary from Llyn Llygeirian to Afon Cafnan) Where #### represents chainage upstream from the downstream boundary Node names may be suffixed by the following: _u upstream copy of surveyed node _d downstream copy of surveyed node _ci culvert inlet _co culvert outlet _cu culvert unit upstream face _cd culvert unit downstream face _s spill unit _h lateral hydrological inflow unit _i interpolate river section Where labelling exceeds the permitted number of characters, the '01' prefix has been dropped from the node label.
Structure representation	See Appendix C - Structure representation
Structure coefficients	Structure coefficients have been determined following inspection of the structure survey drawings and photos. Standard values have been used, based on best practice guidance and modeller experience. Structure coefficients would usually be adjusted during a calibration process if sufficient data is available. For this project modelling, sensitivity testing has been undertaken instead, as there was not sufficient calibration data.
Hydraulic roughness values	See Appendix D – Channel roughness representation. Appropriate values for channel roughness were assigned based on standard literature values and informed by the survey drawings and photographs. 1D roughness values taken from published descriptions of Manning's roughness values in Chow (1959) and Syme (2008).
Other information/ alterations made to model	Bridges The option has been enabled to allow surcharged bridges modelled to be modelled as orifice flow (this is only applicable at one location 0157Bu). River units Additional river units have been added to the section of the 1D model downstream of the last surveyed river unit. This is to ensure the flow propagates through the downstream section of the model without instabilities at the bridge near the downstream end of the model (0000C1 & 0000C2). The river unit cross-sectional profiles have been copied from the last surveyed section (CAFN01_0000) and the slope was continued from the upstream reach. River units added are: CAFN01_-008c, CAFN01_-018c.

See Appendix C for details of structure representation.

See Appendix D for details of channel roughness.

4.3 2D model

The Cefn Coch 2D model domain has been built in TUFLOW and represents the floodplain and wider catchment of the Afon Cafnan and Llyn Llygeirian Tributary channels. The overview of the 2D baseline model set up is detailed in Table 4.4.

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Table 4.4 2D model overview

Item	Comments
Resolution of grid / 2D cell size	2 metres. The level of detail required to model floodplain requires a relatively detailed cell size. The LIDAR resolution in the area is 1m and it is best practice for the grid-size to be no smaller than twice the resolution of the LIDAR.
Orientation of grid	North to South. (aligned with the orientation of main floodplain flow direction)
Model extent	Bounded in the south by the topographic catchment boundaries in the east and west. The southern extent of the model area is 0.7km upstream of the proposed bypass site. The northern and southern extent of the model area are far enough upstream and downstream of the proposed bypass site to ensure boundary affects do not affect the area of interest.
2D boundary conditions	Point source inflows are represented in 1D model. The 2D domain links to the 1D domain through links between cross-section nodes and the river banks in the 2D model in layer '1d_nodes_CAFN_003' 2D HQ (water level-flow) downstream boundary represented approximately 300 m downstream of final 1D cross section. HQ boundary gradient of 0.02 for area adjacent to channel and of 0.1-0.11 in the remaining floodplain, in line with overall fall of land. Gradient informed by LiDAR DTM. The eastern and western limits to the 2D domain are formed along the topographic boundary of the catchment. The upstream boundary forms a glass wall at the top of the modelled area and forces the fluvial inflow to flow downstream. The active 2D area (2d_code_CAFN_003) is sufficiently large enough so as not to artificially influence flood flows.
Ground model	LIDAR DTM with 1m resolution was downloaded from http://lle.wales.gov.uk/GridProducts#data=LidarCompositeDataset on 21/04/2016. The initial LIDAR based DTM has been checked thoroughly for possible missing flow routes, such as road bridges, culverts beneath railway embankments etc., as well as null LIDAR areas.
Topographic modifications	A5025 road embankment with tributary to Afon Cafnan perpendicular to road. Assumed that tributary would pass under road in a culvert. Flooding does not reach this location, therefore no modification made. Landform adjacent to cascading sections (NGR SH 34075 90196) shown on OS MasterMap, but no elevations available. River banks raised as per bank levels of surveyed river channel sections on Llyn Llygeirian Tributary: ▶ both banks at chainage 342-269; ▶ right bank downstream of chainage 157. Bridge parapets/decks raised as per channel and structure survey on Unknown Tributary: ▶ at A5025 road bridge at chainage 157. River banks raised as per bank levels of surveyed river channel sections on Afon Cafnan ▶ left bank at chainage 1172-1087. Bridge parapets/decks raised as per channel and structure survey on Afon Cafnan: ▶ chainage 1328, upstream face of road bridge; ▶ chainage 454, upstream and downstream face; ▶ chainage 000, upstream and downstream face of road bridge.
Representation of buildings	Represented using a high roughness value of 0.3 (Syme, 2008). This approach allows for impedance to flow given by the buildings and for flood volume to be dissipated within the area of the buildings.

Item	Comments
Representation of river banks	LiDAR has been used to represent river bank tops as surveyed bank tops between cross sections is not available. Aerial photography and survey photos have suggested banks are not heavily vegetated for the most part of the modelled channel reaches, and thus assumptions that 1m LiDAR resolution is satisfactory to pick out bank levels and channels between surveyed cross sections. Slight alterations of locations of banks were occasionally made in the 1D-2D link to ensure the 1D banks matched the 2D LiDAR bank locations, however bank levels were generally in agreement when located correctly. Checks have been carried out between the bank levels in the surveyed cross section data and the LIDAR to ensure they are consistent. Where necessary the survey has been used to inform short sections of bank as detailed above for topographic modifications.
1D-2D link	The 1D-2D link has been digitised along the top of bank (2d_bc_hxi_channel_CAFN_004). The 'Flood Modeller' cross sections are a width consistent with the 1D-2D link and deactivated area in the 2D TUFLOW model. Slight alterations of locations of banks were occasionally made in the 1D-2D link to ensure the 1D banks matched the 2D LiDAR bank locations, however bank levels were generally in agreement when located correctly.
Delineation of roughness areas	MasterMap used to determine 2D surface type roughness of flood plain areas and checked against aerial photography on Google Maps (accessed 10 May 2016).
Hydraulic roughness values	Appropriate values for channel roughness assigned based on standard modelling practice and were informed by OS MasterMap data and aerial photography.

2D Surface	**Roughness Value** (Chow, 1959; Syme, 2008)
Land/Grass/general surface	0.04
Buildings/glasshouses/structures	0.3
Rough grassland/ scrub / Trees	0.08
Inland Water	0.035
Path/Roadside/Rail	0.025
Road	0.015
Stability	0.1

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5. Model runs

The 1D-2D Cefn Coch model build described in Section 4 has been run for baseline fluvial events, for a range of annual exceedance probabilities. The following section lists the document structures and naming conventions for the model run files (Table 5.1), along with details of each baseline model run completed (Table 5.2).

Table 5.1 Model folder structure and file names

Folder	File	Description
▶ **Flood Modeller**		
▶ **dat**		
▶ **Design**	CAFN_BASE_036.dat	Baseline model 1D network.
▶ **Sensitivity**	CAFN_BASE_036_n+50.dat CAFN_BASE_036_n-50.dat CAFN_BASE_036_s+20.dat CAFN_BASE_036_s-20.dat	Sensitivity scenario models 1D network. n±50 denotes Manning's n coefficient increased/decreased by 50%. s±20 denotes structural coefficients increased/decreased by 20%
▶ **ied**	CAFN_BASE_F20_003.IED CAFN_BASE_F100_003.IED CAFN_BASE_F100cc_003.IED CAFN_BASE_F1000_003.IED	Baseline event file for fluvial events.
▶ **ief**		
▶ **Design**	CAFN_BASE_F20_008.ief CAFN_BASE_F100_008.ief CAFN_BASE_F100cc_008.ief CAFN_BASE_F1000_008.ief	Baseline simulation file for 1D-2D model. F denotes the results represent a Fluvial event. 'cc' denotes where the results have been run for an event which includes climate change impacts.
▶ **Sensitivity**	CAFN_BASE_F100_008_n+50%.ief CAFN_BASE_F100_008_n-50%.ief CAFN_BASE_F100_008_s+20%.ief CAFN_BASE_F100_008_s-20%.ief CAFN_BASE_F100_008_dp.ief	Simulation file for sensitivity runs 1D-2D model. 'dp' denotes double precision

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Folder	File	Description
▶ **iic**	CAFN_BASE_004.iic	Baseline initial conditions for 1D model.
▶ **Results**		
▶ **Baseline**	CAFN_BASE_F20_008 CAFN_BASE_F100_008 CAFN_BASE_F100CC_008 CAFN_BASE_F1000_008	Standard Flood Modeller 1D results files for each baseline run including: .exy, .uic, .zzd, .zzl, .zzn, .zzu, .zzx
▶ **Sensitivity**	CAFN_BASE_F100_008_n+50 CAFN_BASE_F100_008_n-50 CAFN_BASE_F100_008_s+20 CAFN_BASE_F100_008_s-20 CAFN_BASE_F100_008_dp	Standard Flood Modeller 1D results files for each sensitivity run including: .exy, .uic, .zzd, .zzl, .zzn, .zzu, .zzx
▶ **TUFLOW**		
▶ **Checks**		
▶ **Baseline**	CAFN_BASE_F20_008 CAFN_BASE_F100_008 CAFN_BASE_F100cc_008 CAFN_BASE_F1000_008	Standard TUFLOW check files in MID/MIF MapInfo format, including: 1d_to_2d_check; grd_check; bcc_check; zpt_check.
▶ **Sensitivity**	CAFN_BASE_F100_008_n+50 CAFN_BASE_F100_008_n-50 CAFN_BASE_F100_008_s+20 CAFN_BASE_F100_008_s-20 CAFN_BASE_F100_008_dp	Standard TUFLOW check files in MID/MIF MapInfo format, including: 1d_to_2d_check; grd_check; bcc_check; zpt_check.
▶ **Run**		
▶ **Baseline**	CAFN_BASE_F20_008.tcf CAFN_BASE_F100_008.tcf CAFN_BASE_F100cc_008.tcf CAFN_BASE_F1000_008.tcf	Standard TUFLOW run files. Base denotes the baseline scenario model is being run.
▶ **Sensitivity**	CAFN_BASE_F100_008_n+50.tcf CAFN_BASE_F100_008_n-50.tcf CAFN_BASE_F100_008_s+20.tcf CAFN_BASE_F100_008_s-20.tcf CAFN_BASE_F100_008_dp.tcf	Sensitivity run files. n±50 denotes Manning's n coefficient increased/decreased by 50%. s±20 denotes structural coefficients increased/decreased by 20%

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Folder	File	Description
▶ **model**	CAFN_BASE_004.tbc CAFN_BASE_005.tgc CAFN_001.tmf CAFN_001_n+50.tmf CAFN_001_n-50.tmf	Standard TUFLOW model files: tbc – details the boundary conditions tgc – details the geometry files tmf – details the material layer and roughness values n high/low denotes the increase or decrease in manning's n for the sensitivity runs
▶ **Results**		
▶ **Baseline**	CAFN_BASE_F20_008.xmdf CAFN_BASE_F100_008.xmdf CAFN_BASE_F100cc_008.xmdf CAFN_BASE_F1000_008.xmdf	Standard TuFLOW 2D results files for each baseline run Output in .xmdf format and also maximum outputs in asc grid format
▶ **Sensitivity**	CAFN_BASE_F100_008_n+50.xmdf CAFN_BASE_F100_008_n-50.xmdf CAFN_BASE_F100_008_s+20.xmdf CAFN_BASE_F100_008_s-20.xmdf CAFN_BASE_F100_008_dp.xmdf	Standard TuFLOW 2D results files for each sensitivity run Output in .xmdf format and also maximum outputs in asc grid format .

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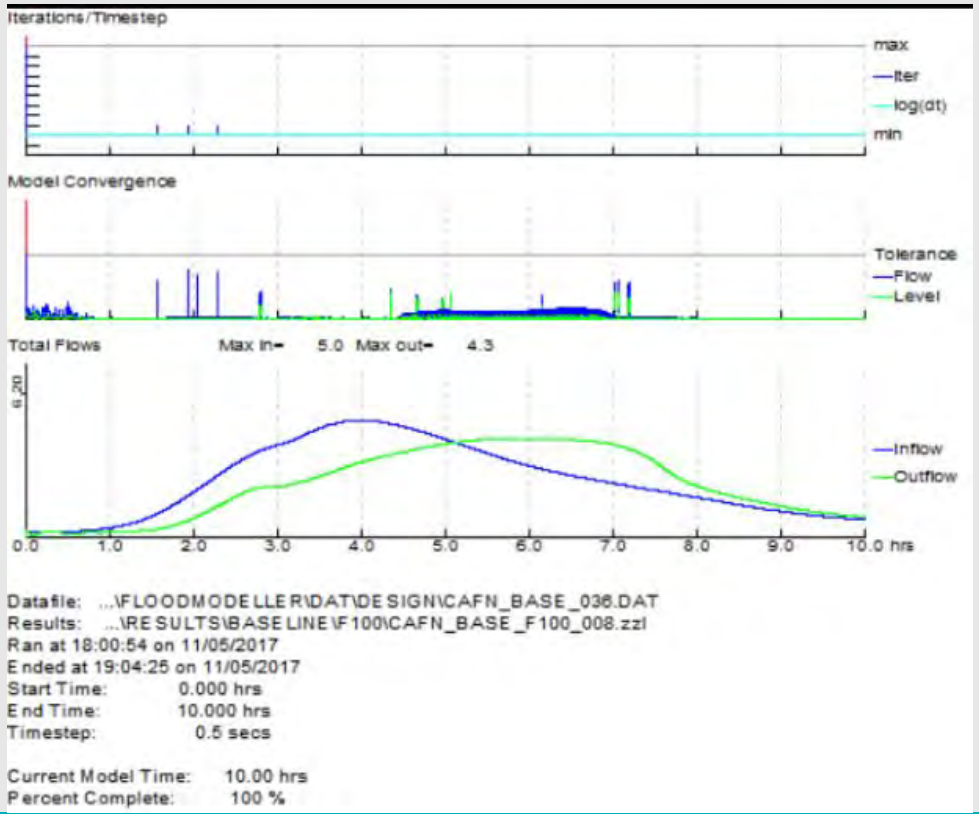
Table 5.2 Design Runs

Item	Comments
Design events	Fluvial 1:20 year AEP Fluvial 1:100 year AEP Fluvial 1:100cc year AEP Fluvial 1:1000 year AEP
Model run parameters and settings	Default parameters were used for all settings except those listed below: Automatic Preissmann Slot for River Sections
1D model stability	Flow and stage graphs for 1D long section and cross sections show a stable model. 1D convergence .bmp files indicate no non-convergence in models.



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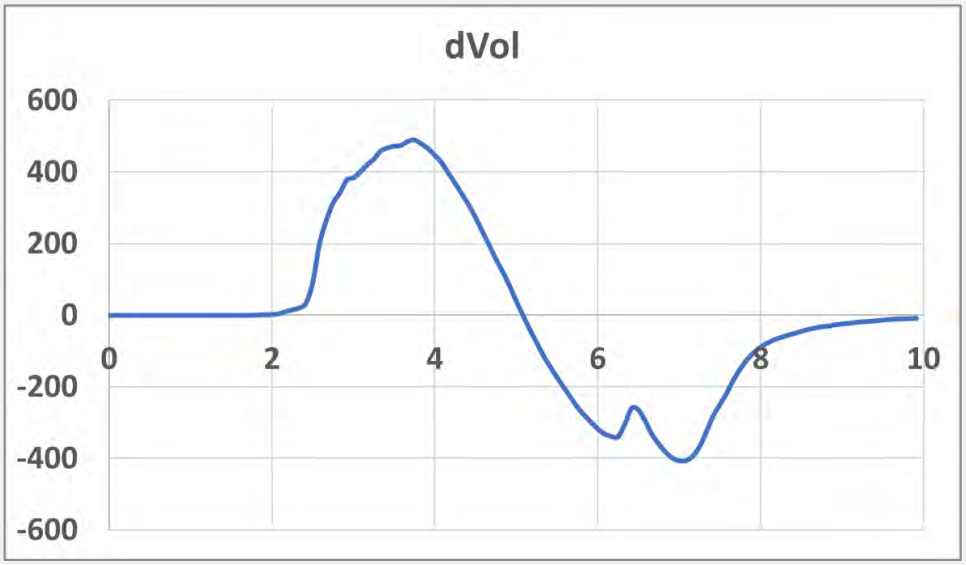
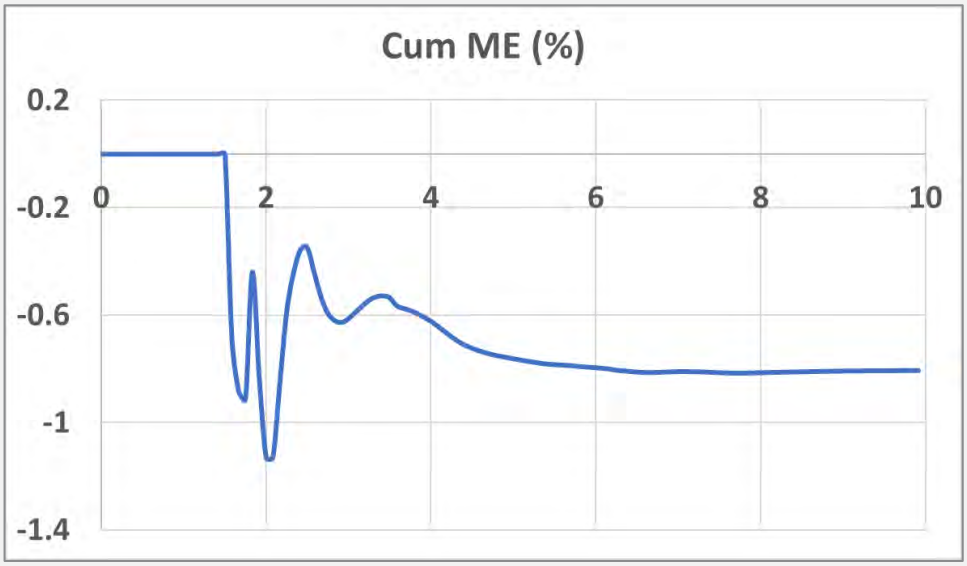
Item	Comments
2D model stability	dVol is sensible (example graphs from CAFN_BASE_F100_008). Final cumulative ME -0.81%, within the recommended +/-1%, the ME briefly drops below the recommended range but soon returns to an acceptable level.  
Model warnings	No model warnings (1D-2D) other than standard warnings for culverts and orifice's becoming surcharged

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6. Baseline model results

Analysis of the flood mechanism is discussed in Section 5.1 and a summary of the results obtained from the baseline hydraulic modelling are presented in a series of maps in Appendix A. These results show the present day and future flood risk (with climate change allowances) to the study area. Results are presented via maps illustrating the fluvial flood extents and via analysis of structure surcharge. Appendix A contains the following flood depth and extent maps which depict the baseline flood estimates:

Figure 6.1 A5025 Cefn Coch baseline peak fluvial flood extents

Figure 6.2 A5025 Cefn Coch baseline peak fluvial depth 1:20 year AEP present day

Figure 6.3 A5025 Cefn Coch baseline peak fluvial depth 1:100 year AEP present day

Figure 6.4 A5025 Cefn Coch baseline peak fluvial depth 1:1000 year AEP present day

Figure 6.5 A5025 Cefn Coch baseline peak fluvial depth 1:100 year AEP climate change (30%)

6.1 Flooding mechanisms

The mechanisms of flood propagation vary according to each of the different baseline scenarios described in Table 5.2. Analysis of the flood propagation for the 1:100 year AEP event shows that there is localised out of bank flow along the Afon Cafnan and Llyn Llygeirian tributary after two hours into the event. As the event progresses flooding starts to become dominant from the Afon Cafnan, in particular south of the local Clych-y-Garn road crossing (on both banks) and predominantly on the left bank midway along the modelled reach. By the peak flow time of the event it is these same areas that are flooded, along with the low-lying drainage terrain towards the downstream extent of the modelled area. Analysis of the other three fluvial events show the same flood flow pathways but varying in extent in line with magnitude of return period flood peak value.

Figure 6.6 Fluvial 1:100 year AEP event – flood propagation

Note: Time stamps on above figures denote the time elapsed since the onset of the event

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On the Llyn Llygeirian tributary, flow is constrained by a field access culvert in the upper reaches (0424Cu), resulting in flooding upstream and floodwaters overtopping the local farm crossing to Pen-y-groes, for all events including the 1:20 year AEP event. The flooding is limited to the corridor of the watercourse.

The A5025 road bridge (0157Bu) which crosses the Llyn Llygeirian tributary has sufficient capacity to allow the passing of the most extreme event flow, the 1:1000 year AEP event, with a peak water level 0.2m below the bridge soffit.

The upper reach of the Afon Cafnan dog-legs around a field. During the flood event, water levels exceed the right bank levels and water spills into the field. Progressively, the field fills with more water and ultimately re-joins the channel at the north-eastern corner of the field effectively bypassing the main channel for a length of approximately 200m.

The reach of the Afon Cafnan from its confluence with the Llyn Llygeirian tributary to the road bridge, upstream of the cascading section, flows through a natural floodplain of low lying land either side of the channel, where flooding is evident on both sides of the channel for both watercourses. The road embankment and culvert structure (1328Cu) act as a control, allowing water to pond on the upstream face of the road. The road crossing starts to become surcharged for the 1:100 year AEP event. The depth of water upstream of the local road (1328Cu) exceeds the road level in the1:1000 year AEP event, causing the road to be overtopped.

The channel cascades over a height of approximately 1.2m a short distance after the road crossing. Downstream of the cascading reach there are two further areas with substantial flooding of the western floodplain. In the mid Afon Cafnan, the floodplain flows are influenced by the topography of the a field drain/ditch which is represented in the underlying topography LiDAR data. Water exceeds the left bank of the channel and fills the low lying areas of the floodplain and bypasses the channel. In the lower reaches, water exceeds both banks and flows within a relatively narrow corridor adjacent to the main channel. The channel and floodplain of a small tributary on the left bank, which is not explicitly represented in the model, are backfilled.

The double barrel culvert crossing (0854C1u and 0854C2u) midway along the Afon Cafnan is overtopped for the 1:20 year AEP event. Whereas the double crossing (0687C1u and 0687C2u) further downstream is not overtopped until the 1:100 year AEP event plus climate change.

Similarly, the double crossings (0454C1u and 0454C2u; and 0340C1u and 0340C2u) are overtopped in the 1:20 year AEP event.

The furthest downstream structure modelled (a rectangular culvert; 0000C1u) becomes surcharged in the 1:100 year AEP event.

The mechanisms of flooding at the specific structure locations are illustrated in Table 6.1 and Table 6.2.

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Table 6.1 Flooding mechanisms at structures along Llyn Llygeirian tributary – 1:100 year AEP event plus climate change

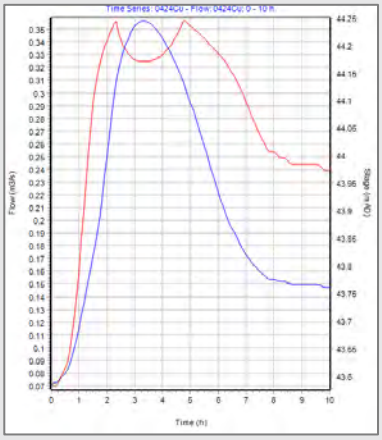
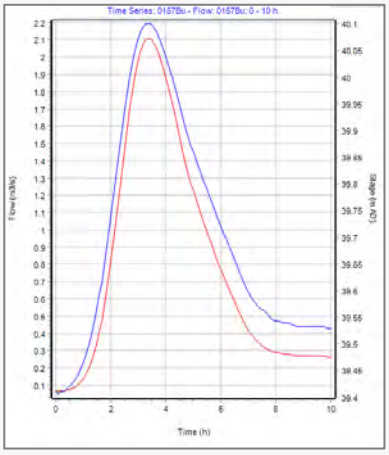
Location	Description	Water level (blue) and Flow (red) vs. Time graphs
	▶ Access track to farm (0424Cu). ▶ Culvert capacity exceeded and flow spilling over from 1hr 20mins into the event. ▶ Water backs up upstream of culvert and shallow flooding of both banks occurs (from 1hr 20mins on right bank and 1hr 35mins on left bank). ▶ Water bypasses via left bank from 1hr 35mins. ▶ Flow through culvert as per graph	
	▶ Road Bridge (A5025) (0157Bu). ▶ Culvert capacity not exceeded. ▶ Flow through culvert as per graph.	

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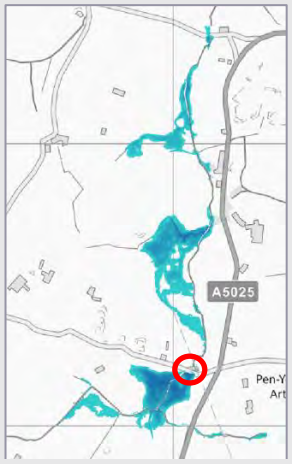
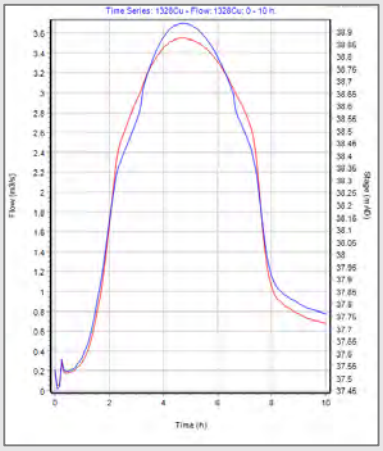
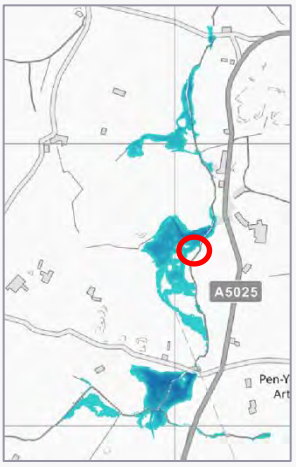
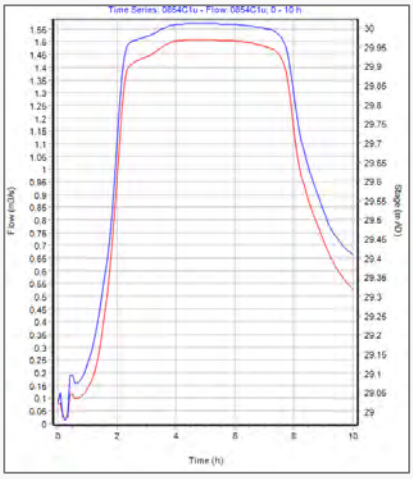
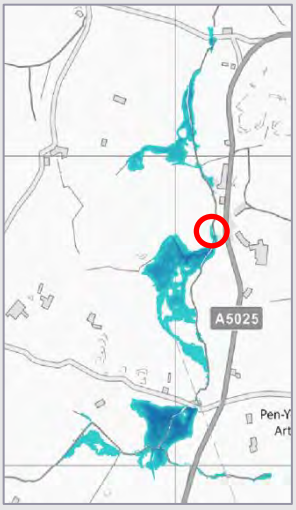
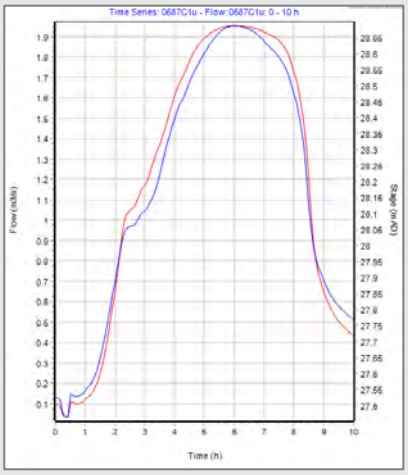
Table 6.2 Flooding mechanisms at structures along Afon Cafnan – 1:100 year AEP event plus climate change

Location	Description	Water level (blue) and Flow (red) vs. Time graphs
	▶ Road Bridge on Afon Cafnan (1328Cu). ▶ Culvert surcharges. ▶ Road embankment elevation restricts any flooding onto the road. ▶ Water spills on right bank at 2hrs 20mins into the event. ▶ Flow through culvert as per graph.	
	▶ Double culvert crossing on Afon Cafnan (0854C1u and 0854C2u). ▶ Culverts surcharge and overtop. ▶ Water spills over at 2hrs 30mins into the event. ▶ Flow through culvert (0854C1u) as per graph.	
	▶ Double culvert crossing on Afon Cafnan (0687C1u and 0687C2u). ▶ Culverts surcharge and overtop. ▶ Water spills over the structure and on the left and right bank around 4hrs 30mins into the event. ▶ Flow through culvert (0687C1u) as per graph.	

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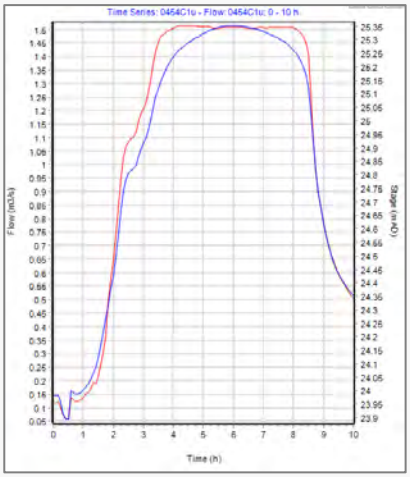
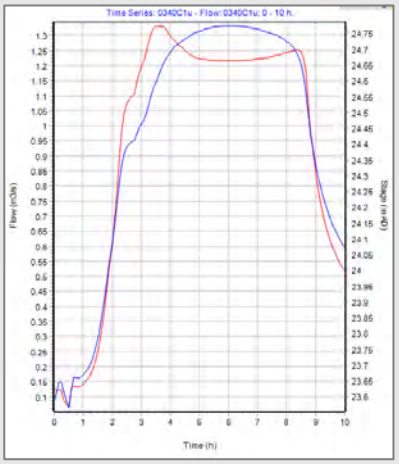
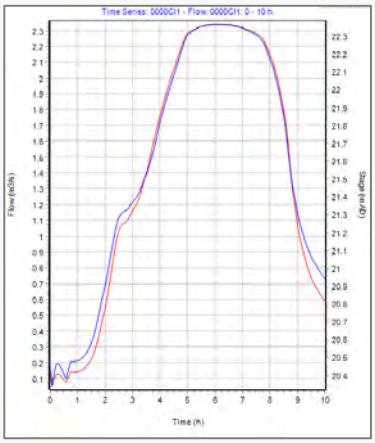
Location	Description	Water level (blue) and Flow (red) vs. Time graphs
	▶ Double culvert crossing on Afon Cafnan (0454C1u and 0454C2u). ▶ Culverts surcharge and overtop. ▶ Water spills over the structure around 3hrs 20mins into the event. ▶ Flow through culvert (0454C1u) as per graph	
	▶ Double culvert crossing on Afon Cafnan (0340C1u and 0340C2u). ▶ Culverts surcharge and overtop. ▶ Water starts to spill on the left and right banks at 3hrs 10mins into the event, and over the structure around 3hrs 25mins into the event. ▶ Flow through culvert (0340C1u) as per graph.	
	▶ Double culvert crossing on Afon Cafnan (0000C1u and 0000C2u). ▶ Culverts surcharge and overtop. ▶ Water starts to spill on the left bank at 4hrs 15mins into the event, and over the structure around 4hrs 55mins into the event. ▶ Flow through culvert (0000C1u) as per graph.	

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7. Sensitivity testing

The purpose of sensitivity testing is to test the validity of the underlying assumptions in the model, and ensure the model is behaving as expected. Sensitivity testing provides a means of assessing how sensitive the predicted depths and extents are to changes in the model parameters and assumptions. It is clear that if a parameter is changed then the resultant flood depth could change. The objective of the sensitivity testing is to highlight the potential range of change associated with adjusted parameters so as to provide confidence in the value selected.

Section 7.1 details the hydraulic model and hydrological input sensitivity tests undertaken, and their application in the 1D and 2D model domains. A discussion on the results of the tests then follow in Section 7.2.

7.1 Sensitivity test method

Table 7.1 details the application of the tests in the 1D and 2D model domains. All sensitivity tests have been performed for the 1:100 year AEP present day scenario.

Table 7.1 Sensitivity test methods

Test	Description
Test 1	a) Manning's (n) roughness increase b) Manning's (n) roughness decrease
1D application	All cross section Manning's values increased and decreased by 50%, including bridges and structures where relevant (i.e. conduit friction)
2D application	For the 2D domain the absolute values are increased and decreased to reflect the realistic upper and lower limits of each landuse class: Land/Grass/general surface – baseline 0.04; test 0.05 / 0.03 (max/min, rough grass) Buildings/glasshouses/structures – baseline 0.30; test 0.5 / 0.1 (max/min, building) Rough grassland/ scrub/Trees – baseline 0.08; test 0.11 / 0.06 (max/min, mixed vegetation) Inland Water/Tidal Water – baseline 0.035; test 0.045 / 0.025 (max/min, inland water) Path/Roadside – baseline 0.025; test 0.03 / 0.02 (max/min, pavement) Road – baseline 0.015; test 0.017 / 0.013 (max/min, road) Stability – baseline 0.10; remains as 0.10 for model stability.
Test 2	a) Structure coefficient + 20% b) Structure coefficient - 20%
1D application	The following structure coefficients increased and decreased by 20% from default value: Culvert Inflow – K; C; Ki Bridge – Orifice discharge coefficient (where applied) Spill units – Weir coefficient.
2D application	No change in 2D domain
Test 3	a) Manning's (n) roughness increase at targeted locations (1D model only)

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1D application	Manning's values increased at selected sections and structures in the 1D model to represent heavily vegetated and/or poorly maintained channels or structures.: Culverts at CAFN01_0854, CAFN01_0454, CAFN01_0687, CAFN01_0340 – baseline 0.011; test with 0.020 Afon Cafnan channel sections: - CAFN01_1668 – banks; baseline 0.05, test with 0.06 - CAFN01_1445 – banks; baseline 0.03, test with 0.035 - CAFN01_1237 – right bank: baseline 0.05, test with 0.06 - CAFN01_1087 – right bank: baseline 0.05, test with 0.06 - CAFN01_0449c – left bank: baseline reported as 0.03 but modelled as 0.05, test 0.05 (so no change applied) Llyn Llygeirian tributary channel sections: - UNKN01_0424 – banks; baseline 0.03, test 0.04 - UNKN01_0420c – right bank; baseline 0.03, test 0.04 - UNKN01_0287 – banks; baseline reported as 0.03 but modelled as 0.05, test 0.05 (no change applied) - UNKN01_0011 – right bank; baseline reported as 0.03 but modelled as 0.45, test 0.045 (no change applied)
2D application	No change in the roughness in 2D domain
Test 4	Storm durations
Inflow hydrology	The 3-hour storm has been taken as the critical duration for the bypass location, identified approximately 100m downstream of HALs 1 and 3. This was derived from catchment descriptors and is reported in Section 3.6. In this sensitivity test, additional hydrographs were created using the method described in Section 3.4, for the 1 hour, 2 hour, 4 hour, 5 hour, 6 hour and 8 hour storm durations to broaden the range of storm durations considered.
Test 5	Method for deriving inflow hydrograph
Inflow hydrology	The test on the sensitivity of model predictions to hydrological inputs investigated the effect of applying hydrological inflows derived using an alternative method to that detailed in Section 3. The baseline approach is detailed in Section 3.8, this was based on subtracting the upstream hydrographs from the downstream hydrograph, and applying the resulting hydrograph laterally to the remainder of the reach. The alternative approach developed in this test is based on disaggregating the contributing catchment area, amending the catchment descriptors pertinent to the intervening area and deriving the hydrograph using ReFH2.2. This allows for the comparison of the resultant hydrographs from the two methods, and the assessment of any impact.

7.2 Sensitivity test results

The following subsections detail the differences in water levels from the baseline 1:100 year AEP event and the sensitivity runs undertaken for the same event (Table 7.1). The model results are analysed by means of increase and decrease in maximum water levels, time to peak of inflow hydrographs, peak flow values, total inflow volumes and inundation extents as applicable. The sensitivity of roughness changes (Test 1) and structure-coefficient changes (Test 2) on the maximum flood depth and inundation extents are shown in difference maps (Figure 7.1).

Test 1: Manning's (n) roughness (+/- 50%)

1D modelled water levels for Manning's roughness sensitivity tests are shown to be within a maximum difference of 0.4m from the water levels of the same baseline 1:100 year AEP event (Table 7.2).

When increasing roughness the water level is increased by 0.34m at the downstream face of the double culvert at the downstream end of the model (-008) on the Afon Cafnan; and the water level is decreased by 0.29m at the double culvert under the local access track mid reach (0854). Analysis of the 2D element of the model shows flood depths are increased by up to 0.28m and decreased by up to 0.04m (Figure 7.1).

When decreasing roughness the water level is increased by 0.19m at the double culvert under the local access track mid reach (0854); and water level is decreased by 0.41m at the double culvert just downstream

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(0687). Analysis of the 2D element of the model shows the flood depth is increased by up to 0.06m and decreased by up to 0.29m (Figure 7.1).

Differences in water levels are within the range that would be expected for a Manning's roughness sensitivity test, where 'n' values are varied as much as 50%. 50% represents a significant change in channel condition a decrease would represent a more maintained channel, and the increase represents a less maintained heavily vegetated channel. Results also show that time to peak is also slightly longer where Manning's roughness values are increased, as expected.

Test 2: Structure coefficient (+/- 20%)

1D modelled water levels for structure coefficient sensitivity tests are shown to be within a maximum difference of 0.2m from the water levels of the same baseline 1:100 year AEP event (Table 7.2).

When increasing the structure coefficients, the water level is increased by 0.13m at the double culvert at the downstream end of the model (0000) on the Afon Cafnan; and the water level is decreased by up 0.17m at the double culvert under the local access track mid reach (0854). Analysis of the 2D element of the model shows the flood depth is increased by up to 0.14m and decreased by up to 0.10m (Figure 7.1).

When decreasing the structure coefficients, the water level is increased by 0.21m at the double culvert under the road upstream of the cascade (1328); and water level is decreased by 0.13m at the double culvert at the downstream end of the model (0000) on the Afon Cafnan. Analysis of the 2D element of the model shows the flood depth is increased by up to 0.14m and decreased by up to 0.13m (Figure 7.1).

The maximum water level is more sensitive to decreasing the structure coefficients, as a lower spill coefficient results in more resistance to flow and therefore a higher water level. The differences in water levels are within the range that would be expected for a structure coefficient sensitivity test of +/- 20%.

Test 3: Manning's roughness (n) high (at specific sections in 1D)

Water levels for the sensitivity test with higher Manning's n roughness, to represent a worst vegetation case at targeted locations are shown to be within a maximum difference of 0.07m from the water levels of the same baseline 1:100 year AEP event (Table 7.2).

The water level is increased by 0.07m at the upstream face of the double culvert near the Cefn Coch settlement close to the A5025 road (0687) on the Afon Cafnan; and the water level is decreased by 0.02m at the downstream face of the double culvert near the downstream side of the Cefn Coch settlement (0454) on the Afon Cafnan. Manning's roughness (n) was increased in the test for both of these culverts, and water levels are increased at the upstream face and decreased at the downstream face of these culverts, as expected.

Differences in water levels are within the range that would be expected when varying Manning's roughness within the range of default values.

Table 7.2 Sensitivity Tests 1, 2 and 3 – summary results – 1:100 year AEP event

	Increase in water level (m)				
	Test 1a (n+50%)	**Test 1b (n-50%)**	**Test 2a (s+20%)**	**Test 2b (s-20%)**	**Test 3**
Maximum	0.34	0.19	0.13	0.21	0.07 (at 1D node 0687)
Minimum	-0.29	-0.41	-0.17	-0.13	-0.02 (at 1D node 0455)

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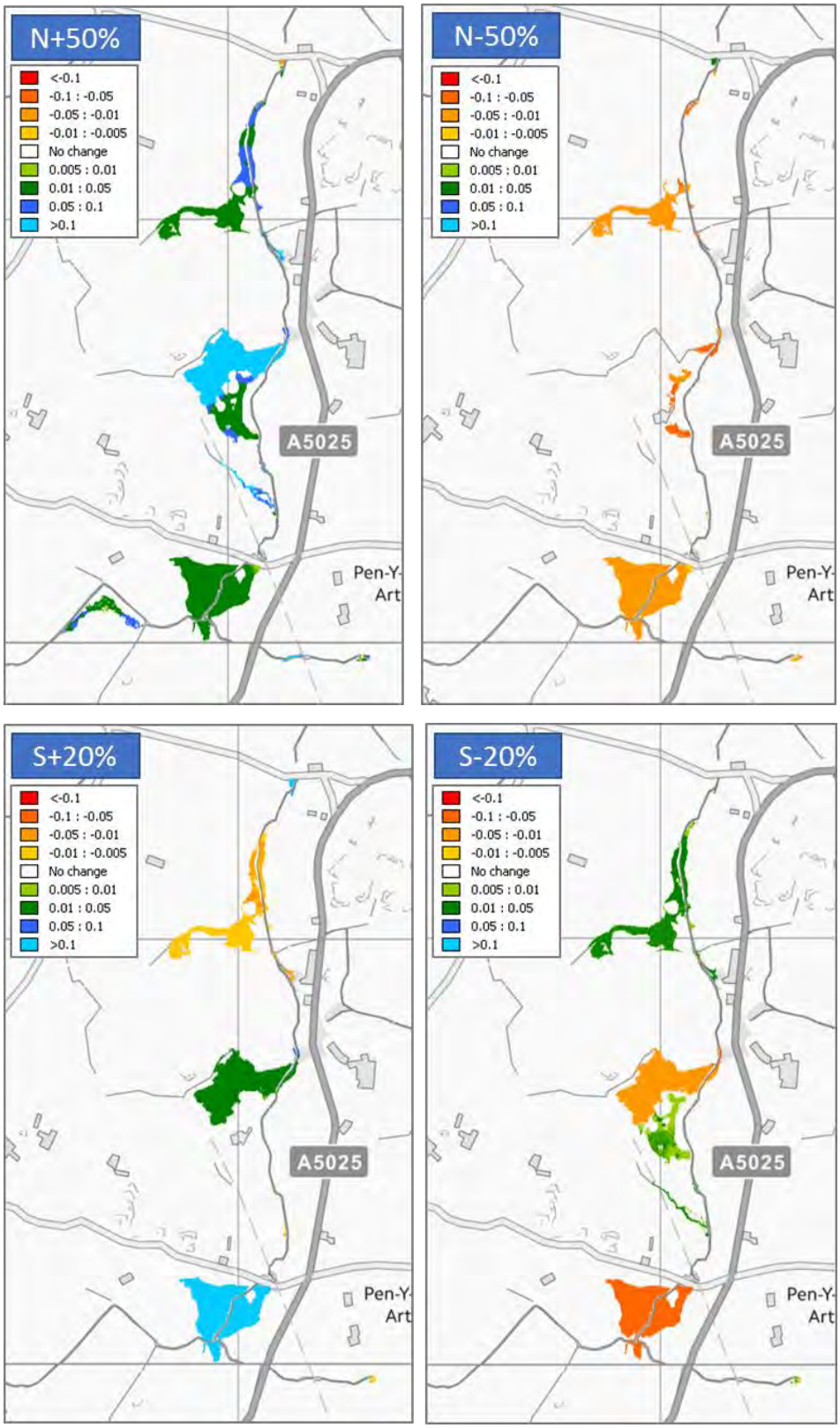
Figure 7.1 Sensitivity tests 1 and 2 – depth difference plots (m)



Note: negative = sensitivity lowers water level; positive = sensitivity increases water level.

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Test 4: Storm durations

The results in Table 7.3 show water levels calculated for various storm durations at the bypass location. The peak water level for 6-hour storm duration is higher by 9cm than the 3-hour baseline result, and is not considered a significant difference. However, the peak levels provide a means to understand uncertainties associated with the storm duration taken. This is considered as within an acceptable and realistic range. These tests quantify the confidence in the critical storm duration previously used in the analysis.

Table 7.3 Sensitivity Test 4 summary results – Critical storm duration

Peak water level (m) at bypass location (model node CAFN01_1354)				
8 hours	**6 hours**	**5 hours**	**4 hours**	**3 hours (baseline)**
39.23	39.27	39.26	39.23	39.18

Test 5: Inflow hydrograph derivation

Section 3 presented a subtraction method to determine the inflows from areas between hydrological assessment (HAL) points. In this sensitivity test an alternative method 'disaggregation method' as set out in Table 7.1 has been used to represent inflow hydrograph from area lying downstream of HAL-1 and HAL-3. The hydrograph derived from the disaggregation method resulted in a 3% reduction in peak flow from the baseline approach detailed in Section 3, and the hydrograph peak time was shortened by 1.5 hour. The hydraulic model was run with this updated inflow hydrograph and the impact was found to be negligible. There was a reduction in total inflow volume by 20 % suggesting a level of conservatism associated with the method used in the baseline modelling. The disaggregation approach resulted in differences to the peak in-channel water levels in the range of -0.19m to 0.04m compared to the baseline results. The maximum flood extent using the disaggregation approach was very slightly smaller than for the baseline result because of the reduced total inflow volume from the new hydrograph. This test therefore adds confidence in the subtraction approach applied for the generation of baseline hydrographs, because it is shown that hydrographs presented in Section 3 are reasonably conservative.

7.3 Sensitivity test conclusions

Results for the Manning's roughness (Tests 1 and 3) and structure coefficient (Test 2) show that the model is less sensitive to changes in structure coefficient than roughness. The model responds appropriately and as expected to the sensitivity tests, with water level differences proportionate to the existing hazard, thus not causing a significant impact on flood results in the study area. It is therefore concluded that the roughness values taken as typical for the channel vegetation condition and surrounding area, and the structure coefficient values adopted for the baseline hydraulic model are appropriate.

Results for the sensitivity testing to hydrological parameters (Tests 4 and 5) showed that the approach deployed in the baseline modelling reported in Section 3, are acceptable as the baseline position is reasonably conservative, adding confidence to the reported values are not underestimates and helping to understand uncertainties around the parameters.

7.4 Double precision test

In addition to assessing the sensitivity to key parameters (as detailed above), the sensitivity of the model performance to the choice of TUFLOW precision was assessed. All model runs documented were run with a single precision version of TUFLOW (TUFLOW Build 2016-03-AE-w64 (single precision)). Sensitivity was

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tested by applying the double precision version of TUFLOW (TUFLOW Build 2016-03-AE-w64 (double precision)) for the 1:100 year AEP flood event. Analysis of the results shows negligible difference in water levels between the single and double precision version of the software across the 1D model. Analysis of the mass balance shows the same cumulative mass balance error for both versions, -0.81%. These results support the use of the single precision version of the software which has been applied to all runs.

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Appendix A
Supporting A3 Figures

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Key

Baseline fluvial
Peak flood extents

- 1:20 year AEP
- 1:100 year AEP
- 1:100 year AEP - plus 30% climate change
- 1:1000 year AEP
- Model boundary
- 1D Model Domain
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 11/05/2017

Meters
0 100 200 300 400
Scale at A3

Wylfa Newydd
A5025 - Cefn Coch
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Figure 6.1
A5025 Cefn Coch baseline peak fluvial flood extents

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Key

Peak flood depth (m)
Baseline
1 : 20 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 11/05/2017

Meters
0 100 200 300 400
Scale at A3

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Figure 6.2
A5025 Cefn Coch baseline peak fluvial depth 1:20 year AEP present day

May 2017 35989-Lon505i1 beltl

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Key

Peak flood depth (m)
Baseline
1 : 100 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 11/05/2017

Meters
0 100 200 300 400
Scale at A3

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A5025 - Cefn Coch
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Figure 6.3
A5025 Cefn Coch baseline peak fluvial depth 1:100 year AEP present day

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Key

Peak flood depth (m)
Baseline
1 : 1000 year AEP fluvial
Present day

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 11/05/2017

Meters
0 100 200 300 400
Scale at A3

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A5025 - Cefn Coch
Hydraulic Modelling

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Figure 6.4
A5025 Cefn Coch baseline peak fluvial depth 1:1000 year AEP present day

May 2017 35989-Lon507i1 beltl

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Key

Peak flood depth (m)
Baseline
1 : 100 year AEP fluvial
Climate change (30%)

- 0.01 - 0.05
- 0.05 - 0.10
- 0.10 - 0.25
- 0.25 - 0.50
- 0.50 - 0.75
- 0.75 - 1.00
- 1.00 - 1.50
- 1.50 - 2.00
- > 2.00
- Model boundary
- 1D Model Domain
- OS Mastermap

Notes:
The depths represent the maximum depth achieved. The flood prediction does not represent a moment in time as maximum depths can be achieved at different times.

Model run date: 11/05/2017

Meters
0 100 200 300 400
Scale at A3

Wylfa Newydd
A5025 - Cefn Coch
Hydraulic Modelling

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Figure 6.5
A5025 Cefn Coch baseline peak fluvial depth 1:100 year AEP climate change (30%)

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Appendix B
Detailed Hydrology Report

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A5025 Bypass – Cefn Coch Hydrology Assessment

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1. Introduction

As part of the Wylfa Newydd DCO Project, several Offline A5025 highway enhancement projects have been identified, one of which is the Cefn Coch A5025 bypass, which is the subject of this technical note. The proposed bypass route passes through agricultural land to the west of the village and the A5025 where it will run parallel to the Afon Cafnan and cross an unnamed tributary, shown on Figure 1.1.

1D-2D modelling will be undertaken to support the assessment of the proposed A5025 bypass at Cefn Coch, Anglesey, NW Wales. Modelling will determine the baseline (present day) fluvial flood risk to the bypass location and nearby receptors, and the future risk including climate change impacts.

Hydrological assessment has determined the inflows which will be represented in the hydraulic model. Natural Resources Wales (NRW) guidance[3] states that a Flood Consequence Assessment must consider the 1% (1 in 100) annual probability of occurrence and 0.1% (1 in 1,000) annual probability of occurrence events, including climate change on fluvial flows up to and including the 1% annual probability of occurrence. In addition, to provide a range of flood events the 20% (1 in 5) and 5% (1 in 20) annual probability of occurrence events have been determined to represent in the hydraulic modelling study.

The purpose of this hydrological assessment is to determine appropriate inflows, required as input to the hydraulic model of the proposed A5025 bypass at Cefn Coch. This report defines the hydrological catchments which will be represented in the Cefn Coch hydraulic model and the flows which have been derived using two industry standard methods: the Flood Estimation Handbook (FEH) (Institute of Hydrology (IOH), 1999) statistical method and the revitalised flood hydrograph method (ReFH) described in the ReFH 2.2: technical guidance (Centre for Ecology & Hydrology (CEH), 2016). The results of the hydrological assessment and the flows to be represented in the hydraulic model are presented in this technical note.

This technical note has the following sections:

- Section 2: Catchment definition;
- Section 3: Derivation of flows using FEH statistical method;
- Section 4: Derivation of flows using ReFH2.1 method;
- Section 5: Final peak flows;
- Section 6: Representation of flows in the hydraulic model; and
- Section 7: References.

[3] Natural Resources Wales, 2015. Good Practice Guide: Producing flood risk hydraulic models and flood consequence assessments for development planning purposes. GPG 101.

2. Catchment definition

2.1 Overview

The Afon Cafnan flows north from Bod-Hedd, flowing into the sea near Cafnan approximately 2.5km north of Cefn Coch. The Llygeirian tributary flows west from Llyn Llygeirian, flowing into the Afon Cafnan 500m west of Llyn Llygeirian approximately 100m downstream of the existing A5025. A site location plan showing these watercourses and their associated FEH catchments is provided in Figure 1.1.

The proposed bypass runs parallel to the Afon Cafnan and crosses the Llygeirian tributary immediately upstream of the confluence with Afon Cafnan. Drainage attenuation ponds are planned near the new bypass which may be within the floodplain. The extent of any influence from the proposed A5025 bypass is not known as there are no significant topographic features that would obviously limit the extent. This will be determined through hydraulic modelling.

2.2 Hydrological assessment

Hydrological assessment has been undertaken for the locations identified on Figure 2.1 for the Afon Cafnan and tributary. Hydrological assessment locations were chosen to represent the inflow at the upper extent of the model (1 - Afon Cafnan, and 3 – Llygeirian tributary) and intervening catchments on Afon Cafnan (2).

A comparison of the Afon Cafnan and tributary catchments identified on the FEH CD-ROM 3 and those derived using topographic data[4] showed there was no significant difference in catchment extent.

As the catchment boundaries are not significantly different, it was considered appropriate to use the catchment data directly from FEH. All catchment descriptor data exported from FEH website for each of the three hydrological assessment locations is provided in Appendix B, with key hydrological parameters for each location presented in Table 2.1. Key hydrological parameters include:

- Catchment area (AREA);
- Standard annual average rainfall (SAAR) for the period 1961-1990;
- The degree of flood peak attenuation within the catchment from reservoirs and lakes indicated by the FARL value (with a value of 1 indicating no attenuation), and
- A measure of catchment responsiveness indicated by the base flow index (BFIHOST).

[4] LiDAR data (1m grid) was only available for the northern area of the Cefn Coch catchment, otherwise OS Terrain data (50m grid) was used.

Table 2.1 Key hydrological parameters

Hydrological assessment location (HAL)	Watercourse	Location description	National Grid Reference (NGR)	AREA (km^2)	SAAR (mm/yr)	FARL	BFIHOST	URBEXT 2000
1	Afon Cafnan	Upstream of confluence with Llygeirian tributary	SH 33900 90050	1.12	978	1	0.477	0.0056
2	Afon Cafnan	Downstream of bypass and Llygeirian tributary confluence	SH 34150 91400	4.34	987	0.882	0.466	0.0029
3	Llygeirian tributary	Upstream of confluence with Afon Cafnan	SH 34000 90000	2.10	996	0.772	0.491	0.003

Inflow hydrographs identified for hydrological assessment locations 1 and 3 will be represented as point inflows in the model, and the inflow hydrographs for hydrological assessment location 2 will be used to calculate the lateral inflows represented within the model. Greater detail on how these inflows will be applied in the hydraulic model is provided in Section 6.

3. Derivation of peak flows using FEH statistical method

Flows were derived using the statistical method set out in the FEH method, using WINFAP-FEH 3 software. The method derives a pooling group of catchments for which there are reliable gauged annual maxima (or peak over threshold) flows and which are hydrologically similar to the subject site. Gauged sites suitable for pooling are included in the HiFlows-UK database now hosted on the National River Flow Archive (NRFA) website (CEH, 2016). A growth curve is derived from the pooled gauged data and applied to the median of annual maximum flood (QMED) for the subject site.

The median flood is derived theoretically for ungauged sites, i.e. the subject sites, but refined using data from an appropriate donor site, if available. A further urban adjustment is applied to account for the urban extent within the catchment.

The hydrological assessment locations on Afon Cafnan downstream of its confluence with the Llygeirian tributary and the Llygeirian tributary are influenced by a lake in the headwaters. The FEH statistical method has been used to account for this lake using the catchment descriptor FARL. In general, pooling groups for these two locations will therefore tend to feature sites with some influence from lakes and reservoirs. No further adjustment to QMED was considered to be required to account for FARL.

3.1 Median annual flood – based on catchment descriptors

A median annual flood estimate (QMED) has been identified using the catchment descriptor equation given in the EA Flood Estimation Guidelines (EA, 2015), at page 43:

$$QMED = 8.3062 \times AREA^{0.8510} \times 0.1536^{1000/SAAR} \times FARL^{3.4451} \times 0.0460^{BFIHOST\wedge 2}$$

where, AREA, SAAR, FARL and BFIHOST are the FEH catchment descriptors: area, standard average annual rainfall, flow attenuation index by reservoirs or lakes, and baseflow index described by hydrology of soil type (HOST) classification, respectively (see Appendix B for all FEH catchment descriptors).

The unadjusted median flood estimates based on catchment descriptors are shown in Table 3.3.

3.2 Adjusting the median annual flood – donor catchments

Where flows are derived using the FEH statistical approach with no gauged data at the subject site, an adjustment to the median flood should always be considered with data from a donor site (or sites) where possible and appropriate. The latest method for determining donor sites (in WINFAP-FEH 3), chooses a donor based solely on distance from the subject catchment, and the influence of the donor catchment falls off as the distance between the donor catchment centroid and the subject site catchment centroid increases. Proposed donor sites with centroids further than 10km have only a small influence on the median flood estimate. The EA Flood Estimation Guidelines (EA, 2015) confirms that hydrological similarity should also be considered when choosing a donor catchment.

Donor catchments have been considered based on data from the NRFA website (CEH, 2016). There are no HiFlows-UK sites on Anglesey which identify QMED values, which means there are no suitable HiFlows-UK donor sites within a reasonable distance of the catchments of interest. A wider search of the NRFA website found other gauges which were considered as potential donor stations and summarised in terms of suitability in Table 3.1. Although no HiFlows-UK data was available for the Cefni at Bodffordd, it was the closest gauge, being the only one of the gauges listed which is on Anglesey. Flow data provided by NRW for the

Cefni at Bodffordd was used to determine an annual maximum (AMAX) series for fourteen full water years and thus identify QMED for the gauge.

Table 3.1 Potential donor stations

Station	Centroid Distance (km)	Consideration	Considered as a donor
102001: Cefni at Bodffordd	14	QMED determined from 15-min flow data	Yes
65006: Seiont at Peblig Mill	39	Suitable for QMED according to HiFlows-UK	Yes
65004: Gwyrfai at Bontnewydd	41	Suitable for QMED according to HiFlows-UK	Yes
65015: Llyfni at Pont Y Cim	42	No QMED value available	No
65008: Peris at Nant Peris	44	No QMED value available	No
65014: Colwyn at Hafod Wydr	47	No QMED value available	No
65001: Glaslyn at Beddgelert	49	Suitable for QMED according to HiFlows-UK	Yes

Note: Sites are listed based on approximate direct-line distance from Afon Cafnan (hydrological assessment location 2), from closest to furthest away.

Gauge stations 102001, 65006, 65004 and 65001 were identified as potential donor sites, based on relevant catchment characteristics, particularly FARL and BFIHOST. These HiFlows-UK sites were identified on HiFlows-UK as suitable for deriving QMED. Adjustment factors were derived using a ratio with the weighting factor applied, as per the EA Flood Estimation Guidelines (EA, 2015):

$$QMED_{s,adj} = QMED_{s,cds} \times (QMED_{g,obs} / QMED_{g,cds})^{a}$$

$$a = 0.4598 \times \exp(-0.02 \times d_{ij}) + (1 - 0.4598) \times \exp(-0.4785 \times d_{ij})$$

where, $QMED_{s,adj}$ is the median flood at the subject site, adjusted with the donor sites (m^3/s);

$QMED_{s,cds}$ is the median flood at the subject site using catchment descriptors (m^3/s);

$QMED_{g,obs}$ is the gauged median flood at the donor site (m^3/s);

$QMED_{g,cds}$ is the median flood at the gauged site using catchment descriptors (m^3/s); and

d_{ij} is the distance between centroids of the subject and donor catchments (km).

The four donor catchments have similar hydrological parameters to the Afon Cafnan (hydrological assessment location 2). In particular, the Afon Cafnan downstream and tributary have FARL (attenuation) values less than 1.0 because of the existence of Llyn Llygeirian upstream. Donor catchments were chosen to reflect amounts of attenuation similar to the Afon Cafnan catchment downstream and tributary. Catchment details and adjustment factors are presented in Table 3.2.

Table 3.2 Donor sites to refine median annual flood (QMED)

	Afon Cafnan[1]	Cefni at Bodffordd	Seiont at Peblig Mill	Gwyrfai at Bontnewydd	Glaslyn at Beddgelert
NRFA Ref	-	102001	65006	65004	65001
AREA (km^2)	4.34	21.01	74.4	47.9	68.6
SAAR (mm)	987	1061	2278	2147	2791
FARL	0.882	0.964	0.85	0.862	0.896
BFIHOST	0.466	0.448	0.499	0.412	0.406
URBEXT	0.3%	0.1%	1.0%	0.2%	0.0%
Centroid X	234160	242964	257840	255036	261419
Centroid Y	389789	380648	360311	356471	351184
Distance between centroids (km)	-	12.7	37.8	39.32	47.26
QMEDcds (m^3/s)	1.44	9.01	37.92	33.21	63.95
QMEDobs (m^3/s)	-	11.85	46.22	20.35	90.39
QMEDobs/ QMEDcds	-	1.315	1.219	0.613	1.413
Record length	-	14	36	32	45
Suitable for QMED (as stated on HiFlows-UK)	-	-	yes	yes	yes
Factors affecting runoff (from NRFA HiFlows-UK site)	-	Weir susceptible to blockage	contains two large ribbon lakes; runoff affected by regulation for hydroelectric power	runoff affected by reservoirs and public water supply abstraction	runoff affected by reservoirs and regulation for hydroelectric power
Adjustment factor as a % (QMEDs,adj / QMEDcds)	-	110%	104%	90%	106%

Note: (1) Afon Cafnan data presented for hydrological assessment location 2 (at the downstream boundary location), however, the data is very similar for the other catchments.

For Cefn Coch, the Cefni at Bodffordd is significantly closer than the other sites and has similar catchment characteristics - it has therefore been used as a single donor to adjust the subject site median flood for all Cefn Coch hydrological assessment locations.

Adjusting the median annual flood – urbanisation.

The median flood values determined using catchment descriptors assume a rural catchment. The flow values were adjusted for urbanisation using the PRUAF method (Kjeldsen, 2010) in line with the EA Flood Estimation Guidelines (EA, 2015). This method is incorporated in WINFAP-FEH 3 (although referred to in WINFAP-FEH 3 as dating from 2009, the paper was issued in 2010), but for this work, it was calculated separately. The urban adjustment factor (UAF) is given by:

$$UAF = (1+URBEXT_{2000})^{0.37} \times PRUAF^{2.16}$$
$$PRUAF = 1+0.47URBEXT_{2000} \times (BFIHOST/ (1-BFIHOST))$$

where, PRUAF = percent runoff urban adjustment factor, and URBEXT and BFIHOST are standard FEH catchment descriptors (see Appendix B).

However, the urban fraction was very small in all three modelled catchments (with URBEXT2000 a maximum of 0.0056, for the upstream Afon Cafnan, hydrological assessment location 1) and the UAF was calculated to be very close to 1.00 in all cases (see also the footnote to Table 3.3).

3.3 Summary of median flood estimate and adjustment

The initial estimate of the median flood from catchment descriptors, adjustment factors from donor sites and for urbanisation, and the final adjusted median flood values are given in Table 3.3. The final adjusted median flood values are taken forward for developing the flood frequency values, in the next section.

Table 3.3 Derivation of median flood estimate

	Hydrological assessment location		
	1	**2**	**3**
Initial median flood Q_{MED} (m^3/s) using catchment descriptors	0.67	1.44	0.46
Adjustment factor from donor sites	1.10	1.10	1.10
Urban adjustment factor	1.00	1.00	1.00
Final adjusted median flood Q_{MED} (m^3/s)	0.74	1.60	0.51

Note: Adjusted median annual flood values have been calculated using urban adjustment factors with four decimal places and therefore the values reported for the adjusted median flood values may be slightly different than those calculated based on the reported values.

3.4 Peak flood flow estimates using FEH statistical method

Pooling groups were derived initially for each catchment using WINFAP-FEH 3.3.4. WINFAP-FEH 3.3.4, dating from August 2014, was the latest version of peak flow data (as at 02/02/2016)[5] available from CEH website (CEH, 2015). These peak flow data were used with the WINFAP-FEH 3 software for this analysis. When choosing hydrologically similar catchments for the pooling group, the filepath in the software was set to choose files from the subset identified as suitable for pooling.

[5] WINFAP-FEH gauge data version 4 and 4.1 were released in May 2016, but as the hydrological assessment had already been undertaken it was not re-calculated with the updated dataset. The calculations were reviewed and determined that peak flows derived using v3.3.4 and presented in this report were slightly higher compared to those derived using v4.1.

The WINFAP-FEH 3 software was used to derive a pooling group of hydrologically similar catchments for each subject site. This was then used to derive a growth curve for flood frequency estimation. A review of the initial pooling groups for each site identified that the pooling groups contained almost all of the same stations, with only two stations being replaced by two alternatives for hydrological assessment locations 1 and 3 compared to hydrological assessment location 2. As these minor differences are not likely to significantly influence the growth curve, growth curves were derived for hydrological assessment location 2 and applied to all three assessment locations. Hydrological assessment locations are shown on Figure 2.1. The pooling group for hydrological assessment location 2 was reviewed and amended where necessary as described below. The final pooling group data is provided in Appendix C. Flow results are given in Table 3.4.

3.5 Hydrological assessment location 2 – (applied to all hydrological assessment locations)

Seventeen gauged stations with records suitable for pooling group construction were selected by the software. These had a combined record length of 513 station-years, greater than the 500 station-years, a minimum recommended for estimating the 1% annual probability event flow. One short record site (49006 Camel at Camelford) was removed from the group as the record was shorter than eight years, leaving a record length of 507 years.

Catchment parameter SPRHOST was found to be less than 20%, indicating a permeable catchment, for two sites (26802 Gypsey Race at Kirby Grindalythe and 44008 South Winterbourne at Winterbourne Steepleton). The annual maxima were reviewed and one and six water year(s), respectively, were considered to be non-flood years (AMAX<QMED/2). Non-flood AMAX data were removed from these gauges, leaving a record length of 500 years. As 500 years is the minimum a further site was added (51002 Horner Water at West Luccombe).

A heterogeneity parameter H2 of 1.4614 indicated that the pooling group was possibly heterogeneous and a review of the pooling group was optional. Review of the sites showed that:

- The pooled sites had rainfall ranging from 757mm/year to 2,555mm/year compared to the subject site (987mm/year). These are between 38% and 259% of the subject site rainfall. Two stations are more than twice that of the subject site and these stations (91802 Allt Leachdach at Intake and 54022 Severn at Plynlimon Flume) could have been considered to have too high rainfall to be included. However, in this case, the similarity rankings of alternative sites needed to make up the required record length would be worse (the pooled sites had a similarity distance of 2.4 or lower and alternative sites would have higher values) and even less like the subject site in general. Therefore it was decided to make no changes to the pooling group based on rainfall.
- FARL is lower at the subject site (0.882) than all of the pooled sites (0.942 – 1.000), but there are limited alternative sites that could be used as very few sites with low FARL are included within the national distribution of available HiFlows-UK sites (as shown by the graphs in WINFAP-FEH). It was therefore not appropriate to remove stations on this basis since replacement sites would likely be less similar overall.
- BFIHOST varies considerably across the pooling group (0.196 – 0.959), with two sites having significantly higher BFIHOST than the subject site (0.466). It was not appropriate to remove all these sites, since replacement catchments would be less similar overall (BFIHOST is no longer used by WINFAP-FEH 3 to identify catchment similarity).
- The URBEXT2000 is low for the subject site (0.0029) and for all the pooled sites (0 - 0.014). Sites for the pooling group should all be rural, with urban adjustment applied separately if required. From EA guidelines, URBEXT2000 ≤0.125 indicates essentially rural; therefore, all pooled sites were rural and it was not necessary to remove sites on this basis.

- Sites 1 (45816 Haddeo at Upton) and 8 (25019 Leven at Easby) had a slightly higher growth curve than the other sites, but none of the catchment descriptors for these sites were significantly different to the subject site.
- None of the sites was identified as discordant (a measure identifying individual stations that are strongly different from the group-average).
- The Generalised Logistic (GL) distribution gave an acceptable fit to the data, with a Z value of -1.196 compared to the limit of (absolute value) 1.64 for acceptable fit.

As a result of the pooling group review, no stations were removed or added to the group. The GL distribution is recommended because it gives the best fit to the data.

3.6 Adjusting the growth curve for urbanisation

It is recommended that the growth curve (which represents a rural catchment) should be adjusted where URBEXT2000 is equal to, or exceeds 0.03 (EA, 2006). All of the Cefn Coch catchments associated with hydrological assessment locations are 'essentially rural' with URBEXT2000 less than 0.014 so no adjustment was necessary.

3.7 FEH statistical method peak flow derivation

The growth curve derived for hydrological assessment location 2 was applied to the median flood estimates for each hydrological assessment location to give peak flows, which are shown in Table 3.4. Results for the acceptable pooled growth curve distribution for hydrological assessment location 2 was reviewed, and the preferred distribution identified. The GL distribution was the only one to give an acceptable fit.

Table 3.4 FEH statistical method peak flows (m^3/s)

	Hydrological Assessment Location			
Annual Probability	**1**	**2**	**3**	**Growth Factor used (for entire catchment i.e. HAL2)**
50%	0.7	1.6	0.5	1
20%	1.0	2.2	0.7	1.4
10%	1.3	2.7	0.9	1.712
5%	1.5	3.3	1.1	2.065
2%	1.9	4.2	1.4	2.626
1%	2.3	5.0	1.6	3.145
0.1%	4.2	9.2	2.9	5.725
Adopted distribution	GL	GL	GL	

4. Derivation of peak flows using ReFH

ReFH 2.1 software[6] was implemented with FEH 2013 rainfall to derive flow hydrographs for the required events. As the catchment areas are relatively small, it is expected that the same event will occur across all the catchments simultaneously. Consequently, the critical storm duration was chosen for all hydrological assessment locations to be the same duration as the Afon Cafnan at the road downstream of the confluence (approximately 100m downstream of hydrological assessment points 1 and 3) (see Figure 2.1 for hydrological assessment locations). Using the storm duration recommended by ReFH2.1 for the proposed bypass location and associated drainage infrastructure ensures that an appropriate, but worst case scenario has been represented. Relevant parameters are shown in Table 4.1. Additional sensitivity tests results for a storm durations can be found in Section 7 of main text.

Table 4.1 Storm duration and timestep parameters for all assessment locations

Parameter	Upstream hydrological assessment locations (1 and 3)	Downstream hydrological assessment location (2)	Final value
Critical storm duration (hr)	2.8	4.1	2.95
Storm duration used (hr)	-	-	3.00
Timestep (hr)	0.15-0.30	0.20-0.40	0.2

Note: there must be an odd integer number of timesteps in the storm duration to derive the design storm profile

ReFH2.1 generated peak flows for all hydrological assessment locations are shown in Table 4.2. Summary ReFH2.1 reports are included as Appendix D.

Table 4.2 ReFH2.1 peak flows (m^3/s)

Annual probability	Hydrological assessment location		
	1	**2**	**3**
50%	0.7	1.6	0.5
20%	0.7	2.0	1.1
5%	1.1	3.0	1.7
1%	1.8	5.1	3.0
0.1%	3.2	9.0	5.3

[6] ReFH 2.1 was the current software at the start of the project, subsequently updated to ReFH 2.2. However, the changes associated with this most recent software update are not expected to change the results significantly.

5. Final FEH statistical peak flows

The FEH statistical and ReFH2.1 results for 5 year, 20 year, 100 year and 1000 year events are repeated, for ease of comparison, in Table 5.1.

Table 5.1 Peak flows (m^3/s)

Annual probability	Method	Hydrological assessment location		
		1	2	3
20%	FEH statistical	1.0	2.2	0.7
	ReFH2.1	0.7	2.0	1.1
5%	FEH statistical	1.5	3.3	1.1
	ReFH2.1	1.1	3.0	1.7
1%	FEH statistical	2.3	5.0	1.6
	ReFH2.1	1.8	5.1	3.0
0.1%	FEH statistical	4.2	9.2	2.9
	ReFH2.1	3.2	9.0	5.3

It is noted from results presented in Table 5.1 that the FEH statistical method flows are higher than the ReFH2.1 values for hydrological assessment location 1 for all events assessed. The results for both methods are similar for hydrological assessment location 2. Although flows for hydrological assessment location 2 are broadly similar it is worth noting that the ReFH2.1 method uses a storm duration that is slightly shorter than the critical storm duration for that catchment. The FEH statistical method flows are significantly lower than the ReFH2.1 flows for hydrological assessment location 3. The attenuation provided by Llyn Llygeirian is a significant influence on the flows derived for hydrological assessment location 3, which is better represented by the FEH statistical method as the FARL value is not used in the ReFH2.1 method.

Following advice on page 100 and 101 of the EA Flood Estimation Guidelines (EA, 2015) the following approach was adopted here:

- Peak flow results from the FEH statistical method have been used for more frequent events – up to and including the 1% annual probability event;
- The ratio of the 0.1% to 1% annual probability flows are determined from the ReFH2.1 results. The ratio was then applied to the 1% annual probability event FEH statistical method peak flow value to determine an equivalent 0.1% annual probability flow; and
- The hydrographs from the ReFH2.1 method have been factored to the identified peak flows.

The 0.1%/1% annual probability ReFH2.1 ratio and resulting 0.1% annual probability peak flows were determined and are provided in Table 5.2.

Table 5.2 Revised 1000 year flow estimates using ratio method

Annual probability	Hydrological assessment location		
	1	2	3
ReFH2.1 0.1%/1% annual probability flow ratio [1]	1.77	1.76	1.77
Revised 0.1% annual probability event	4.1m^3/s	8.8m^3/s	2.9m^3/s

[1] Ratio method flow values have been calculated using peak flows and ratios with four decimal places and therefore the values reported for both the ratio and the ratio method 0.1% annual probability event may be slightly different than those calculated based on the reported values.

Final peak flows using the FEH statistical and ratio methods are given in Table 5.3 and the hydrographs with peak flow are shown on Figure 5.1. Climate change allowance is applied by using a 30% uplift on the 100 year events as per current guidance (Welsh Government, 2011). Although this has been applied to the peak flow for this report, when representing in the model the entire hydrograph will be scaled to this adjusted peak.

Table 5.3 Final peak flows to be modelled (m^3/s)

Annual Probability	Method	Hydrological assessment location		
		1	2	3
50%	Adjusted catchment descriptors	0.7	1.6	0.5
20%	FEH statistical	1.0	2.2	0.7
5%	FEH statistical	1.5	3.3	1.1
1%	FEH statistical	2.3	5.0	1.6
1% + climate change	FEH statistical + 30%	3.0	6.5	2.1
0.1%	Ratio	4.1	8.8	2.9

5.1 Uncertainty

This hydrological assessment has presented an appropriate consideration of hydrology for the catchments influencing the study area. However, it is recognised that there are still limitations in the methods applied. Assumptions made include the following:

- The 0.1% annual probability growth factors are best estimated from rainfall-runoff methods and a ratio applied to statistical method estimates from the 1% annual probability event.

Limitations:

- Historic flood events were not identified, as data were not available.

The assessment of QMED from catchment descriptors is one of the more uncertain aspects of the assessment. Confidence limits have been calculated based on EA Flood Estimation Guidelines (EA, 2015) and presented in Table 5.4. The 95% confidence limit is between half and twice the central estimate.

Derivation of growth factors is also uncertain, being based on a diverse set of catchment descriptors. There is no simple method to derive confidence intervals for pooled growth curves.

Table 5.4 Confidence limits in QMED (m^3/s)

	Hydrological assessment location		
	1	**2**	**3**
QMED	0.7	1.6	0.5
68% confidence limit (lower)	0.5	1.1	0.4
68% confidence limit (upper)	1.1	2.3	0.7
95% confidence limit (lower)	0.4	0.8	0.3
95% confidence limit (upper)	1.5	3.3	1.1

Confidence intervals for the pooled growth curves is not currently available for the statistical method, however, a qualitative assessment has been undertaken and is presented in Table 5.5.

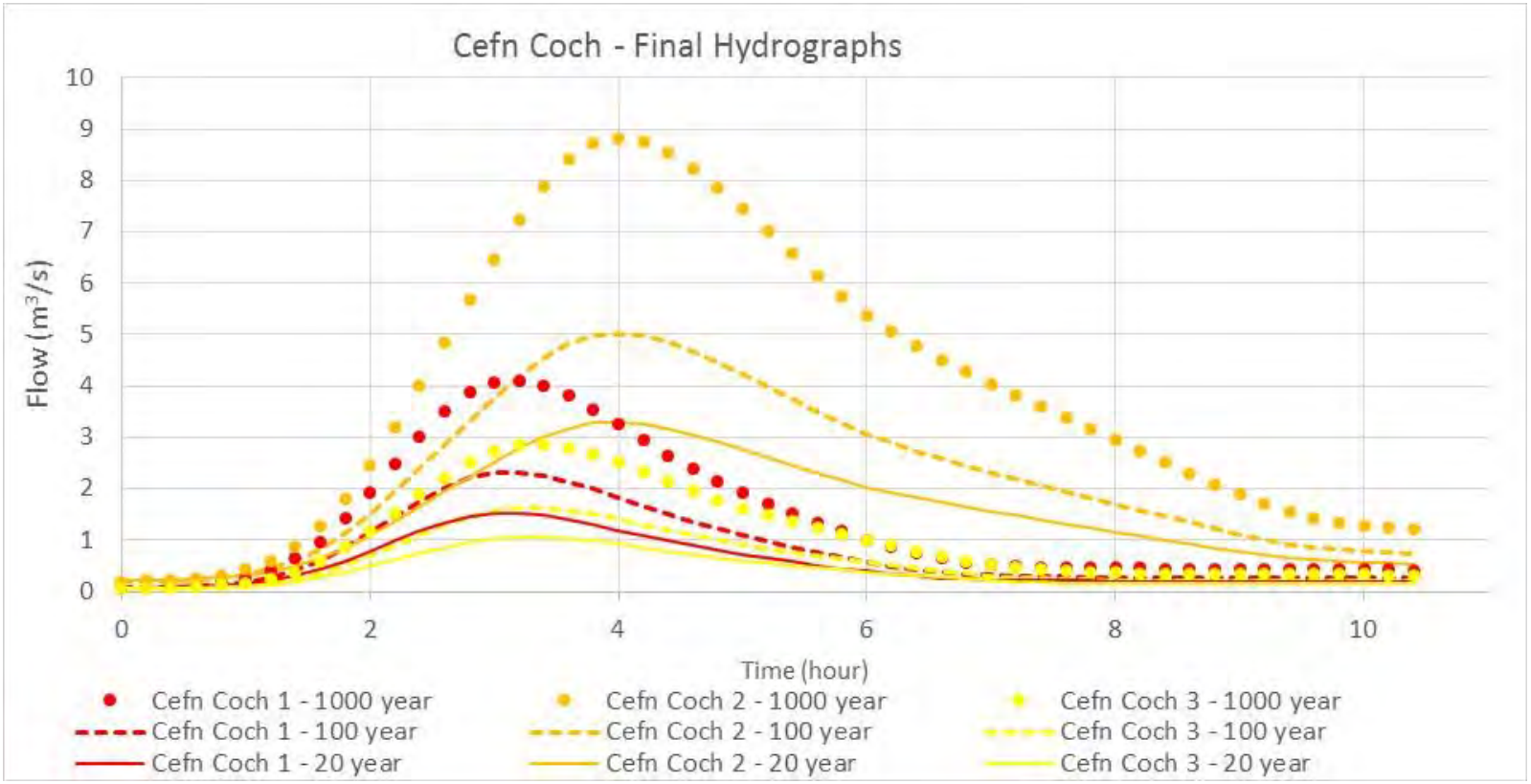
Table 5.5 Uncertainty in the pooling group

Parameter	Comments	Certainty
Length of flood peak record	531 years of pooled record to determine 100 year event maximum.	High
Choice of pooling group	Similarity of all gauges (similarity distance) was less than 2.5 for all sites in the pooling group.	High
Choice of distribution	Goodness-of-fit test was approximately -1.2 which indicates an acceptable fit.	Medium

The uncertainty in both QMED and the growth curve will combine to produce a combined uncertainty.

Again, it is considered that the hydrological assessment has produced the best estimate (central estimate), however, it is acknowledged that there is an uncertainty in many of the components that were used to determine this estimate. It is recommended that the modelling undertake sensitivity runs based on the above confidence limits, however, the specific limits will be separately described as part of the hydraulic modelling study.

Figure 5.1 Final peak flow hydrographs



6. Representation of flows in the hydraulic model

The final peak flow hydrographs represent the total flow at each hydrological assessment location and, so they need to be distributed as the sub-catchments are nested for these hydrological assessment locations. Hydrographs and associated peak flows for hydrological assessment locations 1 and 3 can be applied as derived since they represent the headwater catchment of Afon Cafnan and the Llygeirian tributary.

Lateral inflow hydrographs for the Afon Cafnan to be applied within the model were determined through the consideration of all hydrographs. Flows at hydrological assessment location 2 include the headwater inflows and hydrographs were adjusted to 'remove' the upstream inflow already represented in point inflows at hydrological assessment locations 1 and 3.

- **Afon Cafnan (lateral inflow between the confluence and hydrological assessment location 2)** - The inflow hydrograph was derived by subtracting the hydrographs for hydrological assessment locations 1 and 3 from the hydrographs for hydrological assessment location 2. An alternative disaggregation approach for inflows from catchment areas lying in between hydrological assessment points can be applied and its sensitivity on the results can be explored in hydraulic modelling study.

Hydrographs should be applied as point inflows at the upstream model extents for hydrological assessment locations 1 and 3. The derived lateral inflow hydrographs between the confluence and hydrological assessment location 2, should be applied laterally along the appropriate reach.

7. References

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Author	Reviewer
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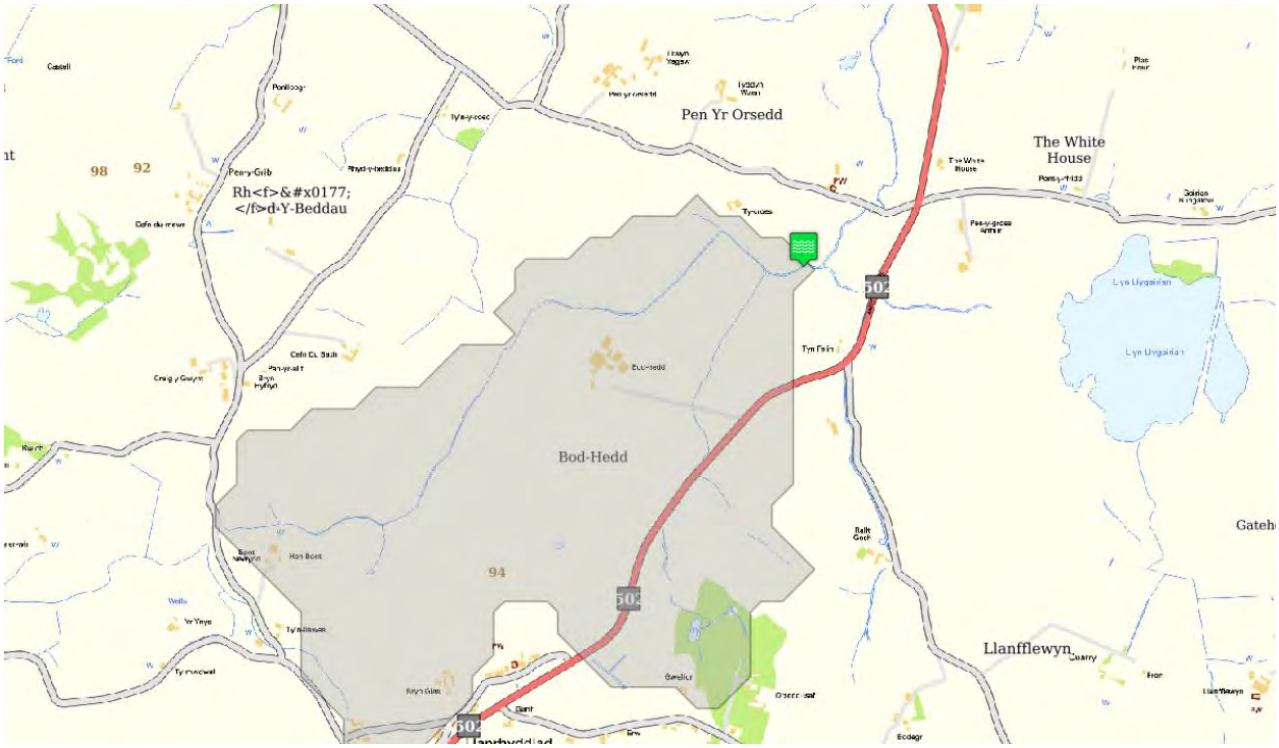
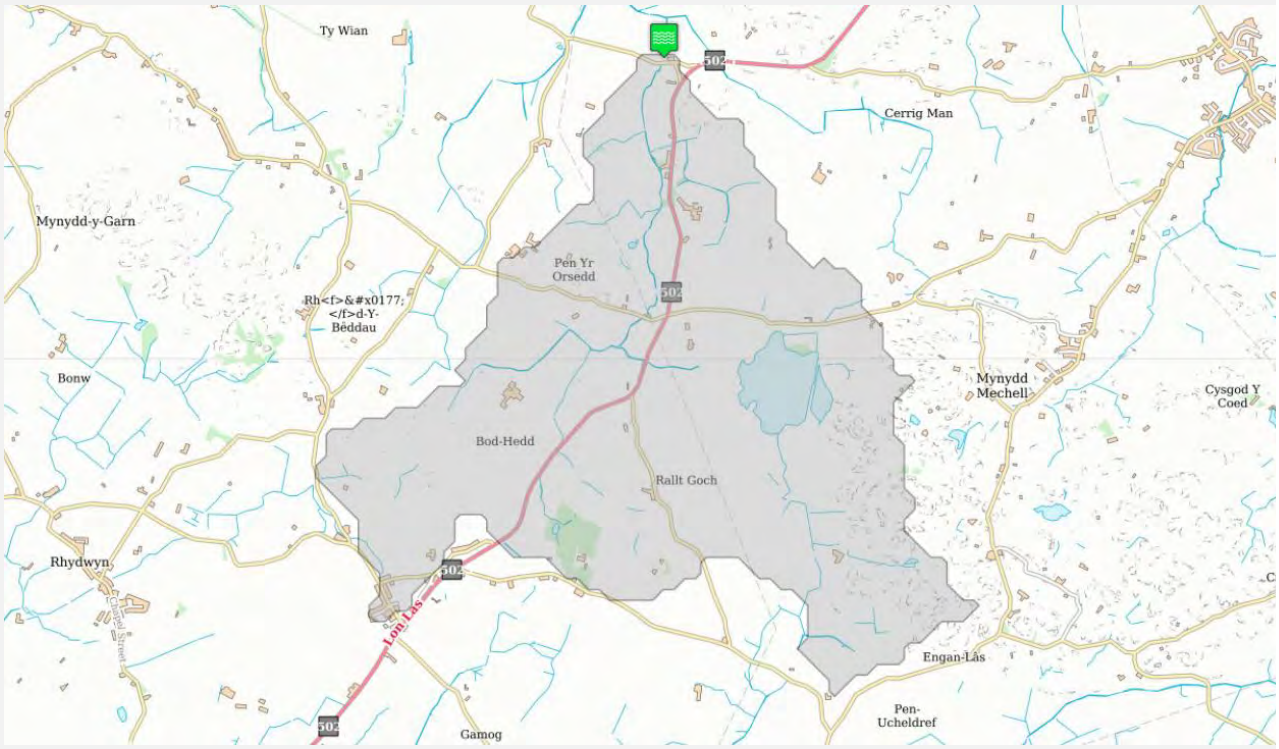
Appendix A
FEH Catchments

Hydrological assessment location 1



Hydrological assessment location 2



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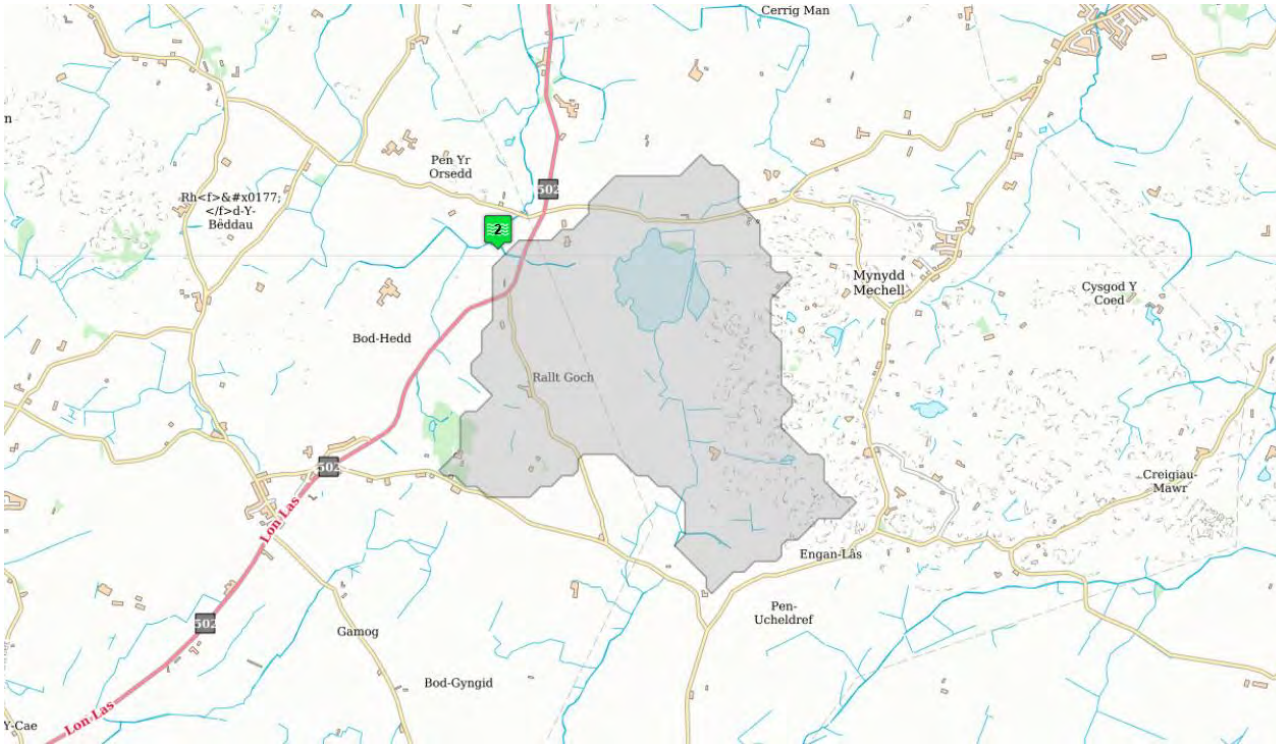
Hydrological assessment location 3



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Appendix B
FEH Catchment Descriptors

NOT PROTECTIVELY MARKED

232000
233000
234000
235000
236000
391000
390000
389000
388000
N
Ty Wian
Pen Yr Orsedd
Afon Llanddygfael
Cerrig Man
Afon Cafnan
Llanddygfael-Groes
A5025
Plas-Y-Nant
Rhŷd-Y-Beddau
Pen-Y-Groes Arthur
Afon Cafnan
Llygeirian Tributary
Llan Llygeirian
Bod-Hedd
Mynydd Mechell
A5025
Rallt Goch
Llanfflewyn
ydwyn
Llanrhyddlad
Gamog
Lon Las
Aber Pwll Fferm
Pen-Ucheldref
Bod-Gyngid
Ucheldref Goed
Ty-Newydd
Pen-Y-Cae

Key

- FEH Catchment: Afon Cafnan (1)
- FEH Catchment: Afon Cafnan (2)
- FEH Catchment: Llygeirian Tributary (3)
- Lakes
- Watercourse (1:50k river)
- A5025 Cefn Coch Proposed Bypass
- Watercourse flow direction

Meters
0 200 400 600 800
Scale at A3

Wylfa Newydd
A5025 - Cefn Coch
Hydrology

amec foster wheeler

Figure 1.1
Cefn Coch Site Location

NOT PROTECTIVELY MARKED

file: H:\Projects\35989 Wylfa NNB Modelling\Design\Drawings (E&I created)\Task 05 A5025\Hydrology

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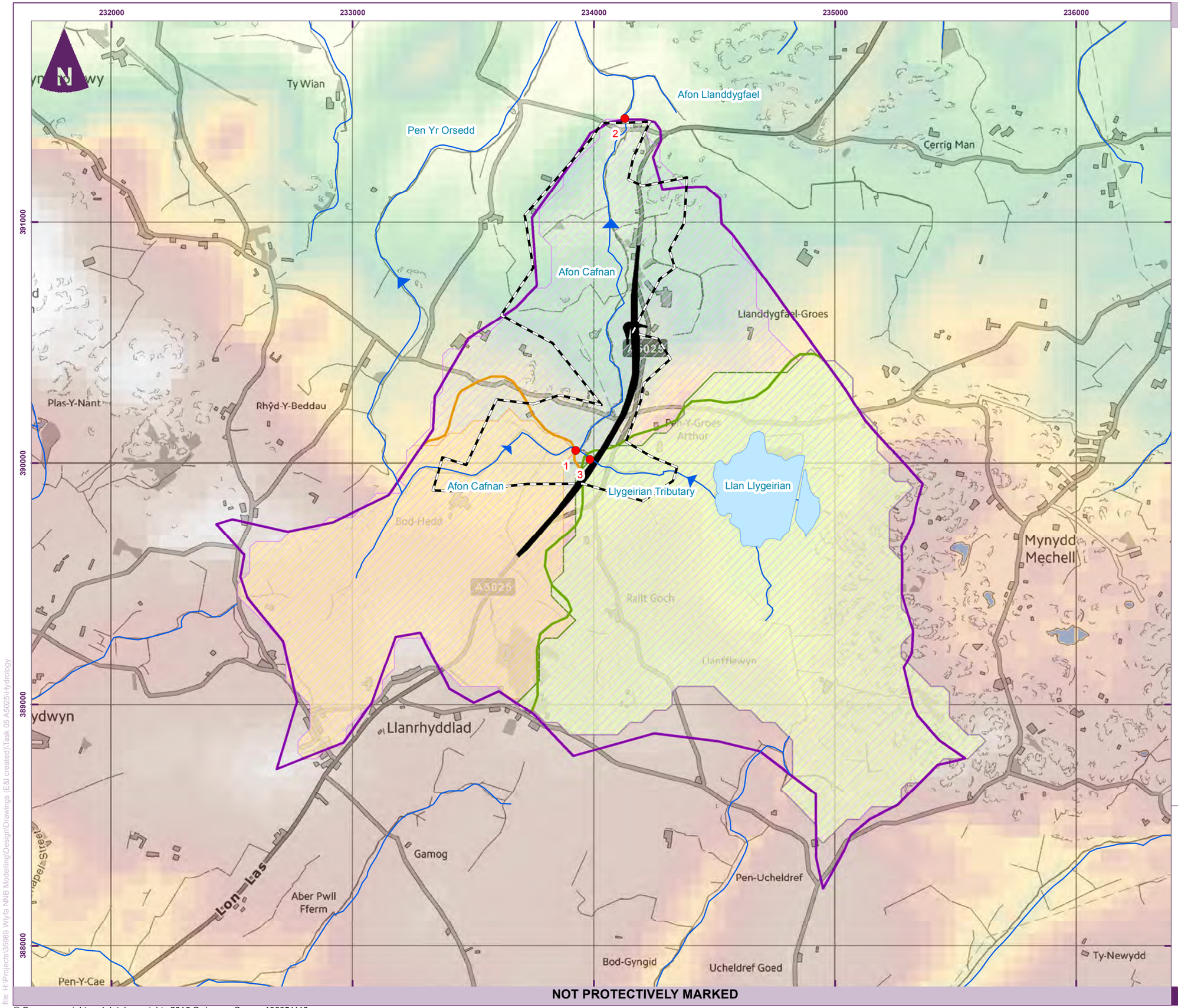

Key

- FEH Catchment: Afon Cafnan (1)
- FEH Catchment: Afon Cafnan (2)
- FEH Catchment: Llygeirian Tributary (3)
- Topographic Catchment: Afon Cafnan (1)
- Topographic Catchment: Afon Cafnan (2)
- Topographic Catchment: Llygeirian Tributary (3)
- Lakes
- Cefn Coch Hydraulic Model Extent
- Watercourse (1:50k river)
- A5025 Cefn Coch Proposed Bypass
- Hydrological Assessment Location
- Watercourse flow direction

OS Terrain 50 (mAOD)

High : 138.0

Low : 14.0

Meters
0 200 400 600 800
Scale at A3

Wylfa Newydd
A5025 - Cefn Coch
Hydrology

amec foster wheeler

Figure 2.1
Cefn Coch Catchment Review

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file: H:\Projects\35989 Wylfa NNB Modelling\Design\Drawings (E&I created)\Task 05 A5025\Hydrology

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Appendix C
Final Pooling Groups

Table C.1 Final Pooling Group – Hydrological Assessment Location 2

Station	Years	Discord	AREA	SAAR	FARL	URBEXT	BFIHOST	SPRHOST
45816 (Haddeo @ Upton)	19	0.942	6.81	1210	0.011	1	0.005	0.59
27051 (Crimple @ Burn Bridge)	40	0.89	8.15	855	0.013	1	0.006	0.309
28033 (Dove @ Hollinsclough)	33	0.654	7.93	1346	0.007	1	0	0.403
76011 (Coal Burn @ Coalburn)	35	1.173	1.63	1096	0.074	1	0	0.196
47022 (Tory Brook @ Newnham Park)	19	1.738	13.45	1403	0.023	0.942	0.014	0.431
25011 (Langdon Beck @ Langdon)	26	1.33	12.79	1463	0.013	1	0.001	0.237
25019 (Leven @ Easby)	34	1.368	15.07	830	0.019	1	0.004	0.525
25003 (Trout Beck @ Moor House)	39	0.614	11.46	1904	0.041	1	0	0.227
26802 (Gypsey Race @ Kirby Grindalythe)	12	0.037	15.85	757	0.03	1	0	0.959
206006 (Annalong @ Recorder)	48	2.134	13.66	1720	0.024	0.98	0	0.336
91802 (Allt Leachdach @ Intake)	34	1.358	6.52	2555	0.003	0.992	0	0.397
54022 (Severn @ Plynlimon Flume)	37	1.219	8.69	2483	0.01	1	0	0.323
27010 (Hodge Beck @ Bransdale Weir)	41	0.086	18.84	987	0.009	1	0.001	0.341
44008 (South Winterbourne @ Winterbourne Steepleton)	27	0.548	20.17	1012	0.015	1	0.004	0.811
203046 (Rathmore Burn @ Rathmore Bridge)	30	0.929	22.51	1043	0.073	1	0	0.43
22003 (Usway Burn @ Shillmoor)	26	0.461	21.87	1056	0.006	1	0	0.302
51002 (Horner Water @ West Luccombe)	31	1.518	20.38	1485	0.003	0.978	0	0.539

Discord=Discordancy

Two gauges were identified as being permeable (SPRHOST<20%). These were investigated to identify influence of non-flood AMAX years in the dataset, i.e. annual maximums less than QMED/2, which were then removed from the dataset:

26802 (Gypsey Race @ Kirby Grindalythe) one non-flood year (chance of flood year 0.92)

44008 (South Winterbourne @ Winterbourne Steepleton)

six non-flood years (chance of flood year 0.82)

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Appendix D
Summary Reports of ReFH2.1 Hydrograph Generation

UK Design Flood Estimation

Generated on Wednesday, May 25, 2016 9:41:32 AM by matthew.ross
Printed from the ReFH Flood Modelling software package, version 2.1.5798.30211

Summary of estimate using the Flood Estimation Handbook revitalised flood hydrograph method (ReFH)

Site details Checksum: BF18-270A

Site name: FEH_Catchment_Descriptors_233900_390050
Easting: 233900
Northing: 390050
Country: England, Wales or Northern Ireland
Catchment Area (km²): 1.12
Using plotscale calculations: No
Site description: None

Model run: 5 year

Summary of results

Rainfall - FEH 2013 (mm):	24.34	Total runoff (ML):	6.18
Total Rainfall (mm):	17.06	Total flow (ML):	14.13
		Peak flow (m³/s):	0.69
Peak Rainfall (mm):	2.91		

Parameters

** Where the user has overriden a system-generated value, this original value is shown in square brackets after the value used.*

Rainfall parameters (Rainfall - FEH 2013 model)

Name	Value	User-defined?
Duration (hr)	3 [2.75]	Yes
Timestep (hr)	0.2 [0.25]	Yes
SCF(Seasonal correction factor)	0.72	No
ARF(Areal reduction factor)	0.97	No
Seasonality	Winter	n/a

Loss model parameters

Name	Value	User-defined?
Cini (mm)	108.42	No
Cmax (mm)	362.7	No
Use alpha correction factor	No	No
Alpha correction factor	n/a	No

Routing model parameters

Name	Value	User-defined?
Tp (hr)	1.36	No
Up	0.65	No
Uk	0.8	No

Baseflow model parameters

Name	Value	User-defined?
BF0 (m³/s)	0.05	No
BL (hr)	29.25	No
BR	1.3	No

Urbanisation parameters

Name	Value	User-defined?
Urban area (km²)	0.01	No
Urbext 2000	0.01	No
Urban runoff factor	0.7	No
Imperviousness factor	0.3	No
Tp scaling factor	0.5	No
Sewered area (km²)	0.00	Yes
Sewer capacity (m³/s)	0.00	Yes

UK Design Flood Estimation

Generated on Tuesday, May 17, 2016 8:43:31 AM by matthew.ross
Printed from the ReFH Flood Modelling software package, version 2.1.5798.30211

Summary of estimate using the Flood Estimation Handbook revitalised flood hydrograph method (ReFH)

Site details Checksum: AAF4-6395

Site name: FEH_Catchment_Descriptors_233900_390050
Easting: 233900
Northing: 390050
Country: England, Wales or Northern Ireland
Catchment Area (km²): 1.12
Using plotscale calculations: No
Site description: None

Model run: 20 year

Summary of results

Rainfall - FEH 2013 (mm):	37.17	Total runoff (ML):	9.80
Total Rainfall (mm):	26.05	Total flow (ML):	22.38
		Peak flow (m³/s):	1.06
Peak Rainfall (mm):	4.44		

Parameters

** Where the user has overriden a system-generated value, this original value is shown in square brackets after the value used.*

Rainfall parameters (Rainfall - FEH 2013 model)

Name	Value	User-defined?
Duration (hr)	3 [2.75]	Yes
Timestep (hr)	0.2 [0.25]	Yes
SCF(Seasonal correction factor)	0.72	No
ARF(Areal reduction factor)	0.97	No
Seasonality	Winter	n/a

Loss model parameters

Name	Value	User-defined?
Cini (mm)	108.42	No
Cmax (mm)	362.7	No
Use alpha correction factor	No	No
Alpha correction factor	n/a	No

Routing model parameters

Name	Value	User-defined?
Tp (hr)	1.36	No
Up	0.65	No
Uk	0.8	No

Baseflow model parameters

Name	Value	User-defined?
BF0 (m³/s)	0.05	No
BL (hr)	29.25	No
BR	1.3	No

Urbanisation parameters

Name	Value	User-defined?
Urban area (km²)	0.01	No
Urbext 2000	0.01	No
Urban runoff factor	0.7	No
Imperviousness factor	0.3	No
Tp scaling factor	0.5	No
Sewered area (km²)	0.00	Yes
Sewer capacity (m³/s)	0.00	Yes

UK Design Flood Estimation

Generated on Tuesday, May 17, 2016 8:44:48 AM by matthew.ross
Printed from the ReFH Flood Modelling software package, version 2.1.5798.30211

Summary of estimate using the Flood Estimation Handbook revitalised flood hydrograph method (ReFH)

Site details Checksum: AAF4-6395

Site name: FEH_Catchment_Descriptors_233900_390050
Easting: 233900
Northing: 390050
Country: England, Wales or Northern Ireland
Catchment Area (km²): 1.12
Using plotscale calculations: No
Site description: None

Model run: 100 year

Summary of results

Rainfall - FEH 2013 (mm):	60.52	Total runoff (ML):	17.02
Total Rainfall (mm):	42.41	Total flow (ML):	38.91
		Peak flow (m³/s):	1.82
Peak Rainfall (mm):	7.24		

Parameters

** Where the user has overriden a system-generated value, this original value is shown in square brackets after the value used.*

Rainfall parameters (Rainfall - FEH 2013 model)

Name	Value	User-defined?
Duration (hr)	3 [2.75]	Yes
Timestep (hr)	0.2 [0.25]	Yes
SCF(Seasonal correction factor)	0.72	No
ARF(Areal reduction factor)	0.97	No
Seasonality	Winter	n/a

Loss model parameters

Name	Value	User-defined?
Cini (mm)	108.42	No
Cmax (mm)	362.7	No
Use alpha correction factor	No	No
Alpha correction factor	n/a	No

Routing model parameters

Name	Value	User-defined?
Tp (hr)	1.36	No
Up	0.65	No
Uk	0.8	No

Baseflow model parameters

Name	Value	User-defined?
BF0 (m³/s)	0.05	No
BL (hr)	29.25	No
BR	1.3	No

Urbanisation parameters

Name	Value	User-defined?
Urban area (km²)	0.01	No
Urbext 2000	0.01	No
Urban runoff factor	0.7	No
Imperviousness factor	0.3	No
Tp scaling factor	0.5	No
Sewered area (km²)	0.00	Yes
Sewer capacity (m³/s)	0.00	Yes

UK Design Flood Estimation

Generated on Tuesday, May 17, 2016 8:45:02 AM by matthew.ross
Printed from the ReFH Flood Modelling software package, version 2.1.5798.30211

Summary of estimate using the Flood Estimation Handbook revitalised flood hydrograph method (ReFH)

Site details Checksum: AAF4-6395

Site name: FEH_Catchment_Descriptors_233900_390050
Easting: 233900
Northing: 390050
Country: England, Wales or Northern Ireland
Catchment Area (km²): 1.12
Using plotscale calculations: No
Site description: None

Model run: 1000 year

Summary of results

Rainfall - FEH 2013 (mm):	98.07	Total runoff (ML):	30.36
Total Rainfall (mm):	68.72	Total flow (ML):	69.42
		Peak flow (m³/s):	3.21
Peak Rainfall (mm):	11.73		

Parameters

** Where the user has overriden a system-generated value, this original value is shown in square brackets after the value used.*

Rainfall parameters (Rainfall - FEH 2013 model)

Name	Value	User-defined?
Duration (hr)	3 [2.75]	Yes
Timestep (hr)	0.2 [0.25]	Yes
SCF(Seasonal correction factor)	0.72	No
ARF(Areal reduction factor)	0.97	No
Seasonality	Winter	n/a

Loss model parameters

Name	Value	User-defined?
Cini (mm)	108.42	No
Cmax (mm)	362.7	No
Use alpha correction factor	No	No
Alpha correction factor	n/a	No

Routing model parameters

Name	Value	User-defined?
Tp (hr)	1.36	No
Up	0.65	No
Uk	0.8	No

Baseflow model parameters

Name	Value	User-defined?
BF0 (m³/s)	0.05	No
BL (hr)	29.25	No
BR	1.3	No

Urbanisation parameters

Name	Value	User-defined?
Urban area (km²)	0.01	No
Urbext 2000	0.01	No
Urban runoff factor	0.7	No
Imperviousness factor	0.3	No
Tp scaling factor	0.5	No
Sewered area (km²)	0.00	Yes
Sewer capacity (m³/s)	0.00	Yes

UK Design Flood Estimation

Generated on Wednesday, May 25, 2016 9:31:35 AM by matthew.ross
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Summary of estimate using the Flood Estimation Handbook revitalised flood hydrograph method (ReFH)

Site details Checksum: 6BC3-8F22

Site name: FEH_Catchment_Descriptors_234150_391400
Easting: 234150
Northing: 391400
Country: England, Wales or Northern Ireland
Catchment Area (km²): 4.34
Using plotscale calculations: No
Site description: None

Model run: 5 year

Summary of results

Rainfall - FEH 2013 (mm):	24.41	Total runoff (ML):	24.73
Total Rainfall (mm):	16.86	Total flow (ML):	55.79
		Peak flow (m³/s):	1.99
Peak Rainfall (mm):	2.88		

Parameters

** Where the user has overriden a system-generated value, this original value is shown in square brackets after the value used.*

Rainfall parameters (Rainfall - FEH 2013 model)

Name	Value	User-defined?
Duration (hr)	3 [4.5]	Yes
Timestep (hr)	0.2 [0.5]	Yes
SCF(Seasonal correction factor)	0.72	No
ARF(Areal reduction factor)	0.96	No
Seasonality	Winter	n/a

Loss model parameters

Name	Value	User-defined?
Cini (mm)	110.46	No
Cmax (mm)	352.48	No
Use alpha correction factor	No	No
Alpha correction factor	n/a	No

Routing model parameters

Name	Value	User-defined?
Tp (hr)	2.21	No
Up	0.65	No
Uk	0.8	No

Baseflow model parameters

Name	Value	User-defined?
BF0 (m³/s)	0.21	No
BL (hr)	33.81	No
BR	1.27	No

Urbanisation parameters

Name	Value	User-defined?
Urban area (km²)	0.02	No
Urbext 2000	0	No
Urban runoff factor	0.7	No
Imperviousness factor	0.3	No
Tp scaling factor	0.5	No
Sewered area (km²)	0.00	Yes
Sewer capacity (m³/s)	0.00	Yes

UK Design Flood Estimation

Generated on Wednesday, May 25, 2016 9:31:59 AM by matthew.ross
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Summary of estimate using the Flood Estimation Handbook revitalised flood hydrograph method (ReFH)

Site details Checksum: 6BC3-8F22

Site name: FEH_Catchment_Descriptors_234150_391400
Easting: 234150
Northing: 391400
Country: England, Wales or Northern Ireland
Catchment Area (km²): 4.34
Using plotscale calculations: No
Site description: None

Model run: 20 year

Summary of results

Rainfall - FEH 2013 (mm):	37.11	Total runoff (ML):	38.99
Total Rainfall (mm):	25.64	Total flow (ML):	87.98
		Peak flow (m³/s):	3.02
Peak Rainfall (mm):	4.37		

Parameters

** Where the user has overriden a system-generated value, this original value is shown in square brackets after the value used.*

Rainfall parameters (Rainfall - FEH 2013 model)

Name	Value	User-defined?
Duration (hr)	3 [4.5]	Yes
Timestep (hr)	0.2 [0.5]	Yes
SCF(Seasonal correction factor)	0.72	No
ARF(Areal reduction factor)	0.96	No
Seasonality	Winter	n/a

Loss model parameters

Name	Value	User-defined?
Cini (mm)	110.46	No
Cmax (mm)	352.48	No
Use alpha correction factor	No	No
Alpha correction factor	n/a	No

Routing model parameters

Name	Value	User-defined?
Tp (hr)	2.21	No
Up	0.65	No
Uk	0.8	No

Baseflow model parameters

Name	Value	User-defined?
BF0 (m³/s)	0.21	No
BL (hr)	33.81	No
BR	1.27	No

Urbanisation parameters

Name	Value	User-defined?
Urban area (km²)	0.02	No
Urbext 2000	0	No
Urban runoff factor	0.7	No
Imperviousness factor	0.3	No
Tp scaling factor	0.5	No
Sewered area (km²)	0.00	Yes
Sewer capacity (m³/s)	0.00	Yes

UK Design Flood Estimation

Generated on Wednesday, May 25, 2016 9:32:21 AM by matthew.ross
Printed from the ReFH Flood Modelling software package, version 2.1.5798.30211

Summary of estimate using the Flood Estimation Handbook revitalised flood hydrograph method (ReFH)

Site details Checksum: 6BC3-8F22

Site name: FEH_Catchment_Descriptors_234150_391400
Easting: 234150
Northing: 391400
Country: England, Wales or Northern Ireland
Catchment Area (km²): 4.34
Using plotscale calculations: No
Site description: None

Model run: 100 year

Summary of results

Rainfall - FEH 2013 (mm):	60.51	Total runoff (ML):	67.73
Total Rainfall (mm):	41.80	Total flow (ML):	152.99
		Peak flow (m³/s):	5.12
Peak Rainfall (mm):	7.13		

Parameters

** Where the user has overriden a system-generated value, this original value is shown in square brackets after the value used.*

Rainfall parameters (Rainfall - FEH 2013 model)

Name	Value	User-defined?
Duration (hr)	3 [4.5]	Yes
Timestep (hr)	0.2 [0.5]	Yes
SCF(Seasonal correction factor)	0.72	No
ARF(Areal reduction factor)	0.96	No
Seasonality	Winter	n/a

Loss model parameters

Name	Value	User-defined?
Cini (mm)	110.46	No
Cmax (mm)	352.48	No
Use alpha correction factor	No	No
Alpha correction factor	n/a	No

Routing model parameters

Name	Value	User-defined?
Tp (hr)	2.21	No
Up	0.65	No
Uk	0.8	No

Baseflow model parameters

Name	Value	User-defined?
BF0 (m³/s)	0.21	No
BL (hr)	33.81	No
BR	1.27	No

Urbanisation parameters

Name	Value	User-defined?
Urban area (km²)	0.02	No
Urbext 2000	0	No
Urban runoff factor	0.7	No
Imperviousness factor	0.3	No
Tp scaling factor	0.5	No
Sewered area (km²)	0.00	Yes
Sewer capacity (m³/s)	0.00	Yes

UK Design Flood Estimation

Generated on Wednesday, May 25, 2016 9:32:39 AM by matthew.ross
Printed from the ReFH Flood Modelling software package, version 2.1.5798.30211

Summary of estimate using the Flood Estimation Handbook revitalised flood hydrograph method (ReFH)

Site details Checksum: 6BC3-8F22

Site name: FEH_Catchment_Descriptors_234150_391400
Easting: 234150
Northing: 391400
Country: England, Wales or Northern Ireland
Catchment Area (km²): 4.34
Using plotscale calculations: No
Site description: None

Model run: 1000 year

Summary of results

Rainfall - FEH 2013 (mm):	98.21	Total runoff (ML):	120.80
Total Rainfall (mm):	67.85	Total flow (ML):	272.93
		Peak flow (m³/s):	8.99
Peak Rainfall (mm):	11.58		

Parameters

** Where the user has overriden a system-generated value, this original value is shown in square brackets after the value used.*

Rainfall parameters (Rainfall - FEH 2013 model)

Name	Value	User-defined?
Duration (hr)	3 [4.5]	Yes
Timestep (hr)	0.2 [0.5]	Yes
SCF(Seasonal correction factor)	0.72	No
ARF(Areal reduction factor)	0.96	No
Seasonality	Winter	n/a

Loss model parameters

Name	Value	User-defined?
Cini (mm)	110.46	No
Cmax (mm)	352.48	No
Use alpha correction factor	No	No
Alpha correction factor	n/a	No

Routing model parameters

Name	Value	User-defined?
Tp (hr)	2.21	No
Up	0.65	No
Uk	0.8	No

Baseflow model parameters

Name	Value	User-defined?
BF0 (m³/s)	0.21	No
BL (hr)	33.81	No
BR	1.27	No

Urbanisation parameters

Name	Value	User-defined?
Urban area (km²)	0.02	No
Urbext 2000	0	No
Urban runoff factor	0.7	No
Imperviousness factor	0.3	No
Tp scaling factor	0.5	No
Sewered area (km²)	0.00	Yes
Sewer capacity (m³/s)	0.00	Yes

UK Design Flood Estimation

Generated on Wednesday, May 25, 2016 9:34:51 AM by matthew.ross
Printed from the ReFH Flood Modelling software package, version 2.1.5798.30211

Summary of estimate using the Flood Estimation Handbook revitalised flood hydrograph method (ReFH)

Site details Checksum: CC0B-47F2

Site name: FEH_Catchment_Descriptors_234000_390000
Easting: 234000
Northing: 390000
Country: England, Wales or Northern Ireland
Catchment Area (km²): 2.1
Using plotscale calculations: No
Site description: None

Model run: 5 year

Summary of results

Rainfall - FEH 2013 (mm):	24.49	Total runoff (ML):	10.96
Total Rainfall (mm):	17.14	Total flow (ML):	25.61
		Peak flow (m³/s):	1.14
Peak Rainfall (mm):	2.92		

Parameters

** Where the user has overriden a system-generated value, this original value is shown in square brackets after the value used.*

Rainfall parameters (Rainfall - FEH 2013 model)

Name	Value	User-defined?
Duration (hr)	3 [3.25]	Yes
Timestep (hr)	0.2 [0.25]	Yes
SCF(Seasonal correction factor)	0.72	No
ARF(Areal reduction factor)	0.97	No
Seasonality	Winter	n/a

Loss model parameters

Name	Value	User-defined?
Cini (mm)	105.88	No
Cmax (mm)	376.13	No
Use alpha correction factor	No	No
Alpha correction factor	n/a	No

Routing model parameters

Name	Value	User-defined?
Tp (hr)	1.54	No
Up	0.65	No
Uk	0.8	No

Baseflow model parameters

Name	Value	User-defined?
BF0 (m³/s)	0.1	No
BL (hr)	30.33	No
BR	1.35	No

Urbanisation parameters

Name	Value	User-defined?
Urban area (km²)	0.01	No
Urbext 2000	0	No
Urban runoff factor	0.7	No
Imperviousness factor	0.3	No
Tp scaling factor	0.5	No
Sewered area (km²)	0.00	Yes
Sewer capacity (m³/s)	0.00	Yes

UK Design Flood Estimation

Generated on Tuesday, May 17, 2016 8:52:06 AM by matthew.ross
Printed from the ReFH Flood Modelling software package, version 2.1.5798.30211

Summary of estimate using the Flood Estimation Handbook revitalised flood hydrograph method (ReFH)

Site details Checksum: 03EC-3231

Site name: FEH_Catchment_Descriptors_234000_390000
Easting: 234000
Northing: 390000
Country: England, Wales or Northern Ireland
Catchment Area (km²): 2.1
Using plotscale calculations: No
Site description: None

Model run: 20 year

Summary of results

Rainfall - FEH 2013 (mm):	37.16	Total runoff (ML):	17.28
Total Rainfall (mm):	26.01	Total flow (ML):	40.38
		Peak flow (m³/s):	1.74
Peak Rainfall (mm):	4.44		

Parameters

** Where the user has overriden a system-generated value, this original value is shown in square brackets after the value used.*

Rainfall parameters (Rainfall - FEH 2013 model)

Name	Value	User-defined?
Duration (hr)	3 [3.25]	Yes
Timestep (hr)	0.2 [0.25]	Yes
SCF(Seasonal correction factor)	0.72	No
ARF(Areal reduction factor)	0.97	No
Seasonality	Winter	n/a

Loss model parameters

Name	Value	User-defined?
Cini (mm)	105.88	No
Cmax (mm)	376.13	No
Use alpha correction factor	No	No
Alpha correction factor	n/a	No

Routing model parameters

Name	Value	User-defined?
Tp (hr)	1.54	No
Up	0.65	No
Uk	0.8	No

Baseflow model parameters

Name	Value	User-defined?
BF0 (m³/s)	0.1	No
BL (hr)	30.33	No
BR	1.35	No

Urbanisation parameters

Name	Value	User-defined?
Urban area (km²)	0.01	No
Urbext 2000	0	No
Urban runoff factor	0.7	No
Imperviousness factor	0.3	No
Tp scaling factor	0.5	No
Sewered area (km²)	0.00	Yes
Sewer capacity (m³/s)	0.00	Yes

UK Design Flood Estimation

Generated on Tuesday, May 17, 2016 8:52:22 AM by matthew.ross
Printed from the ReFH Flood Modelling software package, version 2.1.5798.30211

Summary of estimate using the Flood Estimation Handbook revitalised flood hydrograph method (ReFH)

Site details Checksum: 03EC-3231

Site name: FEH_Catchment_Descriptors_234000_390000
Easting: 234000
Northing: 390000
Country: England, Wales or Northern Ireland
Catchment Area (km²): 2.1
Using plotscale calculations: No
Site description: None

Model run: 100 year

Summary of results

Rainfall - FEH 2013 (mm):	60.45	Total runoff (ML):	30.02
Total Rainfall (mm):	42.31	Total flow (ML):	70.15
		Peak flow (m³/s):	2.96
Peak Rainfall (mm):	7.22		

Parameters

** Where the user has overriden a system-generated value, this original value is shown in square brackets after the value used.*

Rainfall parameters (Rainfall - FEH 2013 model)

Name	Value	User-defined?
Duration (hr)	3 [3.25]	Yes
Timestep (hr)	0.2 [0.25]	Yes
SCF(Seasonal correction factor)	0.72	No
ARF(Areal reduction factor)	0.97	No
Seasonality	Winter	n/a

Loss model parameters

Name	Value	User-defined?
Cini (mm)	105.88	No
Cmax (mm)	376.13	No
Use alpha correction factor	No	No
Alpha correction factor	n/a	No

Routing model parameters

Name	Value	User-defined?
Tp (hr)	1.54	No
Up	0.65	No
Uk	0.8	No

Baseflow model parameters

Name	Value	User-defined?
BF0 (m³/s)	0.1	No
BL (hr)	30.33	No
BR	1.35	No

Urbanisation parameters

Name	Value	User-defined?
Urban area (km²)	0.01	No
Urbext 2000	0	No
Urban runoff factor	0.7	No
Imperviousness factor	0.3	No
Tp scaling factor	0.5	No
Sewered area (km²)	0.00	Yes
Sewer capacity (m³/s)	0.00	Yes

UK Design Flood Estimation

Generated on Tuesday, May 17, 2016 8:52:32 AM by matthew.ross
Printed from the ReFH Flood Modelling software package, version 2.1.5798.30211

Summary of estimate using the Flood Estimation Handbook revitalised flood hydrograph method (ReFH)

Site details Checksum: 03EC-3231

Site name: FEH_Catchment_Descriptors_234000_390000
Easting: 234000
Northing: 390000
Country: England, Wales or Northern Ireland
Catchment Area (km²): 2.1
Using plotscale calculations: No
Site description: None

Model run: 1000 year

Summary of results

Rainfall - FEH 2013 (mm):	98.16	Total runoff (ML):	53.80
Total Rainfall (mm):	68.71	Total flow (ML):	125.70
		Peak flow (m³/s):	5.25
Peak Rainfall (mm):	11.72		

Parameters

** Where the user has overriden a system-generated value, this original value is shown in square brackets after the value used.*

Rainfall parameters (Rainfall - FEH 2013 model)

Name	Value	User-defined?
Duration (hr)	3 [3.25]	Yes
Timestep (hr)	0.2 [0.25]	Yes
SCF(Seasonal correction factor)	0.72	No
ARF(Areal reduction factor)	0.97	No
Seasonality	Winter	n/a

Loss model parameters

Name	Value	User-defined?
Cini (mm)	105.88	No
Cmax (mm)	376.13	No
Use alpha correction factor	No	No
Alpha correction factor	n/a	No

Routing model parameters

Name	Value	User-defined?
Tp (hr)	1.54	No
Up	0.65	No
Uk	0.8	No

Baseflow model parameters

Name	Value	User-defined?
BF0 (m³/s)	0.1	No
BL (hr)	30.33	No
BR	1.35	No

Urbanisation parameters

Name	Value	User-defined?
Urban area (km²)	0.01	No
Urbext 2000	0	No
Urban runoff factor	0.7	No
Imperviousness factor	0.3	No
Tp scaling factor	0.5	No
Sewered area (km²)	0.00	Yes
Sewer capacity (m³/s)	0.00	Yes

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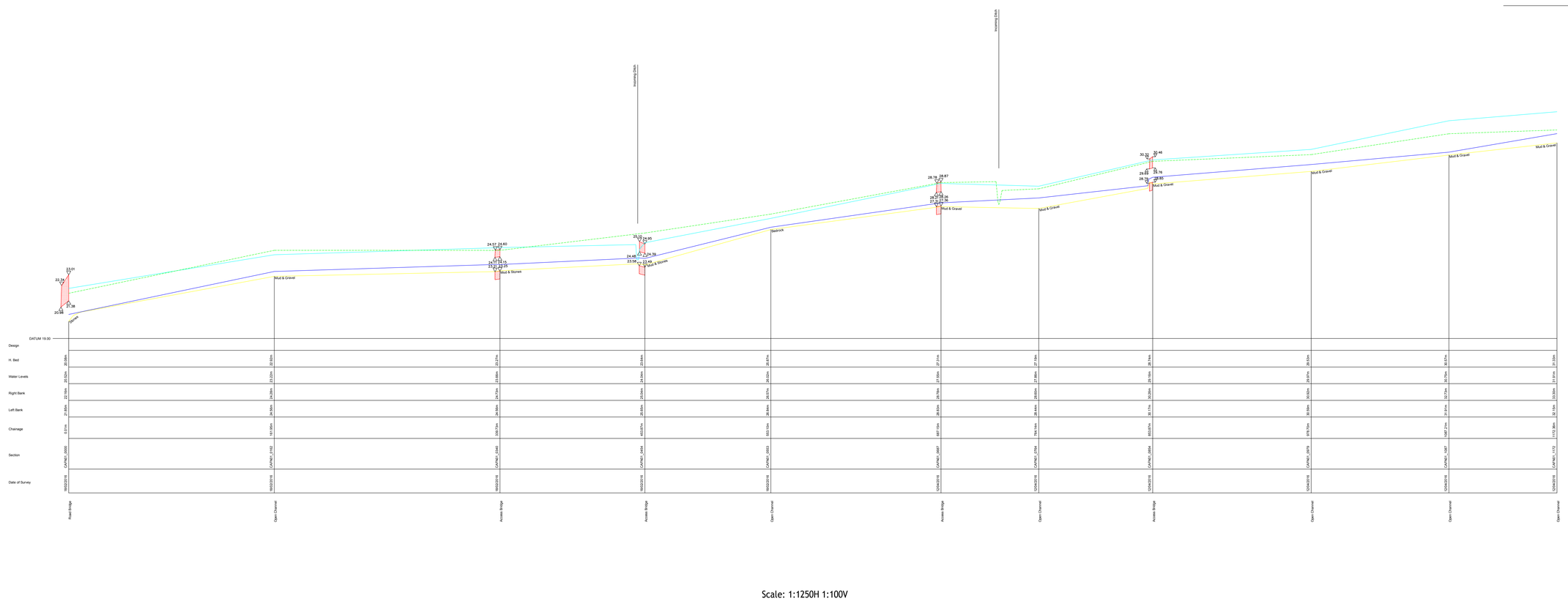
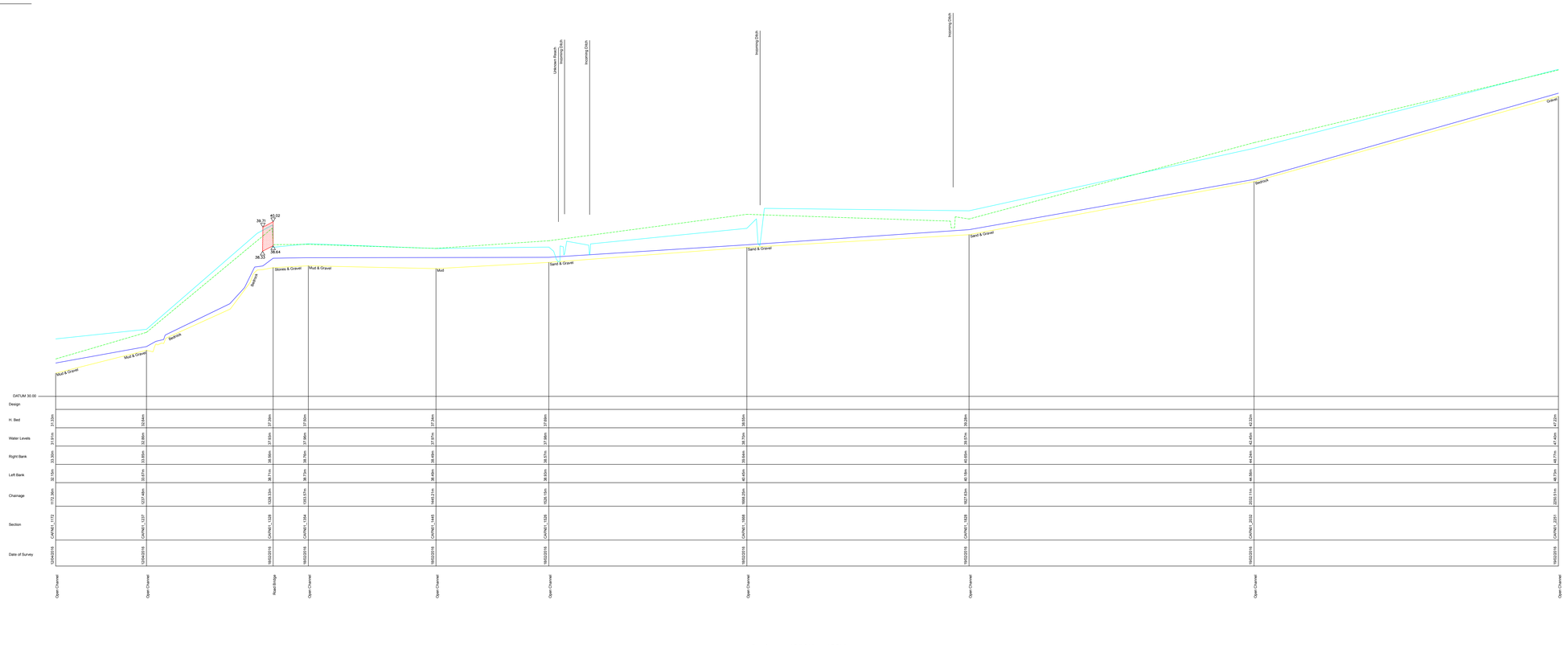
Appendix C
Structure representation


LONG SECTION CONTINUES ON 16AM21696-04
Incoming Ditch
Incoming Ditch
DATUM 19.00
Design
H. Bed
Water Levels
Right Bank
Left Bank
Chainage
Section
Date of Survey
Road Bridge
Open Channel
Access Bridge
Access Bridge
Open Channel
Access Bridge
Open Channel
Access Bridge
Open Channel
Open Channel
Open Channel
Mud & Gravel
Mud & Stones
Bedrock
Mud & Gravel
Mud & Gravel
Mud & Gravel

LONG SECTION CONTINUES ON 16AM21696-03



Scale: 1:1250H 1:100V

Scale: 1:1250

LONG SECTION KEY:

WATER LEVEL
BED LEVEL
SILT LEVEL
STRUCTURES
RIGHT BANK
LEFT BANK

VIEWED LOOKING DOWNSTREAM
POINTS INDICATED BY 'C' ON CROSS SECTIONS AND ADDITIONAL POINTS BETWEEN SECTIONS

Sheet Layout (not to scale)

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SURVEY LEGEND

AB	AIR BRICK	FH	FIRE HYDRANT	PWF	POST & WIRE FENCE
AV	AIR VALVE	FHR	FIRE HYDRANT MARKER	RE	RIGHT BANK
B	BOLLARD	FL	FLOOR LEVEL	RE	ROSEMARY ETC
BC	BRITISH TELECOM	FP	FLAG POLE	RF	RAILWAY FENCE
BDY	BOUNDARY	FWA	FOUL WATER MANHOLE	RTW	RETAINING WALL
BH	BOREHOLE	G	GULLY	RWP	RAINWATER PIPE
BO	BOLLARD LIGHT	GL	GROUND LEVEL	S	SOUTH
BR	BRICKWORK	GP	GATE POST	SH	STAKE HOLE
BS	BUS STOP	GT	GRATED TRENCH	SP	SIGN POST
BW	BRICK WASH	GV	GAS VALVE	SL	SLOPE
BWL	BRICK WALL	H	HEDGE LINE	SLP	SLOPE LEVEL
BWF	BRICK WALL FENCE	HC	HINGE CHAMBER	SMP	SHEET METAL PILING
CBF	CLOSE BOARDED FENCE	HL	INVERT LEVEL	SP	SIGN POST
CBR	CLOSE BOARDED IRON FENCE	HF	HEDGE & FENCE	SWF	SHEEP WIRE FENCE
CL	COVER LEVEL	HIF	INTERWOVEN FENCE	STA	STATION
CLF	Chain LINK FENCE	JB	JUNCTION BOX	SV	SLUICE VALVE
CO	CLEAN OUT	JCB	JOINT CLOSURE BOLT	TBM	TEMPORARY BENCH MARK
CP	CONCRETE POST	LD	LOFT DOOR	TBR	TEMPORARY BENCH MARK
CPF	CHESTNUT PALING FENCE	LFB	LIFEBUOY	TCB/TCP	TELEPHONE CALL BOX/ POST
CR	CREST LEVEL	LP	LAMP POST	TH	TELEGRAPH HOLE
CTY	CABLE T.V. MARKER/2	MB	MOORING BOLLARD	TMH	TELECOM MANHOLE
CUL	CULVERT	MF	MISCELLANEOUS FENCING	TNL	THRESHOLD LEVEL
D	DRAIN	MH	MANHOLE	TP	TELEGRAPH POLE
DL	DECK LEVEL	MKR	MARKER	TLB	TRAFFIC LIGHT BOX
DP	DOWNPIPE	MP	MOORING PILE	TP	TELEGRAPH POLE
DW	DRY STONE WALL COURSE	MPF	MESH PANEL FENCE	TS	TRAFFIC LIGHTS STRIP
EK	EKAN	MV	MUD STONE	TL	TREE LEVEL
EWB	DOG WASTE BIN	NB	NOTICE BOARD	TSB	TUBULAR STEEL RAILINGS
ES	ELECTRICITY SUPPLY	NRA	NATIONAL RIVERS AUTHORITY	TW	TOP WALL
ES	ELECTRICITY BOX	OHC	OVERHEAD CABLE	WB	WASTE BIN
ECF	ELECTRIC CABLE FENCE	OS	ORDNANCE SURVEY	WL	WATER LEVEL/ WATER LINE
EM	ELECTRICITY METER	OSR	ORDNANCE SURVEY RIVALOC	WM	WATER METER
EMK	ELECTRICITY MARKER/2	P	PILE	WMF	WIRE MESH FENCE
EP	ELECTRICITY POLE	PB	PILLAR BOX	WP	WOODEN POST
ET	ELECTRIC TRAP	PC	PEDESTRIAN CROSSING	WPR	WOODEN POST & RAIL FENCE
ETL	ELECTRICITY TRANSMISSION LINE	PO	POST	WV	WATER VALVE
PB	FLOWED BED	PR	POST & RAIL FENCE	YG	YARD GULLY
FW	FOOTWAY	PTM	PARKING TICKET MACHINE		(Approximate levels to Ex survey data only)

REV.	AMENDMENT	DRN	CHKD	DATE

CONTROL USED:

ID	DESCRIPTION	Easting	Northing	Height
STN5	Survey Point Marker	234080.000	390190.000	39.380

STORM GEOMATICS

STORM GEOMATICS LIMITED
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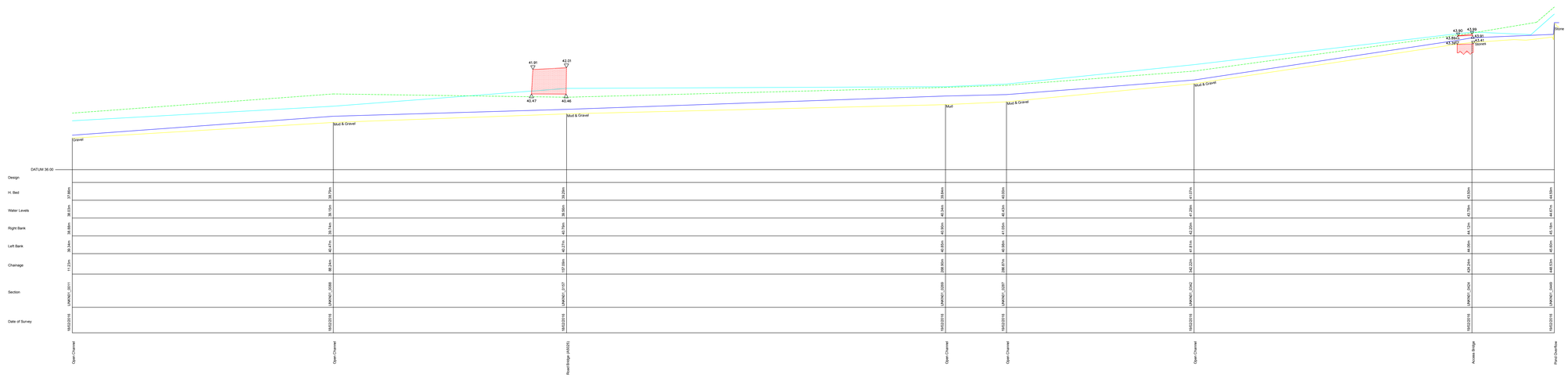
CLIENT
Amec Foster Wheeler

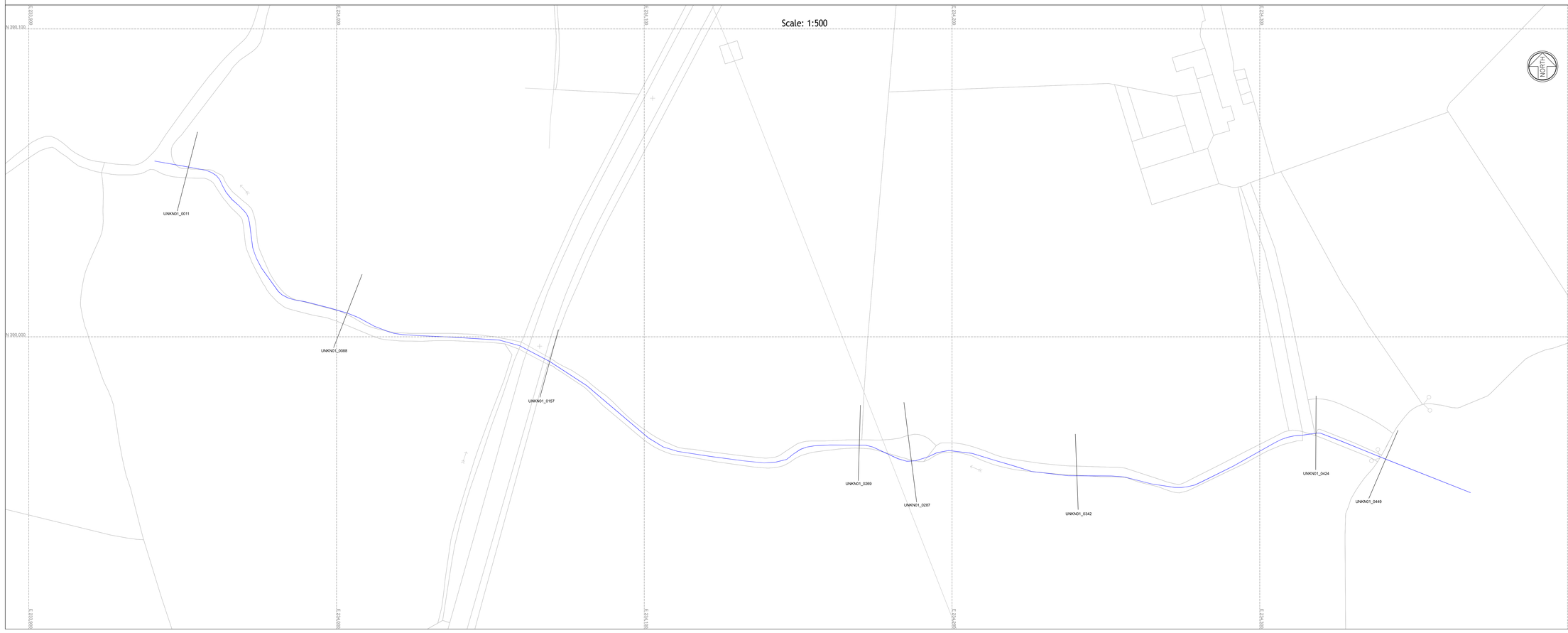
PROJECT
Cefn Coch Watercourse Survey

SITE
Afon Cafnan
Cefn Coch, Anglesey
Long Section & Location Plan
Sheet 2 of 2

SURVEYED BY: Storm Geomatics Ltd — *Project Ref: 281979*
SURVEY DATE: February - April 2016
SCALE: As Shown (A0 Sheet) — DRN: CJT — CHKD: ARP
DATUM: Newlyn (OS) — DATE: 13/04/2016 — DATE: 13/04/2016
GRID: Ordnance Survey — DRAWING NO. 16AM21696/04 — REV. --
CAD FILENAME: CAFN01_LS+LP.dwg



Scale: 1:500H 1:100V



LONG SECTION KEY:

- WATER LEVEL
- BED LEVEL
- SILT LEVEL
- STRUCTURES
- RIGHT BANK — VIEWED LOOKING DOWNSTREAM
- LEFT BANK — POINTS INDICATED BY 'C' ON CROSS SECTIONS AND ADDITIONAL POINTS BETWEEN SECTIONS

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NOTES:
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SURVEY LEGEND

AB	AIR BRICK	FH	FIRE HYDRANT	PWF	POST & WIRE FENCE
AV	AIR VALVE	FHM	FIRE HYDRANT MARKER	RB	RIGHT BANK
BH	BOREHOLE	FP	FLOOD PLAIN	RC	RECTANGULAR
BR	BILLIARD BOLLOW	FP	FENCE POST	RL	ROAD SIGN
BSY	BOUNDARY	FWA	FOUL WATER MANHOLE	RTW	RETAINING WALL
BT	BT MANHOLE	G	GULLY	RWP	RAIN WATER PIPE
BL	BED LEVEL	GL	GROUND LEVEL	SC	STOP COCK
BW	BRICKWORK	GP	GATE POST	SDP	STAND PIPE
CH	CATCH PIT	GV	GAS VALVE	SF	SECURITY FENCE
CH	ROCK CHAIR	CV	CAT H VLVE	SL	SUPPLY LEVEL
BW	BRICK WALL	HW	HEAD WALL	SMH	SURFACE WATER MANHOLE
CC	CONCRETE FENCE	IC	ICE CREAM CHAMBER	SP	SIGN POST / SIGNAL
CSF	CLOSE BOARDED FENCE	L	KERBT LEVEL	SP	SIDE POST
CF	CORRUGATED IRON FENCE	MF	IRON RAILING FENCE	SPF	STEEL PALLISADE FENCE
CP	CONCRETE POST	MH	MANHOLE COVER	ST	STUMP
CLF	CHAIN LINK FENCE	JB	JUNCTION BOX	SV	SLUICE VALVE
CL	CENTRE LINE	KG	KERB TO GULLY	TC	TELEPHONE CABLE
CP	CONCRETE POST	LP	LIFT SHAFT	TBM	TEMPORARY BENCH MARK
CR	CONCRETE RAILING FENCE	LS	LAMP STANDARD	TCB/TCP	TELEPHONE CABLE BOX/POST
CV	CYCLE PATH	LP	LAMP POST	TL	TELEPHONE LINE
CTY	CABLE T.V. MANHOLE	MB	MOORING BOLLARD	TMH	TELECOM MANHOLE
DF	DRAIN FIELD	MF	METAL RAILINGS FENCING	TP	TELEGRAPH POLE
DK	DRIVE KERB	MH	MANHOLE	TL	TRAFFIC LIGHT
DL	DECK LEVEL	MKR	MARKER	TLB	TRAFFIC LIGHT BOX
DP	DRAIN POST	MP	MARKER POST	TP	TELEGRAPH POLE
DPC	DAMP PROOF COURSE	MRF	METAL RAILING FENCE	TSS	TIMBER SLEEPING STRIP
DR	DRAIN	NC	NAIL STONE	TS	TREE STUMP
DW	DRY WASTE BIN	NR	NATIONAL RAILWAYS	TW	TIMBER RETAINING WALKING
EA	ENVIRONMENT AGENCY	NRA	NATIONAL RIVERS AUTHORITY	VP	VENT PIPE
ES	ELECTRICITY BOX	OHC	OVERHEAD CABLE	WB	WASTE BIN
ECP	ELECTRICITY CABLE POST	OP	OVERHEAD POWER	WL	WATER LEVEL / WATER LINE
ECP	ELECTRICITY CABLE PIT	OSR	OPEN STEEL RAILINGS	WM	WATER METER
EMP	ELECTRICITY MANHOLE	P	PILE	WMF	WIRE MESH FENCE
EP	ELECTRICITY POLE	PB	PARKING BOX	WP	WOOD POST
ET	EARTHING ROD	PM	PARKING METER	WPR	WOODEN POST & RAIL FENCE
ETL	ELECTRICITY TRANSMISSION LINE	PO	POST	WV	WATER VALVE
FB	FLOWER BED	PR	POST & RAIL FENCE	YD	YARD GULLY
FBR	FOOTBRIDGE	PTM	PARKING TICKET MACHINE		(abbreviations apply to OS survey data only)

REV.	AMENDMENT	DRN	CHKD	DATE

CONTROL USED:

ID	DESCRIPTION	Easting	Northing	Height
STN1	Survey Point Marker	234080.000	390190.000	39.380

STORM GEOMATICS

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CLIENT
Amec Foster Wheeler

PROJECT
Cefn Coch Watercourse Survey

SITE
Unknown Watercourse
Cefn Coch, Anglesey
Long Section & Location Plan
Sheet 1 of 1

SURVEYED BY: Storm Geomatics Ltd		Project Ref: 281979
SURVEY DATE: February 2016		
SCALE: As Shown (A0 Sheet)	DRN: CJT	CHKD: ARP
DATUM: Newlyn (OS)	DATE: 22/02/2016	DATE: 13/04/2016
GRID: Ordnance Survey	DRAWING NO. 16AM21696/06	REV. –
CAD FILENAME: UNKN01_LS+LP.dwg		

Structure 1	AFON CAFNAN		
Name of Structure	**Road Bridge on Afon Cafnan**		
OS Grid Ref	234066.10 390189.90		
Survey reference	CAFN01_1328		
Included in Model?	Yes	**Model Label/ reason for exclusion**	1328C
Model representation	Culvert based on survey section CAFN01_1328 (surveyed upstream face of culvert). Downstream culvert face based on upstream face. Surveyed skew angle (28°) not represented. This is because when looking at the photos and the survey location plan it is evident that the culvert barrel is not perpendicular to the road centreline, rather it is in line with the channel hence we did not include the skew. Rectangular conduit unit used, upstream invert 37.390 mAOD (lowest elevation in surveyed irregular bed). Height 1.25m (using surveyed soffit 38.64 mAOD). Width 0.96m (distance between survey points). Downstream invert 36.970 mAOD (measured from long section of survey). Culvert length 8.50 m as surveyed. No spill unit (overtopping flows represented in 2D instead due to length of bridge). HX line applied across the face of the bridge where a z line has been use to set the parapet level to 40.02 as per survey.		
Coefficients used	Manning's: bed 0.04 (continuation of bedrock bed), sides and soffit 0.025 (dry stone walls and slabs, Chow, 1959, rubble masonry (cemented) brickwork is closest). Inlet: Conduit type B; K: 0.515; M: 0.667; C: 0.0375; Y: 0.79; Ki 0.5		
Assumptions	Assuming height continuous through culvert and steady slope of bed in line with slope of soffit. The rectangular culvert results in a slightly larger bore area of 0.1m2 compared to the survey drawing. This slightly overestimate the capacity but the crossing is 300m downstream of the site so will unlikely have affect the water levels at site.		

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Photograph	Upstream: Downstream:
Structure 2	**AFON CAFNAN**
Name of Structure	**'Cascade' downstream of road bridge on Afon Cafnan**
OS Grid Ref	234074 390186 (upstream) to 234074 390215 (downstream)

Survey reference	Between CAFN01_1328 and CAFN01_1237		
Included in Model?	Yes	**Model Label/reason for exclusion**	1320d, 1315c, 1315d, 1307c, 1307d, 1297c
Model representation	Series of spill units with short flat sections in between to maintain channel length. Cross sections based on CAFN01_1237, spill sections based on CAFN01_1328. Drop in bed level based on surveyed long section.		
Coefficients used	Modular limit 0.9. Weir coefficient 1.20 (rocky bed).		
Assumptions	Cascading section can be appropriately represented through series of spills coupled with flat sections of bed.		
Photograph	No photograph taken.		
Structure 3	**AFON CAFNAN**		
Name of Structure	**Blockage with timber debris caused by wire fence crossing**		
OS Grid Ref	234104.00 390304.30		
Survey reference	CAFN01_1172		
Included in Model?	Yes.	**Model Label / reason for exclusion**	1172Bl 1172Su-1172Sd
Model representation	Blockage unit with spill Spill is a copy of the cross section, with the bed level raised to the bank level (32.049mAOD).		
Coefficients used	Blockage: 90% (as some flow would pass through the debris) Spill weir coefficient: 1.00 (to account for high roughness of debris) Spill modular coefficient: 0.9 (default)		

Assumptions	Assumption that there is no regular maintenance on the channel and that wire fence across the channel would prevent debris from being flushed away in the case of a flood. Blockage therefore represented in model. From the photo the top of the debris is consistent with part way up the right bank. This elevation of 32.049mAD was read from survey and set as the spill level. Below this elevation, a 90% blockage has been assumed. This allows 10% for seepage through the debris.		
Photograph			
Structure 4	**AFON CAFNAN**		
Name of Structure	**Access bridge for farm track near Cefn-coch**		
OS Grid Ref	234063.30 390609.30		
Survey reference	CAFN01_0854		
Included in Model?	Yes	**Model Label / reason for exclusion**	0854C1 & 0854C2 0852C2Bl 0854Su – 0852Sd

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Model representation	Two concrete culverts based on survey section CAFN01_0854 (surveyed upstream face of culvert). Downstream culvert face based on upstream face (inverts adjusted base on long section). Right culvert is partially collapsed and blocked. Represented with 90% blockage unit. Two parallel circular conduit units used, upstream inverts 28.93 (left) and 28.85 (right) mAOD. Diameter 0.9m. Culvert length 2.60 m as surveyed. Spill unit to represent overtopping flows.
Coefficients used	Manning's: 0.011 (concrete, culvert straight and free of debris, Chow 1959)
Assumptions	Assumption that there is no regular maintenance on the channel and that the blocked and partially collapsed right culvert barrel would be present in the case of a flood. Blockage therefore represented in model. The roughness value used assumed the culvert is free of debris, as no debris is evident in the photo of 'non collapsed' culvert. Given the distance downstream of this culvert the choice of roughness value will not significantly impact the water levels on site if at all.

Photograph	Downstream: Upstream:
Structure 5	**AFON CAFNAN**
Name of Structure	**Access bridge for farm track near Cefn-coch**
OS Grid Ref	234122.40 390745.10

Survey reference	CAFN01_0687		
Included in Model?	Yes	**Model Label/ reason for exclusion**	0687C1 & 0687C2 0687Su – 0683Sd
Model representation	Two concrete culverts based on survey section CAFN01_0687 (surveyed upstream face of culvert). Downstream culvert face based on upstream face (inverts adjusted base on long section). Two parallel circular conduit units used, upstream inverts 27.40 (left) and 27.36 (right) mAOD. Diameter 0.9m. Culvert length 3.80 m as surveyed. Spill unit to represent overtopping flows.		
Coefficients used	Manning's: 0.011 (concrete, culvert straight and free of debris, Chow 1959)		
Assumptions	The roughness value used assumed the culvert is free of debris, as no debris is evident in the photo of culvert. Given the distance downstream of this culvert the choice of roughness value will not significantly impact the water levels on site if at all.		
Photograph			
Structure 6	**AFON CAFNAN**		
Name of Structure	**Access bridge for farm track north of Cefn-coch**		

OS Grid Ref	234074.10 390959.40		
Survey reference	CAFN01_0454		
Included in Model?	Yes	**Model Label / reason for exclusion**	0454C1 & 0454C2
Model representation	Two concrete culverts based on survey section CAFN01_0454 (surveyed upstream face of culvert) offset 0.7m from face. Downstream culvert face based on upstream face (inverts adjusted base on long section). Two parallel circular conduit units used, upstream inverts 23.48 (left) and 23.49 (right) mAOD. Diameter 0.9m. Culvert length 4.50 m as surveyed. No spill unit. Flow over deck modelled in 2D. HX line applied across the face of the bridge to spill water into the 2D, a z line has been use to set the parapet level to 25.06mAOD as per survey.		
Coefficients used	Manning's: 0.011 (concrete, culvert straight and free of debris, Chow 1959)		
Assumptions	Assumed that culvert barrels will be most constricting part of structure. Face of crossing sticks out further, but not included in model representation. The roughness value used assumed the culvert is free of debris, as no debris is evident in the photo of culvert. Given the distance downstream of this culvert the choice of roughness value will not significantly impact the water levels on site if at all.		

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Photograph	Upstream: Downstream:
Structure 7	**AFON CAFNAN**
Name of Structure	**Access bridge for farm track near Pen-y-cefn with public footpath**
OS Grid Ref	234051.20 391070360

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Survey reference	CAFN01_0340		
Included in Model?	Yes	**Model Label / reason for exclusion**	0340C1 & 0340C2 0340Su – 0336Sd
Model representation	Two concrete culverts based on survey section CAFN01_0340 (surveyed upstream face of culvert). Downstream culvert face based on upstream face (inverts adjusted base on long section). Two parallel circular conduit units used, upstream inverts 23.20 (left) and 23.25 (right) mAOD. Diameter 0.9m. Culvert length 3.90 m as surveyed. Spill unit to represent overtopping flows.		
Coefficients used	Manning's: 0.011 (concrete, culvert straight and free of debris, Chow 1959)		
Assumptions	The roughness value used assumed the culvert is free of debris, as no debris is evident in the photo of culvert. Given the distance downstream of this culvert the choice of roughness value will not significantly impact the water levels on site if at all.		

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Photograph	Upstream: Downstream:
Structure 8	**AFON CAFNAN**
Name of Structure	**Road bridge**
OS Grid Ref	234126.70 391377.7

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Survey reference	CAFN01_0000		
Included in Model?	Yes	**Model Label / reason for exclusion**	0000C1 & 000C2
Model representation	Stone bridge with two rectangular openings represented as two rectangular culverts based on CAFN01_0000. Rectangular conduit unit used, upstream inverts 20.19 (left) and 20.20 (right) mAOD, upstream soffits 21.40 (left) and 21.38 (right) mAOD, based on cross section. Downstream inverts based on long section downstream soffit (20.98 mAOD) minus height. Widths 0.606 (left) and 0.626 (right) m (measured of plan at springing level). Culvert length 7.90m as surveyed. No spill unit (overtopping flows represented in 2D instead due to length of bridge). HX line applied across the face of the bridge to spill water into the 2D, a z line has been use to set the parapet level to 22.88mAOD, and road level to 22.33mAOD as per survey.		
Coefficients used	Manning's: bed 0.04 (continuation of bedrock bed), sides and soffit 0.025 (dry stone walls and slabs, Chow, 1959, rubble masonry (cemented) brickwork is closest). Inlet: Conduit type B; K: 0.515; M: 0.667; C: 0.0375; Y: 0.79; Ki 0.5		
Assumptions	Culvert barrel height and width continuous from upstream to downstream.		
Photograph			
Structure 9	**LLYN LLYGEIRIAN TRIBUTARY**		

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Name of Structure	**Pond overflow from lower reach of Llyn Llyfgeirian into Unknown Tributary to Afon Cafnan**		
OS Grid Ref	234335.40 389947.50		
Survey reference	UNKN01_0049		
Included in Model?	No	**Model Label / reason for exclusion**	Could cause problems as this is right at the top of the model. Might include later. Model to start just downstream of overflow. Reduced bed level of surveyed section (banks unchanged).
Model representation	N/A		
Coefficients used	N/A		
Assumptions	Assumed that omission of structure will not impact on flood modelling results.		
Photograph	Looking from d/s to u/s		

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Structure 10	**LLYN LLYGEIRIAN TRIBUTARY**		
Name of Structure	**Access bridge for farm track near Pen-y-groes**		
OS Grid Ref	234318.20 389956.80		
Survey reference	UNKN01_0424		
Included in Model?	Yes	**Model Label / reason for exclusion**	0424C 0424Su – 0420Sd
Model representation	Pipe based on survey section UNKN01_0424 (at upstream face of pipe). Circular conduit unit used, upstream invert 43.41, downstream invert 43.39. Diameter 0.5m. Pipe length 4.40m. Downstream channel cross section copied from surveyed section upstream and bed dropped in line with long section of survey. Spill unit to represent overtopping flows (i.e. spill represented in 1D model only).		
Coefficients used	Manning's n: 0.013 (cast iron, coated, Chow 1959)		
Assumptions	N/A.		

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Photograph	Looking from upstream to downstream: Looking from downstream to upstream:
Structure 11	**LLYN LLYGEIRIAN TRIBUTARY**
Name of Structure	**Road Bridge (A5025)**
OS Grid Ref	234066.10 389980.30

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Survey reference	UNKN01_0157		
Included in Model?	Yes	**Model Label / reason for exclusion**	0157Bu – 0157Bd
Model representation	Bridge based on survey section UNKN01_0157 (at upstream face of bridge). Arch bridge unit used. Springing level 39.7 mAOD, soffit level 40.460 mAOD, length 10.2m, skew angle 12º. No spill unit (overtopping flows represented in 2D instead due to length of bridge). HX line applied across the face of the bridge to spill water into the 2D, a z line has been use to set the parapet level to 12.01mAOD as per survey.		
Coefficients used	Model surcharged bridge as orifice flow with transition distances of 0.1m. Orifice discharge coefficient 1.00.		
Assumptions	The fence crossing the channel is not included, as not considered to pose a significant constriction to flow. Bridge is upstream of proposed development site so representing it with no blockage should provide a conservative result for the development site.		

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Photograph	Upstream: Downstream:

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Appendix D
Channel roughness representation

Manning's roughness values have been determined using definitions detailed in Chow (1959), referenced below. The roughness values chosen for each section of the Cefn Coch model are presented in this appendix.

- Chow, V.T., 1959. *Open-channel hydraulics*: New York, McGraw-Hill, 680 p.

NOT PROTECTIVELY MARKED

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Drain / Reach		Section	Manning's category	Manning's n	Justification	Picture
Afon Cafnan	**2251**	bed	1. Main Channels a. clean, straight, full stage, no rifts or deep pools	0.03	Gravel bed surveyed	
		banks	3 Floodplains c Brush 1. scattered brush, heavy weeds	0.05	Very weedy section may suggest max variant, but adjusted to mid for winter storm event	
	deactivated	right floodplain	3. Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3. Floodplains a. Pasture, no brush 1. short grass	0.03		
Afon Cafnan	**2032**	bed	1. Main Channels a. clean, straight, full stage, no rifts or deep pools	0.03	Gravel bed surveyed	
		banks	3. Floodplains c. Brush 1. scattered brush, heavy weeds	0.05	Very weedy section may suggest max variant, but adjusted to mid for winter storm event	
	deactivated	right floodplain	3. Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3. Floodplains a. Pasture, no brush 1. short grass	0.03		
Afon Cafnan	**1828**	bed	3. Floodplains a. Pasture, no brush 1. short grass	0.03		
		left bank	3. Floodplains a. Pasture, no brush 1. short grass	0.03		

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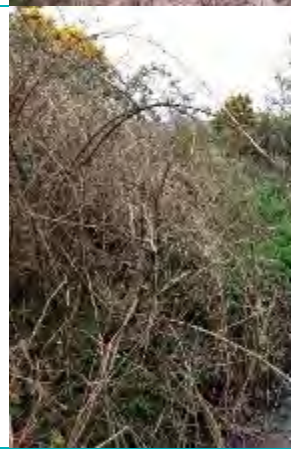
Drain / Reach		Section	Manning's category	Manning's n	Justification	Picture
		right bank	3. Floodplains a. Pasture, no brush 2. high grass	0.035		
	deactivated	right floodplain	3. Floodplains c. Brush 2. light brush and trees, in winter	0.05		
	deactivated	left floodplain	3. Floodplains a. Pasture, no brush 1. short grass	0.03		
Afon Cafnan	**1668**	bed	1. Main Channels a. clean, straight, full stage, no rifts or deep pools	0.03	Sand and gravel bed surveyed	
		banks	3. Floodplains c. Brush 1. scattered brush, heavy weeds	0.05	Very weedy section may suggest max variant, but adjusted to mid for winter storm event	
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Afon Cafnan	**1526**	bed	4. Excavated or Dredged Channels a. Earth, straight, and uniform 4. with short grass, few weeds	0.027		
		banks	3 Floodplains a. Pasture, no brush 1. short grass	0.03		

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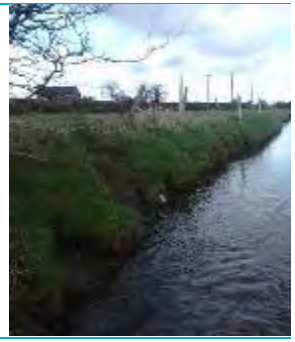
Drain / Reach		Section	Manning's category	Manning's n	Justification	Picture
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	1445	bed	as 1526	0.027		
		banks	as 1526	0.03		
	deactivated	right floodplain	as 1526	0.03		
	deactivated	left floodplain	as 1526	0.03		
Afon Cafnan	**1354**	bed	as 1526	0.027		
		left bank	3 Floodplains c Brush 2. light brush and trees, in winter	0.05		
		right bank	as 1526	0.03		
	deactivated	right floodplain	as 1526	0.03		
	deactivated	left floodplain	3 Floodplains c Brush	0.05		

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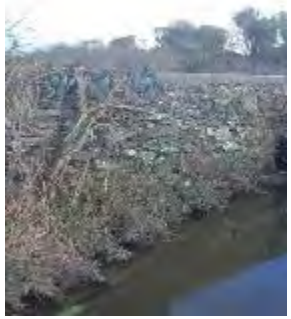
Drain / Reach		Section	Manning's category	Manning's n	Justification	Picture
			2. light brush and trees, in winter			
Afon Cafnan	**1328**	bed	as 1354	0.027		
		left bank	as 1354	0.05		
		right bank	as 1354	0.03		
	deactivated	right floodplain	as 1354	0.03		
Afon Cafnan	**1297c**	bed	copy of 1237	0.045	Aerial photography similar to 1237	
		left bank	copy of 1237	0.03	Aerial photography similar to 1237	
		right bank	copy of 1237	0.05	Aerial photography similar to 1237	
	deactivated	right floodplain	copy of 1237	0.05	Aerial photography similar to 1237	
	deactivated	left floodplain	copy of 1237	0.03	Aerial photography similar to 1237	
Afon Cafnan	**1237**	bed	1. Main Channels d. same as above (clean, winding, some pools and shoals), but some weeds and stones	0.045	stones rather than weeds, rocky section at the end of the cascade reach	
		left bank	3 Floodplains a. Pasture, no brush	0.03		

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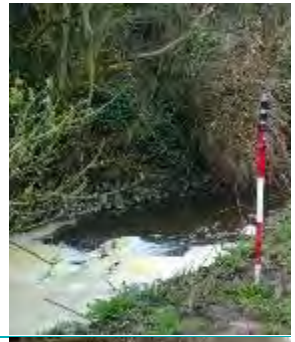
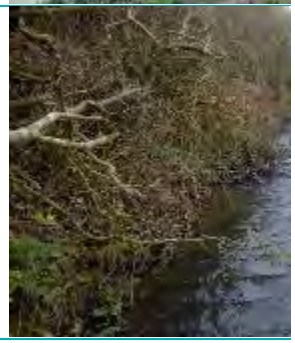
Drain / Reach		Section	Manning's category	Manning's n	Justification	Picture
			1. short grass			
		right bank	3. Floodplains c. Brush 1. scattered brush, heavy weeds	0.05		
	deactivated	right floodplain	3 Floodplains c Brush 2. light brush and trees, in winter	0.05		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Afon Cafnan	**1172**	bed	1. Main Channels e. same as above (clean, winding, some pools and shoals), lower stages, more ineffective slopes and sections	0.048	overhanging trees and 'islands'	
		left bank	same as 1237	0.03		
		right bank	same as 1237	0.05		
	deactivated	right floodplain	same as 1237	0.05		
	deactivated	left floodplain	same as 1237	0.03		
Afon Cafnan	**1087**	bed	same as 1237	0.04		
		left bank	same as 1237	0.03		
		right bank	same as 1237	0.05		
	deactivated	right floodplain	same as 1237	0.05		
	deactivated	left floodplain	same as 1237	0.03		

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Drain / Reach		Section	Manning's category	Manning's n	Justification	Picture
Afon Cafnan	**0979**	bed	1. Main Channels d. same as above (clean, winding, some pools and shoals), but some weeds and stones	0.045	reeds encroaching on channel	
		banks	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Afon Cafnan	**0854**	bed	same as 0979	0.045		
		Right banks	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
		left bank	3 Floodplains c. Brush 1. scattered brush, heavy weeds	0.05		
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Afon Cafnan	**0857c**	bed	same as 0854	0.045		
		banks	3 Floodplains c. Brush 2. light brush and trees, in winter	0.05		
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		

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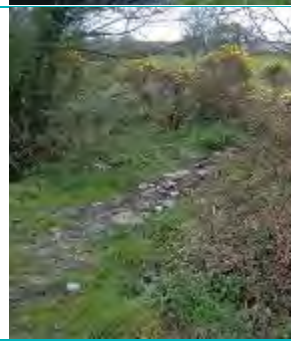
Drain / Reach		Section	Manning's category	Manning's n	Justification	Picture
Afon Cafnan	**0764**	bed	1. Main Channels d. same as above (clean, winding, some pools and shoals), but some weeds and stones	0.045		
		banks	3 Floodplains a. Pasture, no brush 1. high grass	0.035	reeds	
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Afon Cafnan	**0687**	bed	1. Main Channels d. same as above (clean, winding, some pools and shoals), but some weeds and stones	0.045		
		banks	5. Lined or Constructed Channels g. Masonry 2. dry rubble	0.032	stone walls with some weeds	
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Afon Cafnan	**0683c**	bed	1. Main Channels d. same as above (clean, winding, some pools and shoals), but some weeds and stones	0.045		
		banks	3 Floodplains c. Brush 1. scattered brush, heavy weeds	0.05		
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Afon Cafnan	**0553**	bed	1. Main Channels c. clean, winding, some pools and shoals	0.04		

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Drain / Reach		Section	Manning's category	Manning's n	Justification	Picture
		banks	3 Floodplains c. Brush 2. light brush and trees, in winter	0.05		
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Afon Cafnan	**0454**	bed	1. Main Channels c. clean, winding, some pools and shoals	0.033	lower end to account for masonry channel side walls	
		banks	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Afon Cafnan	**0449c**	bed	1. Main Channels c. clean, winding, some pools and shoals	0.04		
		right bank	3 Floodplains c. Brush 2. light brush and trees, in winter	0.05		
		left bank	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		

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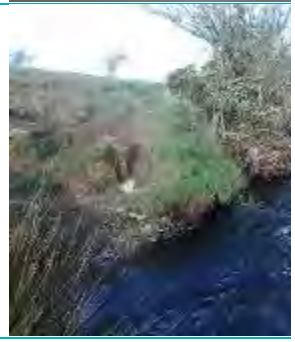
Drain / Reach		Section	Manning's category	Manning's n	Justification	Picture
Afon Cafnan	**0340**	bed	1. Main Channels c. clean, winding, some pools and shoals	0.033	lower end to account for masonry channel side walls	
		right bank	3 Floodplains c. Brush 2. light brush and trees, in winter	0.05		
		left bank	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Afon Cafnan	**0336c**	bed	1. Main Channels c. clean, winding, some pools and shoals	0.033	lower end to account for masonry channel side walls	
		banks	3 Floodplains c. Brush 2. light brush and trees, in winter	0.05		
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Afon Cafnan	**0162**	bed	1. Main Channels c. clean, winding, some pools and shoals	0.04		
		banks	3 Floodplains c. Brush 2. light brush and trees, in winter	0.05	varying between short grass, high grass, brush and trees on both banks	
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		

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Drain / Reach		Section	Manning's category	Manning's n	Justification	Picture
Afon Cafnan	**0000**	bed	1. Main Channels c. clean, winding, some pools and shoals	0.04		
		banks	3 Floodplains c. Brush 2. light brush and trees, in winter	0.035	lower as brush is not dense and few trees only	
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Afon Cafnan	**-008c**	bed	1. Main Channels c. clean, winding, some pools and shoals	0.04		
		banks	3 Floodplains c. Brush 2. light brush and trees, in winter	0.035	lower as brush is not dense and few trees only	
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Afon Cafnan	**-018c**		same as -008c			
	Llyn Llygeirian tributary					
Llyn Llygeirian tributary	**0448c**	bed	1. Main Channels f. same as d (clean, winding, some pools and shoals), with more stones	0.05	stones rather than weeds, rocky bed d/s of outfall weir from Llyn Llygeirian section at the end of the cascade reach	
		banks	3 Floodplains c. Brush 2. light brush and trees, in winter	0.05	varying between short grass, high grass, brush and trees on both banks	
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		

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Drain / Reach		Section	Manning's category	Manning's n	Justification	Picture
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Llyn Llygeirian tributary	**0424**	bed	1. Main Channels d. same as above (clean, winding, some pools and shoals), but some weeds and stones	0.035	lower to account for masonry dry wall on left bank	
		banks	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Llyn Llygeirian tributary	**0420c**	bed	1. Main Channels d. same as above (clean, winding, some pools and shoals), but some weeds and stones	0.04		
		right bank	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
		left bank	3 Floodplains a. Pasture, no brush 2. high grass	0.035		
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush	0.03		

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Drain / Reach		Section	Manning's category	Manning's n	Justification	Picture
			1. short grass			
Llyn Llygeirian tributary	**0342**	bed	1. Main Channels d. same as above (clean, winding, some pools and shoals), but some weeds and stones	0.045	reeds encroaching on channel	
		right bank	3 Floodplains c. Brush 1. scattered brush, heavy weeds	0.05		
		left bank	3 Floodplains a. Pasture, no brush 2. high grass	0.035		
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Llyn Llygeirian tributary	**0287**	bed	1. Main Channels d. same as above (clean, winding, some pools and shoals), but some weeds and stones	0.05	very dense vegetation in the middle of the channel (represented as higher ground/island in cross section), weeds and some brush on the banks	
		banks	3 Floodplains a. Pasture, no brush 1. short grass	0.03	weeds and some brush, accounted for in higher bed roughness	
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Llyn Llygeirian tributary	**0269**	bed	1. Main Channels d. same as above (clean, winding, some pools and shoals), but some weeds and stones	0.05	grass and brush encroaching on channel, right bank with scattered brush and heavy weeds	
		left bank	3 Floodplains a. Pasture, no brush 2. high grass	0.035		
		right bank	3 Floodplains c. Brush	0.05	scattered brush and heavy weeds, accounted for in higher bed roughness	

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Drain / Reach		Section	Manning's category	Manning's n	Justification	Picture
			1. scattered brush, heavy weeds			
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Llyn Llygeirian tributary	**0157**	bed	1. Main Channels d. same as above (clean, winding, some pools and shoals), but some weeds and stones	0.045		
		right bank	3 Floodplains c. Brush 1. scattered brush, heavy weeds	0.05	scattered brush and heavy weeds with masonry wall behind, accounted for in bed roughness	
		left bank	3 Floodplains a. Pasture, no brush 2. high grass	0.035		
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Llyn Llygeirian tributary	**0157**	bed	1. Main Channels c. clean, winding, some pools and shoals	0.033	lower to account for smooth masonry wall and boulders on banks	
		banks	5. Lined or Constructed Channels g. Masonry 1. cemented rubble	0.025		
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		

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Drain / Reach		Section	Manning's category	Manning's n	Justification	Picture
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Llyn Llygeirian tributary	**0088**	bed	1. Main Channels d. same as above (clean, winding, some pools and shoals), but some weeds and stones	0.045		
		right bank	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left bank	3. Floodplains c. Brush 1. scattered brush, heavy weeds	0.05	weeds and some brush, includes dry ditch	
	deactivated	right floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
	deactivated	left floodplain	3 Floodplains a. Pasture, no brush 1. short grass	0.03		
Llyn Llygeirian tributary	**0011**	bed	same as 0088	0.045		
		right bank	same as 0088	0.03		
	deactivated	left bank	same as 0088	0.05		
	deactivated	right floodplain	same as 0088	0.03		

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Drain / Reach		Section	Manning's category	Manning's n	Justification	Picture
	deactivated	left floodplain	same as 0088	0.03		
Llyn Llygeirian tributary	**0000c**	bed	same as 0088	0.045		
		right bank	same as 0088	0.03		
	deactivated	left bank	same as 0088	0.05		
	deactivated	right floodplain	same as 0088	0.03		
	deactivated	left floodplain	same as 0088	0.03		

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Appendix E
Model review updates

The NRW model review (December 2016) concluded that: '…*most aspects of the Cefn Coch model configuration are sound and that results seem realistic. There are no issues that are likely to have a significant influence on results, but there are some issues which should be considered or justified before the model is considered fit for purpose (highlighted in amber). There are also a number of minor/cosmetic issues (green) which the modeller might like to address to make the model more technically correct*'.

The table below contains the amber NRW comments as referenced above. Each comment has been addressed and the table documents the Amec Foster Wheeler response to resolve the issue, along with the specific action taken to facilitate the resolution.

NRW Review Comments	AmecFW Response	Action taken
A section width check has been carried out by exporting the bank deactivation markers from the 1D river sections into GIS and this has shown that the active 1D channel (section) widths are not always consistent with the deactivated width in 2D (e.g. at nodes CAFN01_0553, CAFN01_1828, UNKN01_0088 and some others). This should be investigated and rectified, or justified, as this can cause instability and double counting/loss of volume between 1D and 2D model boundaries.	We will investigate the locations specified and the rest of the model. Where the widths do not match exactly if the difference is greater than one grid cell size this will be improved. Channel widths in TUFLOW to be checked and amended where necessary.	Model up-dated to address disparity in width between 1D channel and 2D HX lines (1d to 2d check file used to assess where difference greater than 1 cell width and MB2.dat used to inform location of high mass balance error). Included moving location of 2D hx lines between real sections, near to interpolates, therefore: 2d_bc_hxi_channel_CAFN_003.MIF replaced with 2d_bc_hxi_channel_CAFN_004.MIF hxe layer up-dated to tie in with hxi up-dates, therefore: 2d_bc_hxe_channel_CAFN_004.mif replaced with 2d_bc_hxe_channel_CAFN_005.mif Up-dated 1D model (by amending deactivation markers at some sections) to tie in with 2D changes, therefore: CAFN_BASE_035.dat replaced with CAFN_BASE_036.dat .tbc layer updated to reflect change in hxi layer, therefore: CAFN_BASE_003.tbc replaced with CAFN_BASE_004.tbc Up-dated materials commands to prioritise the buildings layer by moving reference to end of material list. Therefore: CAFN_BASE_004.tgc replaced by CAFN_BASE_005.tgc
One of the CN lines in the 2d_bc_h.xi layer connecting 1D nodes to the edge of the 2D domain has a type of "1" in the "name" column rather than the "f" column. This should be rectified, but is unlikely to make a large difference to results.		New hxi layer also corrected CN line with '1' in 'name' column to '1' in 'f' column
A 2D HQ boundary has been applied to the downstream extent of the 2D domain, split into four lines with differing gradients		The 2D HQ line was extended on right bank.

NRW Review Comments	AmecFW Response	Action taken
based on LiDAR. However, there is a gap of a cell width on the right bank which has not had one of these HQ boundaries applied, and this is the only place water is out of bank during the most extreme event (see Figure below). The HQ boundary should be extended to include this cell, and the second boundary is unnecessary. Also, on the left bank, only one of these HQ boundaries is active during the 0.1% AEP event, so the second boundary is unnecessary. PO lines could be used at these boundaries in order to check the flow across the boundaries is appropriate and whether all four lines are necessary.		
The ASC map output data types specify "ZUKO" rather than "ZUK0". ASC results have not been supplied, so it should be checked that these hazard results are appropriate if they have been used in preference to xmdf.	Acknowledged there appears to have been a typo in the model run file.	ZUK0 output command updated in respective .tcf files _007.tcf replaced by _008.tcf Updated .tcf outputs .asc and .xmdf files Updated .tcf references new .tbc and new .tgc. In addition, full report updated to reference any new 1D-2D model files created during review updates.
The MB2 map shows locally high MBEs occur on the channel banks where overtopping occurs. This could be improved by ensuring 1D and 2D channel widths match, and by using bank crests defined by the 1D survey sections.	Widths will be checked in line with earlier comment. The 1D survey was not used to force the bank heights as the LIDAR in the area was deemed representative of the bank heights as the LIDAR matched well with the survey. Forcing the LIDAR can miss local spill locations. However there are some more vegetated reaches which we will revisit.	Added a stability patch layer: 2d_mat_stability_CAFN_001.mif, between section CAFN01_1185i and CAFN01_1172 to aid with MB issue. Channel width updates, as noted above, aided the mass balance issue. MB2 analysed for 100 year event before and after updates: Before maximum MB2 was 22.067, after updates maximum MB2 is 15.148.