Flood Study Summary Report

Lands at Ballinahinch, Ashford, Co. Wicklow

M02169-01_FL01 | May 2024

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DOCUMENT FILENAME ***(internal use only)***	M02169-01_FL01 Lands At Ballinahinch, Ashford, Co. Wicklow Flood Study Report R02
DOCUMENT REFERENCE	M02169-01_FL01
TITLE	Flood Study Summary Report
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REVISION HISTORY

Rev. Ref.	**Date**	**Prep**	**Chk**	**App**	**Amendments**	**Reason for Issue**
00	24/01/2022	DC	KS	KS	Original	For Information
01	08/02/2023	KS	DC	KS	Reservoir safety section added, Wicklow CC comments addressed, minor amendments	For Information
02	28/05/2024	DH	PS	KS	Site Boundary updated	For Information

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MAPPING

CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

1 INTRODUCTION

1.1 Terms of Reference

This Flood Study Summary Report was commissioned by Wicklow County Council to summarise an investigation of fluvial (river) flooding affecting Lands at Ballinahinch, Ashford, Co. Wicklow (hereafter referred to as 'the site').

1.2 Statement of Authority

This report and assessment has been prepared and reviewed by qualified professionals with appropriate experience in the fields of flood risk, drainage, wastewater, and hydraulic modelling studies. The key staff members involved in this project are as follows:

- Duncan Chapman *BSc (Hons) PgCert* – Project Consultant with experience in the fields of flood risk assessment and flood modelling
- Paul Singleton *BEng (Hons) MSc CEng MIEI* – Chartered Civil / Environmental Engineer with particular experience in drainage, SuDS, and flood risk assessment, and a recognised industry professional having given industry training in these fields in Ireland and the UK.
- Kyle Somerville *BEng (Hons) CEng MIEI* – Associate and Senior Engineer specialising in the fields of flood risk assessment, flood modelling, drainage and surface water management design.

1.3 Purpose

The assessment is intended to establish existing flood conditions for a site to form a 'baseline' upon which future development proposals and associated planning applications may be based. This report will also determine flood zones relevant to planning policy guidelines specific to flood risk management planning and will provide a basis for appropriate design and mitigation measures to be considered as part of any future development.

The assessment and this report is intended to permit the local planning authority to agree the baseline and form a basis for any future development planning and flood alleviation planning. The assessment also addresses potential flood risk from reservoirs in the event of reservoir failure causing inundation.

This report is not a site-specific Flood Risk Assessment (FRA) and should not be read as such. Site-specific FRA reports are intended to be submitted subsequently in support of planning application(s).

1.4 Approach to the Assessment

It is understood that the project driver has arisen due to the intention by Wicklow County Council to bring forward proposals to develop land adjacent to the Varty River in Ballinahinch. There is an established history of flooding on adjacent lands coinciding with Hurricane Charlie.

Detailed flood mapping was produced for the Vartry River in Ashford as part of the Eastern CFRAM study; however, there is now significant uncertainty around the magnitude of flooding predicted by CFRAM with a tendency to underpredict flooding versus recorded flooding.

A separate work package (included in Appendix B to this report) has been undertaken to better define the contribution of flows from the Vartry Reservoirs catchment to flooding in the Vartry River.

For the purposes of this study, the following have been considered:

- Available information on historical flooding in the area;
- Site level information based on a 3rd party survey (see);
- Site observations from inspections on 3rd September 2021;
- Detailed assessment (by flood modelling) of potential flooding from rivers.

1.4.1 Hydraulic Model Status

For the purposes of this assessment, the primary stakeholders are the Office of Public Works (OPW) and Wicklow County Council (CC). OPW and Wicklow CC data is used to inform this assessment. The site and surrounding environs are included within the OPW / CFRAM, and maps of fluvial flooding produced as part of the study are included in and considered by this assessment.

Review of CFRAM model and associated maps in context of recorded flooding show a significant underestimation. This study has sought to re-model the Vartry River using existing CFRAM survey information, simulate with new flow estimates to establish a revised flood baseline. As such topographic survey data used to produce flood models has been supplied to McCloy Consulting on behalf of Wicklow CC. It is intended the revised flood baseline supersede CFRAM mapping as a basis for local development planning subject to Wicklow County Council (as local planning authority) agreement.

2 SITE SETTING

2.1 Site Location

The site is on lands at Ballinahinch, 1 km west of Ashford town in County Wicklow. The lands are adjacent to an existing housing development.

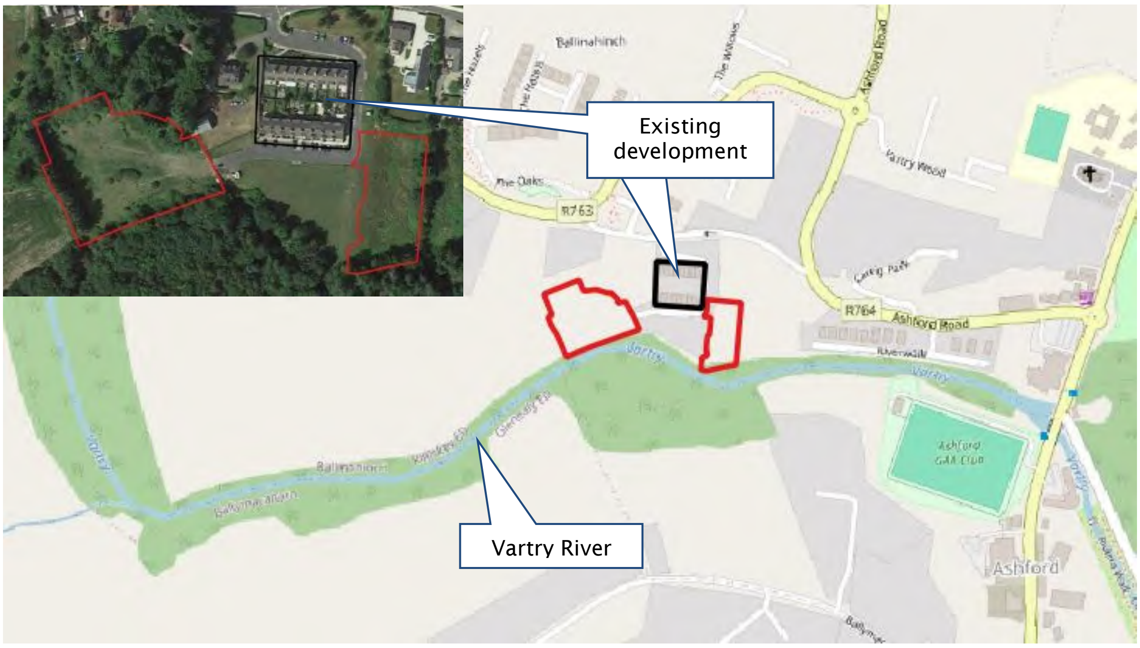


Figure 2-1: Site Location

2.2 Existing Site Description

The existing site characteristics are as follows:

- The application site comprises undeveloped land adjacent to existing residential development.
- Access is via Ballinahinch Road at the north of the site.

It is noted that the site is split into a 'western section' and an 'eastern section' but the two sections are generally referred to as 'the site' in this report.

2.3 Watercourses

The Vartry River borders the south of the site flowing from west to east. A secondary channel of the Vartry River has developed, this bypasses the bend at the site and re-joins the main channel downstream.

The main structures on the Vartry River comprise R772 road bridge and weir upstream of the bridge.

Two tributaries are noted to join the Vartry downstream of the site. These include an unnamed minor tributary upstream of Riverwalk and Ashford tributary joining the Vartry River downstream of Ashford R772 road bridge.

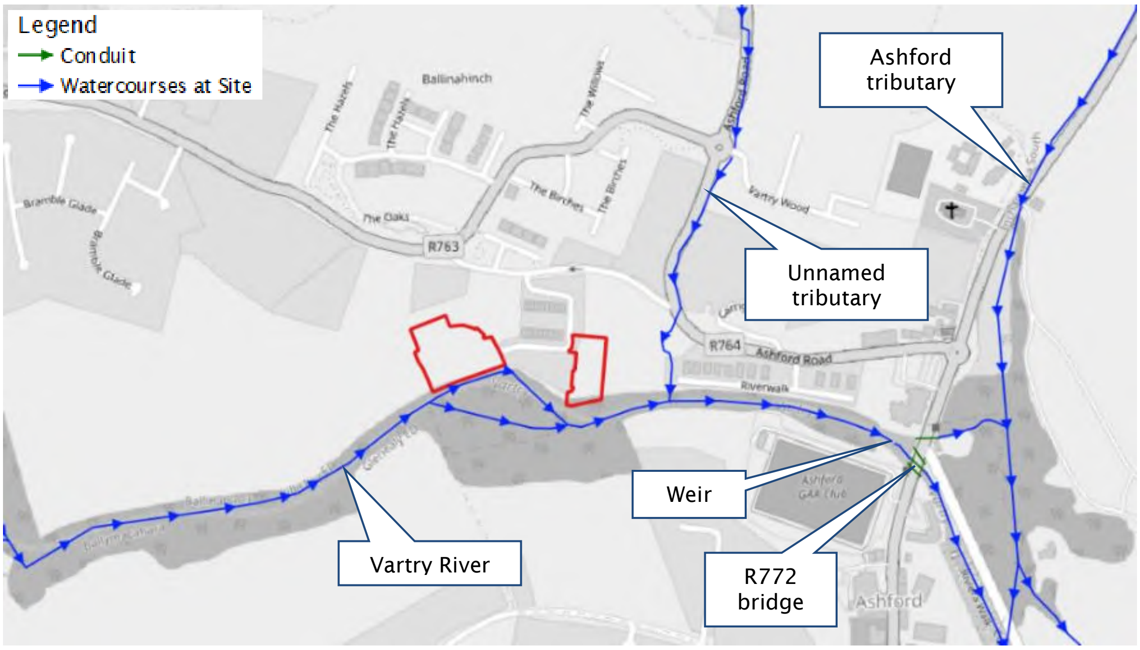


Figure 2-2: Watercourses

3 BACKGROUND INFORMATION REVIEW

As part of the study data collection phase, a number of available sources of information generally as set out in the Planning Guidelines was investigated in order to build an understanding of the potential risk of flooding in the site.

The following review highlights the key findings of the background information review.

3.1 OPW Flood Hazard and Risk Maps

The main source of data to identify flood risk on the River Vartry system is the Eastern Catchment Flood Risk Assessment and Management Study (Eastern CFRAM). The Eastern CFRAM study commenced in June 2011 and was concluded at the end of 2016.

This study included detailed hydraulic modelling of the Vartry River and its tributaries as shown in Figure 3-1. This screenshot from Eastern CFRAM HA10 Hydrology Report shows model extents and key Hydrological Estimate Points (HEPs) along the Vartry River and associated tributaries.

The Vartry River was modelled from Devil's Glen Wood in the west, through Nun's Cross to Ashford town and extends to Broad Lough at downstream extent of the model. Topographic survey was collected as part of this commission in November 2012 and was made available to Wicklow CC for use this in this study.

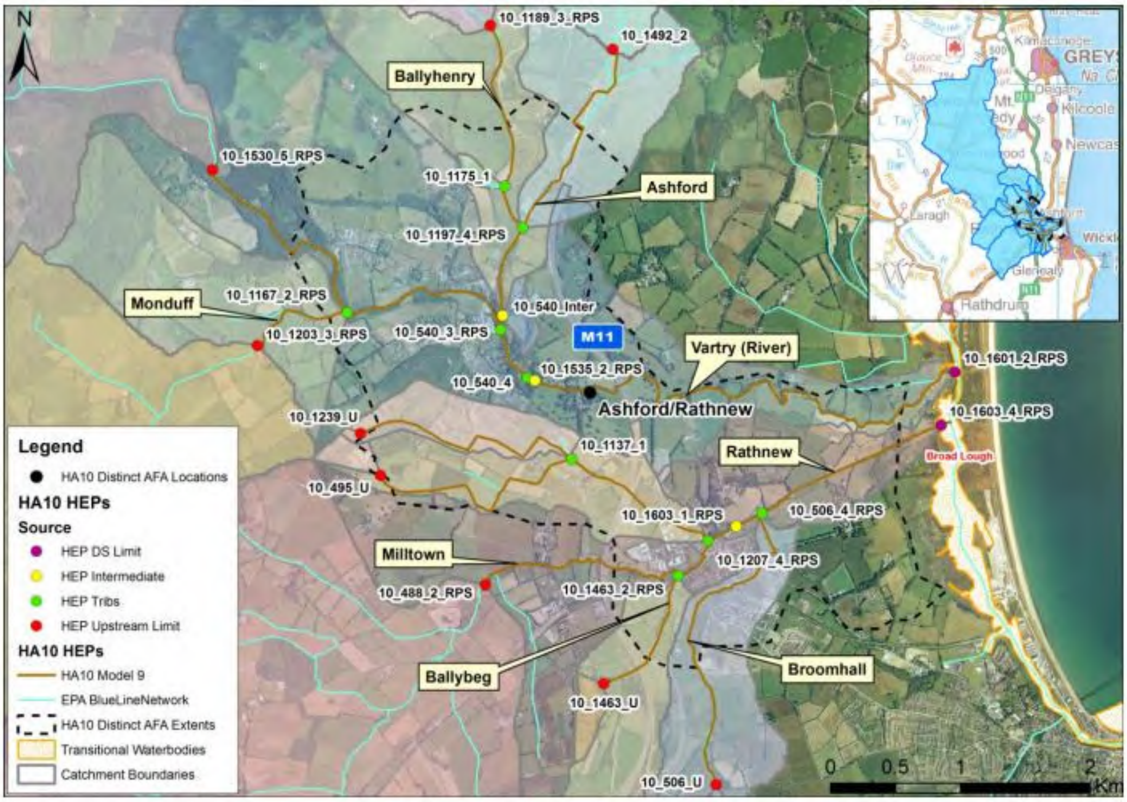


Figure 3-1: CFRAM model extent and HEPs

The associated flood maps have been used to inform the initial stages of this flood study. An extract from the above referenced flood map is shown in Figure 3-2. Copies of the original CFRAM maps are included in Appendix A.

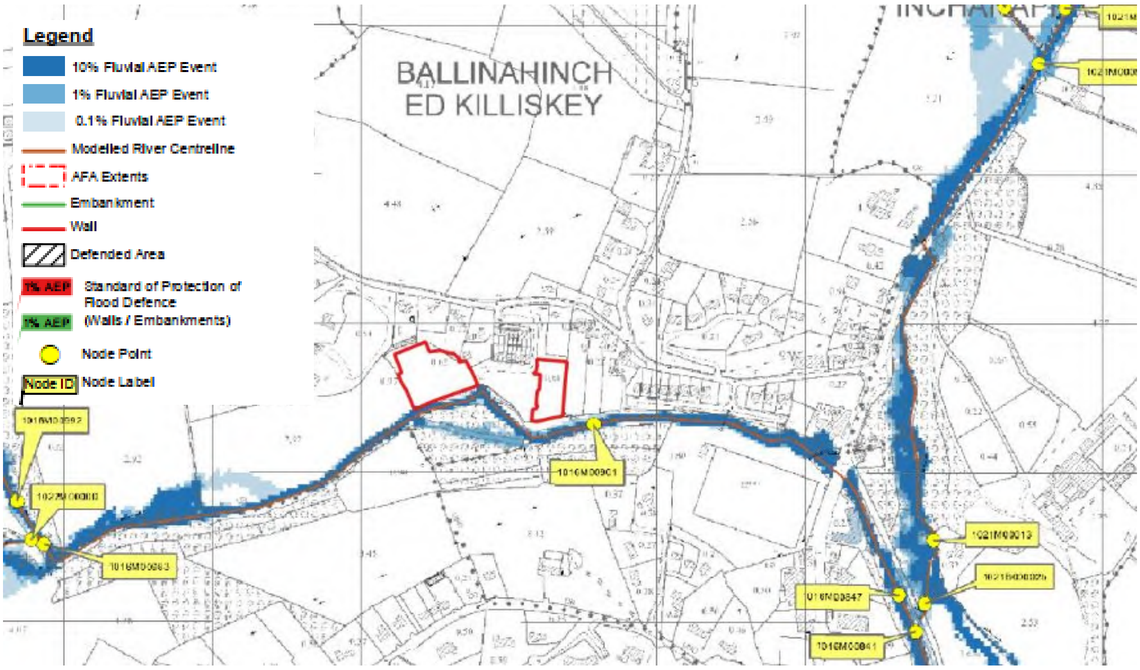


Figure 3-2: Extract from Eastern CFRAM Flood Mapping

3.2 SSFRA for Lands at Ballinahinch

A site-specific flood risk assessment (SSFRA) was carried out by JBA Consulting on behalf of Wicklow County Council in 2016 for the area of lands under investigation in this report. As part of this Wicklow CC provided JBA Consulting with photographs and information from flood records for Hurricane Charlie. This has been reviewed with key analysis presented.

3.2.1 Hurricane Charlie – JBA Analysis

- Hurricane Charlie first appeared as a tropical storm off the coast of South Carolina on Friday 15th of August 1986. The storm moved over Wicklow and Dublin which endured the worst of the storm over the night of the 25^{th} / 26^{th} August.
- JBA interviewed a local engineer, and it was his understanding that the area was very under developed compared to its current condition and there had been a changed hydro – morphology. He remarked that the flooding in 1986 had been exacerbated due to a blockage to the road bridge at Ashford House from a section of wall blown into the river. He noted that the bridge has since been replaced with a higher clearance unit.
- JBA reviewed Met Eireann records and estimated the storm to generate flows between a 1% AEP - 0.1% AEP
- JBA analysed photographs from the event provided by Wicklow County Council and annotated the CFRAM mapping to show the areas that would likely have flooded during the storm (Figure 3-3).
- Photographs from Hurricane Charlie suggest that the CFRAM representation is not appropriate for the1% or 0.1% events and show a significant underestimation in estimated flows.

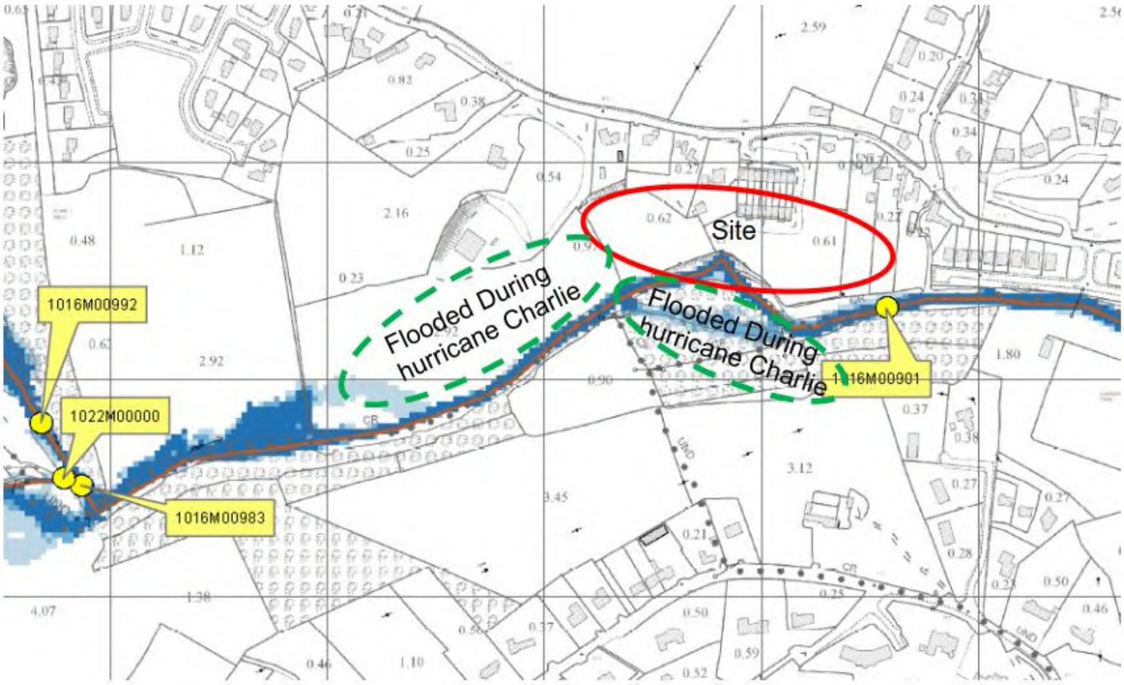


Figure 3-3: Annotated extract from Eastern CFRAM Flood Mapping (JBA Consulting, 2016)

3.3 Internet /Media / Background Search

A media search within the site found no evidence of flooding other than that stated at Hurricane Charlie.

The main change downstream of the site was noted to Ashford weir which was reported to have been badly damaged by Storm Frank in December 2015[1] and was in disrepair until the date of newspaper article (1st September 2018). The weir was observed in September 2021 and found to be partly instated.

3.4 Walkover Survey

A walkover survey was conducted by McCloy Consulting on 3rd September 2021 for purposes of site familiarity and to note structures along the watercourse.

[1] Fundraising efforts to fix Ashford weir - Independent.ie [accessed 28th May 2024]

4 DETAILED FLUVIAL FLOOD ASSESSMENT

4.1 Preamble

The main flood mechanism established by the existing CFRAM and history of flooding in the area is fluvial flooding from the Vartry River. The following assessment therefore seeks to consider in further detail fluvial and overland flooding in the site.

In order to provide a revised flood baseline in the vicinity of the site, a location-specific detailed 1D-2D model (referred to in this report as the “McCloy model”) has been developed for the area using InfoWorks ICM software (version 2021.5). ICM solves full two-dimensional depth averaged shallow water equations to produce a virtual representation of flow paths, velocities, volumes and depths. The river channel and structures have been represented in 1D, while the floodplain / overland flow path has been represented in 2D.

The modelling approach is summarised as follows:

- The watercourses and structures have been modelled using detailed topographic river survey from CFRAM study, dated November 2012. This was reviewed relative to site observations and has been determined to be fit for purpose. The weir at Ashford has been damaged since the survey was carried out (Storm Frank in 2015) but was deemed far enough downstream to not impact water levels at the site. This was tested in the hydraulic model and is discussed in detail later in this report at Section 4.2.
- The natural floodplain has been modelled as a 2D meshed ground model, to allow the accurate representation of out of bank flooding and the resulting overland flow routes. Terrain is based on OSI LiDAR data and ground-based topographic survey in areas of greatest interest.
- Design flows for the 1% AEP and 0.1% AEP events have been calculated based on combining estimates from:
    - Flows calculated form Vartry reservoir catchment refer to *M02169_TN01 Reservoir Routing Model Technical Memorandum* (Appendix B)
    - Flows calculated for intervening area to the site using OPW FSU methodologies (discussed in detail in this report)

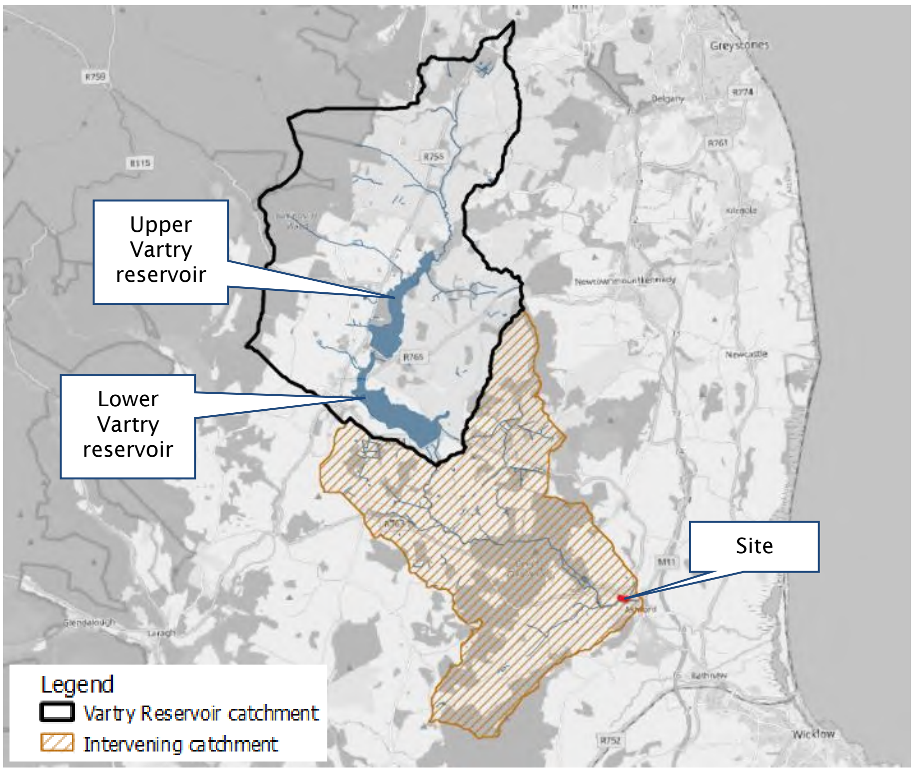


Figure 4-1: Hydrology – Catchment Contribution

4.2 Model Geometry

4.2.1 1-Dimensional Surface Model Areas

4.2.1.1 Watercourses

The site has potential to be affected by flooding from the Vartry River. The main channel at the south of the site has been modelled with secondary channel represented in 2D. Other tributaries downstream of the site have not been modelled as the primary flood mechanism is from Vartry River.

In order to inform the development of the McCloy model for the area, CFRAM survey was obtained from OPW on behalf of Wicklow County Council. This was reviewed in context of any changes post November 2012. The Ashford weir was reported to be partly washed away in December 2015 and current conditions (September 2021) show similar (Figure 4-2).

Given the CFRAM geometry show the weir fully in situ, a model scenario was simulated to represent the weir as per present day conditions (partly removed). This was shown to reduce water levels upstream local to the weir but caused no change to predicted water levels at site for the maximum flood magnitude considered by this assessment (0.1% AEP). As such this geometry was taken forward to be used for baseline.

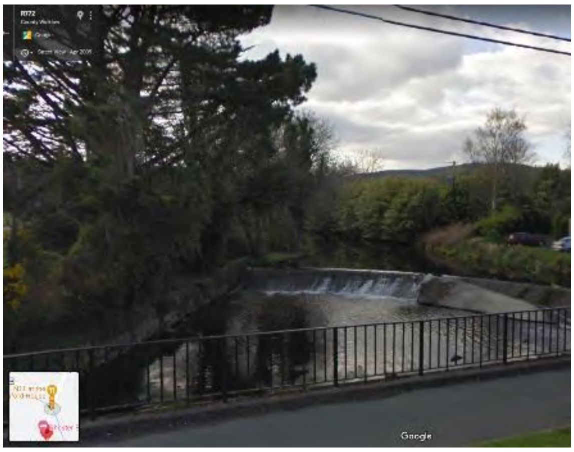
Photo taken April 2009 (Google, 2021)	**Photo taken Sept 2021 (Site Visit)**
	

Figure 4-2: Ashford weir 2009 vs 2021

The CFRAM survey included cross section data at approximately 50 m spacing. The cross-section data was incorporated into the model as a 1D river reach, with the 1-dimensional river network shown on Figure 4-3.

The model extends approximately 200 m upstream of the site where the channel is incised and there is limited out of bank flooding. The model extends 150 m downstream of Ashford bridge to ensure that there was sufficient drop in levels from the site.

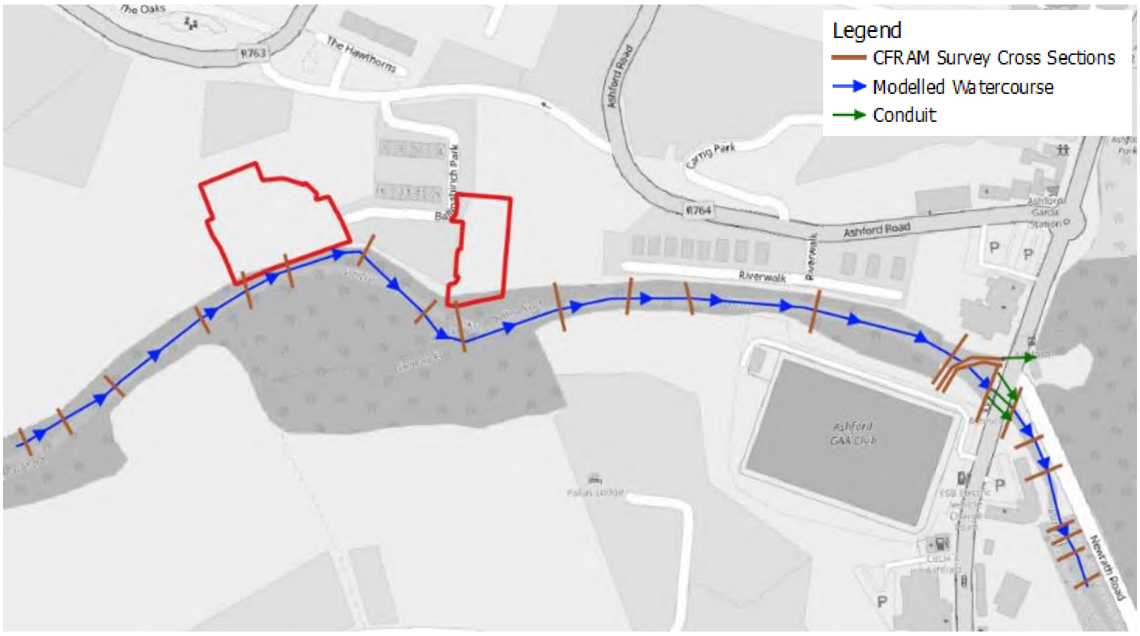


Figure 4-3: Modelled Watercourse

4.2.1.2 Structures

The Ashford road bridge and upstream weir are the only structures within the modelled reach (Figure 4-4). Structure details have been derived from the CFRAM river survey. The weir has been modelled as per present day conditions with approximately 50% of the crest lowered to reflect the portion of the weir that has been washed away.

Ashford bridge comprises of 3 openings in the main channel and a small opening from the leat offtake from upstream of the weir. The leat then flows towards the Ashford tributary but for simplification in the model, a 2D downstream boundary was applied allowing water to be released from the model based on standard channel slope. Details are presented in Table 4-1 below.

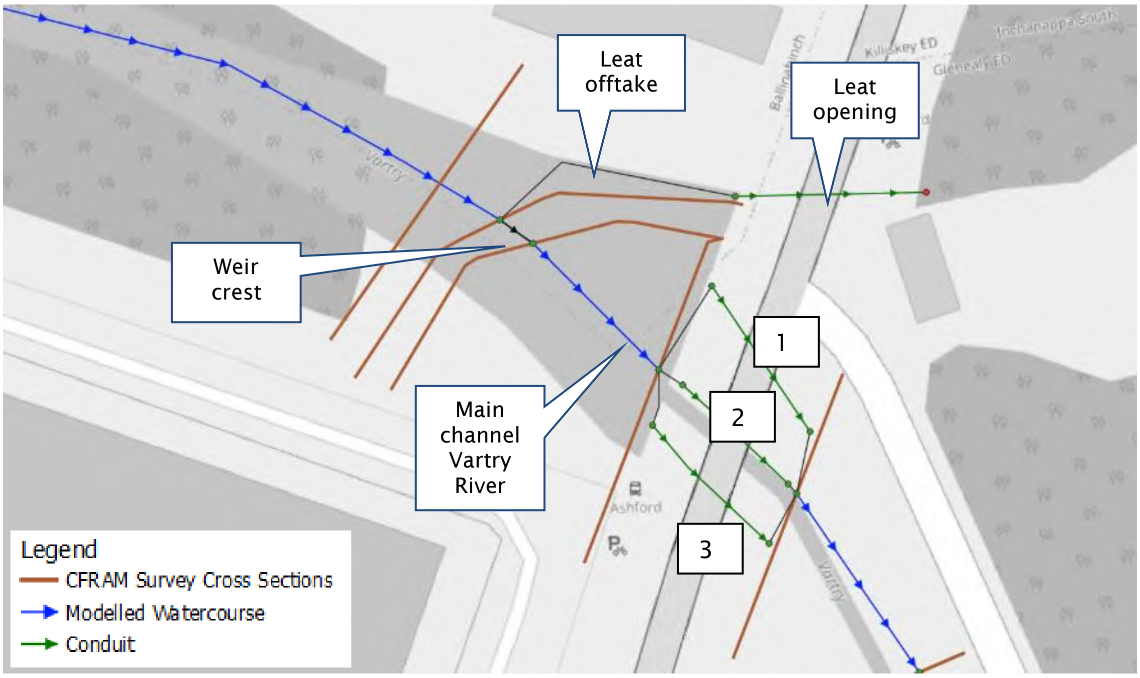
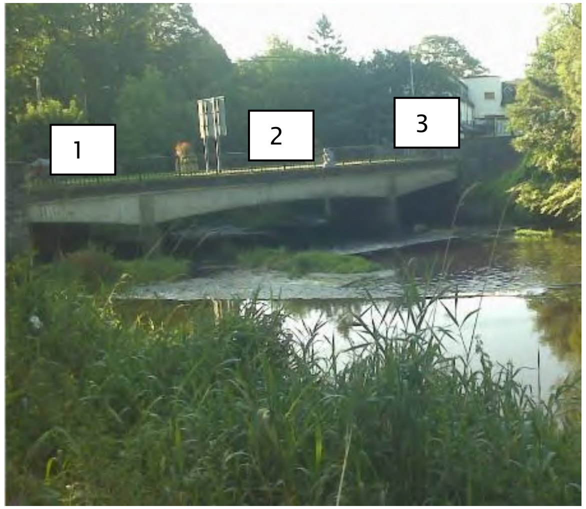


Figure 4-4: Modelled Structures

Table 4-1: Structure Register

<table>
<tr><th>Location</th><th>Photograph</th><th>Detail</th><th>Comment</th></tr>
<tr>
<td>Ashford Road bridge – main channel</td>
<td>
</td>
<td><u>Opening</u>
3 openings
Shape: Rectangle
Dimensions
<table>
<tr><th></th><th>Width (mm)</th><th>Height (mm)</th><th>U/s invert (mOD)</th><th>D/s invert (mOD)</th></tr>
<tr><td>1</td><td>4680</td><td>2370</td><td>16.360</td><td>15.792</td></tr>
<tr><td>2</td><td>13280</td><td>2310</td><td>16.360</td><td>15.792</td></tr>
<tr><td>3</td><td>4910</td><td>2420</td><td>16.460</td><td>15.792</td></tr>
</table>
Roughness (Top): 0.015 and (Bottom): 0.04</td>
<td>Size of conduit applied as per captured survey detail.
Given uneven shape, the height was calculated based on the width and opening area.
Roughness for bed as per river channel with top roughness applied as per conduit material, concrete.</td>
</tr>
<tr>
<td>Ashford Road bridge – leat opening</td>
<td></td>
<td><u>Opening</u>
1 opening
Shape: Arch
Width: 2160mm
Height: 1490mm
Upstream invert (mOD): 18.140
Downstream invert (mOD): 18.050
Roughness (Top): 0.015 and (Bottom): 0.04</td>
<td>Size of conduit applied as per captured survey detail.
Roughness for bed as per river channel with top roughness applied as per conduit material, concrete.</td>
</tr>
</table>

4.2.1.3 Roughness Values

A Manning's n roughness value of 0.04 is used for the river reach in channel and 0.06 for banks based on visual observations during the walkover survey.

Structure roughness values are based on material which was noted to be concrete in all cases based on topographic survey records and ground truthing during walkover surveys. A Manning's n roughness of 0.015 was selected.

4.2.2 2-Dimensional Surface Model Areas

4.2.2.1 Topography

A terrain model was generated to represent the topography of the wider area, primarily defined using 2 m resolution LiDAR data licenced by Ordnance Survey Ireland for use in the project. The LiDAR data in grid format is utilised as the surface used for the base conditions of the model.

The LiDAR data terrain is supplemented with detailed topographic survey data within the site to create a combined surface which includes improved definition in the vicinity of the areas of interest and within the watercourses.

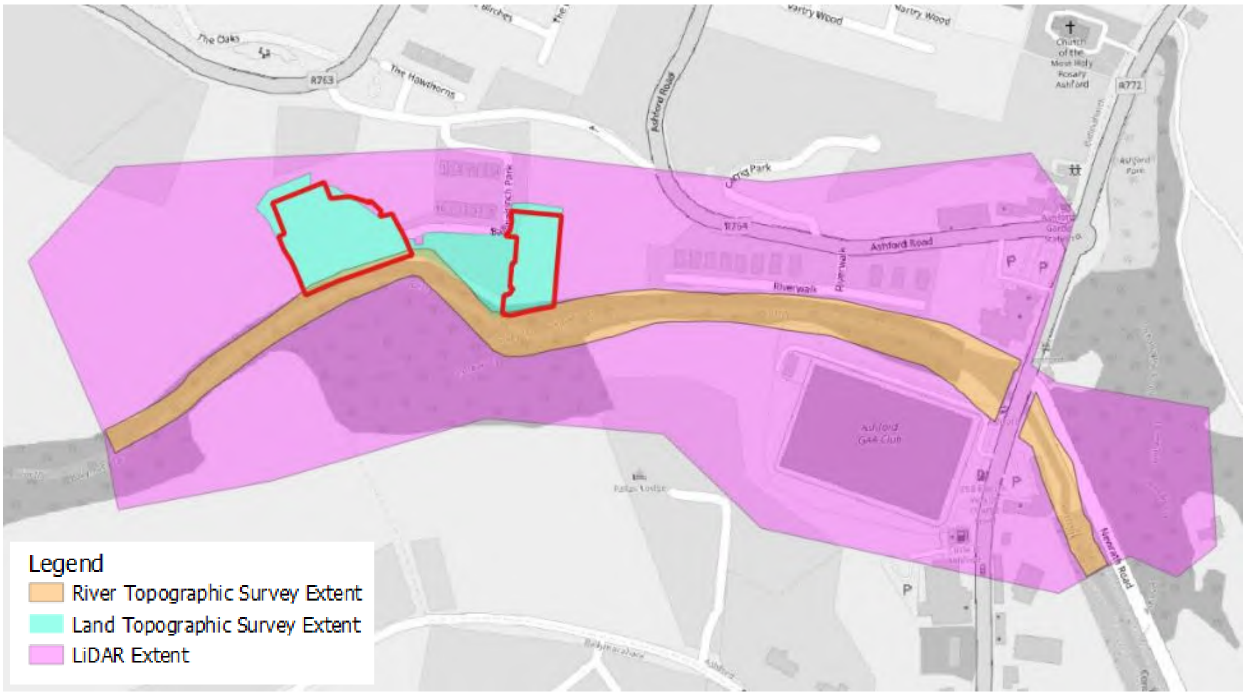


Figure 4-5: Height Data Sources

4.2.2.2 2D Zone

The composite terrain model was used to create a ground model in InfoWorks ICM, and subsequently converted into a 2D mesh. The 2D zone has a maximum triangle size of 5 m^2.

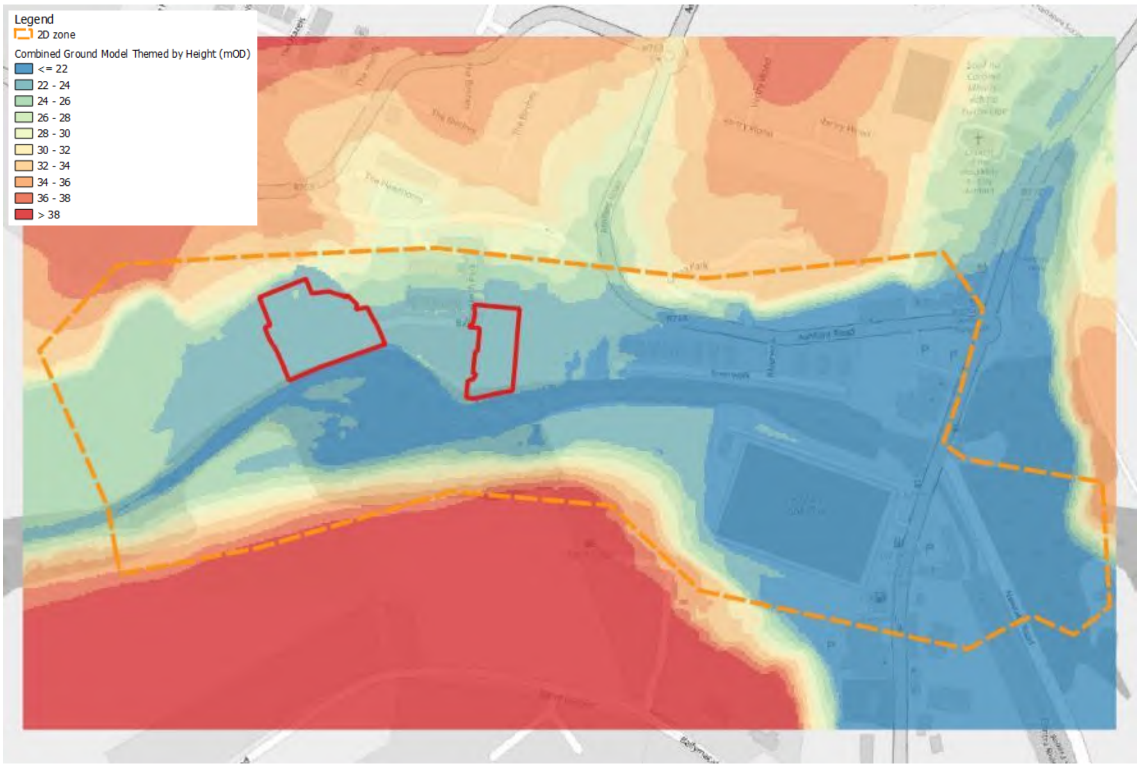


Figure 4-6: Model 2D Domain

4.2.2.3 Boundary Conditions

Boundary conditions for the edge of the 2D surface area have been set to normal depth. The 2D surface has been sized conservatively to ensure that the boundary condition is of sufficient distance from the areas of interest so as not to have an impact on flood levels. The 2D zone is extended sufficiently that water does not leak off the edge of the 2D zone in areas of broad floodplains.

4.2.2.4 Roughness Values

Manning's n roughness values have been applied to the 2D zone with a value of 0.05 to represent the area of which water would flow, which predominantly comprises of green open space. Roughness zones with Manning's n roughness of 0.1 were added to represent wooded areas of floodplain. Refer to Figure 4-7.

Figure 4-7: Roughness applied in 2D

4.3 Hydrological Assessment

The estimation of peak flow for the required design annual probability has been necessary to determine the peak inflow and hydrograph for input to the hydraulic model. A conservative approach has been adopted for the hydrological analysis.

4.3.1 Overview

The 1% and 0.1% AEP design flows have been calculated based on combining estimates from:

- Flows calculated from Vartry reservoir catchment
- Flows calculated for intervening area to the site using OPW FSU methodologies

Figure 4-1 shows the extent of both catchments, each component is considered in detail below before considering how the estimates were combined to provide a hydrograph for input to the hydraulic model.

4.3.2 Reservoir catchment

The hydrological catchment contributing to the Vartry reservoir system has been derived using a geospatial analysis tool using OSI 10 m DTM as 52.9 km^2 as shown in Figure 4-8.

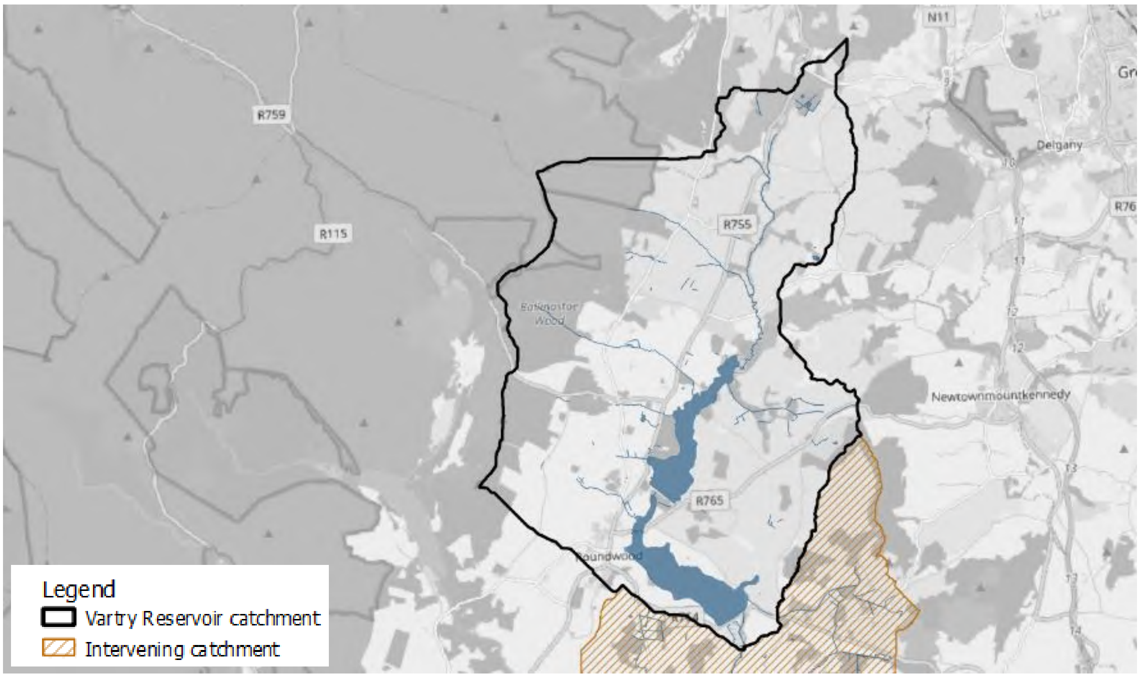


Figure 4-8: Reservoir Routing Catchment

A reservoir routing model fed by direct rainfall was developed to derive peak flows for this catchment. The accompanying *M02169_TN01 Reservoir Routing Model Technical Memorandum* (Appendix B) describes in detail how the peak flows were derived.

The final flows are noted in Table 4-2.

Table 4-2: Final flows calculated from reservoir routing model

Fluvial Flood Probability	Peak flow (m^3/s)
1%AEP	79.79
0.1% AEP	101.67

4.3.3 Intervening flows

Intervening flows have been calculated using an FSU method by the following steps:

- Deriving flow estimate to Ashford (downstream of site) and editing physical catchment descriptors in the FSU dataset to reflect a catchment with no reservoir influence (FARL =1.00)
- Deriving flow estimate to outflow of Lower Vartry
- Subtracting Ashford estimate from Lower Vartry estimate
- Scaling intervening flow to match catchment derived from geospatial tool

4.3.3.1 Hydrological Estimation Points

The 1% AEP and 0.1% AEP event peak flows were determined using the OPW Flood Studies Update (FSU) method. The FSU method is the recommended method of rainfall and flow estimation in Ireland and has been developed to supersede the Flood Studies Report (FSR) method.

No gauged catchment data is available for the modelled watercourse and the flow derivation therefore is based on ungauged locations. The two FSU nodes / "extraction points" used to obtain design flows for Ashford and Lower Vartry estimate are indicated on Figure 4-9.

Figure 4-9: OPW FSU Flow Extraction Point

An ungauged statistical method was carried out for each HEP, a worked example is provided for Ashford estimate (10_1471_3) below:

- QMED – for the purposes of FSU, the Vartry River is ungauged, QMED was derived from catchment descriptors using the 7-variable equation. This is the recommended method for most Irish catchments. Using the FSU 7 variable method via source spreadsheet method outside the FSU portal, the FARL parameter was edited from 0.805 to 1.00 to reflect a catchment with no reservoir influence as the purpose was to calculate flows from intervening catchment.

  QMED from catchment descriptors was shifted upwards based on the most hydrologically similar pivotal site (19020 Ballyedmond catchment).

  This pivotal site had good correlation with the subject site for BFISOIL and SAAR PCDs. It was noted that FARL was equal to 1 which contrasted to the original subject site but was deemed appropriate given the aim to estimate flows from intervening area.

  QMED was calculated from the full record based on the Euclidean scheme. The final uplift factor of x1.38 was applied.
- Growth factors – standard FSU pooled analysis conducted. A pooling group has been derived from 77 hydrometric stations based on similarity of three FSU catchment descriptors (AREA, SAAR and BFI) between subject site and donor site.
- The GLO distribution was fitted to the pooling group and used to derive the growth factors up to 0.1% AEP. This was the same distribution used to estimate flows for CFRAM so was deemed appropriate.

The flow estimates for the two HEPs and calculated intervening flows is presented in Table 4-3 below. A summary of OPW FSU portal outputs is included in Appendix C.

Table 4-3: Flow Estimates for HEPs

HEP	Comment	Area (km^2)	QMED 50% AEP (m^3/s)	1% AEP (m^3/s)	0.1% AEP (m^3/s)
10_1216_1	Lower Vartry	56.14	6.17	11.29	15.00
10_1471_3	Ashford	90.19	24.63	45.07	59.85
N/A	Intervening	34.05	18.46	33.78	44.85

4.3.3.2 Scaling flows to match geospatial tool

The hydrological catchment contributing to the Ashford has been derived using a geospatial analysis tool using OSI 10 m DTM and subtracted from the upstream reservoir catchment (Figure 4-8) to derive the intervening catchment (39.64 m^2) as shown in Figure 4-10.

This catchment is 5.59 km^2 larger than the FSU counterpart, this can be explained by exclusion of tributary to the north, the Ballyduff stream in FSU catchment. The Ballyduff stream has been artificially diverted to flow into the Lower Vartry reservoir against the existing topography accounting for 3.9 km^2 catchment. This stream was excluded from the reservoir model due to in sufficient data to represent so it is essential to be accounted for in this calculation.

The additional 1.69 km^2 is due to larger extents in geospatial tool compared to FSU catchment in the west where additional tributaries join, these have been checked and verified against background mapping and taken forward as it ensures a precautionary approach.

The flows from Table 4-3 were therefore multiplied by scaling factor x1.16, the final flows are presented in Table 4-4.

Table 4-4: Final Flows calculated from Intervening Catchment

1% AEP (m^3/s)	0.1% AEP (m^3/s)
39.33	52.22

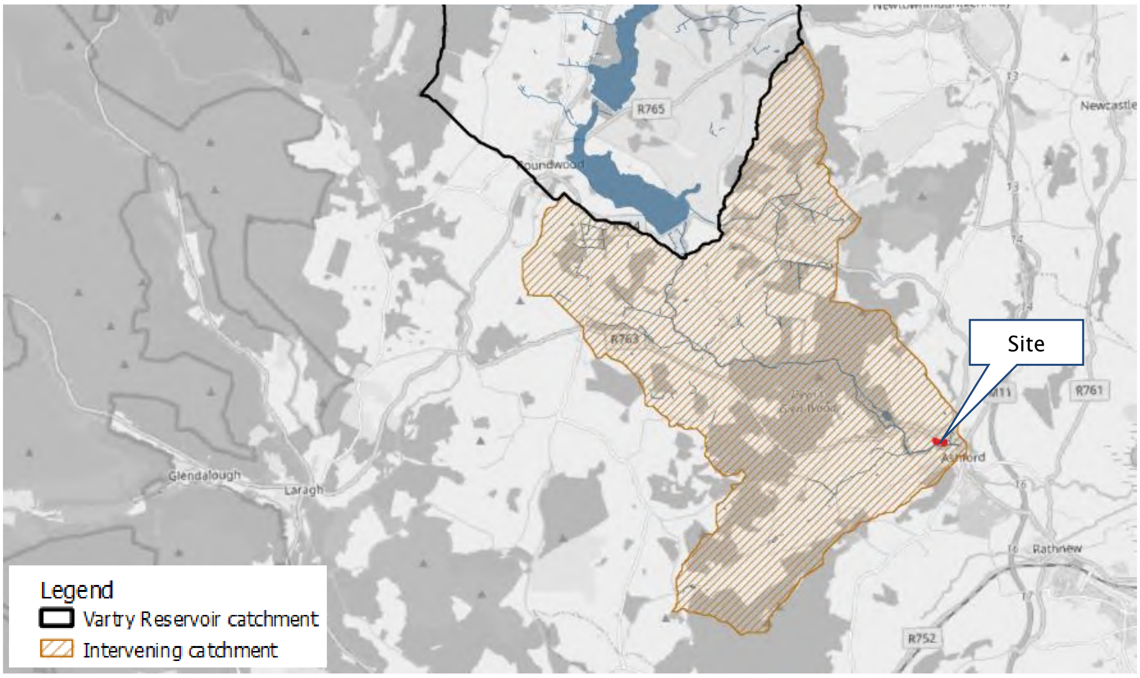


Figure 4-10: Intervening catchment

4.3.4 Combined flows

4.3.4.1 Summary

Peak flows from reservoir routing and intervening catchment were combined as shown in Table 4-5.

Table 4-5: Final combined flows

1% AEP (m^3/s)	0.1% AEP (m^3/s)
119.12	153.89

4.3.4.2 Hydrograph shape

The hydrograph shape for input to the unsteady hydraulic model was derived from review of flow series at Mount Usher Gardens gauging station downstream of the site. This Irish Water gauge converts levels to flows using a rating curve that was assumed fit for purpose. Further details are provided in the *M02169_TN01 Reservoir Routing Model Technical Memorandum* (Appendix B)

The largest flow on record from 30th January 2021 with peak flow of 36.2 m^3/s was scaled upwards to derived hydrographs for 1% and 0.1% AEP.

This approach assumes the response from reservoir routing model and intervening catchment are instantaneous, to understand if this is warranted, the response at the Mount Usher gauge was compared to Vartry gauge for the 30th January 2021 event (Figure 4-11). A four- and half-hour delay was noted between the peaks which suggests the reservoir attenuates the flow whilst the intervening catchment responds quicker.

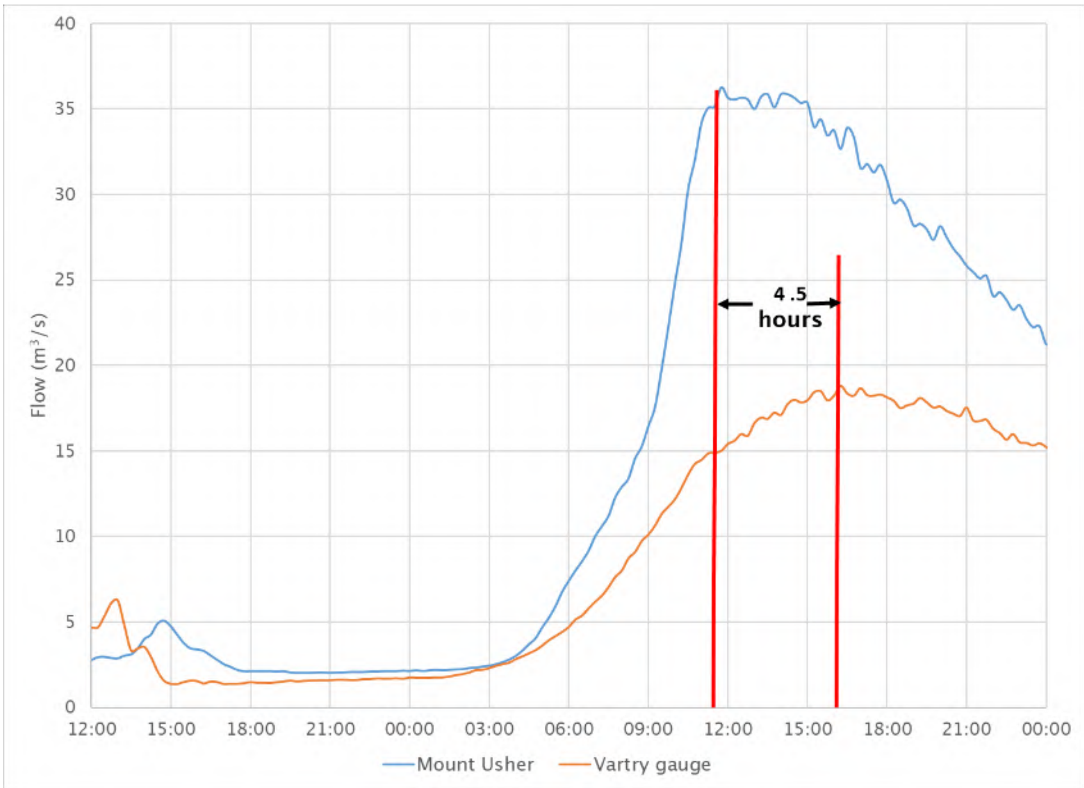


Figure 4-11: Comparison of Vartry and Mount Usher gauge for Jan 30th event

To understand if this would have an impact on peak flows, two scenarios were created for 0.1% AEP:

- Instantaneous: response from reservoir routing and intervening peak at same time and hydrographs combined
- Delayed: response from reservoir routing model delayed by 4.5hrs after response from intervening peak and hydrographs combined

As shown in Table 4-6 and Figure 4-12, there is negligible increase to peaks flow in instantaneous response compared to delayed response circa 3% larger flows. These were tested in the hydraulic model and shown to have no impact on modelled water levels at the lands of interest.

To ensure a precautionary analysis, the instantaneous scenario was taken forward for use in design events.

Table 4-6: Comparison between Flows derived from Instantaneous and Delayed Response for 0.1% AEP

Scenario name	Peak flow (m^3/s)
Instantaneous	153.89
Delayed	149.41

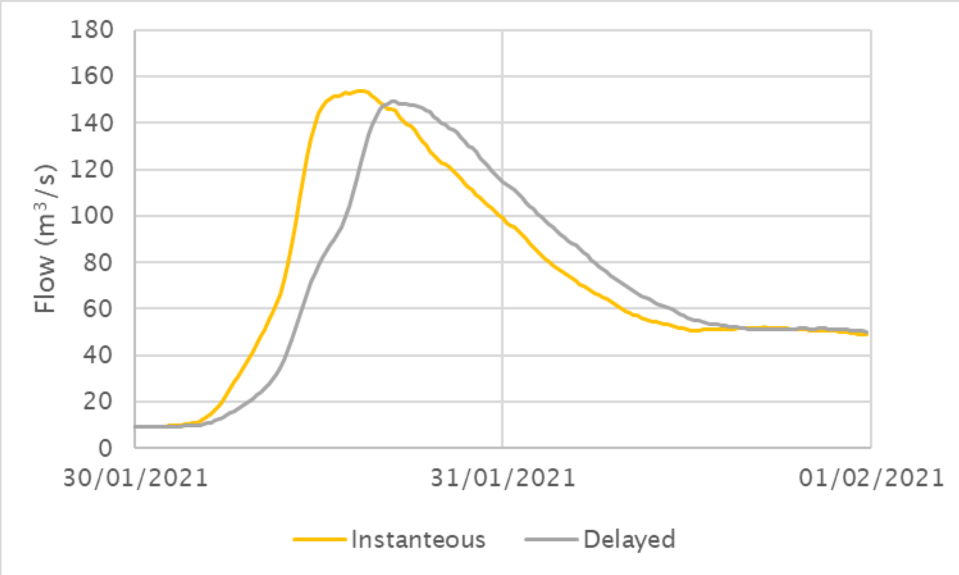


Figure 4-12: Comparison between hydrograph derived from instantaneous and delayed response for 0.1% AEP

4.3.4.3 Application to the model

In summary the hydrograph shape was derived from largest observed flow at Mount Usher and scaled to the design flows from Table 4-5. To prevent instabilities being introduced into the model, the hydrograph (used to uplift flows) was smoothed using an exponential smoothing algorithm (Figure 4-13).

Flows were applied as a lump inflow to the upstream extent of the model due to the small increases in catchment area along the modelled reach. The application of flows derived for the downstream hydrological estimation point at the upstream extent of the modelled reach ensures a precautionary and conservative analysis.

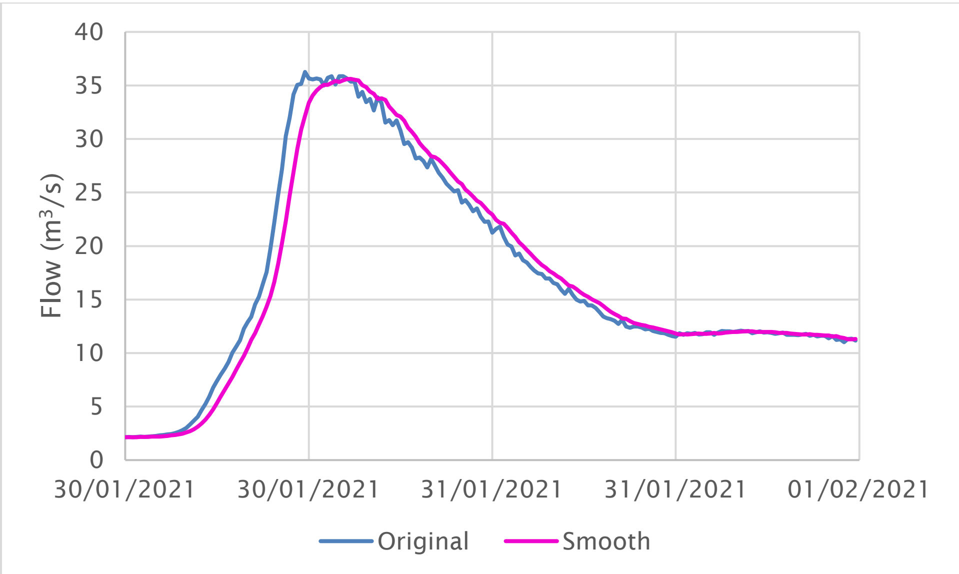


Figure 4-13: Largest Observed Flow Hydrograph at Mount Ushers Gauge: Original v Smooth

4.4 Model Stability

A number of parameters were checked to assess the model stability.

- The mass balance is considered to give an indicator of model stability and relates to the flow entering and leaving the model. The mass balance value for the 1% and 0.1% AEP events was below 1%, which is well within acceptable tolerances.
- The Froude number of each river reach was reviewed. River reaches with an unusually high Froude number were investigated in further detail, to determine if any geometry issues were causing a high Froude number, with amendments made where required.
- A review of stage hydrographs was undertaken across the model to locate any significant spikes in graphs that would suggest issues with model stability. A review of graphs indicated that the model exhibited no abnormal stage variations that would tend to indicate a model instability.

A review of the above parameters indicates that the model is stable, allowing a substantial degree of confidence in model outputs.

4.5 Model Verification

Limited historical flood data was available for detailed model verification; however, the model was verified against observed records of flooding from Hurricane Charlie.

JBA reviewed photographs from the Hurricane Charlie and annotated the CFRAM map to indicate areas flooded during the hurricane (refer to Section 3.2.1). Modelled results have been overlaid on their annotated map to see if the model can replicate similar flood extents for the 1% AEP and 0.1% AEP. A different shading has been used to distinguish the model results from the underlying CFRAM results.

For the 1% and 0.1% AEP, the model replicates flooding to lands observed during Hurricane Charlie both on the left and right banks. On the left bank, the 1% AEP is shown to be contained within the recorded flooding zone up to the boundary of the site. This contrasts to the 0.1% AEP where flooding is shown to extend further on the left bank than observed leading to flooding within the lands of interest.

This was deemed appropriate given rarity of the event, JBA estimated Hurricane Charlie to generate flows between the 1% and 0.1% AEP. It is therefore plausible that the 0.1% AEP could generate flooding larger than shown in Hurricane Charlie. Overall, the model has shown to replicate flooding from an observed event which builds confidence in its modelled predictions.

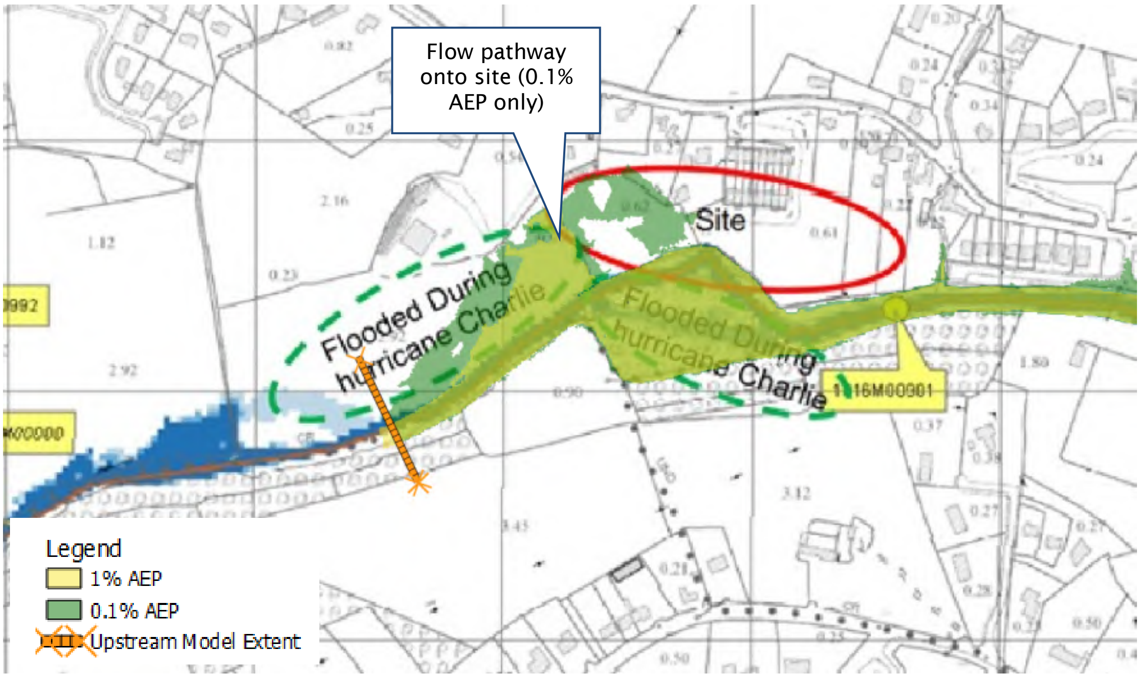


Figure 4-14: Modelled Vs Observed Flood Records

4.6 Sensitivity

Model sensitivity analysis was carried out to assess the sensitivity of the simulation to changes in base parameters. The sensitivity testing makes comparisons to the base model and was carried out for the 1% AEP fluvial event consistent with CFRAM.

4.6.1 Sensitivity to Roughness

The sensitivity of the modelled water levels to channel and floodplain roughness was assessed by varying the standard values of Manning's n for the base model.

Increasing the roughness value of the river reaches by 20% causes a maximum increase in flood level of 0.27 m and average of 0.21 m across the extent of lands of interest. The model is sensitive to changes in 1D roughness model output with new flow paths developed to the west of the site. Flooding is shallow reaching a maximum depth of 0.1 m.

Increasing the roughness value of the 2D Zone by 20% causes an increase in flood level of 0.02 m.

It is therefore considered that the model is more sensitive to river roughness values than 2D Zone roughness values, but the sensitivity is generally within acceptable limits and would not cause the ultimate finding of the model to be unreliable. Careful consideration has been given to conservatively specifying Manning's n values and there is therefore reasonable confidence in model results.

4.6.2 Sensitivity to Downstream Boundary Condition

Default boundary conditions are set as normal flow depth, which estimate depth of water as a function of roughness and slope. The sensitivity of the modelled water levels to downstream boundary condition was assessed by artificially increasing the downstream water level of the watercourse.

In order to investigate the potential effect of the model downstream boundary, the downstream boundary level has been increased by 0.5 m. The increase in water levels is localised and extends to the downstream extent of Ashford bridge where there is an increase of 0.08 m. Upstream of this location, water levels equalize showing that the bridge and weir act to control water levels.

It is therefore apparent that the model at the site is not sensitive to the downstream boundary condition. Careful consideration has been given to siting the downstream model extent sufficiently downstream so as not to cause an impact on flood levels in the vicinity of the site.

4.6.3 Sensitivity to Flow

The design flows were derived using best industry techniques and the most conservative flows were selected and there is therefore reasonable confidence in the results. In order to determine the effect of underestimation of flows on the model and what could be expected if an extreme event were to occur, the flows in the model have been increased by 20%. The hydrograph length / shape is unchanged and there is therefore an overall increase of mass within the model.

Increasing the flow by 20% causes a maximum increase in flood level of 0.29 m and average of 0.24 m across the site. The model is fairly sensitive to increases to flow with new flow paths developed to the west of the site. Flooding is shallow reaching a maximum depth of 0.15 m.

4.6.4 Sensitivity Analysis Summary

The results of the sensitivity analysis are generally within acceptable limits and the sensitivity analysis has demonstrated that the model can be deemed reliable.

4.7 Assumptions and Limitations of Modelling

The representation of any complex system by a model requires a number of assumptions to be made. In the case of the hydraulic model developed for the purposes of the study it is assumed that:

- The terrain model (based on LiDAR and topographical survey information) accurately represents the surface topography and associated flow paths.
- The design flows are an accurate representation of flows of a given return period.
- Roughness does not vary with time.

The primary limitations of the study are noted as follows:

- Sewerage and culverted surface water drainage has not been modelled.
- No allowance for infiltration has been made within the model.
- The model does not represent any topographic features smaller than the minimum resolution of the underlying terrain model derived for the site.

5 FLUVIAL MODEL RESULTS

5.1 Introduction

Model results are presented for baseline flood zones and the mechanisms of flooding are discussed in detail including comparison with CFRAM results and culvert blockage / climate change.

5.2 Baseline / Flood Zones

An extract from the existing scenario, present day Flood Zone Map is shown in Figure 5-1.

It has been determined that the 1% AEP (Flood Zone A) event causes slight flooding within the site along the western boundary of the 'western section'. For 0.1% AEP (Flood Zone B), approx. half of the 'western section' is shown to be flooded. The 'eastern section' of the site is not affected by flooding in either event. The main mechanism of flooding to is driven by overtopping of left bank upstream of the site leading to progression of flows overland. For the 1% AEP, these are contained to the western site boundary due to a low bund that exists around the lands of interest leading to water returning to the Vartry River. For the 0.1% AEP, the overland flow pathway progresses onto the site via a low spot to the north of bund.

It was noted that the topographic survey on the site has limited definition in the area where the flow pathway progresses onto the lands of interest.

Figure 5-1: Flood Zones A and B

5.3 Comparison with CFRAM

As stated throughout this report, there is significant uncertainty around the magnitude of flooding predicted by CFRAM with a tendency to underpredict flooding versus recorded flooding.

As shown in Figure 5-2, modelled results have been compared to the CFRAM results for lands of interest, these show a significant increase to flooding across the reach modelled. The CFRAM results show no out of bank flooding upstream of the lands of interest for the largest magnitude tested (0.1% AEP) and very limited right bank overtopping with water shown to flow through secondary drainage channel only.

Figure 5-2: Comparison of modelled results with CFRAM

The difference in flood extents is expected given the increase in flows applied to the model. Table 5-1 compares the in-channel water levels generated from CFRAM with the revised estimate for the closest in-channel comparable model node (see Figure 5-2).

For the 1% AEP, modelled water levels have increased by 1.58 m compared to CFRAM.

Table 5-1: Comparison of modelled levels to CFRAM modelled levels

	CFRAM Flood Level (mOD) *Node 1016M00901*	McCloy Flood Level (mOD) *Point 110*
1% AEP	19.79	21.37
0.1% AEP	20.16	21.79

5.4 Blockage

Ashford road bridge is located downstream of the site, the R772 road is elevated up to 4 m above the watercourse with potential to cause impounding effect to floodplain upstream. There is no bypassing of the bridge for the 1% AEP event.

Potential for additional flood hazard has been determined by modelling a scenario to account for a 50% blockage of the bridge to coincide with a 1% AEP magnitude flood event. The main channel conduits (1-3) were edited to reflect a blockage occurring to the main Vartry River. Due to the bridge opening geometry and upstream catchment use (agricultural), the likelihood of a significant blockage occurring is assessed as low-moderate.

The modelled scenario allows for a 50% blockage, considered to be conservative at this location. The blockage scenario caused a flood level of 21.43 mOD, representing an increase in flood levels of up to 0.06 m vs the present-day 1% AEP flood at the downstream extent of the site. This reduces to 0.001 m at the upstream extent of the site and confirms blockage of Ashford bridge will have negligible impact on flood levels at the site.

5.5 Climate Change

As per Wicklow SFRA, an estimation of the effect of climate change has been derived for the Mid-Range Future Scenario (MRFS) through modelling an increase of design flows by 20% for the 1% AEP event. Wicklow SSFRA states that the 0.1% AEP should only be considered for where development is critical or extremely vulnerable.

The conservative approach was taken, and reservoir component peak flow derived from 20% uplift to flow hydrograph instead 20% uplift to rainfall hyetographs further details are provided in *M02169_TN01 Reservoir Routing Model Technical Memorandum* (Appendix B)

The increased flows result in a 1% AEP + Climate Change flood level of 23.12 mOD – 21.66 mOD between upstream and downstream extents. This represents a maximum increase in flood levels of up to 0.29 m across the site and leads to new flow pathways developing to the west of the lands of interest.

The increased flows result in a 0.1% AEP + Climate Change flood level of 23.41 mOD – 22.09 mOD between upstream and downstream extents. This represents a maximum increase in flood levels of up to 0.32 m across the site and leads to wider flood extents to west of the lands of interest.

6 RESERVOIR FLOOD RISK

6.1 Reservoir Inundation Zone

No reservoir inundation zone mapping is available for the Varty Reservoir complex; however, given the proximity of the site to the Vartry River which would coincide with the flow route of any inundation flowpath, then it is reasonable to expect that the site would be inundated by an uncontrolled release or catastrophic failure of the reservoir dam(s).

6.2 Reservoir Condition & Management

Wicklow County Council has provided a copy of a Dam Safety Inspection Report for Lower Vartry Reservoir dated September 2016, produced for Irish Water by Arup.

Ireland does not have specific dam safety legislation. It is understood that Irish Water has or is developing a dam safety and risk management plan with the dam safety strategy and dam safety inspection regime used by ESB.

The Inspection Report is undertaken per the general format required for Section 10 reports for the UK Reservoirs Act 1975. The report highlights a number of recommendations for action by the reservoir manager.

As part of this assessment a review has been undertaken to the estimates of probable maximum flood (PMF) used in the Inspection Report, with a view to ensuring that the outcomes of the McCloy reservoir routing study did not invalidate flood estimates in the Inspection Report.

In summary McCloy model estimate for 0.1% AEP discharge is approximately 37% lower than PMF outflow estimate. The hydrology on which the Inspection report makes its assessment remains valid.

In the absence of any known technical change to the basis of the Inspection report,

and

that the lower reservoir is being managed broadly per the provisions of Reservoirs legislation for England and Wales in the absence of similar guidance or legislation for Ireland;

and

where Irish Water is a state controlled body and there is certainty that it is a responsible reservoir manager and is duty bound to implement the recommendations of the Panel Engineers report and ensuring ongoing inspection by a Supervising Engineer or similar,

<u>then the risk of reservoir failure is low and not significant for purposes of development control or planning downstream.</u>

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

The findings of the Flood Study show a significantly larger flood extent for the lands of interest compared to the existing CFRAM mapping. The increase in flood extents can be justified when comparing to observed flood records for the following reasons summarised in Table 7-1.

There is sufficient confidence in the inputs and modelling methodologies to permit the findings of this study to be accepted as superseding CFRAM findings at the site.

In relation to the site, the study outcome results in A very minor portion of Flood Zone A along the western boundary with a significant section of the 'wester section' affected by Flood Zone B. The 'eastern section' of the site is not affected by flooding in either event.

Table 7-1: CFRAM and McCloy Estimate comparison summary

	Representation of reservoirs	Comparison at Mount Usher gauge (highest flow from 3-year record estimated to be 100-50% AEP)	Recorded flooding from Hurricane Charlie (estimated to be between 1% to 0.1% AEP)	Conclusion
CFRAM	Coarse lumped parameter	1% AEP estimate is 15% smaller than highest observed flow	Cannot replicate	Flows underestimated for catchment
Model	Reservoir routing model developed with key spillway structures represented	1% AEP estimate is 329% largest than highest observed flow	1% AEP matches extents 0.1% larger than recorded	Best current estimate for flows in catchment*
* Additional flow data at gauges on the Vartry River may better refine estimates.				

7.2 Recommendations

7.2.1 Flood Zones

Flood Zones are based on the definitions provided in the Planning Guidelines and implemented by the SFRA. Flood Zones for purposes of determining suitability of land use are based on the **present-day hydrology scenario**. Zones are applicable as follows:

- Flood Zone A - More than 1% probability (1 in 100) for river flooding.
- Flood Zone B - Between 0.1% and 1% probability for river flooding and 0.1%.
- Flood Zone C - Areas with less than 0.1% probability of river flooding.

7.2.1.1 Flood Zone C

Flood Zone C is deemed to be areas of low probability of flooding and covers all areas which are not in Flood Zones A or B. From a flood risk perspective, all development in this zone is appropriate.

7.2.1.2 *Flood Zone B*

Flood Zone B is deemed to be areas of moderate probability of flooding – between 0.1% and 1% AEP. Notwithstanding any prior zoning in the area, master planning should consider the following in relation to any proposed development at the area of interest:

- Highly vulnerable development (including dwelling houses) would be considered inappropriate in this zone unless the requirements of a Justification Test can be met, i.e. where there is an overriding planning need agreed with the local authority.
- Less vulnerable development (retail, leisure etc.) within Flood Zone B is likely to be appropriate.

7.2.1.3 *Flood Zone A*

Flood Zone A is deemed to be areas of high probability of flooding – greater than 1% AEP. Notwithstanding any prior zoning in the area, master planning should consider the following in relation to any proposed development:

- Most development is considered inappropriate in this zone and would only be considered in exceptional circumstances.
- Highly vulnerable development would be likely to be considered inappropriate in this zone as it would not meet the criteria of a Justification Test.
- Less vulnerable development (retail, leisure etc.) may be acceptable but would be subject to meeting the requirements of a Justification Test.

7.2.2 Design Levels

Required levels of freeboard are dependent on the vulnerability classification of the proposed development, summarised as follows:

- The minimum finished floor level (FFL) for highly vulnerable development should be above the Flood Zone B level plus suitable freeboard, whereby the recommended level of freeboard is 500 mm over and above the adjacent Flood Zone B fluvial flood level.
- The minimum FFL for less vulnerable development should be above the Flood Zone A level plus suitable freeboard whereby the recommended level of freeboard is 500 mm over and above the adjacent Flood Zone A fluvial flood level.

Future development proposals in the area of interest are to apply the above levels of freeboard through a site-specific FRA. Proposals should seek to ensure that other built development incorporates a suitable level of freeboard proportionate to its intended use.

7.2.3 Effect of Climate Change

A site-specific FRA for any proposed development should confirm that proposals are not at risk of flooding relative to an adjacent post-development climate change flood level.

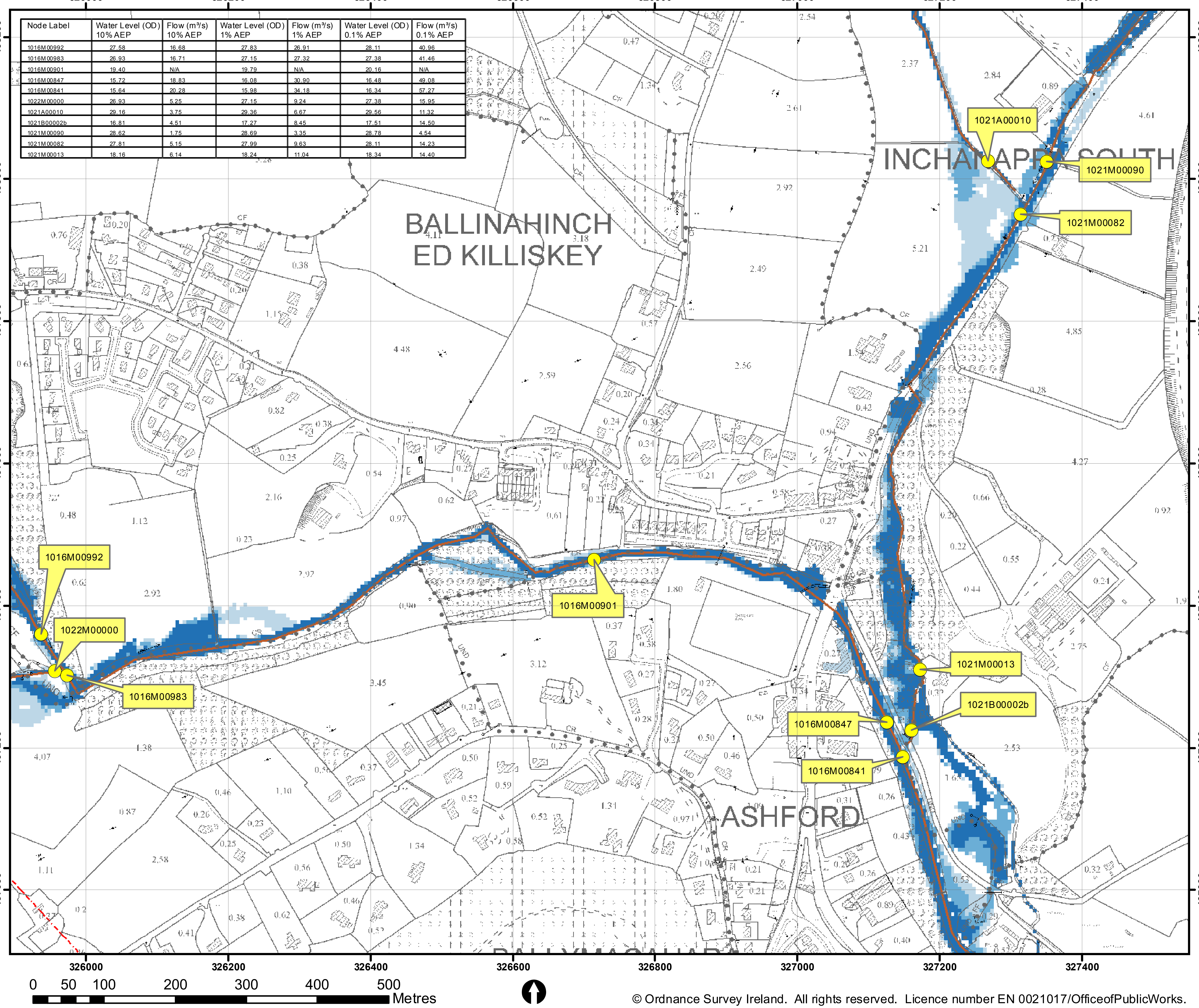
The preferred method to achieve resilience to climate change is to specify finished development levels above the climate change flood level, nominally incorporated through provision of a suitable freeboard which would accommodate the predicted effect of climate change,

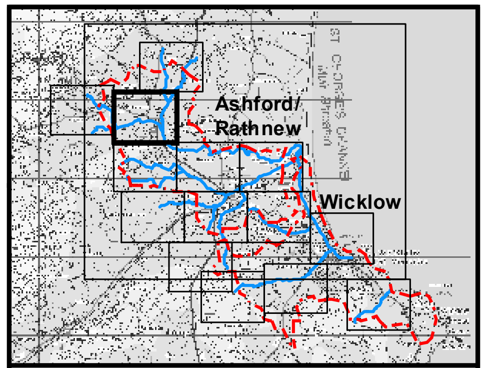
Post-development climate change flood levels shall be determined by modelling an increase in fluvial flood flows per the requirements of the SFRA and OPW guidance / policy.

Appendix A

CFRAM Flood Mapping

Node Label	Water Level (OD) 10% AEP	Flow (m^3/s) 10% AEP	Water Level (OD) 1% AEP	Flow (m^3/s) 1% AEP	Water Level (OD) 0.1% AEP	Flow (m^3/s) 0.1% AEP
1016M00992	27.58	16.68	27.83	26.91	28.11	40.96
1016M00983	26.93	16.71	27.15	27.32	27.38	41.46
1016M00901	19.40	N/A	19.79	N/A	20.16	N/A
1016M00847	15.72	18.83	16.08	30.90	16.48	49.08
1016M00841	15.64	20.28	15.98	34.18	16.34	57.27
1022M00000	26.93	5.25	27.15	9.24	27.38	15.95
1021A00010	29.16	3.75	29.36	6.67	29.56	11.32
1021B00002b	16.81	4.51	17.27	8.45	17.51	14.50
1021M00090	28.62	1.75	28.69	3.35	28.78	4.54
1021M00082	27.81	5.15	27.99	9.63	28.11	14.23
1021M00013	18.16	6.14	18.24	11.04	18.34	14.40





IMPORTANT USER NOTE:
THE VIEWER OF THIS MAP SHOULD REFER TO THE DISCLAIMER, GUIDANCE NOTES AND CONDITIONS OF USE THAT ACCOMPANY THIS MAP.

Legend

- 10% Fluvial AEP Event
- 1% Fluvial AEP Event
- 0.1% Fluvial AEP Event
- Modelled River Centreline
- AFA Extents
- Embankment
- Wall
- Defended Area
- 1% AEP / 1% AEP — Standard of Protection of Flood Defence (Walls / Embankments)
- Node Point
- Node ID — Node Label

FINAL

REV:	NOTE:	DATE:

EASTERN CFRAM STUDY

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Map:
Ashford/ Rathnew Fluvial Flood Extents

Map Type:	EXTENT		
Source:	FLUVIAL		
Map Area:	HPW		
Scenario:	CURRENT		
Drawn By :	C.C.	Date :	15 November 2017
Checked By :	D.I.	Date :	15 November 2017
Approved By :	S.P.	Date :	15 November 2017

Drawing No. :
E10WIC_EXFCD_F2_02

Map Series : Page 2 of 15

Drawing Scale : 1:5,000 @A3

Appendix B

Vartry Reservoirs Flood Routing Analysis

Technical Memorandum - Reservoir Flood Routing Analysis

PROJECT: VARTRY RESERVOIRS & VARTRY RIVER, ASHFORD, CO. WICKLOW

Rev. Ref.	Date	Prep	Chk	App	Amendments	Reason for Issue
00	24/01/2021	DC	PS	DKS	Original	For Information

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

1.1 Terms of Reference

McCloy Consulting has been engaged by Wicklow County Council to undertake an assessment of the effect of flood routing across Varty Reservoirs, with a view to reducing uncertainty in flood estimates in the Vartry River downstream, and specifically in relation to proposed development lands at Ballinahinch, upstream of Ashford Co. Wicklow.

1.2 Project Background

It is understood that the project driver has arisen due to the intention by Wicklow County Council to bring forward proposals to develop land adjacent to the Varty River in Ballinahinch. There is an established history of flooding on adjacent lands coinciding with Hurricane Charlie.

Detailed flood mapping was produced for the Vartry River in Ashford as part of the Eastern CFRAM study; however, there is now significant uncertainty around the magnitude of flooding predicted by CFRAM with a tendency to underpredict flooding versus recorded flooding.

The river reach of interest is downstream of a reservoir complex comprising Upper and Lower Vartry reservoirs. Hydrology and recent flood events have been subject to independent review and analysis. A review of flood data, flood events and flood hydrology data is included at Section 3 of this Technical Note.

1.3 Brief and Scope of Work

The full Client brief extends to a comprehensive hydrological review and flood study to determine Flood Zones. Those aspects of the brief to which this Memorandum relates are specific to Vartry River hydrology, require the undertaking of a full review of the River Vartry hydrology and determination of a revised flow estimate, using gauged data from the Vartry Reservoir.

The agreed scope of work in response to this element of the Brief is as follows:

- Consultation and information gathering with the Reservoir Manager (Irish Water / Dublin CC); site inspections to allow us to characterise the reservoir outlet structure(s) and develop an understanding of the reservoir management and operation.
- Review and undertake a suitable statistical analysis of any available gauged or radar rainfall data and gauge data in the reservoir (water levels, spill flows etc) that would allow calibration of the routing model.
- Develop a routing model (notionally a 1D or linked 1D-2D rainfall-fed model) to route runoff from the upper catchment and determine storage / outflow /spill characteristics in the reservoir system. The model will include identification and suitable stress testing of loss models converting rainfall to runoff.
- If possible, calibrate the model to suit observed inflows or recorded rainfall vs reservoir outflows, or verify the model in terms of downstream observed flooding (Hurricane Charlie or any other flood records).
- Provide a Technical Memorandum recording the work undertaken and outcomes.

1.4 Context

This Technical Memorandum is intended to supplement and be read in conjunction with site specific hydrological analysis of flood flows for a Flood Study for development lands at Ballynahinch, Ashford.

This Memorandum discusses development of reservoir routing model, model proving, design simulations and limitations and uncertainties.

2 AREA OF INTEREST

The area of interest for purposes of this analysis comprises the Vartry Reservoir complex, Upper and Lower Vartry reservoirs and the Vartry River to Ashford Co. Wicklow as shown on Figure 2-1.

The catchment to Ashford is 92.4km^2 with dominant land use forestry and rural pasture. The Vartry River rises to the eastern side of the Wicklow Mountains National Park, flows through two large reservoirs before passing a steep sided gorge at Devil's Glen and onto small town at Ashford.

The flow regime is significantly impacted by abstraction from drinking water reservoirs within the upper catchment. Downstream of Lower Vartry, water is abstracted, treated at on site Water Treatment Plant and transported to Carrowhill in South Dublin to provide Public Water Supply.

It was noted that an upgrade of Lower Vartry and WTP was approved by Wicklow County Council in November 2016 subject to 6 conditions being met and works completed in November 2021. For the purposes of this report, it is assumed that the works to Lower Vartry are complete, and the planning conditions have been implemented.

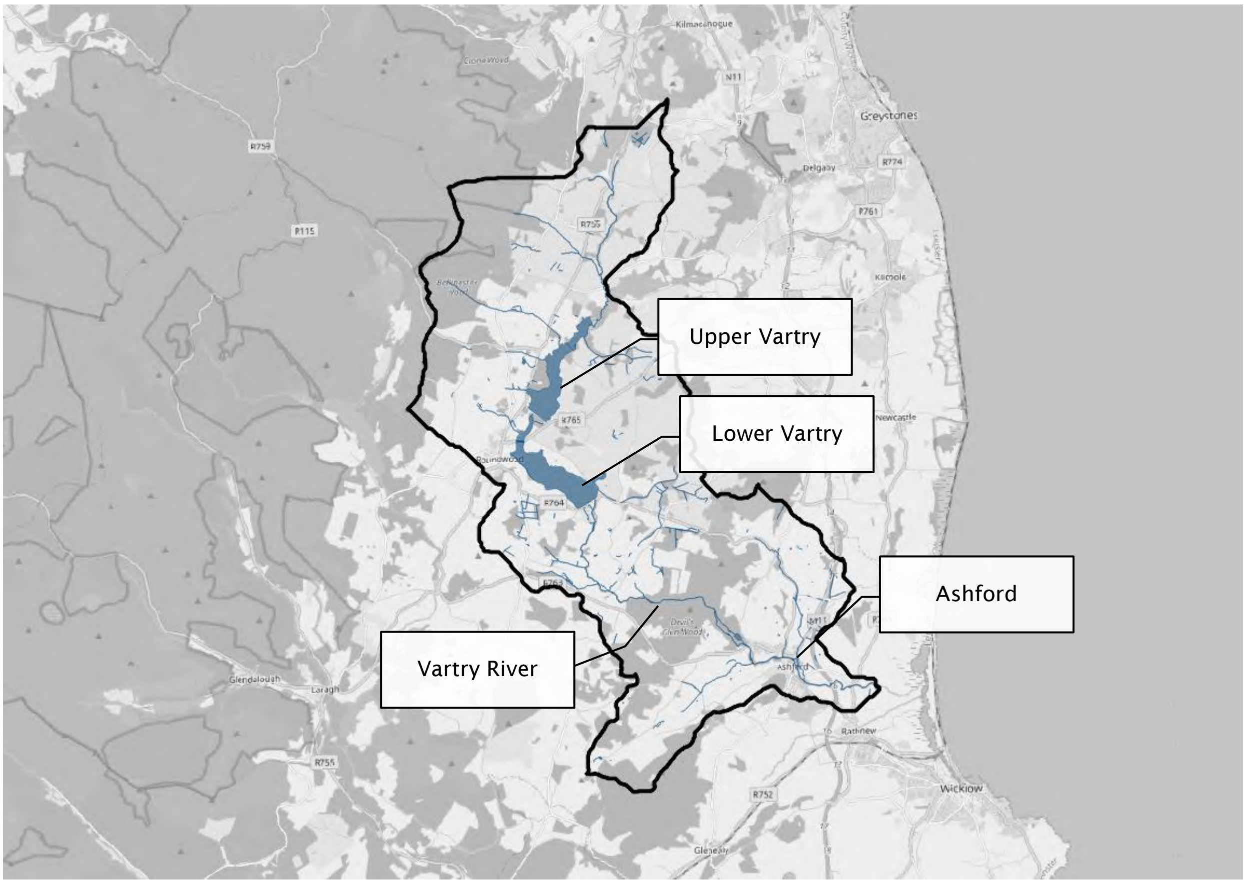


Figure 2-1: Area of interest

3 HYDROLOGY AND FLOOD DATA REVIEW

3.1 Preamble

Hydrological data has been collated and reviewed to understand the current flood regime in the Vartry River catchment. There is uncertainty in relation to the validity of the current best available flood mapping (CFRAM) for the area along the Vartry River as this is not consistent with records of recorded flooding from Hurricane Charlie. These records are specific to lands west of Ashford town, Ballynahinch. This area is the focus of the investigation as a driver to reduce uncertainty around flood hydrology.

3.2 CFRAM Flood Data

The main source of data to identify flood risk on the River Vartry system is the Eastern Catchment Flood Risk Assessment and Management Study (Eastern CFRAM). The Eastern CFRAM study commenced in June 2011 and was concluded at the end of 2016.

This study included detailed hydraulic modelling of the Vartry River and its tributaries as shown in Figure 3-1. This screenshot from Eastern CFRAM HA10 Hydrology Report[1] shows model extents and key Hydrological Estimate Points (HEPs) along the Vartry River and associated tributaries.

The Vartry River is modelled from Devil's Glen Wood in the west, through Nun's Cross to Ashford town and extends to Broad Lough at downstream extent of the model.

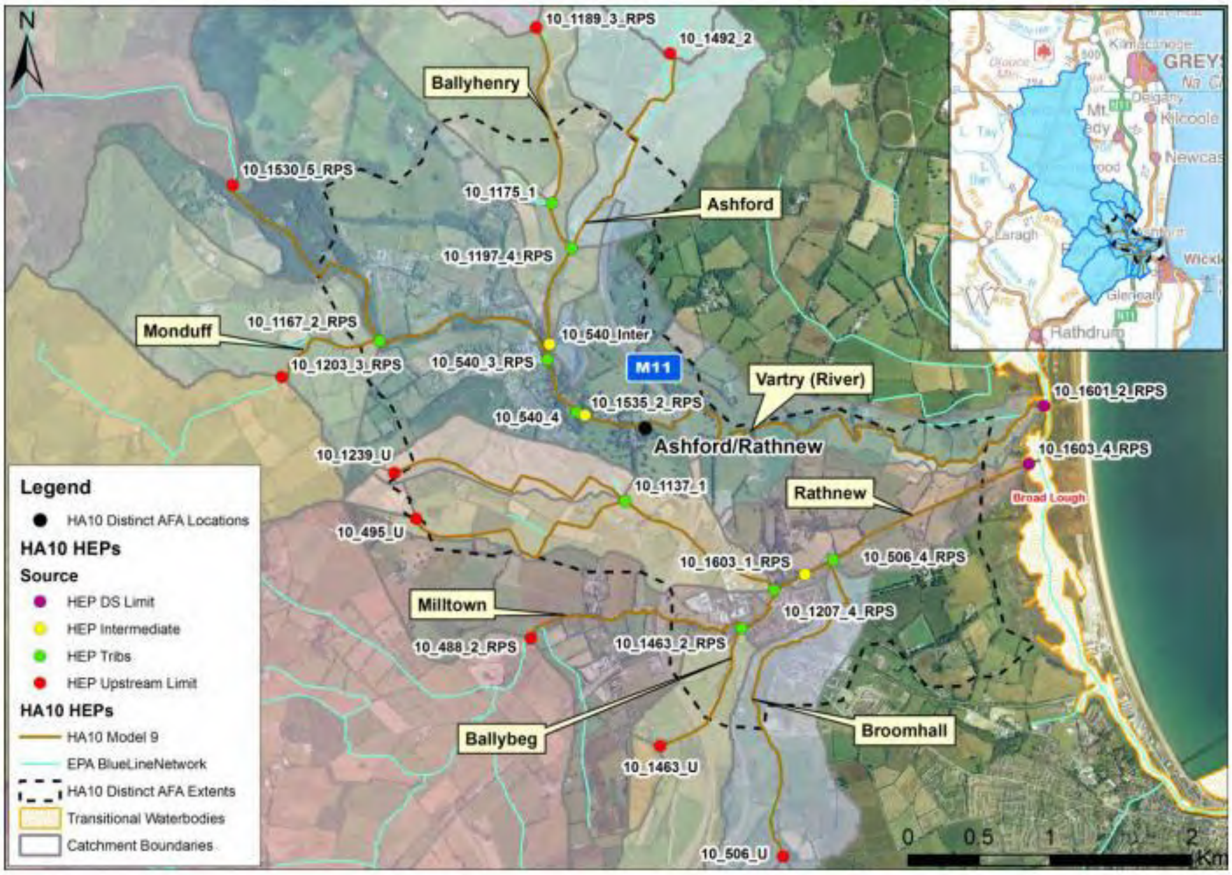


Figure 3-1: CFRAM model extent and HEPs

Eastern CFRAM HA10 Hydrology Report

Final flood maps for the 10%, 1% and 0.1% AEP are publicly available through the CFRAM Study website. A screenshot has been extracted for lands west of Ashford town as shown in Figure 3-2. The model nodes reporting flows and levels are presented in table below.

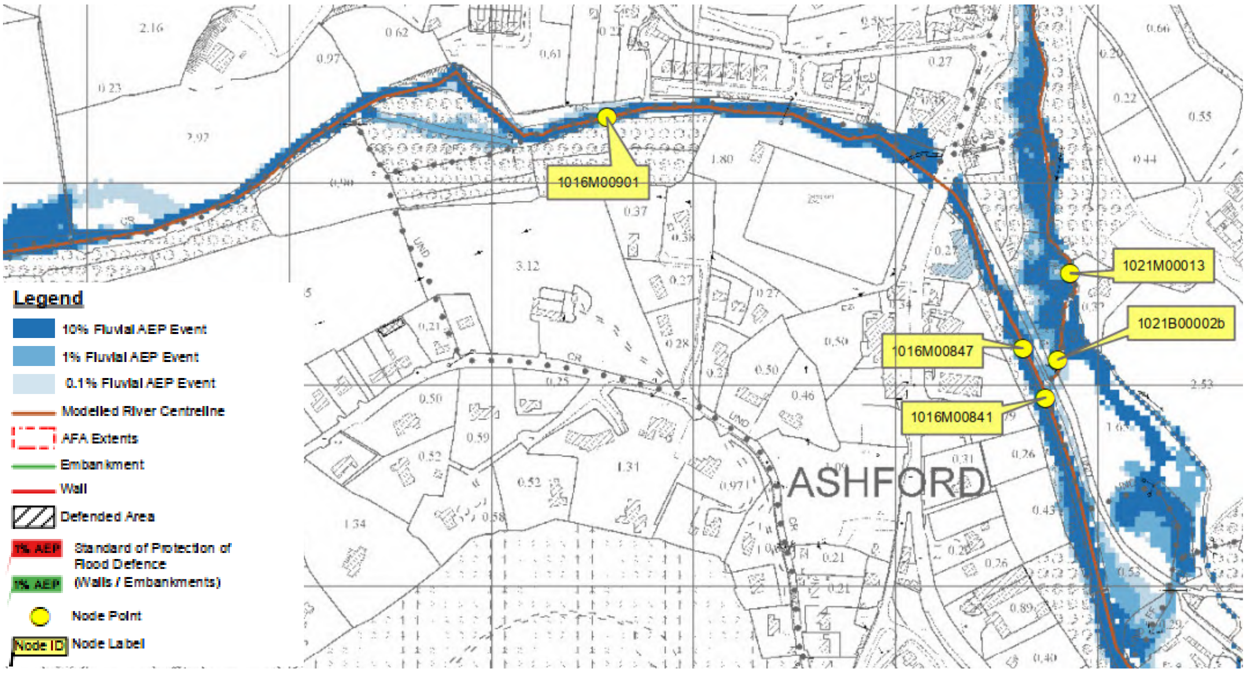


Figure 3-2: Extract from Eastern CFRAMS Final flood mapping

Table 3-1: CFRAM modelled report nodes

Model Node	Location description	10% AEP Flow (m^3/s)	1% AEP Flow (m^3/s)	0.1% AEP Flow (m^3/s)
1016M00901	Downstream of Ballynahinch, Ashford	N/A	N/A	N/A
1016M00847	Upstream of confluence with Ashford tributary	18.83	30.90	49.08

The CFRAM hydrological methodology for the Vartry River has been reviewed based on the associated Hydrology Report. The relevant Hydrological Estimation Point (HEP) is HEP - 10_1530_5_RPS (as shown in Figure 3-1) which is derived from an ungauged statistical method, the methodology for which is summarised below:

- QMED – for the purposes of FSU, the Vartry River is ungauged, QMED has been derived from catchment descriptors and shifted upwards based on the available pivotal sites. An uplift factor of x1.26 was applied.
- Growth factors – standard FSU pooled analysis conducted. A pooling group has been derived from the 92 hydrometric stations located in Eastern and South Eastern Region of Ireland. The group was selected based on similarity of three FSU catchment descriptors (AREA, SAAR and BFI) between subject site and donor site.
- The GLO distribution was fitted to the pooling group and used to derive the growth factors up to 0.1% AEP.
- Representation of Vartry reservoirs – there is no explicit mention of how Vartry reservoirs are represented in the methodology. As per FSU QMED methodology, Equation 2.8, the impact of reservoirs is represented by the FARL physical catchment descriptor (PCD).

$$QMED = 1.237 \times 10^{-5} AREA^{0.937} BFI_{soil}^{-0.922} SAAR^{1.306} FARL^{2.217} DRAIND^{0.341} S1085^{0.185} (1 + ARTDRAIN2)^{0.408} \quad 2.8$$

FARL is defined as the 'Index of flood attenuation by reservoirs and lakes.' Values close to 1 indicate the absence of attenuation due to lakes and reservoirs whereas values below 0.8 indicate a substantial influence on flood response. For this HEP estimated FARL is 0.771.

- In summary, CFRAM methodology has undertaken a standard FSU approach for an ungauged catchment. Vartry reservoirs are represented coarsely by FARL parameter in estimation of QMED.

3.3 JBA Flood Risk Assessment - Hurricane Charlie

A flood risk assessment was carried out by JBA Consulting on behalf of Wicklow County Council in 2016 for a planning application west of Ashford at Ballynahinch. As part of this WCC provided JBA Consulting with photographs and information from flood records for Hurricane Charlie. This has been reviewed with key analysis presented.

3.3.1 Hurricane Charlie – JBA Analysis

- Hurricane Charlie first appeared as a tropical storm off the coast of South Carolina on Friday 15th of August 1986. The storm moved over Wicklow and Dublin which endured the worst of the storm over the night of the 25th/26th August.
- JBA interviewed a local engineer and it was his understanding that the area was very under developed compared to its current condition and there had been a changed hydro – morphology. He remarked that the flooding in 1986 had been exacerbated due to a blockage to the road bridge at Ashford House from a section of wall blown into the river. He noted that the bridge has since been replaced with a higher clearance unit.
- JBA reviewed Met Eireann records and estimated the storm to generate flows between a 1% - 0.1% AEP
- JBA analysed photographs from the event provided by Wicklow County Council and annotated the CFRAM mapping to show the areas that would likely have flooded during the storm (Figure 3-3).
- Photographs from Hurricane Charlie suggest that the CFRAM representation is not appropriate for the1% or 0.1% events and show a significant underestimation in estimated flows.

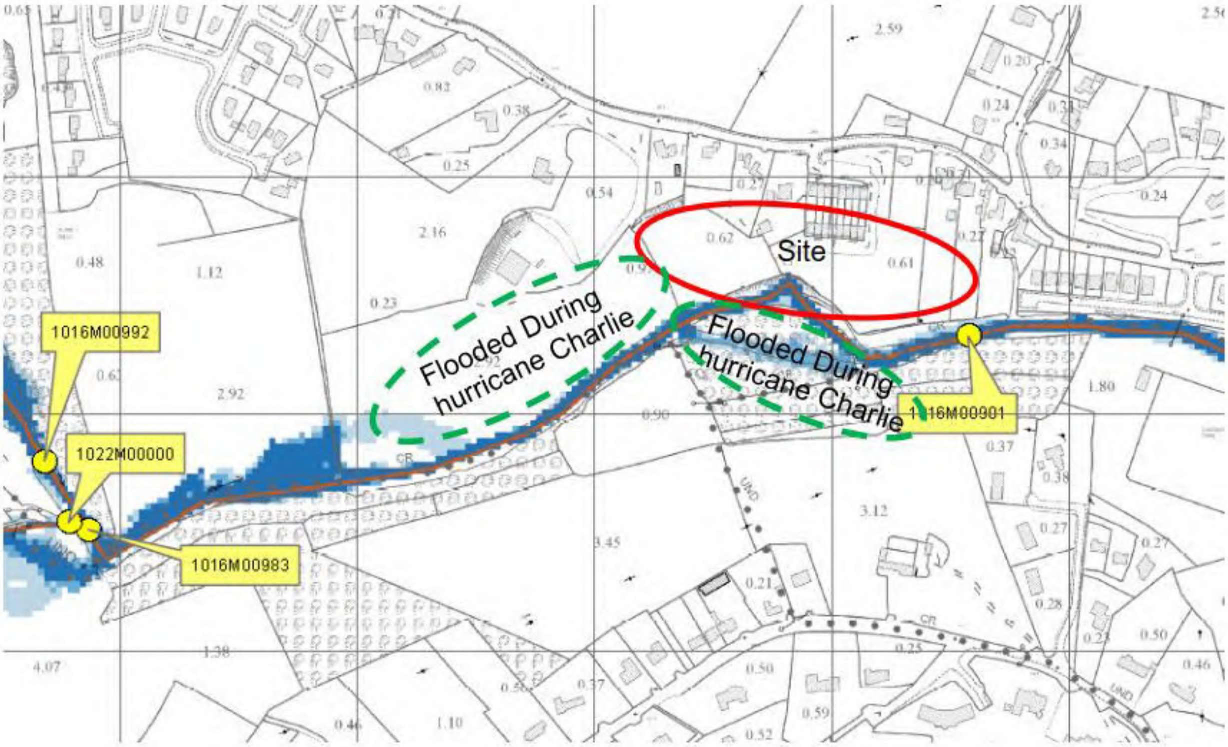


Figure 3-3: Annotated extract from Eastern CFRAMS Flood Mapping (JBA Consulting, 2016)

3.4 Hydrometry & Flow Records

3.4.1 Gauging stations

The Vartry catchment is ungauged for purposes of FSU methodologies. During data collection, three gauges were identified on the Vartry River. Table 3-2 and Figure 3-4 provides details of hydrometric data.

Table 3-2: Details of gauging stations on Vartry River

Name	Temporal	Type	Period of record	Responsible Body
Devil's Glen Record (EPA no. 10020)	15min	Water Level	1952 -1979	ESB data provided by EPA
Vartry	15min	Water Level & Flow	Jun 2018 - Aug 2021	Irish Water
Mount Usher Gardens	15min	Water Level & Flow	August 2018 - Aug 2021	Irish Water

Figure 3-4: Gauging stations on Vartry River

Each gauged record has been considered in detail:

- Devil's Glen record is short, outdated and in the absence of a rating curve was ruled out as being a source of useful information for the study.
- One of the planning conditions of the upgrade to Lower Vartry reservoir was to ensure that two hydrometric gauging stations were installed on the Vartry River:
  - Vartry Gauging Station- this was to be installed within the WTP compound and accurately measure the combined flows from the water treatment plant discharge and the spillway channel
  - Mount Usher Gardens Gauging Station – this was installed downstream of Ashford and upstream of the confluence with the Ashford tributary.

Both gauges were observed during a site inspection in September 2021.

Following consultation with Irish Water, data was provided for both gauges (Vartry, Mount Usher) including water levels, and flows calculated from rating curves. Rating curves and associated gauged flow estimates are assumed to be fit for purpose. It was noted that spot flow gaugings had been used to construct the rating curve, but these were limited to low flow conditions only.

Due to un upgrade at Vartry Gauging station with the construction of a weir, two rating curves were provided for the data series pre weir and post weir as noted in time series below

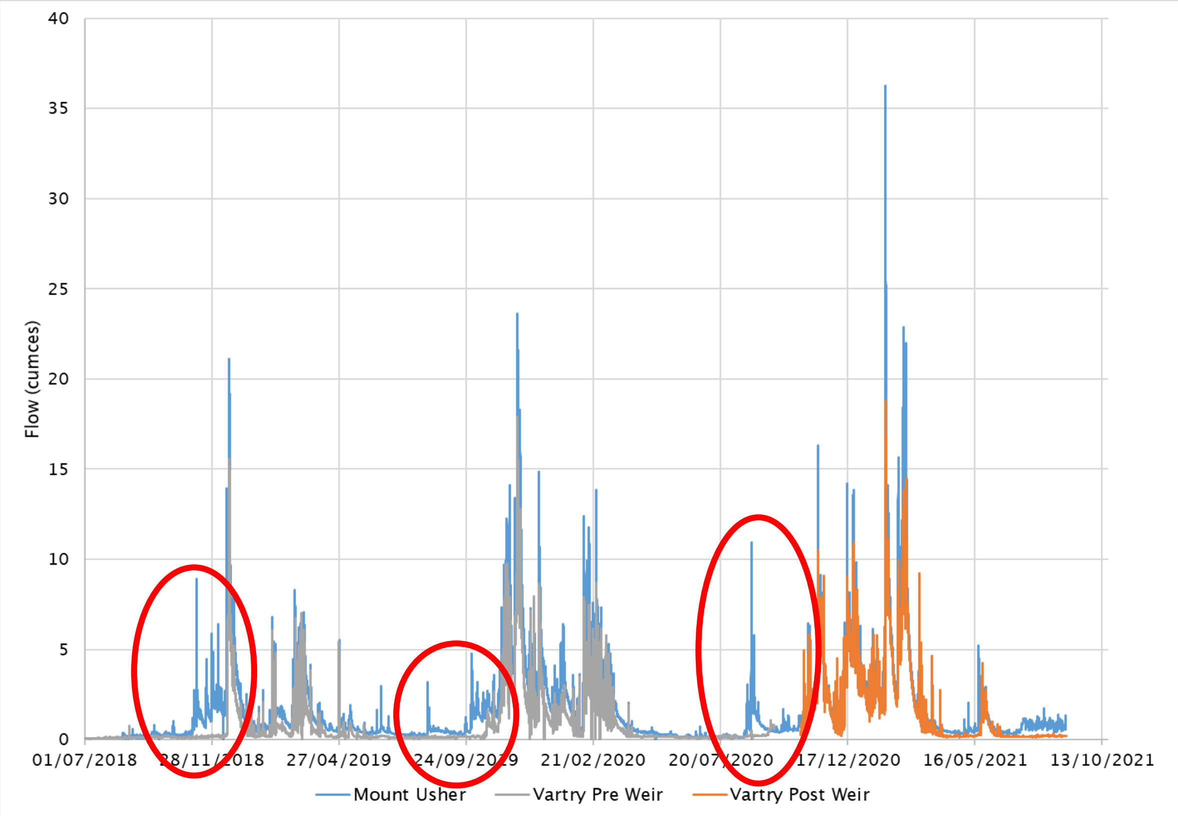


Figure 3-5: Flow time series for Irish Water gauging stations

Figure 3-5 presents the available short three-year record for both gauges, the following is noted:

- Focusing on Vartry series only (grey and orange), elevated flows (exceeding 5 cumecs) are noted from late October to early June (average 6 month window). A planning condition of Lower Vartry works committed to discharging 5 Mega /litres per day to the Vartry River but this is negligible on the scale of the graph (0.06 cumecs) so it is likely elevated flows are related to spilling of the reservoir.
- Vartry and Mount Usher records tend to correlate best in later winter months with peak flows noted at Vartry gauge and Mount Usher. The red circles show the records when peak flow is observed at Mount Usher with no corresponding record at Vartry gauge. This is consistent with the summer draw down of Vartry reservoirs to their lowest levels in October followed by recharge through the winter. The response noted from Mount Usher originates from intervening catchment from Lower Vartry reservoir to Ashford.
- Focusing on Mount Usher gauge, the highest flows recorded is 30th January 2021 with maximum peak flow of 36.2m^3/s. This is *5.3 cumecs larger than the CFRAM 1% AEP flow node for the same location*, downstream of Ashford bridge and upstream of confluence with Ashford tributary (Table 3-1).

  To understand if this January 2021 event was rare, a nearby EPA gauging station was used and rarity estimated on the FSU portal. The closest EPA gauge that is also validated for use on FSU is Rathdrum, 12km southwest of Ashford.

  A single site analysis was carried out using the FSU Portal for the 69-year record at Rathdrum (Figure 3-6), the Jan 2021 event is estimated to be between a 100 - 50% AEP and therefore is frequently exceeded.

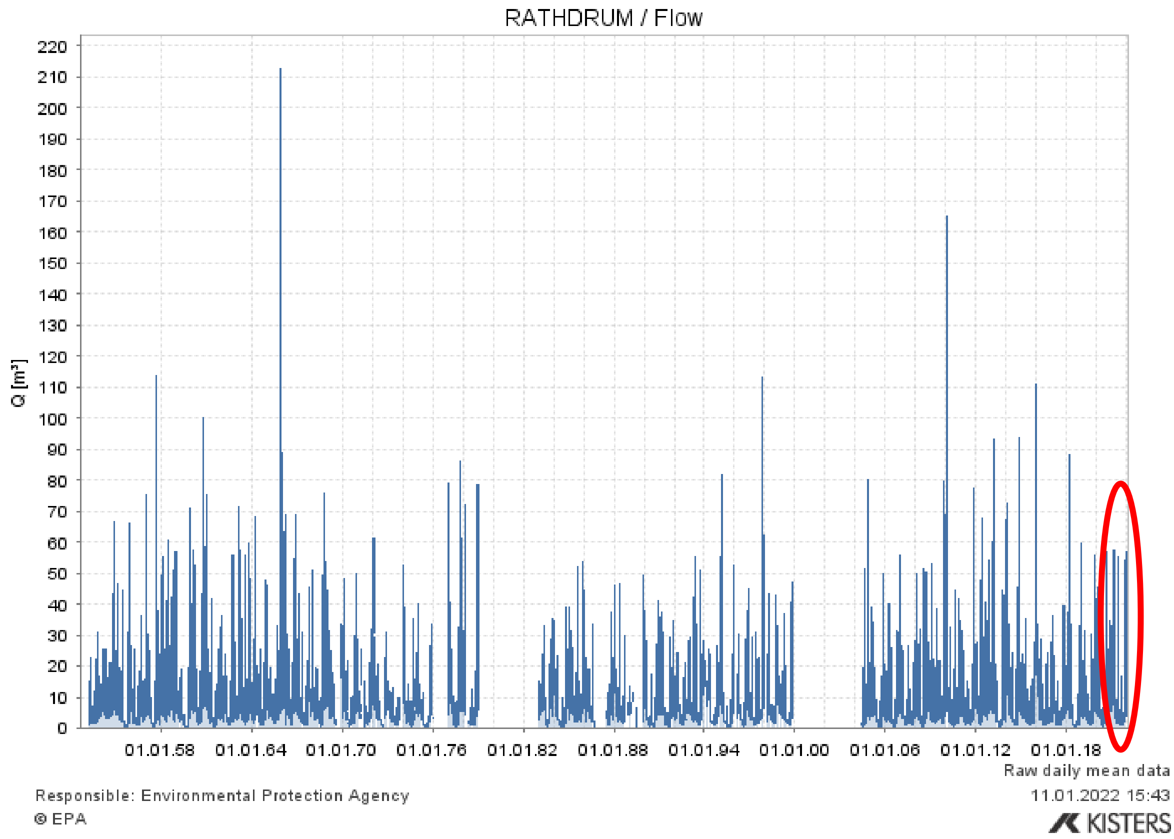


Figure 3-6: Rathdrum flow series

Given the close proximity to Mount Usher gauge, it is reasonable to assume that the rarity of the event would be broadly similar for the Vartry River. Assuming the event at Mount Usher has a similar probability, then the result infers that flows adopted for CFRAM extreme / 1% AEP floods may have a probability equivalent to a high probability flood, and that CFRAM flood estimates (extents and level) are a significant underestimate.

Table 3-3: Comparison in maximum observed flow with CFRAM model results at Mount Usher gauging station

	Highest maximum flow on record (Estimated as 100-50% AEP)	CFRAM model node (1016M00847) 1% AEP flow
Mount Usher	36.2	30.90

3.4.2 Reservoir levels

Daily reservoir levels were provided by Irish Water for the Upper and Lower Vartry reservoirs respectively for a four-year period from January 2018 to 30th September 2021.

The level data is deemed sensitive information and is not permitted to be fully reproduced. Time series is not presented but analysis was carried out to assess the number of days when the Lower Vartry reservoir level exceeded the Top Water Level (TWL) / spill weir for three water years (Table 3-4). Seasonality of spells on or above TWL are described in Section 5.2.

Table 3-4: Lower Vartry: number of days reservoir exceeded TWL

Water year (1st Oct – 30th September)	No. of days levels above TWL
2018 – 2019	120
2019 -2020	171
2020-2021	182

3.4.3 Rainfall

Rainfall was provided by Met Eireann for the wider catchment area to Ashford as shown in Table 3-5 and Figure 3-7 below.

Table 3-5: Met Eireann daily rain gauges

Name	Temporal	Period of record
Ballinastoe	Daily	1948 to 1979
Roundwood (Valve Tower)	Daily	1941 - 1988
Ashford (Glanmore Gardens)	Daily	1984 - April 2021
Ballynahinch	Daily	1998 - April 2021
Roundwood (Filter Beds)	Daily	1941 - April 2021

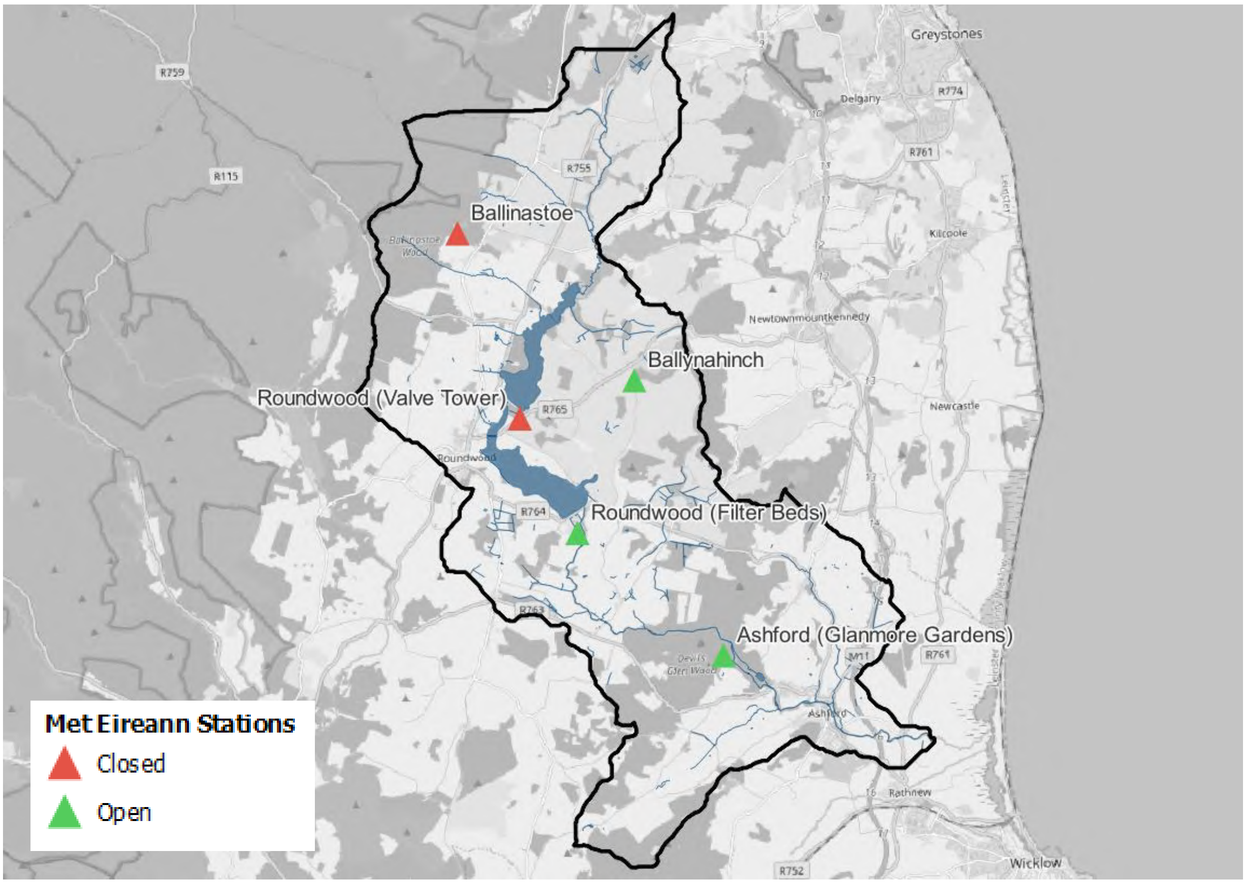


Figure 3-7: Met Eireann daily rain gauges

3.5 Summary

Flood data and hydrometric records have been collated and reviewed to understand the current flood risk along the Vartry River.

Analysis and review of data confirms that the flood regime to Ashford is significantly impacted by the Vartry reservoirs. No other significant pressures have been identified between the outflow of Lower Vartry and Ashford. The abstraction of water downstream of reservoirs at Annagolan Bridge has ceased, to comply with a planning condition of works carried out to Lower Vartry reservoir.

Current flood mapping (CFRAM) for the Vartry River has been reviewed and it is concluded that there is significant uncertainty in flood extents and the flows it reports. There are several points of evidence to suggest that the CFRAM mapping is underestimating flows.

- Hurricane Charlie was estimated to generate flows between a 1% to 0.1% AEP The flood extents it generated based on photographs are significantly larger than the CFRAM flood extents for 0.1% AEP.

  This would suggest bigger flows would be required to replicate the same flood extent as recorded in Hurricane Charlie.
- Analysis of hydrometric data from 3-year record at Irish Water gauge at Mount Usher show the largest event to be 15% larger than the 1% AEP flow estimated from the CFRAM model. The largest event was estimated to be a frequently exceeded event (100- 50% AEP) based on nearby gauge.

  This would suggest that the 1% AEP flow from the CFRAM model is significantly underestimating flood flows.
- Review of the CFRAM hydrology confirm that Vartry Reservoir is coarsely represented by use of FARL attenuation parameter in derivation of QMED. In reality the flows downstream will be influenced by the specific spillway structures at the reservoirs. Initial analysis would suggest that the reservoirs are able to convey extreme flood flows without significant attenuation making the FARL assumption overly simplistic.

These points raised highlight the need to better define flood response from the reservoir system in isolation as this holds the largest uncertainty in estimating flood flows along the Vartry River. An understanding of the specific spillway structures is required to determine a more accurate estimation of flood flows. Based on this analysis, there is an expectation that the flows generated will significantly exceed that generated from CFRAMs.

This report will further discuss the development of the reservoir routing model including hydrological setting, reservoir configuration before detailing model development, calibration and derivation of design hydrology.

4 VARTRY RESERVOIRS HYDROLOGICAL SETTING

4.1 Topographical Catchment

The hydrological catchment contributing to the Vartry reservoir system has been derived using a geospatial analysis tool using OSI 10m DTM and compared with the nearest FSU catchment to assess any differences as shown in Figure 4-1 below.

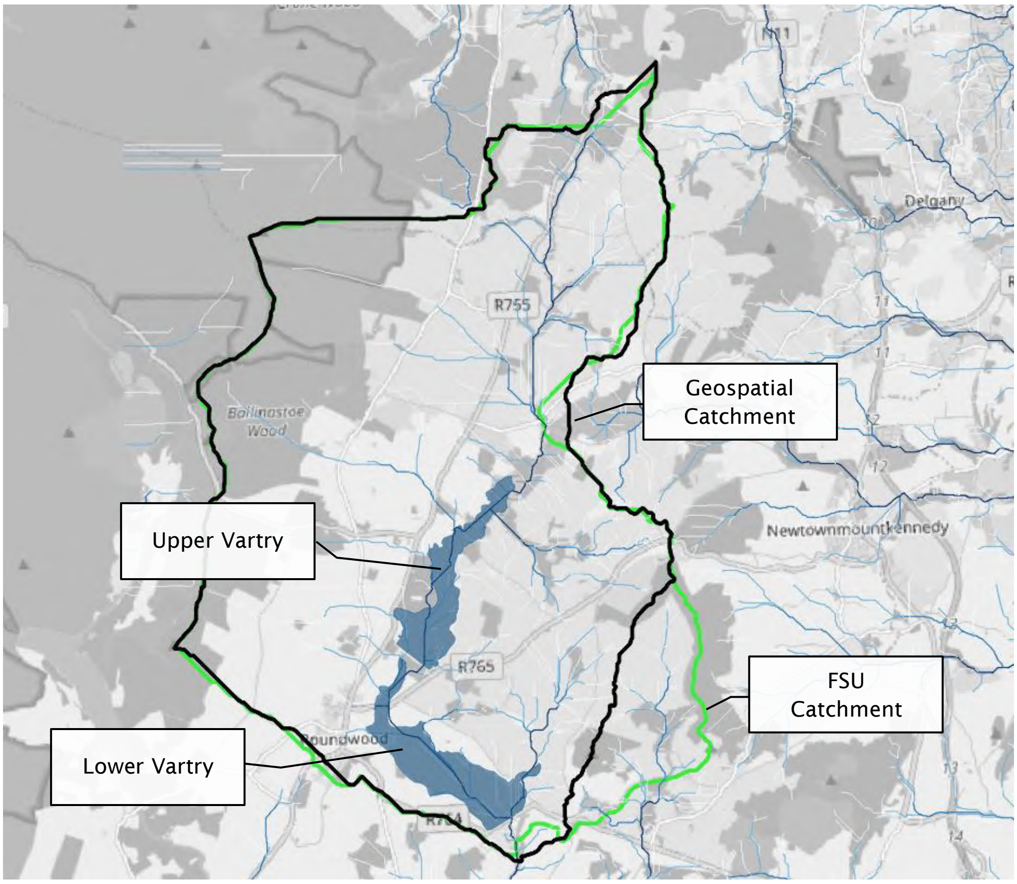


Figure 4-1: Topographical Catchment and Flow Routing

The geospatial catchment draining to the Lower Vartry was derived as 52.9km^{2}. while the FSU catchment area is 56.1km^{2}. Both catchments are shown to match closely apart from the area to the southeast where the Ballyduff stream has been artificially diverted to act as a catchwater drain for the Lower Vartry (Figure 4-2).

The Vartry Manual states that during winter conditions (when the reservoir is spilling), the majority of flow is diverted to the Lower Reservoir via the catchwater while an unspecified amount is allowed to drain on the original watercourse to provide water for livestock downstream.

The indirect catchment has an area of 3.9km^{2} which accounts for the difference between catchments.

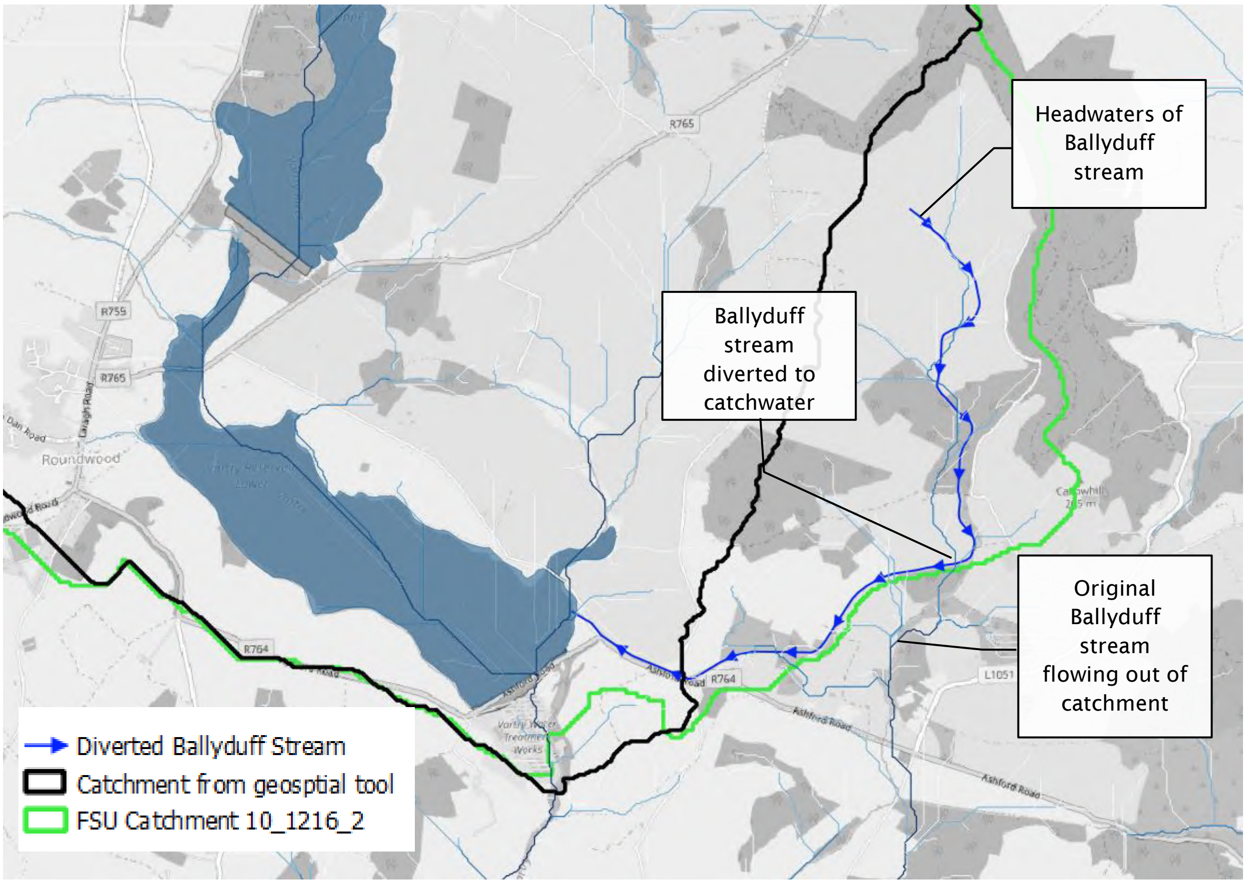


Figure 4-2: Comparison of FSU and Geospatial catchment

4.2 Physical Catchment Descriptors

Physical catchment descriptors (PCDs) have been reviewed for the FSU catchment above to provide a hydrological context to the catchment and inform the best approach for the reservoir routing model. T

FSU PCDs are scheduled in Table 4-1. The following PCDs of particular significance are noted:

- The catchment is rural with principal land uses pasture, woodland, and peat. Woodland and peat cover would be expected to cause a delayed catchment response to rainfall.
- There is no urban contribution or arterial drainage schemes that would cause any flashy inflow response.
- The baseflow contribution is high at 0.70 where values closer to 1 typically indicate permeable soils.

Table 4-1: PCD summary for reservoir system

Name	Description	Value
STATIONNR	Station Identification	10_1216_1
AREA	Area	56.14
NORTH	Northings	201442
EAST	Eastings	321559
FARL	Flood Attenuation by Reservoirs and Lakes	0.71
ALLUV	Proportion of extent of floodplain alluvial deposit	0.04
PEAT	Proportion of Peat Cover	0.10
FOREST	Proportion of Forest Cover	0.17
PASTURE	Proportion of Grassland/Pasture/Agriculture	0.62
S1085	Mainstream slope	4.41
MSL	Mainstream Length	15.18
DRAIND	Drainage Density	0.89
ALTBAR	Mean Elevation	289.40
NETLEN	Network length	49.83
ARTDRAIN2	percentage of upstream river network length included in Drainage Schemes	0
ARTDRAIN	percentage of catchment area with Benefiting Lands from Drainage Schemes	0
BFISOIL	measure of the base flow characteristics of catchments.	0.70
SAAR	Standard Period Average Annual Rainfall	1176
FLATWET	Index of catchment wetness	0.54
URBEXT	Index of urban extent	0

5 RESERVOIR CONFIGURATION

5.1 Configuration

The Vartry Reservoir system main aim is to collect and abstract water for Public Water Supply (PWS) for Dublin County. The Vartry reservoir system consists of two reservoirs in direct cascade with the lower reservoir extending to the toe of the upper reservoir. Water from the upper reservoir is either released or overflows into the lower reservoir from where it is abstracted for treatment at works at downstream face of lower reservoir. The lower reservoir also provides a constant compensation flow to the Vartry River and can also overflow via side spillway.

Figure 5-2 shows the configuration for the Vartry reservoir system and details key dimensions and invert levels. This should be viewed alongside Table 6-1 which provides an explanation of each key component of the reservoir and photograph relating to Upper and Lower Vartry reservoirs.

Figure 5-2 has been created using a selection of data sources including:

- Vartry Manual 1998
- Dam Safety Inspection Report Upper Vartry Reservoir (Arup June 2016)
- Vartry Lower Reservoir – The Planning and Design of Upgrade Works (Hopkins and Fleming 2018)
- Site Inspection and discussions with Ned Fleming in September 2021
- Planning Application 16363 – Wicklow County Council Vartry Water Treatment Site[2]

Each reservoir is considered in brief detail before the management of the system is discussed.

5.1.1 Upper Vartry

Upper Vartry reservoir was completed in 1923 and has capacity of 5,633 Ml at Top Water Level (TWL). It is supplied with water from 39.6km^2 catchment.

The bell mouth spillway crest level was raised in 1999 but there are no other records of recent upgrades.

5.1.2 Lower Vartry

Lower Vartry reservoir was completed in 1868 and has a capacity of 11,283 Ml at Top Water Level. The direct catchment for water supply is 56.0km^2 and includes a catchwater bringing runoff from an indirect catchment with an area of 3.9km^2.

It was noted during data collection and site inspection that upgrades were taking place at the Lower Vartry reservoir to improve the yield of water for PWS for Dublin. Ongoing siltation and algae blooms had led to reduction in yield of water to approximately 42ML/d whereas the system could originally abstract 75ML/d.

The main upgrades relevant to this study include:

- Upgrade spillway channel, approximately 170m of channel regraded to 1:55 slope. This will ensure the PMF to be passed without exceeding the modular depth of the spillway weir and without drowning the road arches.
- Upgrade of draw-off tower and dam pipework to ensure a consistent 75ML/D abstraction rate for PWS
- Irish Water agreement to provide 5ML/D compensation flow back into the Vartry to ensure ecological condition of the downstream watercourse
- Construction of gauging station on River Vartry immediately downstream of input of compensation flow. This monitors compensation flows and flow contribution from spillway.

[2] Planning Application 16363 http://www.eplanning.ie/WicklowCC/AppFileRefDetails/16363/0 [Accessed 9th November 2021)

- Construction of gauging station on River Vartry downstream at Ashford town centre to monitor reservoir flows.

During the site inspection upgrades were underway with spillway channel completed and recent media (November 2021) confirms that all the upgrades have been completed.

This assessment assumes the upgrades to be in place for purpose of the reservoir routing model.

5.2 Management

DCC were consulted via the resident reservoir engineer via email correspondence and an accompanied site visit on 3rd September 2021.

The following information was provided on management of reservoir:

- The Vartry Water Supply (including the Upper and Lower Reservoirs) is operated by Dublin City Council on behalf of Irish Water.
- Water flows from the Upper to the Lower Reservoir and it is from the Lower that water is abstracted to the water treatment plant via a Draw Off Tower intake. Plant capacity is 80 Ml/d and there is a requirement that 5 Ml/d compensation water is supplied to the river downstream of the Lower Dam.
- Both dams have uncontrolled spillways – when they fill, they overflow, but water can also be transferred from the Upper to the Lower via a low level Draw Off Tower intake.
- When the reservoirs are overflowing, the valves in the Upper Tower are shut. When drawdown commences, the Lower Reservoir is allowed drop by approximately one metre before the Upper 24-inch outlet is partially opened and then as drawdown proceeds, both reservoirs are drawn down together.
- The reasoning behind the delayed drawdown of the Upper is to ensure that in the event of heavy rain, the Lower does not overflow whilst there is still available storage capacity in the Upper.

The daily change in reservoir storage was provided for the Upper and Lower Vartry for a 50-year period from 1964 – 2013. This has been used to understand how the reservoirs is managed and how levels vary overtime. A classic curve is observed as shown in Figure 5-1 below.

This has been considered in the wider context of information presented earlier including gauging stations downstream of reservoirs and reservoir levels to create a typical annual timeline.

- Starting in early summer, June/July, reservoir levels are high from the preceding winter and begin to drop as the reservoir is drawn down. During this period there is no spilling of reservoir leading to the flow response at Ashford observed from intervening catchment only. This is noted in records from gauging stations downstream (as discussed in Section 3.4.1).
- The reservoir levels are lowest in late September and begin to recharge up to top level in October/November.
- According to Figure 5-1, based on median records from 1964 -2013, spilling is observed from December to early June, as noted by flat lines where reservoir storage is exceeded leading to activation of spillways. In reality the initial spilling is shown to vary between years starting as early as mid-October and extending to early June (as noted in year 2020- 2021 see Figure 3-5).

  The Upper Vartry is shown to be on spill for longer than the Lower, but this is expected given the management regime noted (above) where levels in the Lower are allowed to drop by one metre first before the Upper is drawn down.

For the context of flood flows, it can be assumed that flood attenuation capacity within the reservoir complex, and correspondingly the period when flooding is most likely, will therefore occur in the six-month window from late October/November to May/early June when the reservoir is on spill.

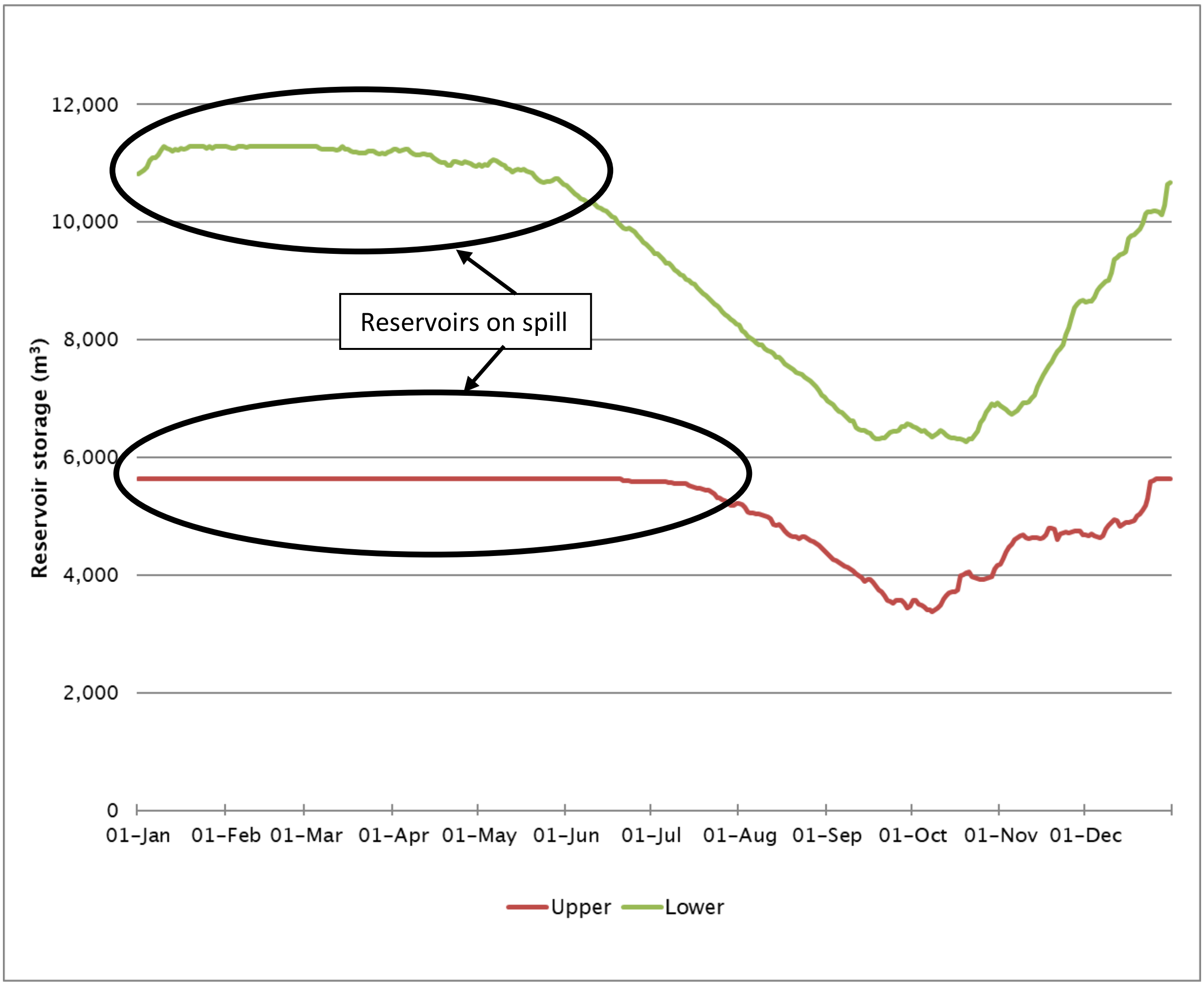


Figure 5-1: Vartry Reservoirs Storage Median 1964-2013

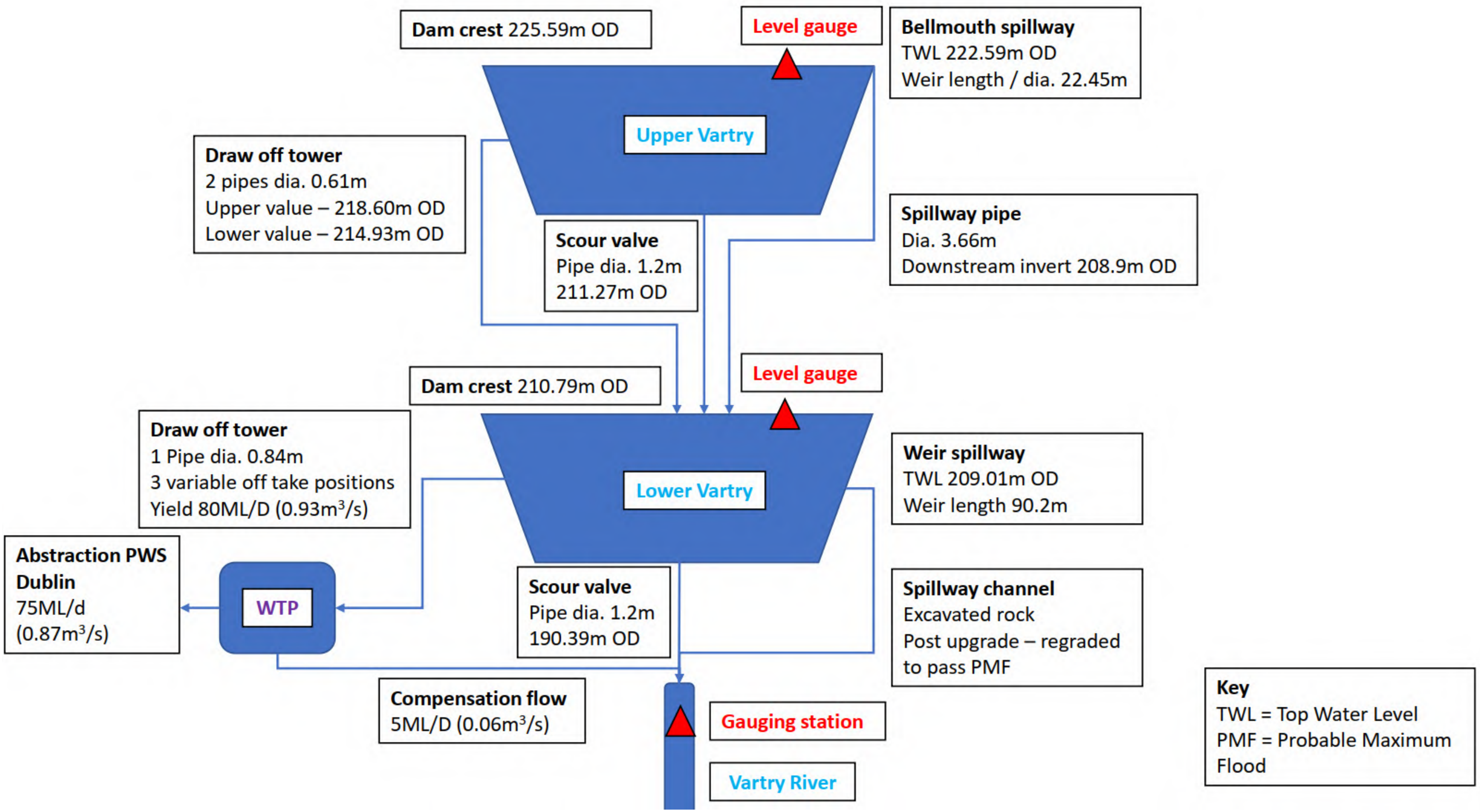
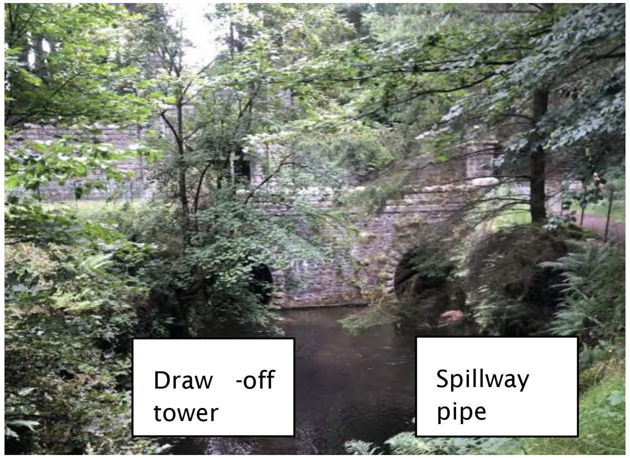


Figure 5-2: Vartry Reservoir configuration

Table 5-1: Reservoir components of Vartry reservoir system

Reservoir component	Description	Upper Vartry	Lower Vartry
Dam crest	The top of the dam not designed to flow water.	Photo taken along dam crest (public footpath) showing wave wall noted to the right. Upper Vartry is shown on far right. Photo taken during site inspection (April 2019) 	Photo taken along dam crest (R764 Road), spillway is shown to right of photo and Lower Vartry in back drop. Photo taken in April 2019- Google Maps (2021) 
Draw-off Tower	Intake towers specialised for drinking water reservoirs. They have multiple openings at various depths and equipped with valves allowing drinking water to be abstracted at	Draw off tower, 2 sluice valves noted to be raised at site inspection (September 2021) consistent with partial release of water into Lower Vartry.	Draw off tower noted to not be in operation at time of photo as temporary sluice in operation during upgrade works to water treatment works.

	the level of highest quality.		
Spillway structure	They are used, when a reservoir is full, to pass floodwater safely, and in a controlled way, over a dam, around it or through it	Bellmouth spillway structure not overtopping as noted in site inspection (September 2021) 	Weir spillway structure not overtopping as noted in site inspection (September 2021) 

Spillway channel /pipe	Channel or pipe used to convey water	Photo taken looking upstream at downstream end of spillway pipe. The left arch is outflow from Draw off Tower and was flowing during site inspection (September 2021) The right arch is outflow from spillway weir and no flow noted during site inspection (September 2021)  	Photo taken looking upstream showing spillway channel with recent upgrades to deepen bed and banks and increase slope. 
Scour valve	The scour is an outlet pipe that runs through the bottom of the dam. It is usually large because of its uses. The scour can be used in an emergency, it can be opened to let water out of the reservoir very quickly.	No photo available and pipe assumed to be closed.	No photo available and pipe assumed to be closed.

6 RESERVOIR ROUTING MODEL DEVELOPMENT

6.1 Preamble

Given the established significant uncertainty around flood estimation in the Varty River and the likely significant source of that uncertainty being the influence of the Varty Reservoir complex, a hydraulic model has been developed to allow estimation of routing of rainfall across the reservoir and its upstream catchment, and estimation of its flood response in terms of outflows.

A rainfall fed reservoir routing model representing the catchment draining to Lower Vartry (including Upper Vartry) reservoir has been developed. This incorporates all known information from Irish Water on spillway structures and has been calibrated to flow gauge immediately downstream of Lower Vartry for 3 events based on the available 3-year gauge record.

Model parameters described subsequently have been tested and adjusted iteratively to achieve calibration with gauged events. Calibration of the model is described separately in Section 7.

6.2 Model Parameters

The model boundary encloses the entire surface water catchment draining to the Lower Vartry reservoir. A 250m buffer was applied to the geospatial catchment to ensure all flow pathways were captured to the site.

Attempts were made to burn the diverted Ballyduff catchwater into the 10m DTM but there was insufficient data to allow its representative within the hydraulic model. It is therefore assumed that flows generated from the Ballyduff stream would follow the natural topographic watercourse out of the catchment (Figure 4-2). The quantum of water lost from the model is not significant in the context of extreme flood estimation.

The model extent is shown on the following figure.

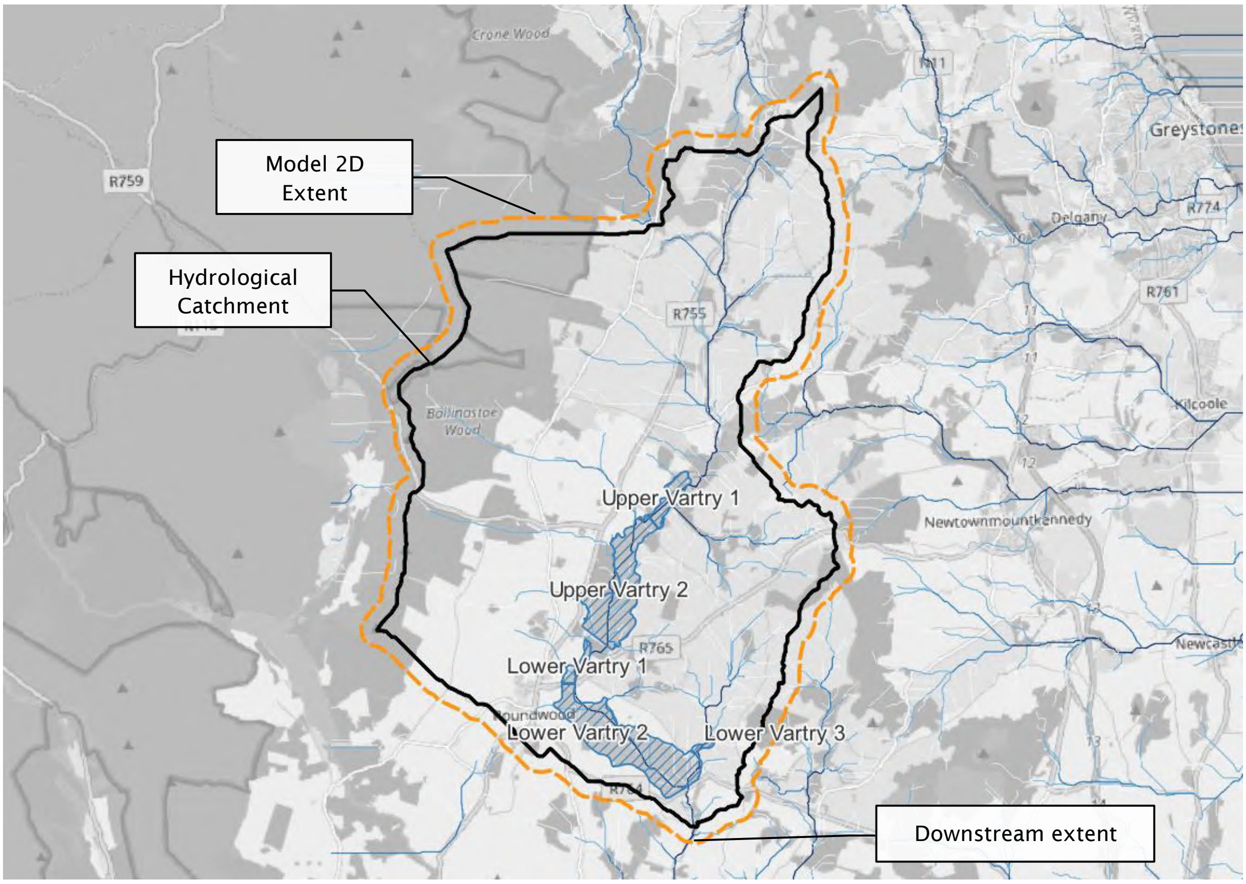


Figure 6-1 Model 2D Zone

6.3 Ground Model

The height data was imported to the modelling software as a ground model, and subsequently converted into 2D mesh elements (the surface used to simulate flows across the topography within the model).

6.4 Inflow Hydrology

The rainfall reservoir routing model was fed with hyetographs derived from observed rainfall for calibration events and design rainfall profiles derived from FSU portal.

Full details are discussed in Section 7.

6.5 Initial Conditions

Initial conditions were applied in the model for two purposes:

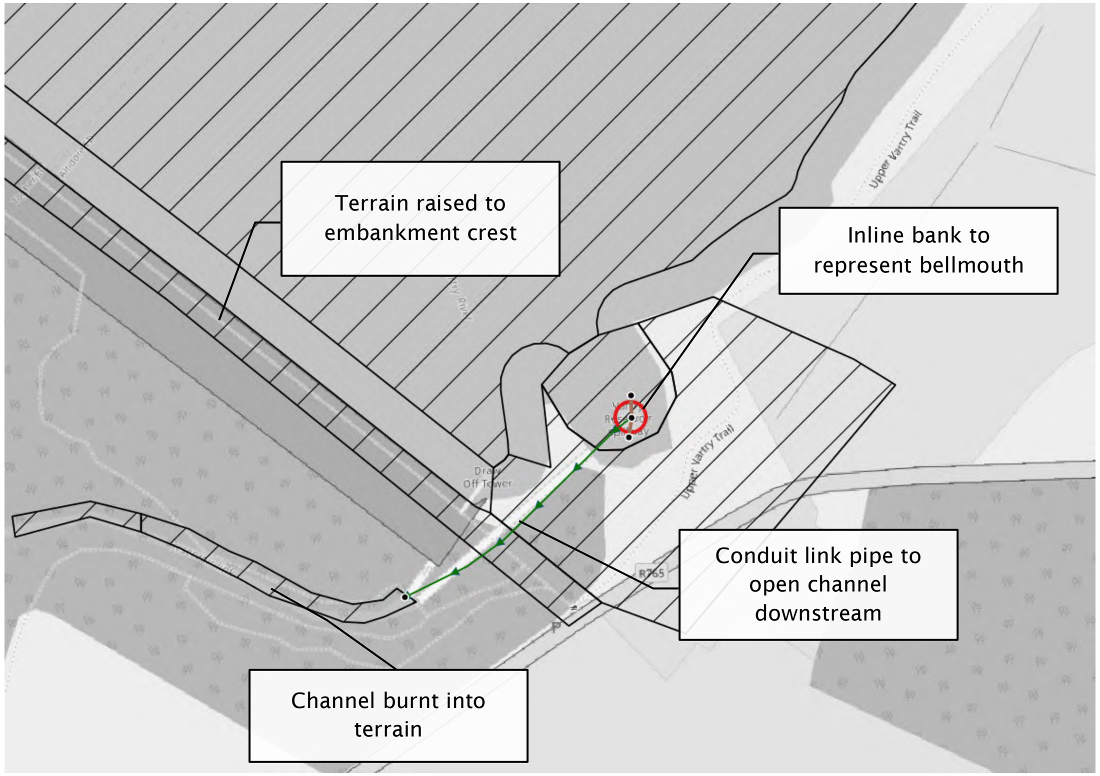
- Sim providing initial state – for calibration events to replicate a wet catchment prior to application of rainfall and to reduce simulation time as only the peak rainfall was required to be applied.
- Initial conditions 1D/2D - for setting initial water levels within the reservoirs for both calibration and design events. Five initial condition zones were established to allow variation in water levels across the reservoir footprint, zones are labelled in Figure 6-1 above.

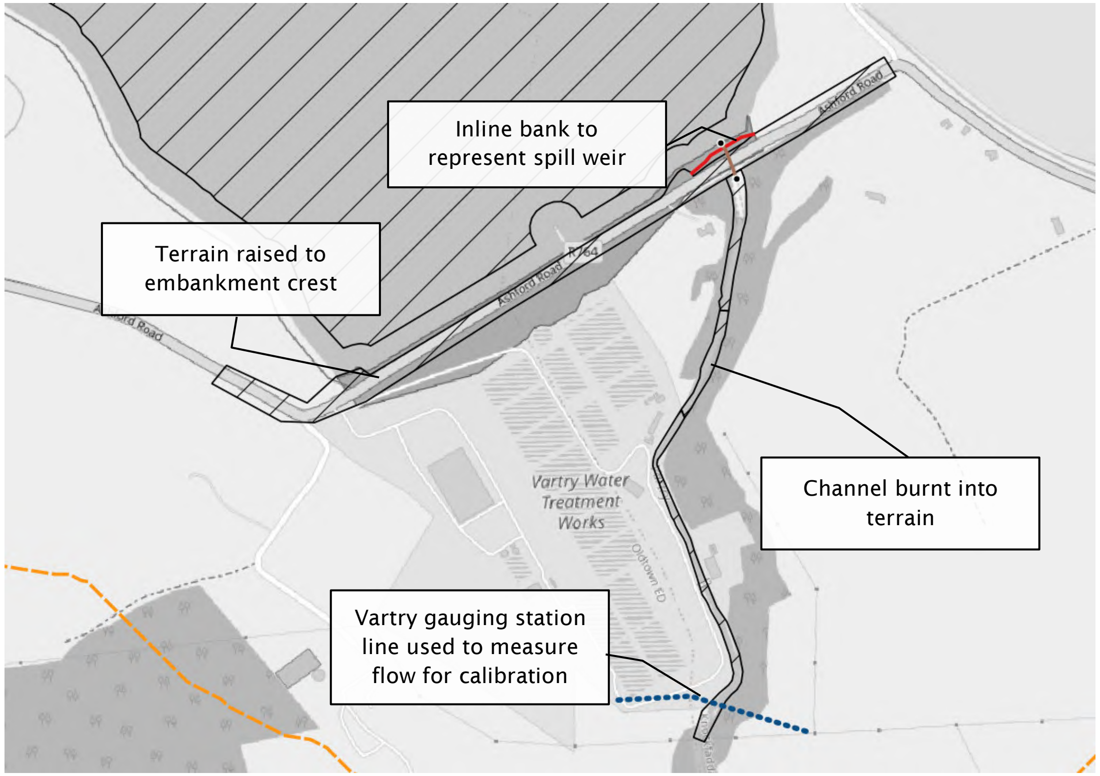
6.6 Reservoir Representation

Following a review of Vartry reservoir configuration, the following assumptions and simplifications were made in order to model the system:

- Given the reservoir is typically on spill for approximately 6 months of the year, it was assumed that these conditions should be replicated for design events and the model calibrated for events when reservoir is already spilling.
- When the reservoir is spilling, the spillway structures control the volume of water that will be released to the Vartry River, so it is essential these are represented in the model. Valves from draw off towers and scour valves were assumed to be closed for model simulations when reservoir on spill so excluded from the model.
- Loss of water from the system for PWS was ignored as this was likely to vary between events due to works carried out at Lower Vartry and estimated 0.5cumecs to 0.96cumecs which is negligible in context of flows generated from design events

The figure below summaries how the spillway weirs and channel/pipes were represented in the model for Upper and Lower Vartry. Table 6-1 then presents the building blocks for the rest of the catchment model.

Model Schematic	Description
Upper Vartry 	**Two inline banks** to represent bellmouth spill weir with bank line 35m long totalling 70m. Crest level set to TWL. **Conduit** 3.66m diameter used to transport flows from inline bank to gorge section downstream **Mesh zone** used to modify the terrain model to represent: • Embankment crest level • Drop reservoir levels to represent reservoir bed (219.5mOD) and ensure flood mapping representative • Spillway channel to ensure flows conveyed from end of pipe to Lower Vartry. • Terrain modifications around bellmouth for model stability.

Lower Vartry	**Inline banks** to represent spill weir with bank line 90.2m. Crest level set to TWL. **Mesh zone** used to modify the terrain model to represent: • Embankment crest level • Spillway channel to ensure flows conveyed spill weir to Vartry River downstream • Drop reservoir levels to represent reservoir bed (22.2mOD) and ensure flood mapping representative Ashford Road bridge was not modelled as is there is a significant drop from weir crest to culvert bed level, so it was deemed not hydraulically significant.
	

6.7 Model Geometry

Key geometry data sources, assumptions and rationalisations are scheduled in the following table.

Table 6-1 Model Geometry and Approach Commentary

Parameter	Data Source	Approach
Infiltration Surfaces	GSI EPA Soil Maps	A blanket approach was applied to the entire 2D zone based on geology, soil conditions and the calibration exercise. A patch was applied to reservoir footprint to prevent water being lost from the reservoir floor to infiltration.
Rainfall	Ballynahinch rain gauge FSU	Observed rainfall was applied from Ballynahinch rain gauge for calibration events. A simplified approach excludes spatial or temporal variation across the catchment. Hyetographs were derived from FSU depth – duration – frequency models for design events
Initial Conditions	Irish Water	Recorded reservoir levels were used for calibration events Reservoirs assumed to be on spill /TWL for design events
2D Line source	N/A	Baseflow contributions were applied to perimeter of reservoir (excluding dam length) for calibration events only
Ground Model	OSI	10m DTM from OSI was used for entire model
2D Zone	N/A	The hydrological catchment draining to the site was buffered by minimum 300m and used as the model 2D Zone boundary to ensure the entire catchment and areas of interest were covered.
Mesh Zone	Various - See Reservoir configuration	Mesh zones were used to modify the terrain model to represent: • embankment levels • reservoir bed • Spillway channels to ensure flows is conveyed from spillway weir downstream. • Small edits to ensure stability
Mesh Level Zone	N/A	Mesh level zone was used to ensure water could be conveyed through roads crossing the reservoir.
Boundary Conditions	N/A	Normal conditions applied to the boundary of the 2D Zone. The downstream boundary has been carefully sited to ensure any flooding at the site has a significant elevation difference to the 2D boundary and would not be influenced by any boundary condition.
Roughness Zones	Prime 2	Roughness differentiated at reservoirs and wooded areas. Elsewhere the catchment assumed to be uniform. Reservoir roughness was determined from calibration exercise.

Parameter	Data Source	Approach
Culverts	Various - See Reservoir configuration	Culvert used to represent pipe from Upper Vartry bellmouth spill to open channel below.
Inline bank	Various - See Reservoir configuration	Spillway structures were represented by use of inline bank with the bank length equating weir length as per configuration. Spillway coefficients were revised following the calibration exercise.

6.8 Modelling Assumptions and Limitations

The representation of any complex system by a model requires a number of assumptions to be made. For the purposes of the study it is assumed that:

- The terrain model sufficiently accurately represents the surface topography and associated flow paths.
- Roughness does not vary with time.

The primary limitations of the model are noted as follows:

- The model does not represent any topographic features smaller than the minimum resolution of the underlying terrain model derived for the site.

Wider assumptions and limitations in relation to the approach are discussed in Section 7.3.

7 MODEL CALIBRATION & DESIGN STORMS

7.1 Model Calibration

This section presents model calibration for the November 2019, February 2020 and December 2020. An explanation of our approach to calibration based on the available data is provided, followed by derivation of rainfall inputs. Model calibration and validation is then discussed in detail with supporting figures.

7.1.1 Available data

Calibration was achieved by running the model for three past events. The choice of events was largely governed by the data available, which comprised:

- Daily rain series from Ballynahinch rain gauge in the catchment (1998 - April 2021)
- Daily reservoir levels for Upper and Lower Vartry (January 2018 to September 2021)
- Observed flow series at Vartry gauging station (June 2018 - Aug 2021)

The observed flow series is the limiting factor on data availability given the short record length, so was reviewed and three events identified when the reservoir was already on spill by inspection of reservoir levels (see Figure 7-1and Table 7-1 below).

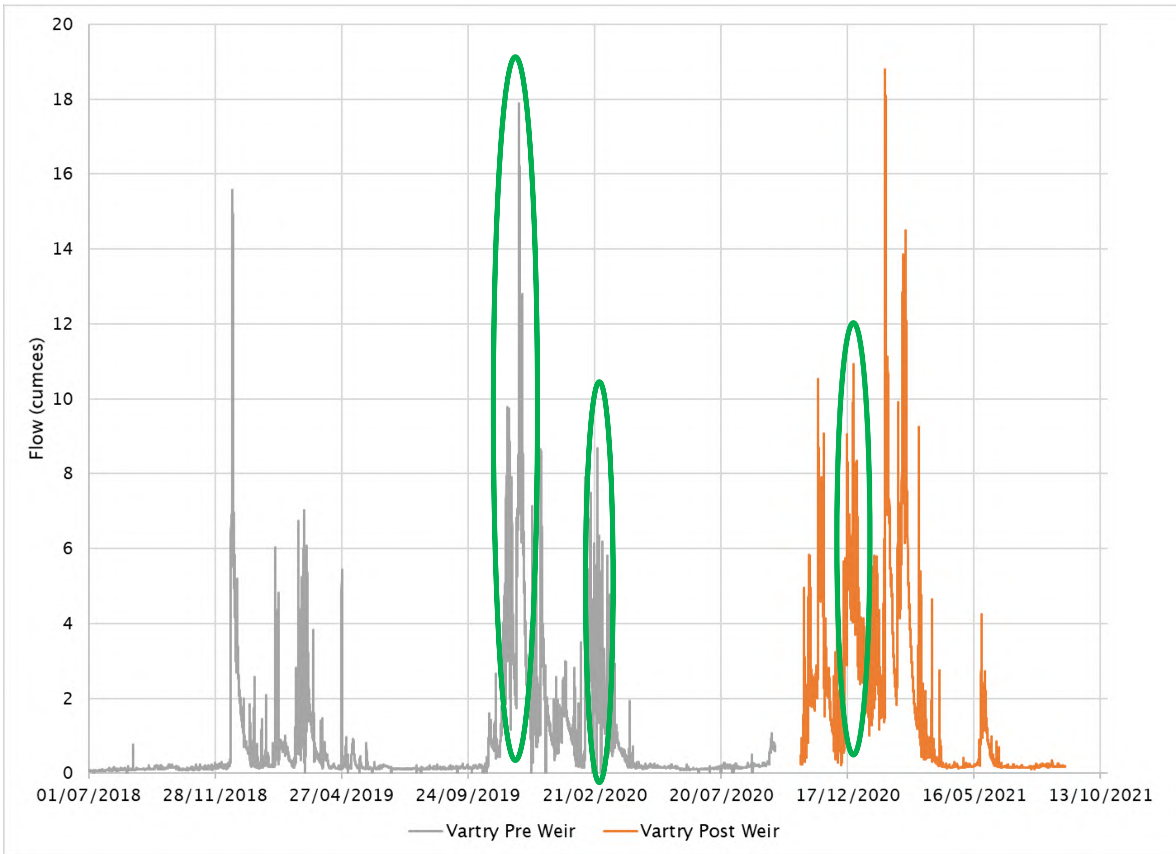


Figure 7-1: Recorded events identified for calibration

Table 7-1: Calibration events

Event date	Start	End	Comment
November 2019	21/11/2019	24/11/2019	2nd largest event on record
February 2020	21/02/2020	26/02/2020	7th largest event on record
December 2020	20/12/2020	24/12/2020	5th largest event on record

Other events were considered but rejected for final calibration:

- January 2021 - largest event on record but rainfall record is dubious; has the 3rd highest rainfall total at the Ballynahinch gauge so the model will not be able to replicate the peak flow
- February 2021 – no rainfall data available for gauge, marked as missing
- Dec 2018 - initially tested in calibration phase but excluded as reservoirs are not on spill

7.1.2 Flow data at Vartry gauge

The observed flow data was reviewed at the gauge for each event as spiking is present across the record. This increases uncertainties in the record as the 'actual' peak flow of the event is unknown.

November 2019 is provided as an example where the flow is shown to vary between 15.01m^3/s to 17.89m^3/s at the peak of the event as shown in Figure 7-2. The recorded data was smoothed using an exponential smoothing algorithm. The smoothed flow series (blue line) has been used for comparing flows for model calibration.

The same procedure was run for the additional two calibration events. Peak flows from final smoothed flow series are summarised in Table 7-2.

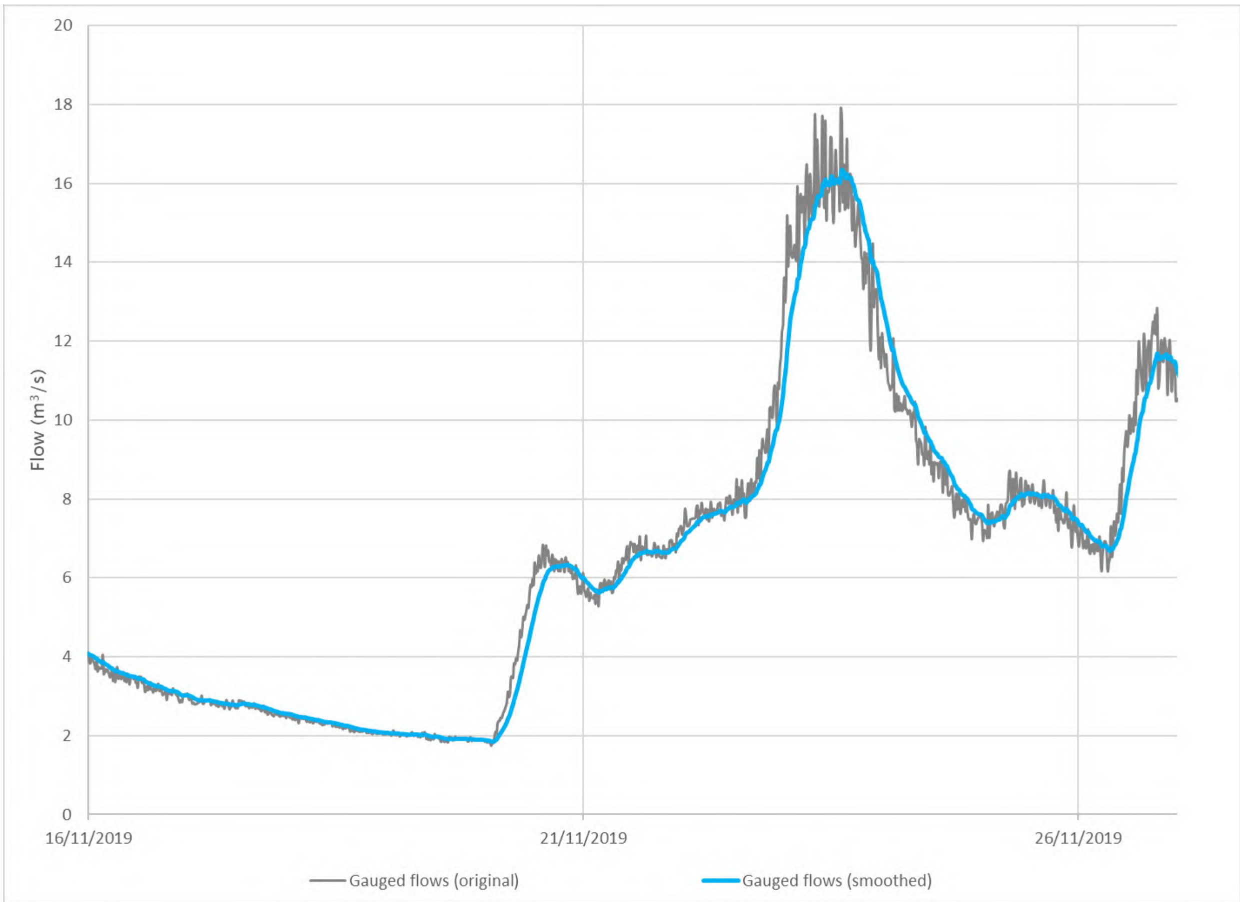


Figure 7-2: November 2019 flow series: original vs smoothed

Table 7-2: Observed Vartry flows: spiking vs smoothed

	Observed peak flow at gauge (range due to spiking flows) (m^3/s)	Observed peak flow smooth (m^3/s)
Nov 2019	17.89 – 15.01	16.35
Feb 2020	8.69 – 7.00	7.59
Dec 2020	10.94 to 10.44	10.59

7.1.3 Application of boundary conditions

This section describes our approach to deriving model boundary conditions as follows:

- Reservoir levels were applied as an initial water level to the reservoir surface based on the recorded water level at the time of initiation.
- Observed rainfall was obtained for each calibration event from Ballynahinch rain gauge and applied to every cell within the 2D flow area.
- Rainfall is converted to runoff (flow) and routed across the surface using the 2D model, based on shallow water routing equations.
- Model infiltration is applied to all cells to replicate losses due to infiltration, percolation to groundwater, evaporation, and transpiration.
- An arbitrary low baseflow was also applied to the perimeter of reservoirs.

Each component of the boundary condition is discussed in detail in context of November 2019 event. The same procedure was applied for other calibration events.

7.1.3.1 Reservoir levels

Initial reservoir levels have been set to ensure the reservoir was performing as intended at the start of the November 2019 event. The start of the event was dictated by application of rainfall and was 19th November 2019.

For context the TWL for the Upper and Lower Vartry are 222.59m OD and 209.01m OD respectively. For zone ID context refer to Figure 6-1.

Table 7-3: Initial reservoir levels 19th November 2019

Zone ID	Elevation (m AD)	Justification
Upper Vartry 1	222.85	RGL +0.1m to allow water to flow downstream
Upper Vartry 2	222.75	Reservoir gauged level (RGL)
Lower Vartry 1	209.20	RGL+0.1 to allow water to flow downstream
Lower Vartry 2	209.10	Reservoir gauged level (RGL)
Lower Vartry 3	209.10	Reservoir gauged level (RGL)

7.1.3.2 Rainfall

Observed rainfall was obtained for each calibration event from Ballynahinch rain gauge. This is the only active gauge within the catchment.

The rainfall was then extracted that contributed to each rainfall event. The rainfall time series was plotted before and after the observed peak at Vartry gauge to identify the rainfall that directly contributed to the flood event. Figure 7-3 below shows November 2019; orange denotes the period of rainfall that was used in model simulations. This captures rainfall to the peak (45mm) and several days after due to anticipated lag in the reservoir response.

This also provided a qualitative assessment of antecedent conditions before the storm event. As noted, no rainfall was recorded for four days prior to this event.

Following review, rainfall was converted to rainfall intensity (mm/hr) for application to the hydraulic model.

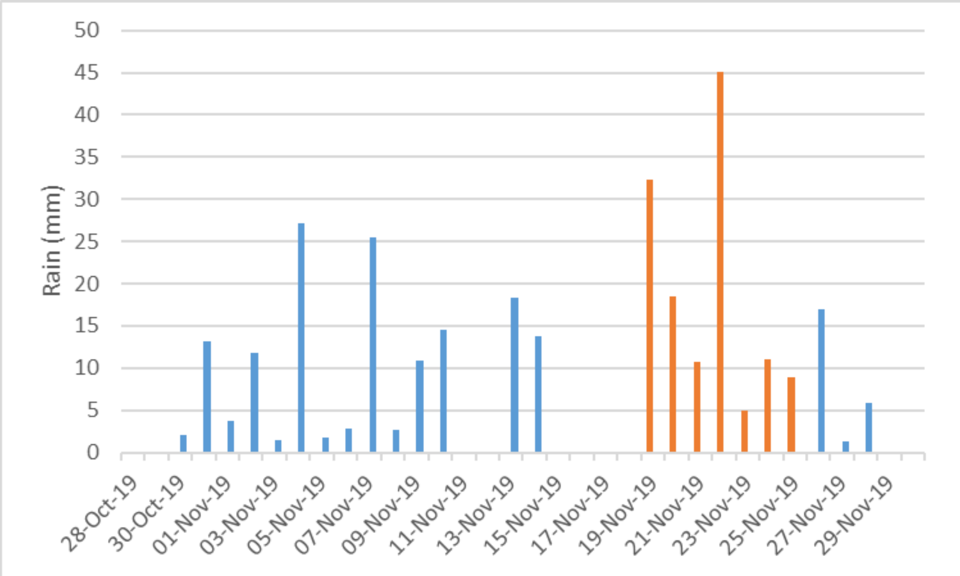


Figure 7-3: Antecedent rainfall November 2019 event

The rarity of the rainfall events has been assessed by FSU analysis; the highest daily total spanning (24hr period) has been compared with FSU growth curve for catchment draining to Vartry gauge for 24hr storm event.

In the case of November 2019, the highest total is on 22nd November, 45.1mm rainfall. Based on table below, this correlates to between a 100% to 50% AEP rainfall event. This confirms that the events tested are frequently exceeded.

Table 7-4: FSU rainfall growth curve for 24hr storm

Return Period (AEP)	Rainfall Depth (mm)
100%	8
50%	50

7.1.3.3 Model infiltration

The catchment is shown to be underlaid with majority Till with some areas of blanket peat to the north and east and alluvium deposits within the valleys.

This is consistent with EPA Soil Map showing the site to be fine loamy drift /brown soils derived from mudstone, shale or slate bedrocks.

Typical infiltration for brown soils were applied to the 2D zone based upon 2D Horton Infiltration model included within the InfoWorks ICM software. This model converts the direct rainfall applied to the mesh into a runoff volume which is determine by the parameters set for the surface.

The Horton infiltration model was selected as it is the single model within the software which simulates in the absence of rainfall, i.e. after the event. Horton infiltration parameters reflective of the underlying soil conditions applied to the model are detailed further in the table below.

Table 7-5: Horton Infiltrating Parameters

Soil Type	Horton Initial (mm/hr)	Horton Limiting (mm/hr)	Horton Decay (1 / hour)
Brown soils	1.3	0.001	1

7.1.3.4 Baseflow

Baseflow was applied to the perimeter of each reservoir excluding the area along the embankment crest. An arbitrary steady flow 0.25 cumecs was applied.

This is to try and replicate the slow soil pathway response that the routing model cannot replicate.

There was no information to quantify baseflow, but its inclusion was justified by review of the superficial geology showing alluvium deposits over bedrock in the valleys.

7.1.4 Calibration Outcome

Having applied boundary conditions as described above, calibration performance was assessed by comparing modelled flows to recorded flows at Vartry gauge.

The key parameters that were changed for calibration were:

- Weir coefficients on inline banks representing spillway structures
- Reservoir roughness

These were iteratively changed to provide the best match at the Vartry gauge in terms of peak flow for the events tested. Manning *n* roughness of the reservoir was raised above 'typical' parameter limits to try and replicate the attenuation and slowing down of velocities in reservoir body. As both parameters are shown to interact with each other, a matrix of model simulations were carried out to identify the best match for the events tested.

Table 7-6 lists the final parameters dataset, this was used as the baseline for design model simulations.

Table 7-6: Final calibrated parameters

	Parameter value
Weir coefficient C_d	0.8
Reservoir Manning's *n* roughness	0.25

To showcase this, Figure 7-4 below compares the modelled response to observed flow at Vartry gauge for November 2019 event. Three varying reservoir Manning's *n* roughness scenarios were tested: 0.25, 0.5 and 1 with the weir coefficient of 0.8 for reservoir spillway structures. Overall, the model is shown to replicate peak flow well compared to the observed for all scenarios.

Review of Figure 7-4 in isolation would indicate that the best match is the black line compared to the smoothed gauged flow. However, the model was tested against two additional events, and it was deemed that the green line (reservoir roughness 0.25) should be selected for reasons of ensuring a precautionary analysis.

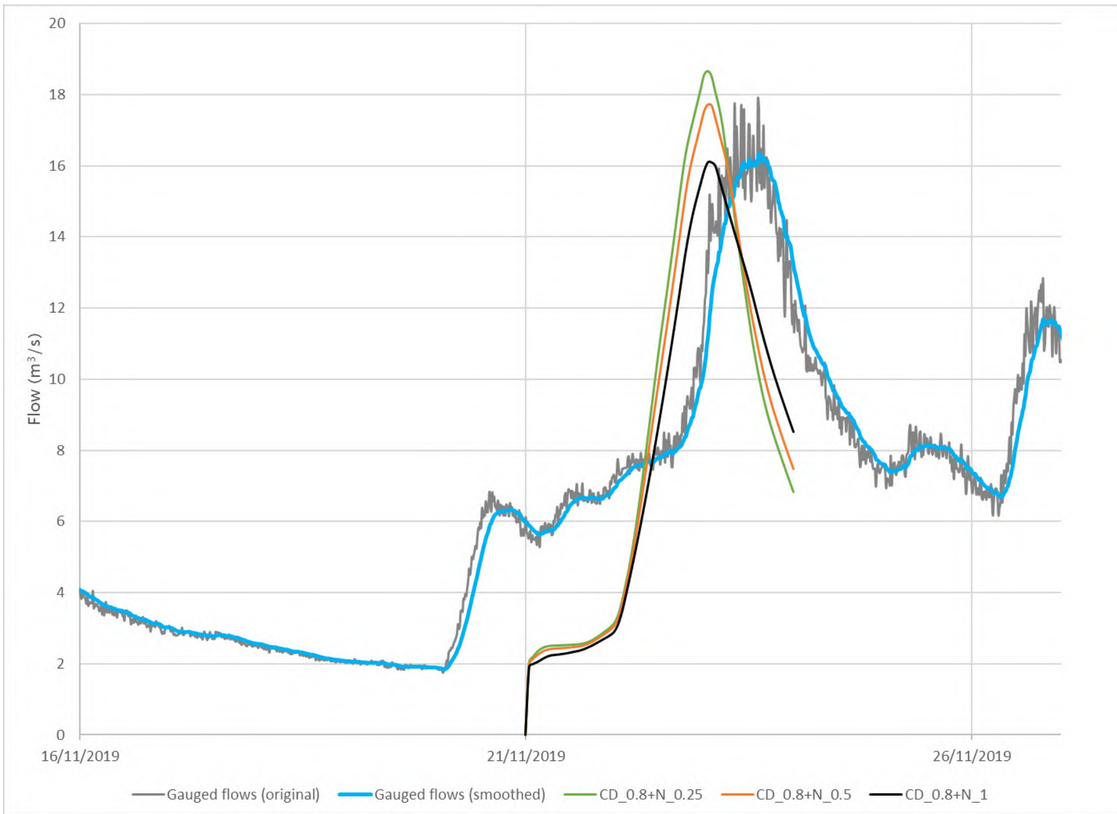


Figure 7-4: Modelled flows at Vartry gauge, November 2019

Table 7-7 summarises the results from the three calibration events tested.

The model is shown to replicate the observed peak flow within ±20%. This is an acceptable tolerance limited by the model methodology given likely variability and sensitivity to a number of factors, primary among which are temporal and spatial variation of rainfall (affecting mass of water in the model), and model roughness and infiltration.

The model is unable to fully replicate the gauged time to peak and associated reservoir water level, however this is not a significant limitation where the project objective is to reduce uncertainty in relation to estimates of peak flood flows. The model predicted flood peaks in advance of observed peaks. Given the permeable catchment over elevated bedrock, it is anticipated that a real-world delay is likely as a result of significant reservoir re-charge via shallow groundwater, which cannot be replicated by the model methodology.

Table 7-7: Calibration summary for Vartry gauge

	Observed peak flow smooth (m^3/s)	Modelled flows at gauge (m^3/s)	Difference in observed vs modelled peak flow (m) at gauge Absolute (m) and percentage (%)
Nov 2019	16.35	18.77	+2.42 (13%)
Feb 2020	7.59	7.39	-0.2 (-3%)
Dec 2020	10.59	8.68	-2.14 (-22%)

7.1.5 Summary

The outcome achieves a satisfactory level of calibration in relation to peak discharge for three calibration events. These events are estimated to be associated with between a 100% - 50% AEP rainfall event so frequently exceeded.

While there remains a range of uncertainty, the outcome significantly reduces the level of uncertainty noted in previous hydrological assessments and reviews.

7.2 Design Storms

Outflows from the Vartry Reservoir system are ultimately intended to feed into a component part of fluvial catchment flood estimation for the wider hydrological catchment draining to a subject site downstream at Ballinahinch, Ashford.

The reservoir routing model is simulated based on design rainfall derived from a Flood Studies Update (FSU) portal analysis. Given the need to combine outflows with a downstream fluvial analysis, an appropriate methodology was required to allow conversion of rainfall / pluvial probability to fluvial flood probability. In the absence of a calibrated rainfall-runoff model for Ireland (such as the equivalent Revitalised Flood Hydrograph (ReFH) method for the UK), the most appropriate method is design event method stated in Flood Estimation Handbook (FEH) Volume 4[3].

Figure 7-5 is an extract from this report and shows approach taken marked by annotated red lines; to generate a 100-year fluvial flow peak, a 140-year rainfall event is required. The graph is non-linear and at larger flows, the conversion factor is reduced to 1 where a 1000-year flow equates to 1000-year rainfall event.

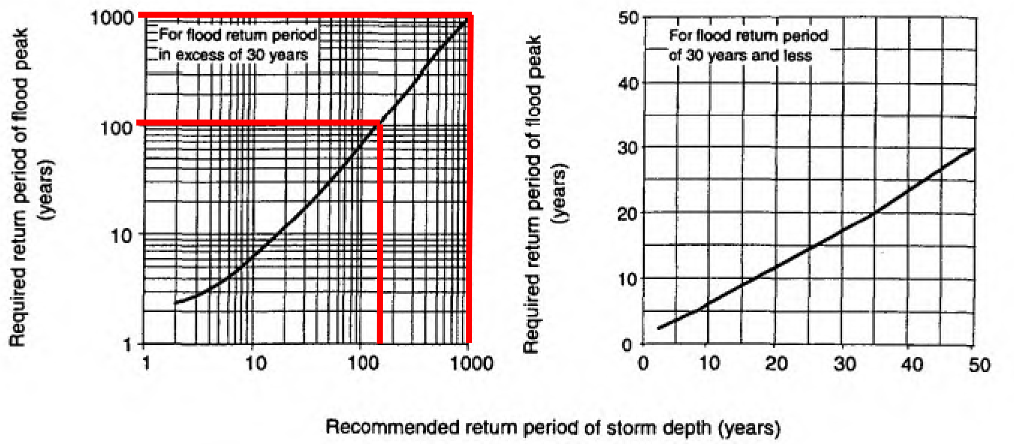


Figure 7-5: Storm return period to yield flood peak of required return period

Design storms were therefore simulated for 140-year return period (1.4% AEP) and 1000-year return period (0.1% rainfall AEP) rainfall events.

7.2.1 Initial Conditions

Design storms are evaluated with a starting assumption of "on weir" conditions in the Vartry Reservoir complex. This approach is conservative and appropriate given the intended use of the data in terms of downstream flood risk assessment, where the precautionary principle is advocated by the Planning Guidelines[4]. The assumption is also justified for the following reasons:

[3] NERC (2008) FEH Handbook Restatement and application of the Flood Studies Report rainfall-runoff method Flood-Estimation-Handbook-4-Restatement-And-Application-Of-The-Flood-Studies-Report-Rainfall-Runoff Method_Helen-Houghton-Carr version 2.pdf (ceh.ac.uk) [Accessed 14th December 2021)

[4] Office of Public Works (2009) The Planning System and Flood Risk Management – Guidelines for Planning Authorities, Technical Appendix A (Department of the Environment, Heritage and Local Government.)

- Monitoring data at the reservoirs (Section 5.2) tends to indicate that the reservoirs are on weir for a significant period in any given year. A winter storm would therefore likely coincide with on-weir conditions.
- All calibration events, none of which are extreme, have winter seasonality commencing with on-weir conditions.
- FSU Depth-Duration-Frequency models from which rainfall inflows derived are most suitable for estimating distinct storms. Seasonality and antecedent conditions (such as preceding reservoir levels) remain significant factors in relating design storms to a flood event, and it is not realistic to select an extreme isolated storm and assume dry prior conditions.

7.2.2 Critical Duration

Criteria for criticality for purposes of downstream flood estimation is the peak discharge downstream of Lower Vartry Reservoir. The peak flood is influenced by the attenuating volume available in the reservoir complex and as such is influenced by storm duration and peakiness.

Criticality has therefore been assessed for 1% AEP by simulating 3hr, 12hr, 24hr and 48hr hour storms. The outcome is shown in the following chart. It is therefore determined that 24hr is critical and has been taken forward for design storm analysis.

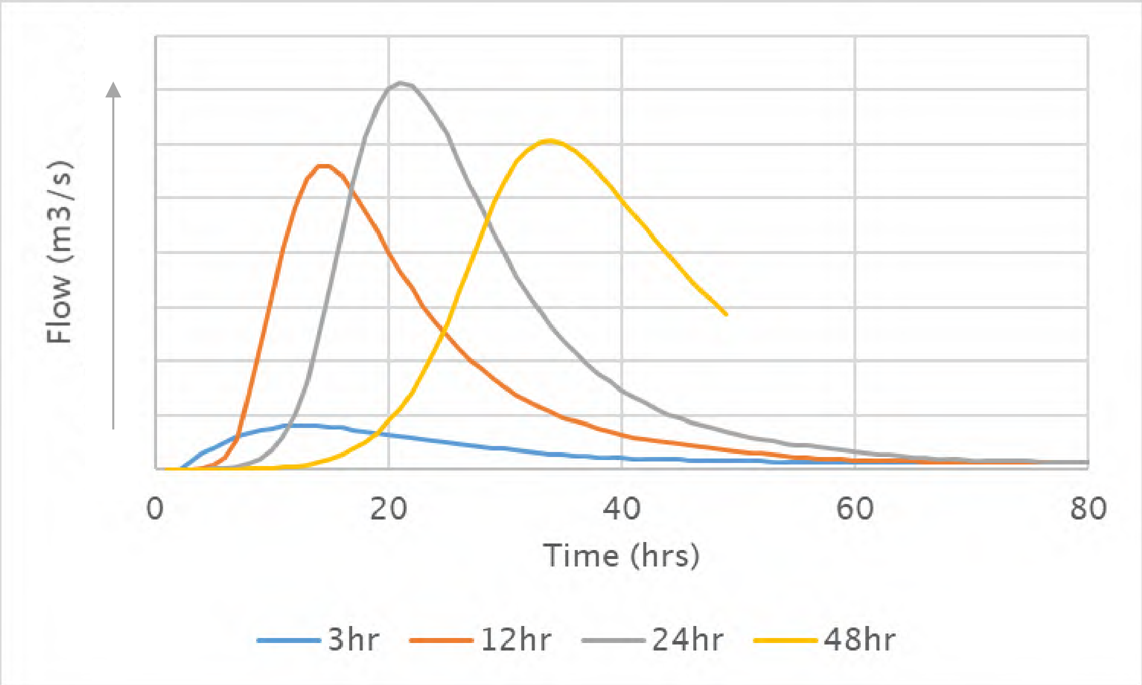


Figure 7-6: Critical analysis for 1% AEP

7.2.3 Design Storm Outcomes

The outcome of design storm simulations, in terms of outflow from Lower Vartry Reservoir, is shown in the following table.

Fluvial Flood Probability	Peak flow (m^3/s)
1%AEP	79.79
0.1% AEP	101.67

7.2.4 Climate Change

OPW Climate Change adaptation guidance requires that to assess the effect of climate change that an uplift of +20% (Mid Range Future Scenario) is applied to flood discharge (fluvial flooding) and rainfall depth.

The reservoir routing model is intended to provide a fluvial discharge at its outflow but is rainfall fed; it cannot be inferred that a +20% uplift to rainfall depth would result in a +20% increase in outflow. Therefore, to assess climate change rainfall hyetographs were scaled by +20% to allow evaluation of climate change outflows.

Fluvial Flood Probability	Peak flow (m^3/s) derived from 20% uplift to rainfall hyetographs	Peak flow (m^3/s) derived from 20% uplift to flow hydrograph
1% AEP	95.2	95.7
0.1% AEP	113.6	122.0

Rainfall and flow uplift closely match for the 1% AEP with a 1% increase in the uplift. This increases to 7% for the 0.1% AEP. The precautionary principle embedded in the planning guidelines would direct practitioners to use the more conservative outcome dependent on the nature of the assessment downstream.

7.3 Assumption and Limitations

The following key assumptions and limitations apply to the outcome of the calibration and design flow assessment:

i. Calibration assumes that rainfall observed at Ballynahinch rain gauge is representative of rainfall over the Vartry Reservoir catchment, and that there is no significant spatial or temporal variation that would affect calibration outcomes.

ii. Calibration assumes that the rating / gauged flows provided by Irish Water for Vartry gauge is fit for purpose

iii. Calibration and design flow simulations exclude the loss of water from Lower Vartry reservoir for PWS, the capacity of which have been assessed as insignificant in the context of peak flows passing.

iv. Design simulations assume that model calibration achieved for high probability rainfall events can be extrapolated for extreme rainfall analysis, and that temporal variation in roughness or infiltration that would reasonably coincide with more extreme rainfall would not significantly affect the model outcome. This assumption could only be tested where gauge data was available coinciding with a more extreme storm, to allow any necessary adjustment to calibration.

v. The methodology (and all currently available techniques) are limited in that they are unable to replicate the high baseflow response that it is anticipated to be significant in the catchment. Actual catchment response is likely to be high-surface infiltration with shallow sub-surface groundwater flow to the reservoirs. Model infiltration parameters are unrealistically high (vs catchment conditions) as to apply high infiltration would cause full loss of that water from the model. This effect is replicated in the more rapid surface water response vs recorded delayed observed response by gauge data.

vi. The assessment assumes that flooding will occur while the reservoir is on spill. The reservoir is on spill typically 4 6 months per year. Assumption of occurrence of an event with an annual equivalent probability and assuming that it occurs within part of that year would in reality cause the probability of that event to reduce. This approach is conservative, but could be further enhanced by a seasonally weighted joint-probability analysis, the scope and complexity of which lies outside this project.

8 SUMMARY OF FINDINGS

8.1 Summary of Findings

This project has sought to reduce uncertainties in flood mapping on the Vartry River. Review of available flood data concluded that the CFRAM flood mapping significantly underestimates flood risk along the Vartry River. The flood regime in Ashford is heavily impacted by the Upper and Lower Vartry reservoirs system These reservoirs have been coarsely represented in the CFRAM mapping by a lumped attenuation parameter. In reality the generation of flood flows are controlled by specific spillway structures at the downstream extent of the reservoirs.

To improve confidence in the flow estimates from the Vartry reservoir system, a review of the reservoir system configuration was undertaken, and reservoir routing model developed to estimate fluvial flows that would be generated from the catchment. This was calibrated to the Vartry gauging station and then simulated with design rainfall to predict flood flows.

Review of the current reservoir system show that the reservoir is on spill for approximately four to six months of the year. It was assumed that a flood would occur when the reservoir is already spilling. Three events were selected from the three-year record at the gauge and using observed rainfall, model parameters were adjusted to provide the best match in terms of peak flow. The model is shown to replicate the observed peak flow within ±20% which is deemed satisfactory given the assumptions and uncertainties in model boundary conditions.

Following calibration, the model was simulated with design rainfall to estimate outflows for a range of fluvial return periods as detailed in table below.

	Peak flow (m^3/s)	% larger than CFRAM flow in Ashford
1%AEP	79.79	258%
0.1% AEP	101.67	207%

The flows have been reviewed in context of the modelled CFRAM flood flows at Ashford and show to be between 200- 260% larger. This is striking given the reservoir catchment ($53km^2$) is close to half the size of the catchment to Ashford ($92km^2$). However, such an increase to flows is expected due to the mismatches presented comparing CFRAM flood flows with recorded flood data at Ashford.

There remains residual uncertainty in the estimates derived; however, the quantum of uncertainty by the outcome of this study, and the flow estimates produced are precautionary and advocated as fit for purpose in downstream flood risk assessment. The estimates are a considerable improvement over a simple lumped attenuation parameter for purposes of flood estimation.

8.2 Next Steps

The outcome of this assessment is intended to supplement and inform hydrological flood estimation for reaches of the Vartry Reservoir downstream.

Description of that work specific to the initial site included in the wider work package is addressed separately in *M02169_FR01 Lands at Ballynahinch, Ashford Flood Study Report.*

8.3 Recommendations

The flows derived by the assessment are suitable to inform hydrological flood estimation and flood studies at any site downstream of Varty Reservoir and the outcome is recommended to supersede flow data indicated on CFRAM flood mapping.

Due to orders of magnitude of underestimation predicted by CFRAM it is recommended that CFRAM flood outlines and predicted water levels for the Vartry River downstream of the Varty Reservoir complex are disregarded for flood risk planning purposes.

It is recommended that the assumptions noted in the model build and calibration sections are tested where new data becomes available; and / or where gauge data is revised (due to e.g. a revised gauge rating).

Appendix C

Hydrology Summary

Ashford Flow Extraction Point

Flood Estimation Report #12830 (M02169-01 Ballinahinch Wicklow)

Generated 09-12-2021 13:45

Subject site

Attributes

Name	Unit	Value
Coordinate [X]		-680193.819118102
Coordinate [Y]		6985438.89118088
Distance	km	26.3143518076822
Station Number		10_1471_3
Location		
Water Body		
Catchment		
Hydrometric Area		
Organisation		
FSU Rating Classification		
Drainage works	year	
Contributing Catchment Area	km^2	90.186
Center Northing	m	203240
Center Easting	m	321770
Northing	m	197469
Easting	m	326879
A-Max series gap in years	year	
A-Max series number of years	year	
A-Max series number of usable years	year	
A-Max series end year	year	
A-Max series start year	year	
FARL		0.805
ALLUV		0.043
PEAT		0.065
FOREST		0.2413
PASTURE		0.6431
S1085	m/km	10.7847
MSL	km	24.661
DRAIND	km/km^2	0.885
ALTBAR		245.7
NETLEN	km	79.782
T4		
T3		

SAAPE	mm	531.5
T2		
ARTDRAIN2		0
ARTDRAIN		0
TAYSLO		0.526869
STMFRQ		79
BFISOIL		0.660324415
SAAR	mm	1130.94
RWSEG_CD		10_1471
TOP_RWSEG		
Bankfull		
HGF	m^3/s	
MAF	m^3/s	
FAI		0.2108
FLATWET		0.54
URBEXT		0.0048
HGF/QMED		
centroidx3857		-688746.325950545
centroidy3857		6995596.331927
x3857		-680193.819118102
y3857		6985438.89118088

Pivotal site

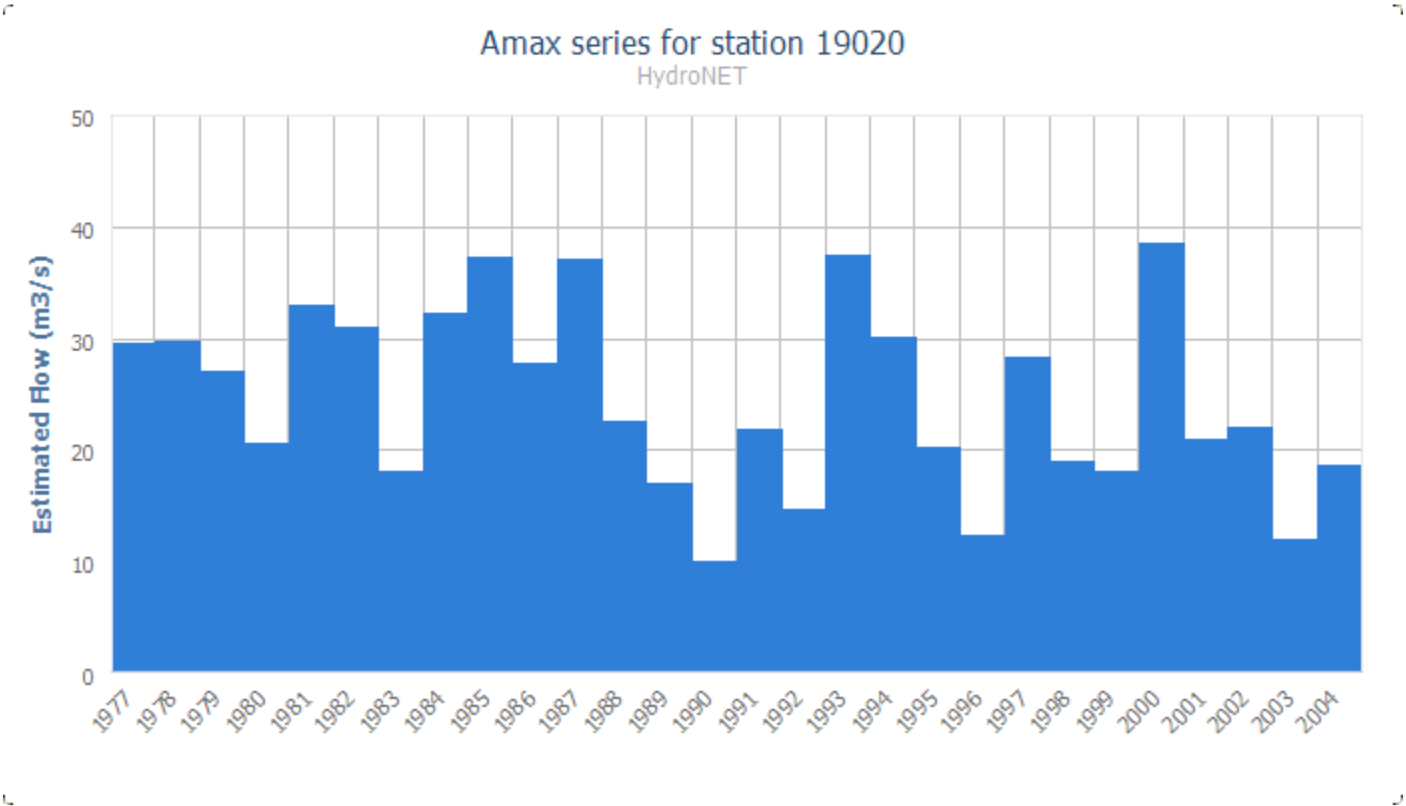
Attributes

Name	Unit	Value
Coordinate [X]		-913423.823806461
Coordinate [Y]		6789650.95856127
Station Number		19020
Location		BALLYEDMOND
Water Body		OWENNACURRA
Catchment		Owennacurra
Hydrometric Area		19
Organisation		EPA
FSU Rating Classification		A2
Drainage works	year	0
Contributing Catchment Area	km^2	73.9548
Center Northing	m	81380
Center Easting	m	183810
Northing	m	76618
Easting	m	185923
A-Max series gap in years	year	0
A-Max series number of years	year	28
A-Max series number of usable years	year	28
A-Max series end year	year	2004
A-Max series start year	year	1977
FARL		1
ALLUV		0.0067
PEAT		0
FOREST		0.1783
PASTURE		0
S1085	m/km	11.01655
MSL	km	13.672
DRAIND	km/km^2	0.989
ALTBAR		0
NETLEN	km	73.147
T4		0.036724334984388
T3		0.029079800310601
SAAPE	mm	533.07
T2		0.19574843425857
ARTDRAIN2		0
ARTDRAIN		0
TAYSLO		0.815422
STMFRQ		57
BFISOIL		0.664
SAAR	mm	1179.07
RWSEG_CD		19_712
TOP_RWSEG		19_1205
Bankfull		?
HGF	m^3/s	25
MAF	m^3/s	24
FAI		0.05
FLATWET		0.63
URBEXT		0
HGF/QMED		1.1160714285714
x3857		-913423.823806461
y3857		6789650.95856127

centroidx3857		-916922.562522268
centroidy3857		6797630.93654123
Distance	km	302.083916662703

Map

Amax Series Chart



QMED Estimates

Subject rural QMED	11.03
Subject urban QMED	11.11
Pivotal gauged QMED	22.4
Pivotal adjustment factor QMED	1.38
Subject adjusted QMED	**15.33**

Pooling Group

Station	**Amax years**
19020 BALLYEDMOND	28
19046 STATION ROAD	9
16006 BALLINACLOGH	33
25027 GOURDEEN BRIDGE	42
25044 COOLE	40
29001 RATHGORGIN	40
26018 BELLAVAHAN	48
06012 CLAREBANE	47
26010 RIVERSTOWN	35
19016 OVENS	11

13002 FOULKS MILL	19
16005 AUGHNAGROSS	30
19015 HEALYS BR.	28
25038 TYONE	17
06070 MUCKNO	27
25014 MILLBROOK	54
30021 CHRISTINAS BR.	26
22009 WHITE BRIDGE	24
25020 KILLEEN	35
34011 GNEEVE BRIDGE	30
29071 CUTRA	26
25022 SYNGEFIELD	22
06011 MOYLES MILL	48
26014 BANADA BRIDGE	16
26020 ARGAR	33
18001 MOGEELY	48
35001 BALLYNACARROW	29
30037 CLOONCORMICK	21
30005 FOXHILL	49
07004 STRAMATT	48
26006 WILLSBROOK	52
26008 JOHNSTONS BR.	49
29004 CLARINBRIDGE	32
26009 BELLANTRA BR.	35
25029 CLARIANNA	33
29011 KILCOLGAN	22
06026 ACLINT	46
34024 KILTIMAGH	28
07011 ODALYS BR.	22
15007 KILBRICKEN	25
26058 BALLINRINK BR.	24
16012 TAR BR.	28
30020 BALLYHAUNIS	16
16003 RATHKENNAN	27
34005 SCARROWNAGEERAGH	13
25023 MILLTOWN	33
25158 CAPPAMORE	18
25040 ROSCREA	19
18005 DOWNING BR.	50
09010 WALDRONS BRIDGE	19
18004 BALLYNAMONA	45
36018 ASHFIELD	50
25030 SCARRIFF	48
30007 BALLYGADDY	31
16001 ATHLUMMON	33
07001 TREMBLESTOWN	18
36012 SALLAGHAN	47
36071 GOWLY	20
26022 KILMORE	33
24030 DANGANBEG	25
25016 RAHAN	48
25002 BARRINGTONS BR.	51
35004 BIG BRIDGE	14
06025 BURLEY	30
16007 KILLARDRY	51
16004 THURLES	48
12013 RATHVILLY	30

25025 BALLYHOONEY	31
06014 TALLANSTOWN	30
06031 CURRALHIR	18
26108 BOYLE ABBEY BR.	15
07006 FYANSTOWN	19
15004 MCMAHONS BR.	51
14013 BALLINACARRIG	49
20006 CLONAKILTY W.W.	25
26019 MULLAGH	51
35071 LAREEN	30

Adopted Growth Factors

Return Period	Growth Factor	Design Peak Flow (m^3/s)
1.3	0.84	12.88
2	1	15.33
5	1.21	18.55
10	1.35	20.7
20	1.49	22.85
30	1.57	24.07
50	1.68	25.76
100	1.83	28.06
200	2	30.67
500	2.23	34.19
1000	2.43	37.26

Hydrograph Width Estimation Summary

Hydrograph summary is not available for this report because the hydrograph was not transferred to the subject site.

Audit Trail Report #12830 (M02169-01 Ballinahinch Wicklow)

User ID:	duncan.chapman@mccloyconsulting.com
Name:	Chapman, Duncan
Company:	McCloy Consulting
Address:	
Report date & time:	09-12-2021 13:45
Start of Calculation:	25-10-2021 16:34

Decisions made by the user:

Decision	User comment	System information	Date
2.1 Subject site accepted	N/A	Location 10_1471_3	25-10-2021 16:36
2.3 Pivotal site rejected	Estimate required downstream of Vartry reservoir, intervening catchment from Vartry to site. Reservoir catchment model will be used to estimate flows from reservoir.	Station: 19020 BALLYEDMOND	25-10-2021 16:54
2.1 Subject site accepted	N/A	Location 10_1471_3	25-10-2021 18:51
2.1 Subject site accepted	N/A	Location 10_1471_3	17-11-2021 15:25

2.4 Pivotal site accepted	Reason for accepting: 19020 most hydrological similar rating of 0.29, FARL value =1 this is acceptable as we are attempting to calculate flows for intervening area and not influence of reservoir. Reason for ignoring warnings: FARL value =1 this is acceptable as we are attempting to calculate flows for intervening area and not influence of reservoir.	Station: 19020 BALLYEDMONDWarnings: - Proportion of lakes/reservoirs in the catchment differs appreciably. Difference: (0.195).- The pivotal site does not lie upstream or downstream of the subject site. The pivotal site lies 302.08km SW of the subject site The user has been notified that 143 candidates where either hydrologically or geographically closer to the subject site than the chosen pivotal site. The user has accepted to reject these sites in preference of the chosen pivotal site.	18-11-2021 12:33
2.1 Subject site accepted	N/A	Location 10_1471_3	18-11-2021 12:39
2.4 Pivotal site accepted	Reason for accepting: test Reason for ignoring warnings: test	Station: 10002 RATHDRUMWarnings: - Proportion of lakes/reservoirs in the catchment differs appreciably. Difference: (0.127).- The pivotal site does not lie upstream or downstream of the subject site. The pivotal site lies 13.62km SW of the subject site The user has been notified that 129 candidates where either hydrologically or geographically closer to the subject site than the chosen pivotal site. The user has accepted to reject these sites in preference of the chosen pivotal site.	18-11-2021 12:43
2.1 Subject site accepted	N/A	Location 10_1471_3	18-11-2021 12:51

2.4 Pivotal site accepted	Reason for accepting: test Reason for ignoring warnings: test	Station: 10004 LARAGHWarnings: - Proportion of lakes/reservoirs in the catchment differs appreciably. Difference: (0.181).- The pivotal site does not lie upstream or downstream of the subject site. The pivotal site lies 17.94km SW of the subject site The user has been notified that 188 candidates where either hydrologically or geographically closer to the subject site than the chosen pivotal site. The user has accepted to reject these sites in preference of the chosen pivotal site.	18-11-2021 12:52
2.1 Subject site accepted	N/A	Location 10_1471_3	18-11-2021 13:02
2.4 Pivotal site accepted	Reason for accepting: PCDs match apart from FARL but we are calculating intervening area downstream of reservoir so FARL is 1 for this catchment. Reason for ignoring warnings: PCDs match apart from FARL but we are calculating intervening area downstream of reservoir so FARL is 1 for this catchment.	Station: 19020 BALLYEDMONDWarnings: - Proportion of lakes/reservoirs in the catchment differs appreciably. Difference: (0.195).- The pivotal site does not lie upstream or downstream of the subject site. The pivotal site lies 302.08km SW of the subject site The user has been notified that 143 candidates where either hydrologically or geographically closer to the subject site than the chosen pivotal site. The user has accepted to reject these sites in preference of the chosen pivotal site.	18-11-2021 13:09
2.8 QMED data transfer performed	N/A		18-11-2021 13:09

2.11 Pooling group accepted	N/A	Pooled group accepted with the following stations: [19020, 19046, 16006, 25027, 25044, 29001, 26018, 06012, 26010, 19016, 13002, 16005, 19015, 25038, 06070, 25014, 30021, 22009, 25020, 34011, 29071, 25022, 06011, 26014, 26020, 18001, 35001, 30037, 30005, 07004, 26006, 26008, 29004, 26009, 25029, 29011, 06026, 34024, 07011, 15007, 26058, 16012, 30020, 16003, 34005, 25023, 25158, 25040, 18005, 09010, 18004, 36018, 25030, 30007, 16001, 07001, 36012, 36071, 26022, 24030, 25016, 25002, 35004, 06025, 16007, 16004, 12013, 25025, 06014, 06031, 26108, 07006, 15004, 14013, 20006, 26019, 35071] and distribution: GLO	18-11-2021 13:19
3.1 Hydrograph pivotal site rejected	test	Station: 06012 CLAREBANE	18-11-2021 15:09
2.8 QMED data transfer performed	N/A		09-12-2021 14:43
2.11 Pooling group accepted	N/A	Pooled group accepted with the following stations: [19020, 19046, 16006, 25027, 25044, 29001, 26018, 06012, 26010, 19016, 13002, 16005, 19015, 25038, 06070, 25014, 30021, 22009, 25020, 34011, 29071, 25022, 06011, 26014, 26020, 18001, 35001, 30037, 30005, 07004, 26006, 26008, 29004, 26009, 25029, 29011, 06026, 34024, 07011, 15007, 26058, 16012, 30020, 16003, 34005, 25023, 25158, 25040, 18005, 09010, 18004, 36018, 25030, 30007, 16001, 07001, 36012, 36071, 26022, 24030, 25016, 25002, 35004, 06025, 16007, 16004, 12013, 25025, 06014, 06031, 26108, 07006, 15004, 14013, 20006, 26019, 35071] and distribution: GLO	09-12-2021 14:43
2.13 Module 2 finalized	N/A	Finished pooled analysis with the following distribution selected: GLO.	09-12-2021 14:44