Auburn Flood Risk Review

Final Report

October 2021

www.jbaconsulting.ie

Kinwest Limited
6 The Orchard
Graigavern Lodge
Ballybrittas
Co. Laois

JBA Project Manager

Tim Cooke
Unit 3 Block 660
Greenogue Business Plaza
Rathcoole
Co. Dublin

Revision History

Revision Ref/Date	Amendments	Issued to
21/10/2020-SP3.P01	Draft Report	Kinwest Limited
26/10/2020-A4.C01	Final Report	Kinwest Limited

Contract

This report describes work commissioned by Waterman Moylan Consulting Engineers, on behalf of Kinwest Limited. Kinwest's representative for the contract was Mark Duignan of Waterman Moylan. David Casey and Daniel Lordache of JBA Consulting carried out this work.

Prepared by .... David Casey BSc MSc PGCert MCIWEM

Senior Engineer

Reviewed by .... Ross Bryant BSc MSc CEnv MCIWEM C.WEM

Principal Analyst

Purpose

This document has been prepared as a Flood Risk Review for Kinwest Limited. JBA Consulting accepts no responsibility or liability for any use that is made of this document other than by the Client for the purposes for which it was originally commissioned and prepared.

JBA Consulting has no liability regarding the use of this report except to Kinwest Limited

Copyright

Carbon Footprint

A printed copy of the main text in this document will result in a carbon footprint of 58g if 100% post-consumer recycled paper is used and 73g if primary-source paper is used.

JBA is aiming to reduce its per capita carbon emissions.

Executive summary

JBA Consulting have been appointed to provide a Flood Risk Assessment (FRA) for a proposed residential development in the townland of Auburn. A dwelling identified as Auburn House is currently onsite but the primary development lands are identified as greenfield.

Review of the available historic information does not highlight any instances of historic flooding within the site or surrounding area. The area has been subject to predictive modelling under the CFRAM study and associated 'Streamstown' update. Review of the flood maps following the update iteration places a large area of the site in Flood Zone B. However, it should be noted that the CFRAM study is a relatively high level assessment of flood risk and can be superseded by a site-specific hydraulic model.

Consultation has been undertaken with the OPW regarding the model setup and assumptions of the CFRAM/Streamstown flood model, and Fingal County Council regarding the existing hydrological environment and culvert location/dimensions. A site walkover was also undertaken to confirm the hydrological environment in the area.

Based on the OPW/Fingal CoCo consultations and site walkover, JBA has developed a site-specific flood model of the site and Hazelbrook Stream to confirm the flood risk. The main difference between the CFRAM/Streamstown Update and JBA flood models is the inclusion of the onsite watercourses within the JBA model.

The JBA model, which has been based on a detailed assessment of the local watercourse network, displays a significantly reduced Flood Zone B (0.1% AEP) within the site. The local stream retains the 0.1% AEP event in-bank through the site and back into the Hazelbrook Stream. A localised low point (approx. $14m^2$) along the river bank still experiences inundation during the 0.1% AEP event. The application of the FRA guidelines including the sequential approach has been based on the JBA flood extents.

The proposed design has been assessed against a range of flood events, 1%, 0.1% AEP and climate change (HEFS), including a number of blockage (residual risk) events. The results confirm that the proposed residential dwellings will not be impacted by any of the flood events, and a sufficient freeboard has been provided.

In summary, the detailed site-specific flood model shows a greatly reduced Flood Zone B extent within the site boundary due to the inclusion of the onsite stream network. All residential development is located in Flood Zone C, therefore the proposed dwellings are not at risk of inundation from any of the modelled flood events, including the climate change & residual risk scenarios. Furthermore, there is no increased risk of inundation downstream of the site from the proposed development.

Contents

List of Figures

Abbreviations

AEP .... Annual Exceedance Probability

CFRAM .... Catchment Flood Risk Assessment and Management

DoEHLG .... Department of the Environment, Heritage and Local Government

FEMFRAM........................ Fingal and East Meath Flood Risk and Management

FRA .... Flood Risk Assessment

FRAM .... Flood Risk Assessment and Management

GSI .... Geological Survey of Ireland

OPW .... Office of Public Works

PFRA .... Preliminary Flood Risk Assessment

SFRA .... Strategic Flood Risk Assessment

1 Introduction

Under the Planning System and Flood Risk Management Guidelines for Planning Authorities (DoEHLG & OPW, 2009) proposed development must undergo a Flood Risk Assessment prior to planning to ensure sustainability and effective management of flood risk.

1.1 Terms of reference

JBA Consulting was appointed by Kinwest Ltd to prepare a Flood Risk Assessment (FRA) for a site at Malahide, Co. Dublin.

1.2 Flood Risk Assessment Aims and Objectives

This study is being completed to inform the future development of the site as it relates to flood risk. It aims to identify, quantify and communicate to the client the risk of flooding to land, property and people and the measures that would be recommended to manage the risk in order to facilitate the development of the site.

The objectives of the FRA are to:

- Identify potential sources of flood risk;
- Confirm the level of flood risk and identify key hydraulic features;
- Assess the impact that the proposed development has on flood risk;
- Develop appropriate flood risk mitigation and management measures which will allow for the long-term development of the site.

Recommendations for development have been provided in the context of the OPW/DECLG planning guidance, "The Planning System and Flood Risk Management". A review of the likely effects of climate change, and the long-term impacts this may have on developments has also been undertaken.

For general information on flooding, the definition of flood risk, flood zones and other terms see 'Understanding Flood Risk' in Appendix A.

1.3 Development Proposals

The proposed development subject to this SHD application provides for the preservation and protection of the existing Protected Structure of Auburn House and its stables as 1 no. residential dwelling; the conversion of the existing stables of Auburn House to provide for storage space for the main Auburn House and the construction of 368 no. new residential dwelling units (comprising 87 no. houses, 238 no. apartments & 43 no. duplex units) for an overall total of 369 no. residential units. The development shall consist of 127 no. 1-bedroom apartments and duplex apartments, 145 no. 2-bedroom apartments and duplex apartments, 9 no. 3-bedroom apartments and duplex apartments, 45 no. 3-bedroom houses, 36 no. 4-bedroom houses, 6 no. 5-bedroom houses and the existing 11-bedroom Auburn House. The proposed development shall also provide 1 no. childcare facility, landscaped public open space, car parking and all associated ancillary site development infrastructure including foul and surface water drainage, internal roads, cycle paths and footpaths, and boundary walls and fences. Vehicular access to the proposed development is to be via a new entrance at the R107 Malahide Road/Dublin Road entrance, with the existing entrance to Auburn House acting as a pedestrian/cyclist entrance and access to existing properties outside the application site, there will be a secondary entrance comprising modifications of the existing vehicular entrance off Carey's Lane to the south west of the development, the closure of the existing vehicular entrance to Little Auburn, the provision of ESB substations, 1 no. new foul pumping station, public lighting; proposed foul sewer works along Back Road and Kinsealy Lane and all associated engineering and site works necessary to facilitate the development. The building heights range from 2 storey to 5 storey buildings with balconies or terraces being provided to the apartments and duplex units.

Figure 1-1 shows the proposed design layout for the residential development at this site.

Figure 1-1: Residential design plan

2 Site Background

2.1 Site Location

The site is located in Auburn, Malahide, Co. Dublin. It is largely surrounded by low density residential properties and agricultural fields. To the east of the site is Malahide Castle and Feltrim Quarry is approximately 900m to the south west.

A review of the Fingal County Council Development Plan Malahide-Portmarnock 2017-2023 zones this site as 'RA', to provide new residential communities subject to the provision of the necessary social and physical infrastructure. Figure 2-1 shows the site location, watercourses and surrounding area.

There are two fluvial watercourses within proximity of the site and a network of streams/field drains draining the site to the southeast corner, and ultimately back into the Hazelbrook Stream.

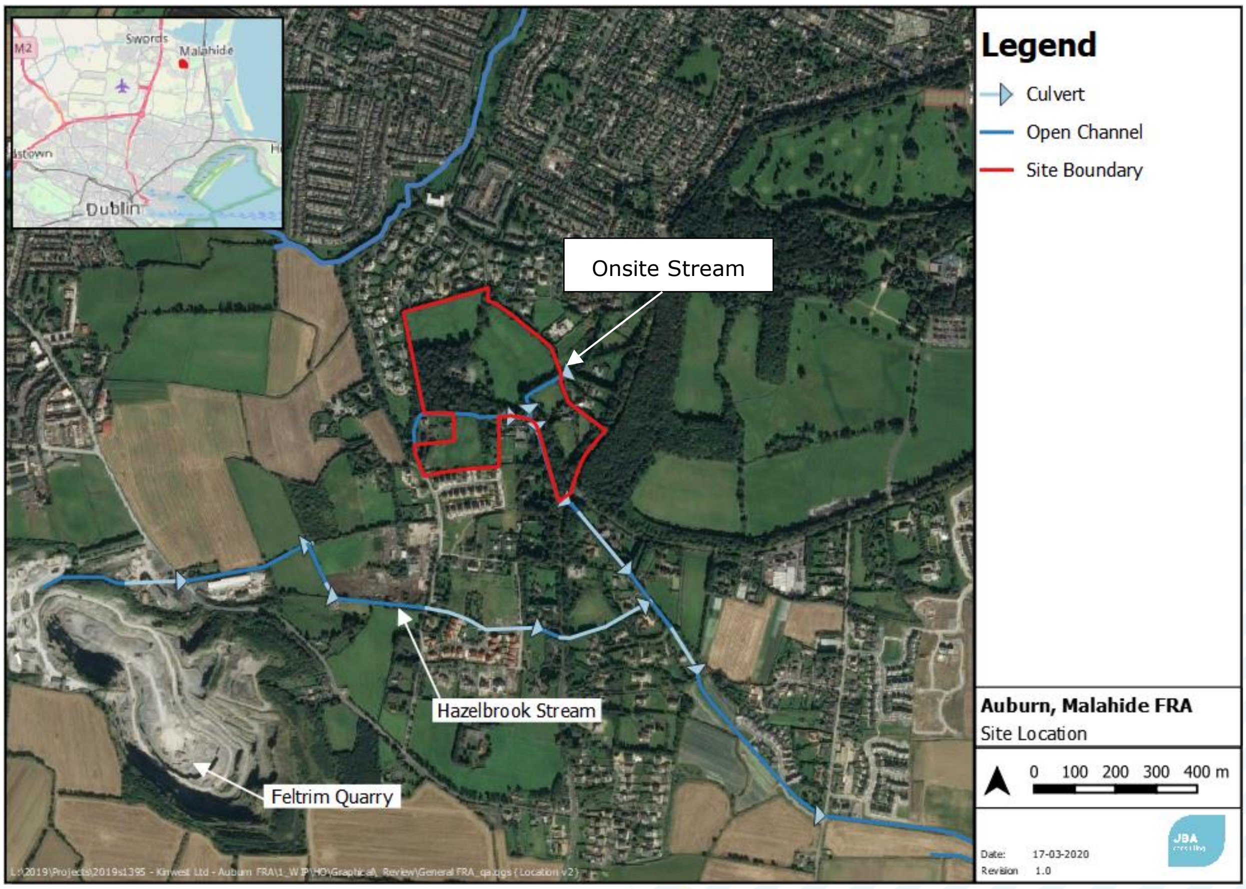


Figure 2-1: Site Location and Watercourses

2.2 Watercourses

The closest watercourse is the Hazelbrook Stream. The watercourse originates to the west of the site near the Feltrim quarry and flows in an easterly direction to the south of the site. It is a tributary of the Sluice River which flows out into the Baldoyle Estuary and ultimately the Irish Sea. The watercourse is also known as the Streamstown River.

There is a second watercourse to the north of the site which may also provide a source of flood risk in extreme events.

The site also contains large drainage ditches for localised runoff and drainage. These drain the site to the south and into the Hazelbrook Stream. Refer to Figure 2-2 for photographs of the watercourse through the site.

Figure 2-2: Watercourse Through Site

2.3 Topography

Topographic survey of ground levels across the site range from 8-14mOD with the lower areas in the south east corner of the site. Refer to the site topographic survey contained in the supporting documentation within the application.

On a regional level, the high point is located west of the site at the Feiltrim Quarry, with the natural gradient falling in an east to south east direction. Within the site, all falls are towards the Hazelbrook Stream which ultimately continues to fall in a south-easterly direction. The regional topography is provided in Figure 2-3.

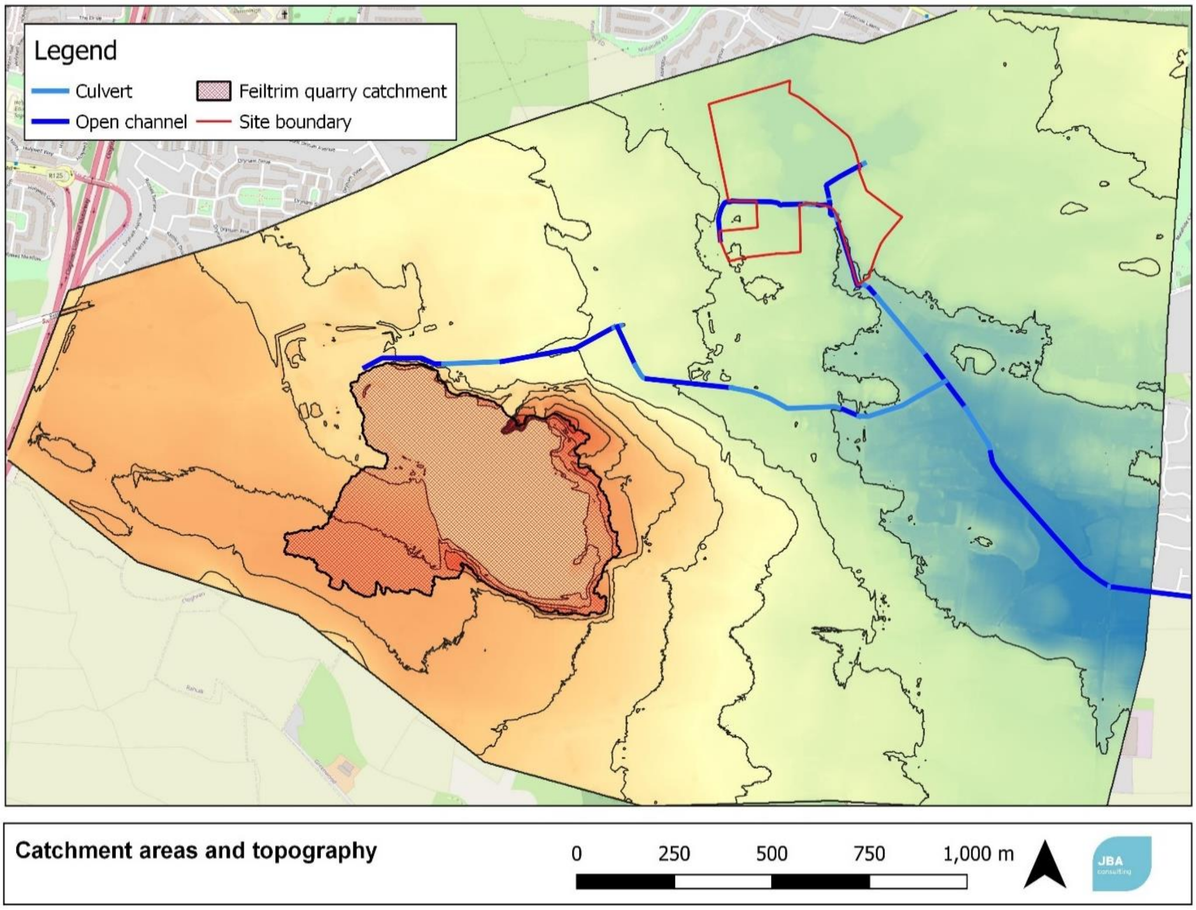


Figure 2-3: Regional Topography

2.4 Geology

The Geological Survey of Ireland (GSI) groundwater and geological data viewer was consulted to review the site and local area. The bedrock at the site location is identified as Malahide Formation, Waulsortian Limestones and Tober Colleen Formations. The subsoils within the site are identified as Limestone Till (TL) and Alluvium soils. Alluvium soils can be an indication of historical flooding to the area, refer to Figure 2-4.

The groundwater vulnerability at the site is classified as 'High to Extreme.' This classification is due to the proximity of the bedrock to the surface. At the site location itself the bedrock is not exposed. There are no karst features, wells or springs identified at the site location which could be an indication for groundwater flooding.

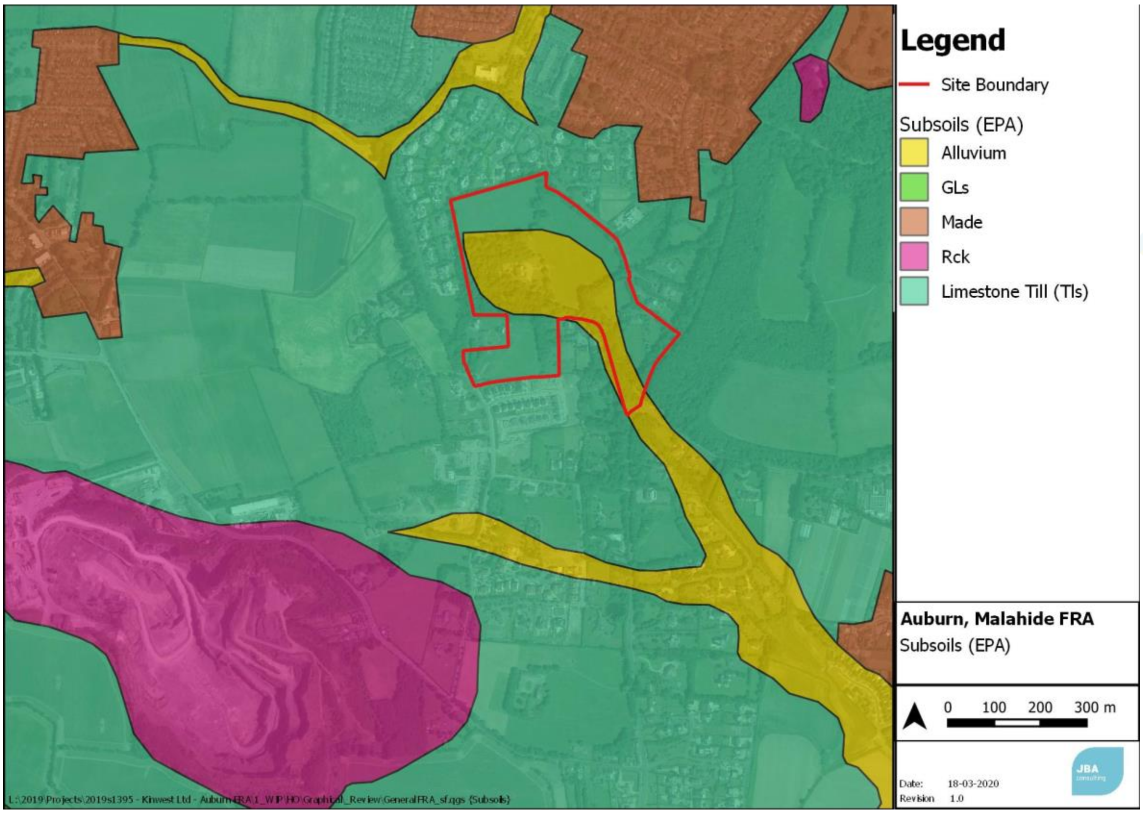


Figure 2-4: Subsoils (EPA)

3 Flood Risk Identification

An assessment of the potential and scale of flood risk at the site was conducted using historical and predictive information. This identifies any sources of potential flood risk to the site and reviews historic flooding information. The findings from the flood risk identification stage of the assessment are provided in the following sections. Further detail on the Planning Guidelines and technical concepts are provided in Appendix A.

3.1 Flood History

A number of sources of flood information were reviewed to establish whether there was any recorded flood history at or near the site location. This includes the OPW's website, www.floodinfo.ie and general internet searches.

3.1.1 Floodinfo.ie

The OPW host a national flood hazard mapping database that is now incorporated into www.floodinfo.ie, which highlights areas at risk of flooding through the collection of recorded data and observed flood events. Refer to Figure 3-1. Several past flood events were noted in the area;

- 2004: Flooding from Streamstown Stream, approx. 170m south of the site, affecting the Malahide Road and one residential property in the area. There was no evidence to suggest the site was flooded at that time.
- 2002: Flooding north of the site in Mill View Lawn, approx. 780m north of the site, as a result of Tidal Flooding in February.
- 2011: Flooding occurred in Kinsealy Court Swords, approx. 1km west of the site location.

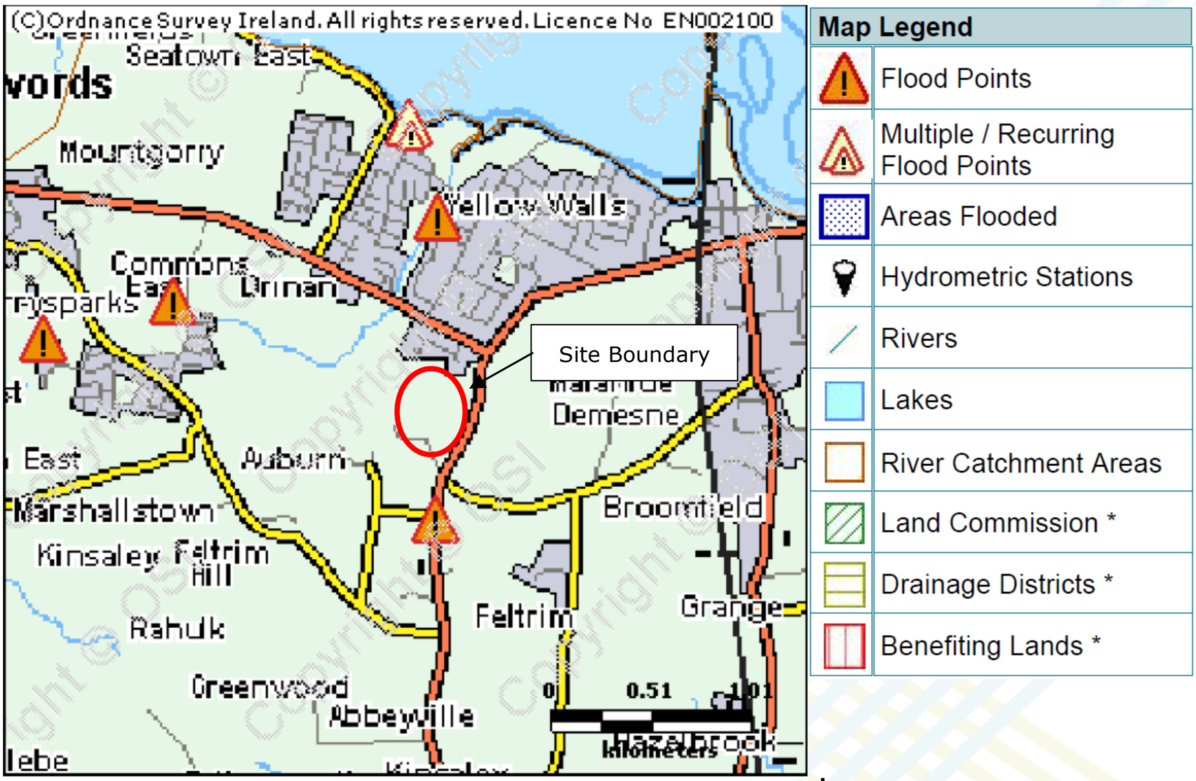


Figure 3-1: Floodmaps.ie

3.1.2 Internet Search

An internet search was conducted to gather information about whether the site had been flooded previously. During this search the following information was found;

- Jan 2018 several newspaper reports advised of flooding causing closure to sections of the Malahide Road. There was however no evidence of flooding within the site boundary.

3.2 Predicted flood mapping

The subject site and surrounding area have been subject to four predictive flood mapping studies:

- The OPW Preliminary Flood Risk Analysis (PFRA);
- The Fingal East Meath Flood Risk Assessment and Management Study (FEMFRAMS);
- The Fingal County Council Strategic Flood Risk Assessment and Management Plan (SFRA);
- The Streamstown Mapping Update (OPW, 2018).

3.2.1 The OPW Preliminary Flood Risk Analysis (PFRA)

The Preliminary Flood Risk Assessment (PFRA) is a requirement of the EU Flood Directive (2007/60/EC). PFRA deliverables include flood probability mapping for various sources: pluvial (surface water), groundwater, fluvial and tidal. The PFRA is a preliminary or 'indicative' assessment. The analysis was undertaken by the OPW to identify areas potentially prone to flooding. The fluvial and coastal data has largely been superseded by the more detailed CFRAMS flood mapping for fluvial and tidal sources, however the PFRA mapping still provides valuable information regarding pluvial and groundwater flooding.

The PFRA pluvial flood extent maps identify the potential for pluvial flood risk to the site from the 1% and 0.1% AEP events. No groundwater flood risk is identified for the site. Figure 3-2 shows the pluvial flood risk indicated within and around the site. As per the FSU catchments, this indicative mapping does not appear consistent with topographic survey of the site or the presence of drainage ditches within the site.

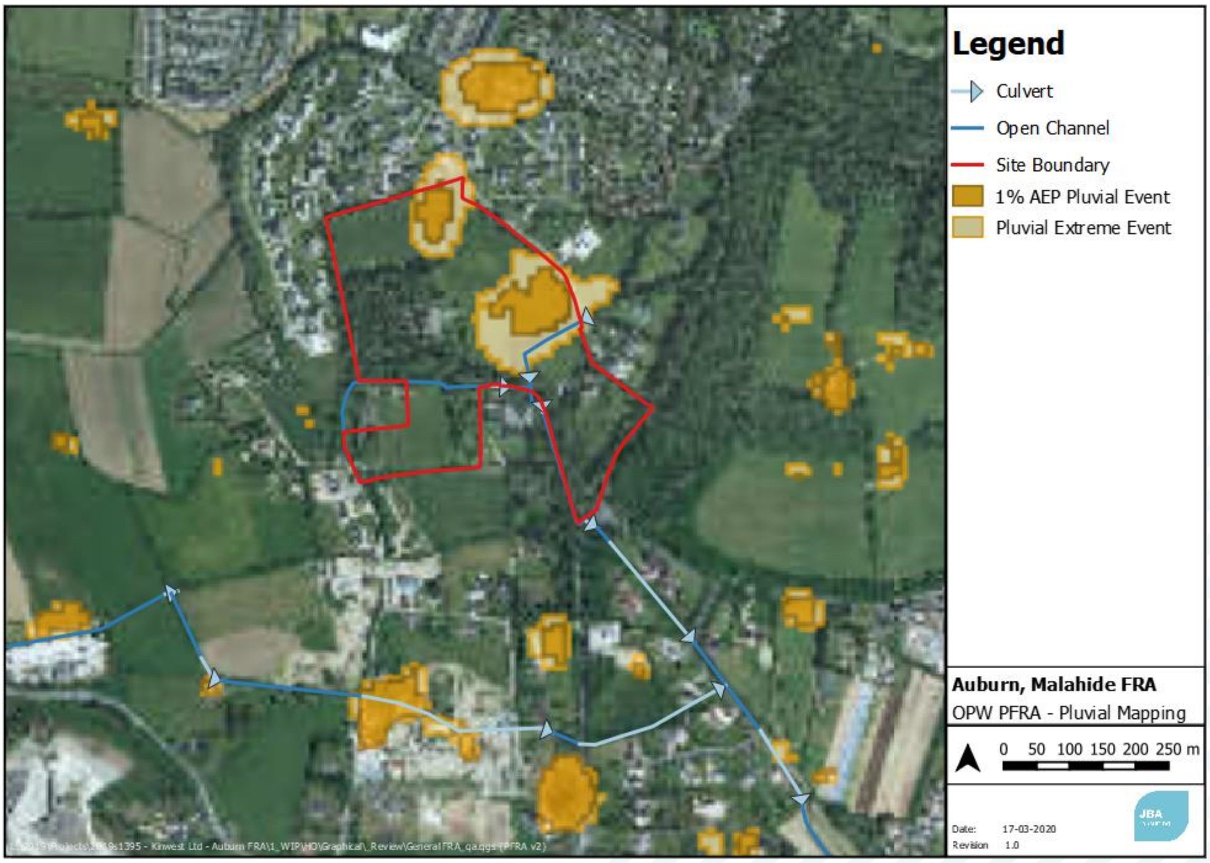


Figure 3-2: OPW PFRA Pluvial Risk Map (MyPlan.ie)

3.2.2 The Fingal East Meath Flood Risk Assessment and Management Study (FEM FRAMs)

The FEMFRAM study was a detailed flood mapping study undertaken in the north Dublin region as a pilot study area for the CFRAM programme. Following the detailed hydraulic modelling, flood maps were produced for the 10%, 1%, and 0.1% AEP fluvial flood events. As shown in Figure 3-3, the FEMFRAM mapping did not identify significant flooding within the red line boundary for any fluvial events up to and including the 0.1% AEP event. FEMFRAMs does acknowledge a drainage ditch through the site as a modelled watercourse however there is no associated flooding on site. Only minor overlap of flood zones along the southern boundary is observed.

Note: the FEM FRAM model has been updated during the Streamstown Update, see Section 3.2.4 and is considered superseded at this stage.

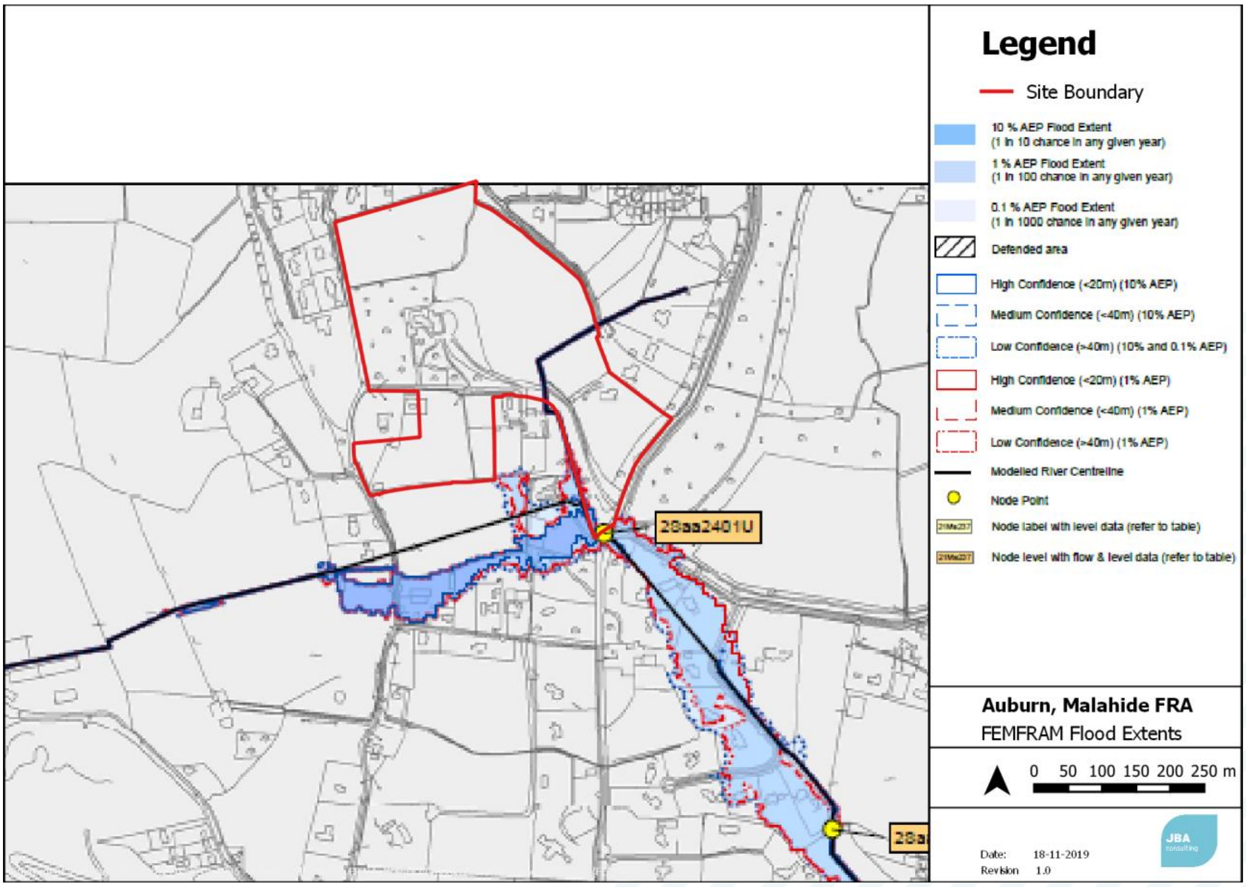


Figure 3-3: OPW FEMFRAM mapping

3.2.3 The Fingal County Council Strategic Flood Risk Assessment and Management Plan (SFRA)

The Fingal County Council Development Plan (CDP) 2017-2023 is the governing document for development in the area. It aims to set out the priorities and goals of the council over the lifetime of the plan for spatial and sectoral development. Under the Fingal CoCo CDP 2017-2023 the site is zoned as New Residential (R2).

As part of the Development Plan, a Strategic Flood Risk Assessment (SFRA) was commissioned to inform development based on flood risk. The SFRA informs the strategic land use planning decisions by providing an assessment of flood risk within the region and enables the application of the sequential approach. A range of flood sources have been investigated as part of the SFRA (PFRA, FEMFRAM, Eastern CFRAM etc.), however the final flood maps are based on FEMFRAM mapping for the site area. The SFRA is based on the planning system and flood risk management guidelines and uses the same sequential approach.

With specific reference to Section 5.9.14 of the SFRA, an FRA is required to be undertaken to demonstrate that developments would not have adverse flood risk impacts.

The baseline mapping is the FEM FRAM flood maps, as presented in Section 3.2.2, which have been superseded by the Streamstowm update.

3.2.4 The Streamstown Mapping Update (2018)

Following the release of the FEM FRAMS flood maps in 2010 public consultation regarding the Streamstown area flood map in 2015 raised several objections including:

- Claims that the route of the modelled watercourse was incorrect;
- Flood extents did not match the lack of evidence/absence of flood events recorded in the area;

Further investigation of the area and claims in 2016 found the wrong river centreline had been surveyed, and a portion of culverted stream to the south had not been included in the original FEMFRAMS modelling. To address this, the OPW commissioned a flood map update study, remodelling the watercourse to include the correct river route and the dual watercourses identified in Figure 2-1.

The study produced a more accurate schematisation of the watercourse and completed a new hydrologic estimation of peak flows used as inputs into the hydraulic model. Within the resultant mapping, portions of the site are shown to be within Flood Zone B and at risk of flooding during the 0.1% AEP event. Figure 3-4 shows a map of the updated flood outlines.

The source of flooding occurs approximately 1km to the south-west of the site where overtopping of the left bank of the watercourse is generating an overland flow path which terminates within the site.

It should be noted that although in the wider context of the Streamstown river system the update improved on the accuracy of flood extents, an existing stream within the site has not been included in the updated model. The implications on the absence of this stream on the final flood extents are expanded in Sections 4.4.2 and 5.2.3.

The section of the stream that has been excluded has been provided in Figure 4-2.

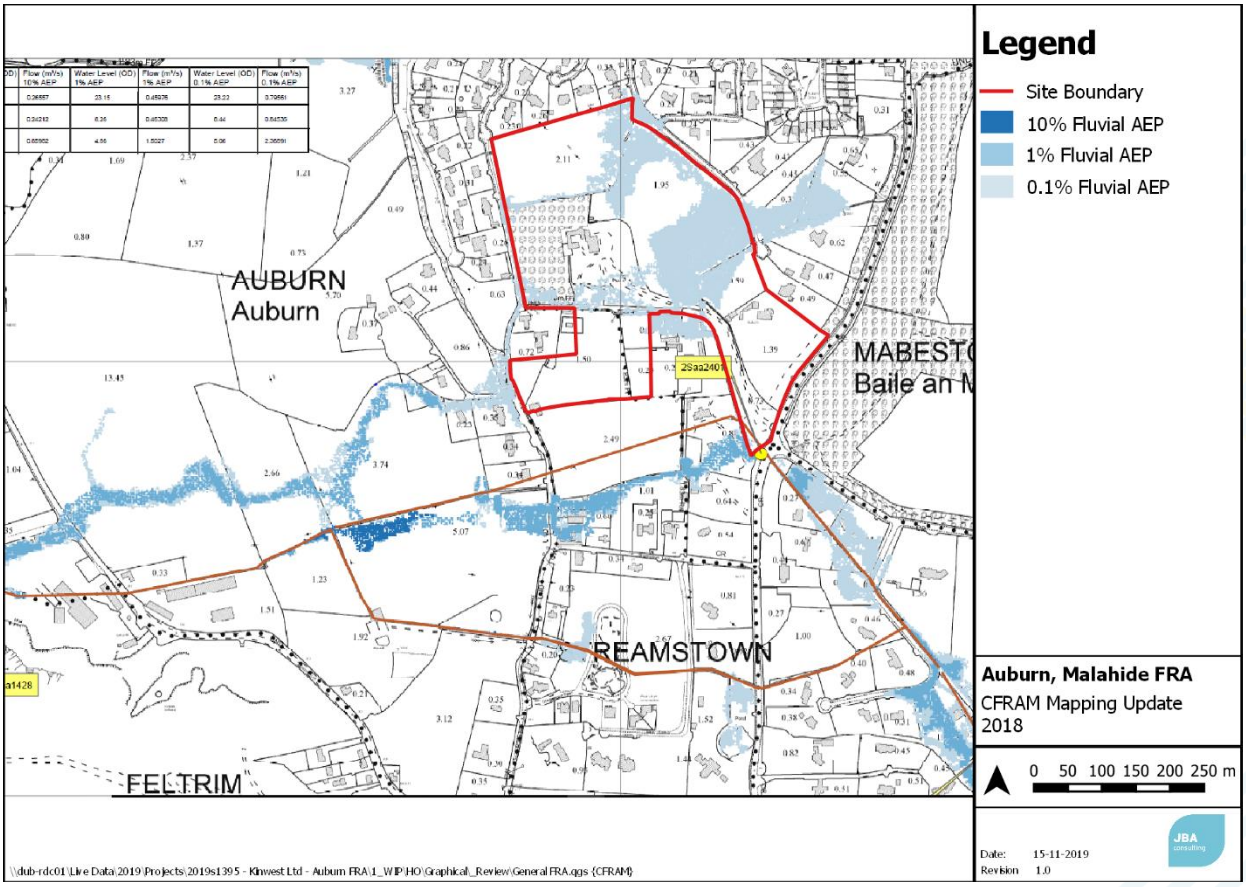


Figure 3-4: Streamstown Stream Update Mapping

3.3 Sources of flooding

The initial stage of assessing flood risk requires the identification and consideration of probable sources of flooding.

3.3.1 Fluvial Flooding

Review of the flood mapping information in the original FEMFRAM / SFRA mapping shows the site to be within Flood Zone C. Remodelling of the area and the publication of the Streamstown Mapping Update Report now shows the site to be substantially within Flood Zone B (Figure 3-4). However, it has been acknowledged by the OPW that these predicted flood extents are uncalibrated and should be used as a trigger for a more detailed site-specific flood risk assessment to reduce uncertainty.

The source of flooding is an indirect overland flow pathway which originates at the Feltrim Quarry. It is highly likely that the overland flows will be intercepted by the local drainage network in the area before reaching the site.

3.3.2 Pluvial Flooding

Review of the PFRA pluvial flood map shows parts of the site to be at risk of pluvial flooding for both the 1% and 0.1% AEP events. As the site is currently a greenfield site and will be developed with considerable hardstanding area, the risk of surface water runoff is increased and will need to be managed. This can generally be managed through a surface water drainage design for the site and with the use of sustainable drainage systems.

3.3.3 Coastal Flooding

The site is approximately 2.5km to the coast. The watercourses potentially impacting the site are not influenced tidally near the site and therefore the site is not at risk from coastal flooding.

3.3.4 Groundwater Flooding

Review of the available geological and hydrogeological data shows groundwater vulnerability to be 'high' to 'extreme' however the presence of the subsoil deposits and a lack of karst features at the site indicate an overall low risk from groundwater flooding to the site.

3.4 Flood Source Summary

The main source of flooding to the site is fluvial flooding caused by overtopping of the Hazelwood Stream. The most up to date predictive flood mapping of the area shows the site is within Flood Zones B and C. It is acknowledged that a site-specific flood risk assessment is required to reduce the uncertainty of predicted flood extents at the site and that the results of a detailed SSFRA may result in further amendment of flood zones.

Based on the findings above it is clear that a site specific flood model is required to provide an accurate assessment of the flood risk to the site. Internal drainage within the site including any culverted structures will also need to be considered within a detailed FRA. The flood model and associated works are presented in Section 4.

4 Flood Model Assessment

4.1 Hydrology

To assist in the estimation of potential flood risk to the proposed development from the River Ward and the local watercourse, this section provides flow estimates for the 1% and 0.1% AEP flood event flows expected along the watercourse that flows through the northern section of the site. A summary of the hydrology estimation process is provided in this section. Refer to Appendix E for a detailed overview of the hydrology process.

4.1.1 Catchment Characteristics

The physical characteristics of the catchment influence the hydrology, this includes catchment size, soil type, steepness and the average annual rainfall. Table 4-1 outlines the parameters calculated for the river catchments.

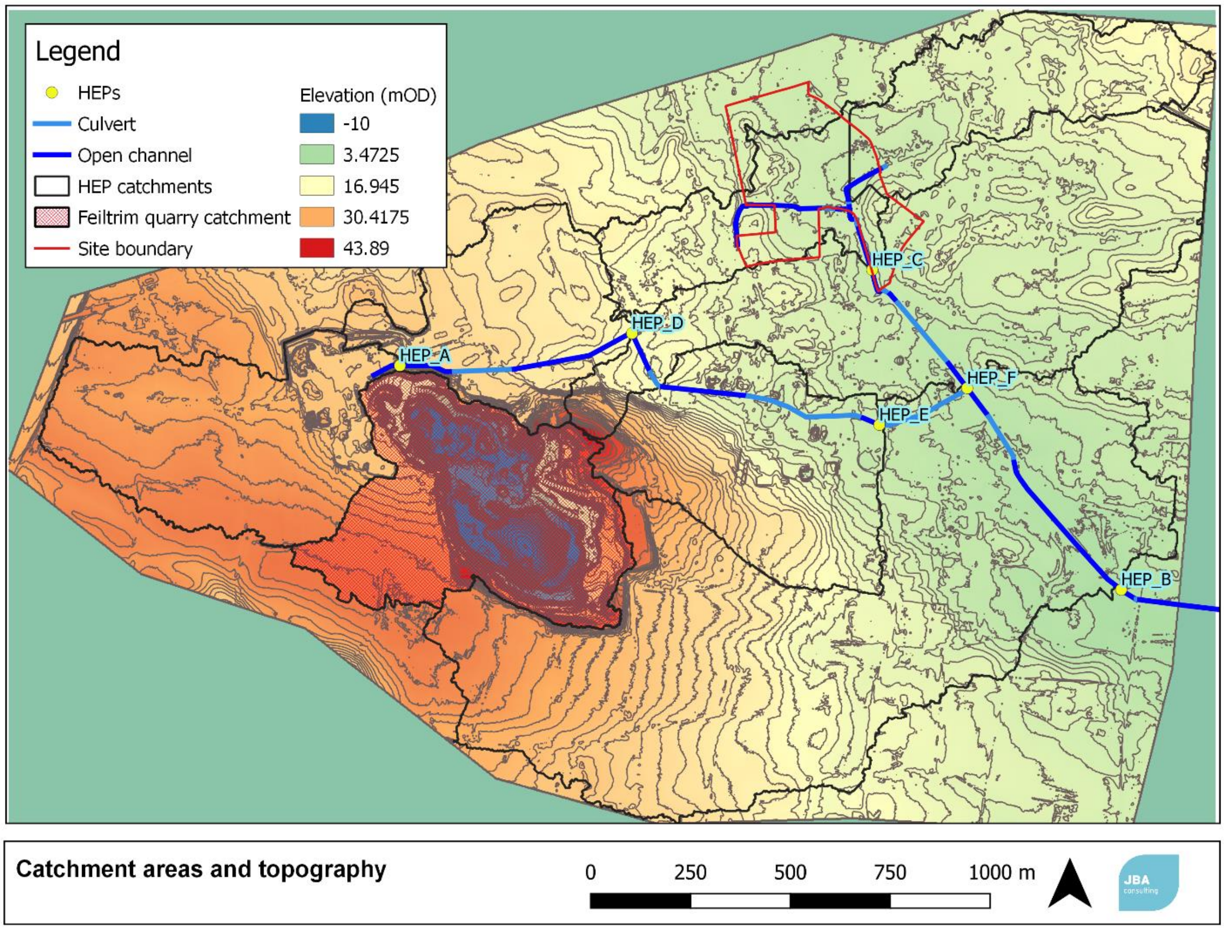


Figure 4-1: Catchment Delineation

Table 4-1: Catchment Characteristics (source: OPW FSU)

Variable	HEP_A	HEP_B	HEP_C	HEP_D	HEP_E	HEP_F
Area	0.33	2.87	0.39	0.56	0.30	1.55
SAAR	703.08	703.08	703.08	703.08	703.08	703.08
FARL	1.00	1.00	1.00	1.00	1.00	1.00
BFI Soil	0.57	0.57	0.57	0.57	0.57	0.57
Urban area	0.05	0.27	0.02	0.04	0.05	0.14
URBEXT	0.15	0.09	0.05	0.07	0.16	0.09
MSL	0.64	3.76	1.61	1.32	0.90	3.06
S1085	10.5	7.05	4.93	10.87	18.05	7.77
DrainD	0.12	0.12	0.12	0.12	0.12	0.12
ArtDrain2	0.00	0.00	0.00	0.00	0.00	0.00
Soil (number)	2.00	2.00	2.00	2.00	2.00	2.00
SMDBAR	7.00	7.00	7.00	7.00	7.00	7.00
M5-2day	56.30	56.30	56.30	56.30	56.30	56.30
M5-1day	47.60	47.60	47.60	47.60	47.60	47.60
r	30	30	30	30	30	30

4.1.2 Flow Estimation

Two flood estimation methods were compared under the hydrological analysis:

- IH 124
- Flood Studies Report Rainfall Runoff Method (FSR RR)

The IH124 method is designed for smaller catchments and therefore using these values ensures that an appropriate method is used, and conservative flows that are still representative of the catchment are applied. The FSR RR is designed for steeper catchments with areas larger than 1km^2. The peak flows presented in Table 4-2 have been incorporated into the model.

Table 4-2: Final Design Flows (m^3/s)

AEP%	HEP_A	HEP_B	HEP_C1	HEP_C2	HEP_D	HEP_E	HEP_F
1%	0.30	1.79	0.20	0.1	0.39	0.30	1.03
0.1%	0.53	3.19	0.35	0.18	0.71	0.53	1.83

4.1.3 Growth Curves

As part of the ECFRAM study growth curves were derived for catchments less than 10km^2. Table 4-3 shows the ECFRAM small catchments growth curve which was applied for all the sub-catchments, as provided in Figure 4-1 within the JBA model.

Table 4-3: ECFRAM small catchments growth curve

AEP%	Growth Factor
50%	1.00
10%	1.79
1%	3.32
0.1%	5.92

4.2 Hydraulic Model

4.2.1 Model Set-up

To assess flood risk at the site a 1D-2D ESTRY-TUFLOW hydraulic model was constructed and is in line with the CFRAM standard. It allows for the modelling of river channels, streams, floodplains and hydraulic structures to predict water levels for a range of scenarios (see Figure 4-2 for hydraulic model structure). The hydraulic model was developed in the following stages:

- A 1D-2D ESTRY-TUFLOW model of the Hazelbrook Stream and surrounding stream watercourses created using a DTM and available surveyed data.
- The existing structures were inserted into the model based on survey, and a baseline condition was established.
- Hydraulic simulations were run to derive the existing flood extent to determine Flood Zones A, B and C at the site (the 1% and 0.1% AEP flood events).
- A number of residual risks were also assessed for the site. Scenarios examining the effect of climate change (+30% flow under the HEFS scenario), and a partial blockage of the culverts through the site were run.

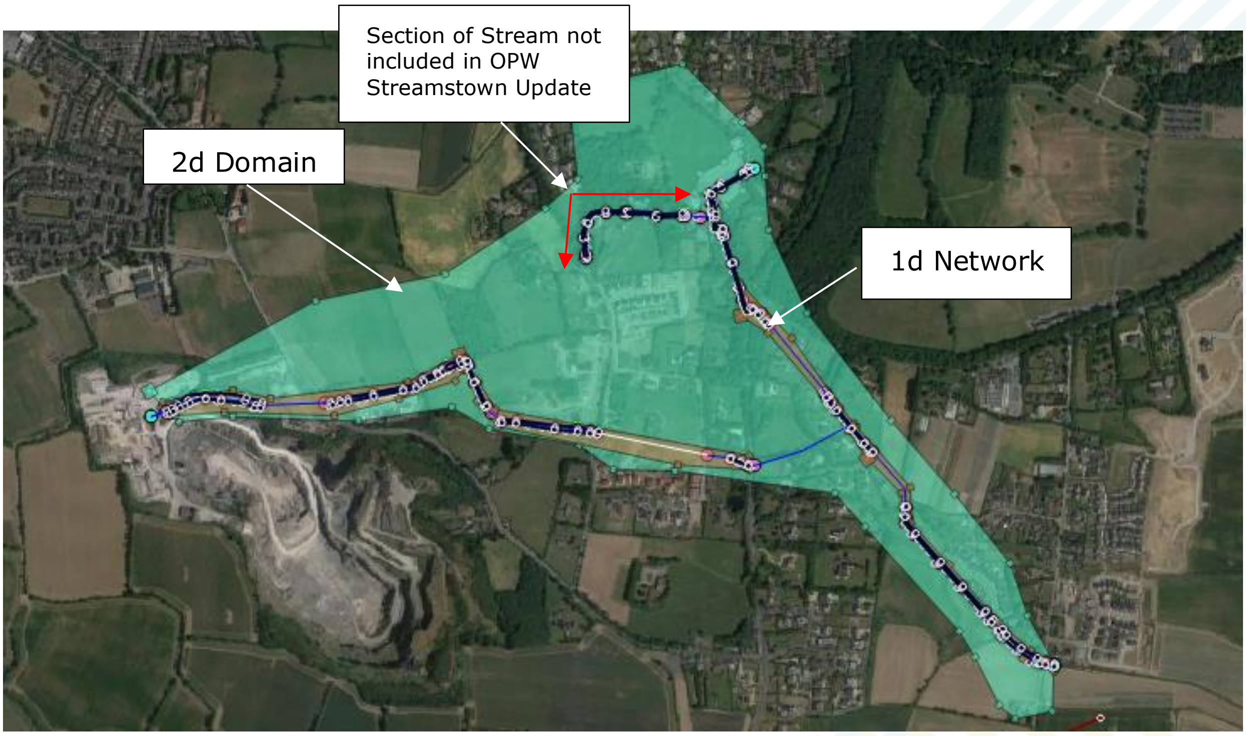


Figure 4-2: Model Setup

4.3 Model Results and Flood Mechanism

The flood extents for Flood Zone A and Flood Zone B can be seen in Figure 4-3.

Review of Figure 4-3 confirms that there is limited inundation predicted on the site during the 0.1% AEP event. The areas experiencing inundation have been identified as low lying areas along the stream banks. There are no overland flow pathways through the site during any flood event.

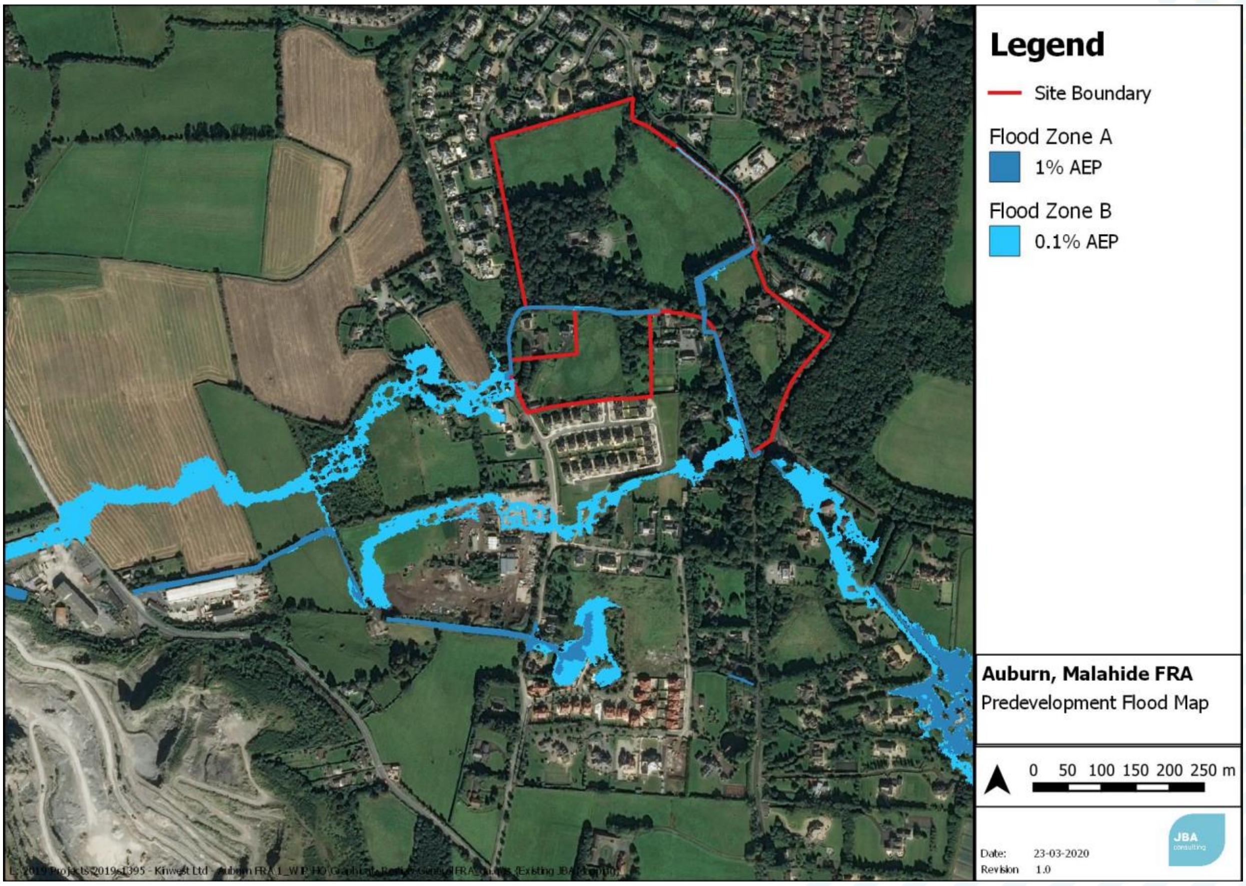


Figure 4-3: Pre-Development Flood Extents

4.4 CFRAM Comparison

Review of the OPW flood maps presented in Figure 3-4 , shows a flow pathway onto the site during the 1% and 0.1% AEP flood events which differs to the JBA model findings. There two predominant reasons for this, which are provided below:

- Revised hydrology
- Updated model

4.4.1 Hydrology

Following the Streamstown mapping update process and the site visits undertaken as part of the FRA process, the route of the Hazelbrook stream has been modified since the FEM FRAM study. Review of the LIDAR area covering the study area also resulted in a revised catchment area for the Hazelbrook Stream. As noted during the site walkover, the Hazelbrook stream does not continue through the Charleville Lodge estate and 100% of the flows are diverted along the Streamstown section.

Slight modification has been made to the upstream catchment area contributing to HEP A, the furthermost upstream catchment based on the potential inflows entering the Feltrim quarry. Based on the detailed review of the topography, the contributing catchment to the quarry has been slightly enlarged which results in a corresponding reduction in the HEP A catchment.

Review of an EIAR recently (2013) submitted as a planning application within a development in the Feltrim quarry stated that surface water pumping from the quarry will cease during a 'Red' warning rainfall event. This will ensure that no contributing flows from the Feltrim Quarry to the Hazelbrook Stream during a flood event. Sensitivity analysis has been undertaken on the possibility of contributing flows from the quarry.

Overall, the combination of the factors above results in a minor reduction in the peak flood flows along the Hazelbrook Stream.

4.4.2 Updated Model

Regarding the flood extents specifically within the site boundary. The CFRAM flood maps show that there is a flow pathway through the site during the 0.1% AEP event. Following the site walkover and review of the site survey information, it was observed that a watercourse is located onsite that is connected to a comprehensive drainage ditch network. It was noted that the stream and drainage channel have sufficient flow capacity for inclusion into the flood model. The results confirm that this stream/drainage channel has capacity to convey the 0.1% AEP flood flows through the site without resulting in bank overtopping.

This section of the stream has not been included in the Streamstown update, refer to Figure 4-2, and has a notable impact on the flood extents and flow pathways through the site. A thorough analysis on the impact that this stream has on the flood extents is provided in 5.2.3.

4.5 Post-Development Flood Extents

As outlined in Section 1.3 the proposed development mainly involves the construction of residential housing and apartment blocks. The baseline 1% and 0.1% AEP flood extents have been overlain on the proposed design as provided in Figure 4-4.

Review of Figure 4-4 confirms that there is no bank overtopping during the 1% AEP event within the site boundary. There is a single localised area of inundation during the 0.1% AEP event, as provided in Figure 4-4 but does not present a flood risk to the residential properties.

The proposed development needs to be assessed in accordance to the impacts on flood levels upstream and downstream of the site. The aim of the hydraulic model is to confirm that there is no increased risk of inundation from the 1% and 0.1% AEP flood events upstream or downstream of the site.

Figure 4-3 also provides the model nodes through the site that will be used to assess the impact on flood levels from the proposed development.

Appendix D provides additional analysis of the impact from the proposed development from the baseline flood events. The pre- and post-development flood levels and impacts from the HEFS climate change scenario estimated flows are also provided. Review of the tables in Appendix D confirm that there is no increase in flood risk for all the modelled events downstream of the site.

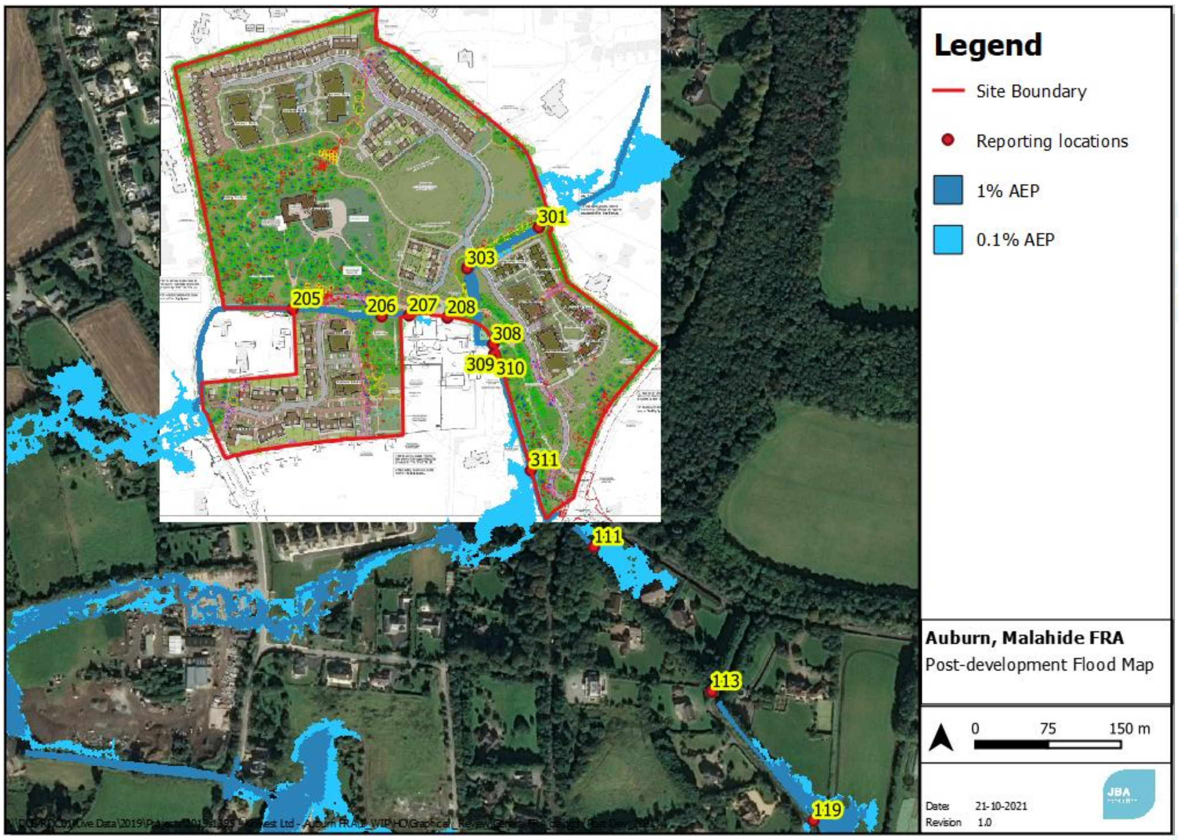


Figure 4-4: Post Development Flood Extents

5 Flood Risk Assessment and Mitigation

5.1 Flood Risk/Mitigation Measures

From reviewing the available sources of flooding outlined in Section 3 there is predicted fluvial flooding at the site. This is based on the FEM FRAM flood mapping of the area and the updated Streamstown update.

The hydraulic model has been updated based on the site walkover and new survey data which captures the local drainage and stream watercourse that runs through the site. The results show that the overland flood waters are intercepted by this stream system and retained in bank. Once this system is incorporated into the model there is no inundation within the site. The JBA hydraulic model therefore confirms that the majority of the site is located in Flood Zone C, and at a low risk of inundation. All of the residential dwellings are located in Flood Zone C based on the JBA model.

5.1.1 Building Finished Floor Level

All of the residential properties are located in Flood Zone C and with the majority located a sufficient distance from the stream through the site. The FRA will focus on the dwellings located in close proximity to the watercourses. According to the Fingal SFRA guidance document, FFLs for highly vulnerability developments such as housing need to be placed at a minimum of 500mm above the 0.1% AEP event. Review of Table 5-1 below provides the 0.1% AEP flood level, proposed FFLs and the provided freeboard through the site. Review of Table 5-1 confirms that the required minimum freeboard has been achieved onsite and that the design meets the SFRA design standards.

Further reference is placed on the 0.1% AEP HEFS flood event which produces the highest flood levels onsite. The results from this event are presented in Table 5-2 and confirm that the proposed FFLs provide sufficient freeboard to protect the dwellings from the predicted 0.1% HEFS flood event.

In summary, the proposed FFLs provide sufficient freeboard protection over the 0.1% AEP and 0.1% AEP HEFS flood events through the site. A minimum freeboard of 0.75m is provided to the 0.1% AEP event and 0.74m to the 0.1% AEP HEFS event through the site.

Table 5-1: 0.1% AEP Level and Freeboard

	Model Node	Minimum FFL (mOD)	0.1% AEP (mOD)	Freeboard (m)
Onsite	205	10.6	9.86	0.74
	206	10.6	9.17	1.43
	207	9.9	9.16	0.74
	301	10.35	8.8	1.55
	303	9.6	8.8	0.8
	308	11.15	8.79	2.36
	311	11.25	8.64	2.61
Downstream	111	N/A	8.37	N/A
	113	N/A	6.65	N/A

5.1.2 Basement

The proposed design contains two underground basement car parks, located in Apartment Blocks 2 and Block 4. It should be noted that Block 2 is located at the northern extent of the stie and approx. 220m from the Hazelbrook Stream, while Block 4 is located in the southern end of the site and 50m east of the Hazelbrook Stream.

The basement car parks and associated entrances are located in Flood Zone C and are therefore at low risk of inundation from fluvial sources. The ramp levels are set at >10.5mOD and >11.15mOD respectively for Block 2 and Block 4. This provides a freeboard of 0.3m (Block 2) and 2.3m (Block 4) over the 0.1% AEP flood levels.

An extensive stormwater system is provided onsite to manage fluvial/surface flows which will minimise the risk of pluvial flooding to the basement car park.

5.1.3 Access/Egress

There are two access routes provided to the development, one via Carey's Lane and one via Malahide Road. Internal access routes are provided to each dwelling onsite. Review of Figure 4-4 confirms that all the access routes are not at risk of inundation from the 1% AEP flood event.

In summary, access to the development can be maintained during a 1% AEP flood event.

5.1.4 Stormwater design/Pluvial Flood Risk

Review of the PFRA flood maps indicates that sections of the site are at risk of pluvial inundation, which are identified as low-lying areas within the site. Flood risk within the site will be managed by the provision of a stormwater system which will capture runoff from hardstanding areas. The site profile will be modified as part of the proposed development.

The increase in the hardstanding area onsite could potentially increase the surface water runoff from the site, if not mitigated. A stormwater water system is included within the proposed development which will capture and manage surface water flow from hardstanding areas. The stormwaters need to comply with the overarching Fingal County development policy and the GDSDS guidance document.

To minimise the risk of pluvial flooding, a threshold of 150mm is required from the FFL to the external ground levels. This should also apply to the basement entrance ramps. No further mitigation measures are required to manage the pluvial flood risks.

5.2 Residual Risk/Additional Assessment

Residual risks are defined as risks that remain after all risk avoidance, substitution and mitigation measures have been taken. The flood risk assessment identifies the following as the main sources of residual risk to the proposed development:

- Climate Change
- Blockage of the Culvert

5.2.1 Climate Change

As per the OPW guidelines, it is necessary to assess the potential impact of climate change on flood risk. The climate change assessment has been based on the High-End Future Scenario (HEFS). A scenario was run to estimate an increase of 30% (HEFS) on the peak flood flows. Review of the results confirms that there is some overtopping onsite during this scenario. However, the post-development analysis confirms that sufficient freeboard is provided to ensure no flood risk to the residential dwellings during the 0.1% AEP HEFS event. Therefore, the impact of climate change does not pose a flood risk to the residential developments onsite. Refer to Table 5-2 for the flood levels and available freeboard.

When reviewed against the FFLs provided in Table 5-2, where the minimum freeboard provided is 0.68m, no residential development is at risk of inundation from the 0.1% HEFS flood event.

Note, the impact analysis is provided in Appendix D that also includes the 0.1% AEP HEFS flood event. Review of the results contained in Appendix D confirm that there is no increase in flood levels downstream of the site.

Table 5-2: 0.1% AEP HEFS Level and Freeboard

	Model Node	Minimum FFL (mOD)	0.1% HEFS AEP (mOD)	Freeboard (m)
Onsite	205	10.6	9.92	0.68
	206	10.6	9.41	1.19
	207	9.9	9.4	0.5
	301	10.35	9.09	1.26
	303	9.6	9.09	0.51
	308	11.15	9.08	2.07
	311	11.25	8.85	2.4
Downstream	111	N/A	8.42	N/A
	113	N/A	6.7	N/A

5.2.2 Blockage of Site Culverts & Malahide Access Culvert

Six culvert blockage scenarios have been developed as part of the residual risk assessment process. The main culvert system onsite is located along Malahide Road which acts as the main control device from the site. Various other culverts/bridges are located onsite, and blockages of these culverts/bridges could present a flood risk to the residential properties.

Specific model scenarios have been developed to model a blockage of 66% for each of the culverts/bridges that present a flood risk to the development. The maxima of the peak flood levels from the six blockage scenarios are shown in Table 5-3 below. The minimum freeboard is 0.88m.

The location of the culverts assessed for blockage and relevant flood extents from the residual risk blockage events are presented in Appendix C.

The results presented in Table 5-3 and Appendix C confirm that the proposed development is not at risk of inundation from possible blockage of the culverts/bridges onsite.

Table 5-3: 1% AEP Blockage Scenario Levels and Freeboard

	Model Node	Minimum FFL (mOD)	Maximina of six Blockage Scenario Levels (mOD)	Freeboard (m)
Onsite	205	10.60	9.72	0.88
	206	10.60	9.28	1.32
	207	9.90	8.54	1.36
	301	10.35	8.5	1.85
	303	9.60	8.5	1.1
	308	11.15	8.49	2.66
	311	11.25	8.46	2.79

5.2.3 Comparisons with CFRAM Flood Maps

As highlighted in Section 3.2.4, the OPW have specifically updated the model and resulting flood extents for the Streamstown river system, including the site area. It has been highlighted that a section of the stream onsite has not been modelled in the OPW update. Therefore, the main difference the Streamstown update and the JBA model is the inclusion of the stream body within the site. Figure 4-2 provides the extent of the stream not included in the Streamstown update.

The greater detail provided in the JBA model provides more refined flood maps that take into account the site-specific conditions. To provide clarification of the flood mechanisms onsite and to outline why the two studies provide different flood extents, the CFRAM approach has been replicated. This entails removal of the stream within the site.

As sections of the stream have been removed, this results in more dispersed overland flows through the site. The overland flow path highlighted along the western boundary does not exist in reality as the existing stream will capture the flows and convey it through the site.

A comparison between the CFRAM flood map and the JBA model with the stream removed is provided in Figure 5-1. The flood extents are broadly similar with the differences down to minor changes in the site elevation. The CFRAM model is based on LIDAR data while the JBA model is based on site specific survey data, which is more accurate.

The two main flow pathways on site are highlighted in Figure 5-1. With the removal of the stream from the model, the floodwaters follow the prevailing topography along the western boundary of the site and enters the site via two low points.

Regarding the eastern flow path, it appears from review of the flow characteristics that within the OPW study this flow path has been directly applied to the LIDAR/ground elevation rather than to the stream channel. This has a notable impact on the flood extents when compared to the JBA flood maps with the stream specifically modelled.

The results highlight the limitations of the CFRAM study when considering site specific conditions. The extension of the streams to represent the actual conditions results in the removal of the flow pathway along the site’s western boundary and refinement of the flow path from the east.

For residual risk purposes, the proposed design has been assessed with the stream watercourse removed and the results are presented in Figure 5-2. While some of the residential properties are located within the flow path, under this scenario the depths are shallow and does not result in any inundation of the residual properties onsite.

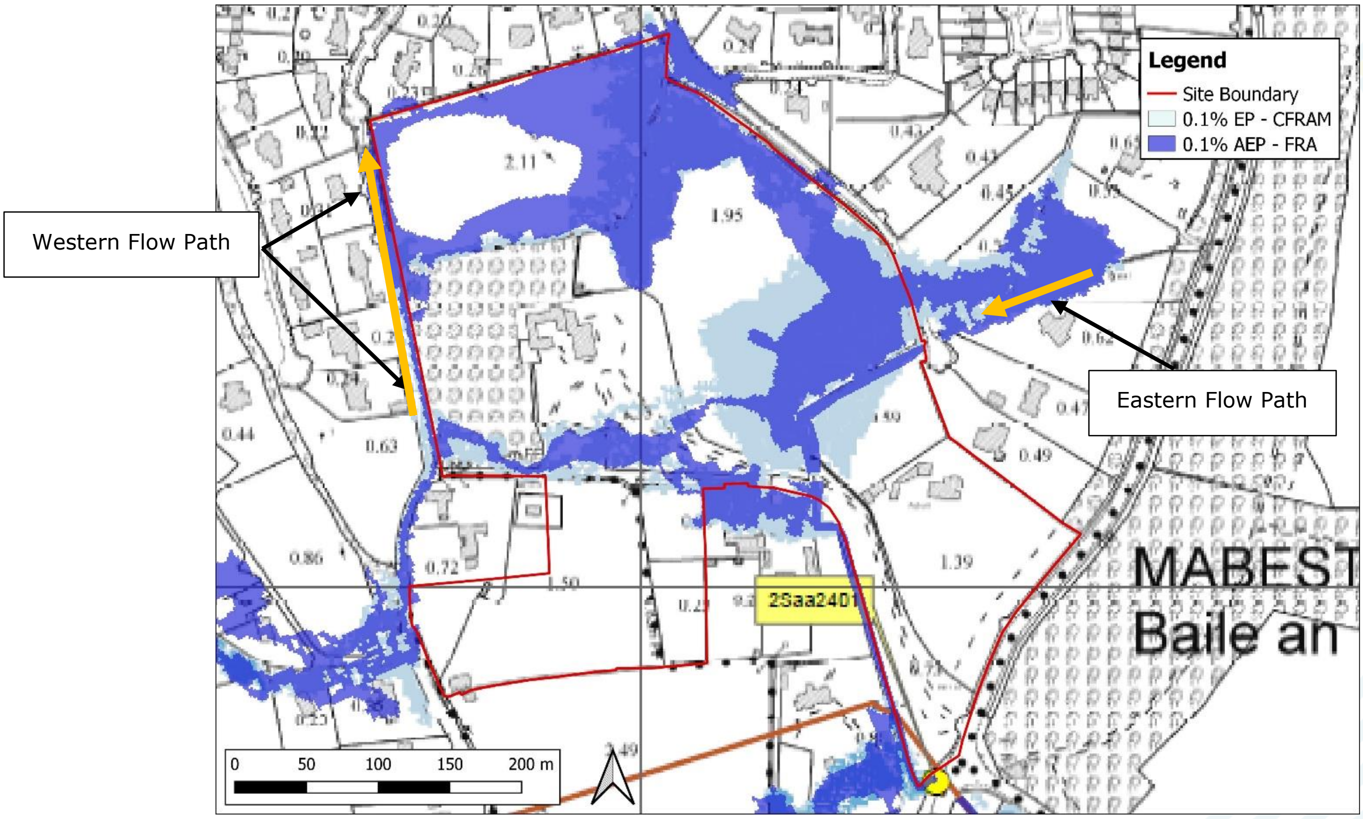


Figure 5-1: Removal of stream-Existing Flood Extents

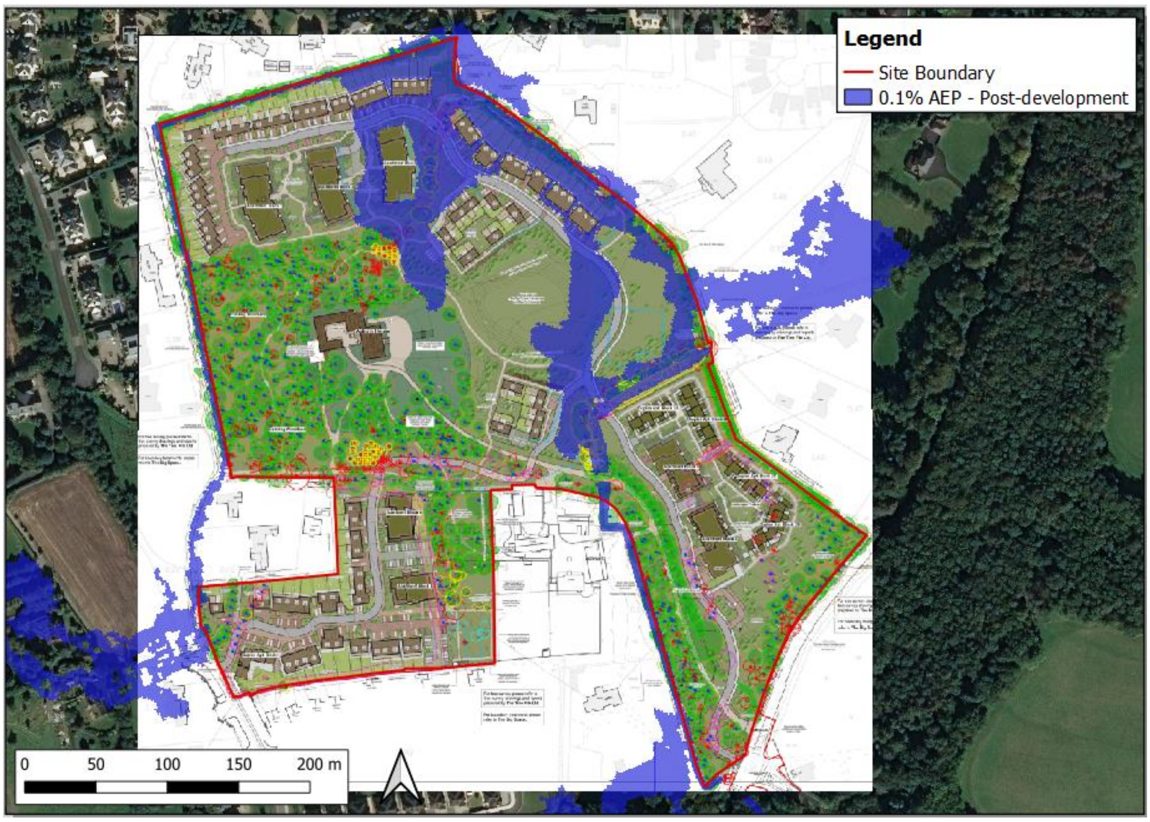


Figure 5-2: Removal of stream-Post-Development Flood Extents

6 Conclusion

JBA Consulting has undertaken a detailed Flood Risk Assessment for a proposed residential development in Auburn, Malahide, Co Dublin. The nearest river watercourse to the site is identified as the Hazelbrook Stream. The watercourse and connecting drainage network traverse the site.

A review of the available historic information confirms that the site has not experienced historic flooding. However, the area has been subject to predictive flood modelling under the FEM FRAM/CFRAM studies. The resulting flood maps indicate that inundation of the site occurs during the 0.1% AEP flood event.

Due to the identified flood risk, a site-specific hydraulic model has been developed and based on a detailed review of the watercourses in the study area. A stream within the site boundary has been included that has not been modelled in the FEM FRAM/CFRAM study. Therefore, the **JBA model is considered the most accurate representation of flood risk in the area.**

The results from the detailed site-specific model confirm that **all development onsite is located in Flood Zone C**. A localised area (approx. $14m^2$) along the banks of the stream are located on in Flood Zone B (0.1% AEP event) but this will be retained as greenspace.

The proposed design **places residential properties within Flood Zone C** - low probability of flooding. As no residential property is located in Flood Zone B, there is no requirement to provide a Justification Test.

The proposed design has been appraised against numerous flood events; 1% AEP, 0.1% AEP, climate change and residual risk such as blockages. Review of the results confirm that there is no bank overtopping/inundation during any flood event. There is a low risk of inundation to the residential properties during any flood event.

The resulting FFLs provide a minimum freeboard of 0.40m above the highest flood level through the site, which is the 0.1% HEFS climate change event. **A freeboard of 0.75m is provided over the 0.1% AEP event which meets the SFRA guidance requirements.**

A detailed impact analysis has been undertaken to identify the possible impacts downstream of the site, up to the 0.1% AEP HEFS flood event. The results confirm that **there is no increase in flood levels downstream of the site during any event including the 0.1% AEP HEFS flood.**

Regarding pluvial flood risk, review of the OPW PFRA flood does not indicate any pluvial flooding within the site. Surface water within the site will be managed through the provision of a stormwater system. The system will restrict discharge from the site to its greenfield equivalent and attenuation will be provided as per the Fingal development plan guidelines, which requires that stormwater discharge to be limited to the site's greenfield equivalent and that attenuation storage be provided.

In summary the key areas of the proposed residential dwellings are located within Flood Zone C, and therefore is suitable for the development of residential dwellings.

This Flood Risk Assessment was undertaken in accordance with 'The Planning System and Flood Risk Management Guidelines' and is in agreement with the core principles contained within.

Appendices

A Understanding Flood Risk

Flood risk is generally accepted to be a combination of the likelihood (or probability) of flooding and the potential consequences arising. Flood risk can be expressed in terms of the following relationship:

Flood Risk = Probability of Flooding x Consequences of Flooding

A.1 Probability of flooding

The likelihood or probability of a flood event (whether tidal or fluvial) is classified by its Annual Exceedance Probability (AEP) or return period (in years). A 1% AEP flood has a 1 in 100 chance of occurring in any given year.

In this report, flood frequency will primarily be expressed in terms of AEP, which is the inverse of the return period, as shown in the table below and explained above. This can be helpful when presenting results to members of the public who may associate the concept of return period with a regular occurrence rather than an average recurrence interval and is the terminology which will be used throughout this report.

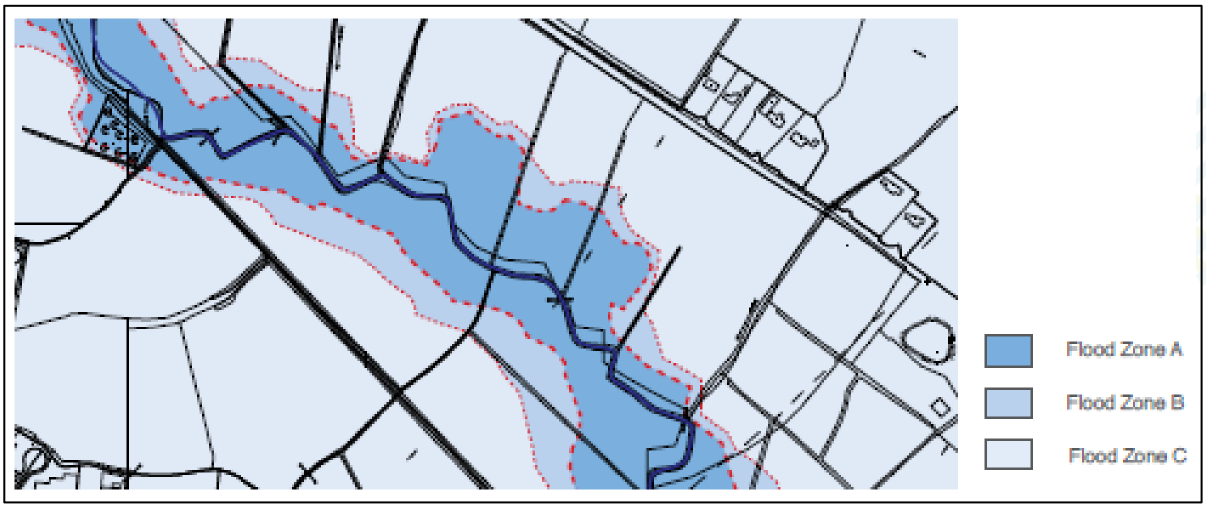
Return Period (years)	Annual Exceedance Probability (%)
2	50
10	10
50	2
100	1
200	0.5
1000	0.1

A.2 Flood Zones

Flood Zones are geographical areas illustrating the probability of flooding. For the purposes of the Planning Guidelines, there are 3 types or levels of flood zones, A, B and C.

Zone	Description
Flood Zone A	Where the probability of flooding is highest; greater than 1% (1 in 100) from river flooding or 0.5% (1 in 200) for coastal/tidal flooding.
Flood Zone B	Moderate probability of flooding; between 1% and 0.1% from rivers and between 0.5% and 0.1% coastal/tidal.
Flood Zone C	Lowest probability of flooding; less than 0.1% from both rivers and coastal/tidal.

It is important to note that the definition of the flood zones is based on an undefended scenario and does not take into account the presence of flood protection structures such as flood walls or embankments. This is to allow for the fact that there is a residual risk of flooding behind the defences due to overtopping or breach and that there may be no guarantee that the defences will be maintained in perpetuity.



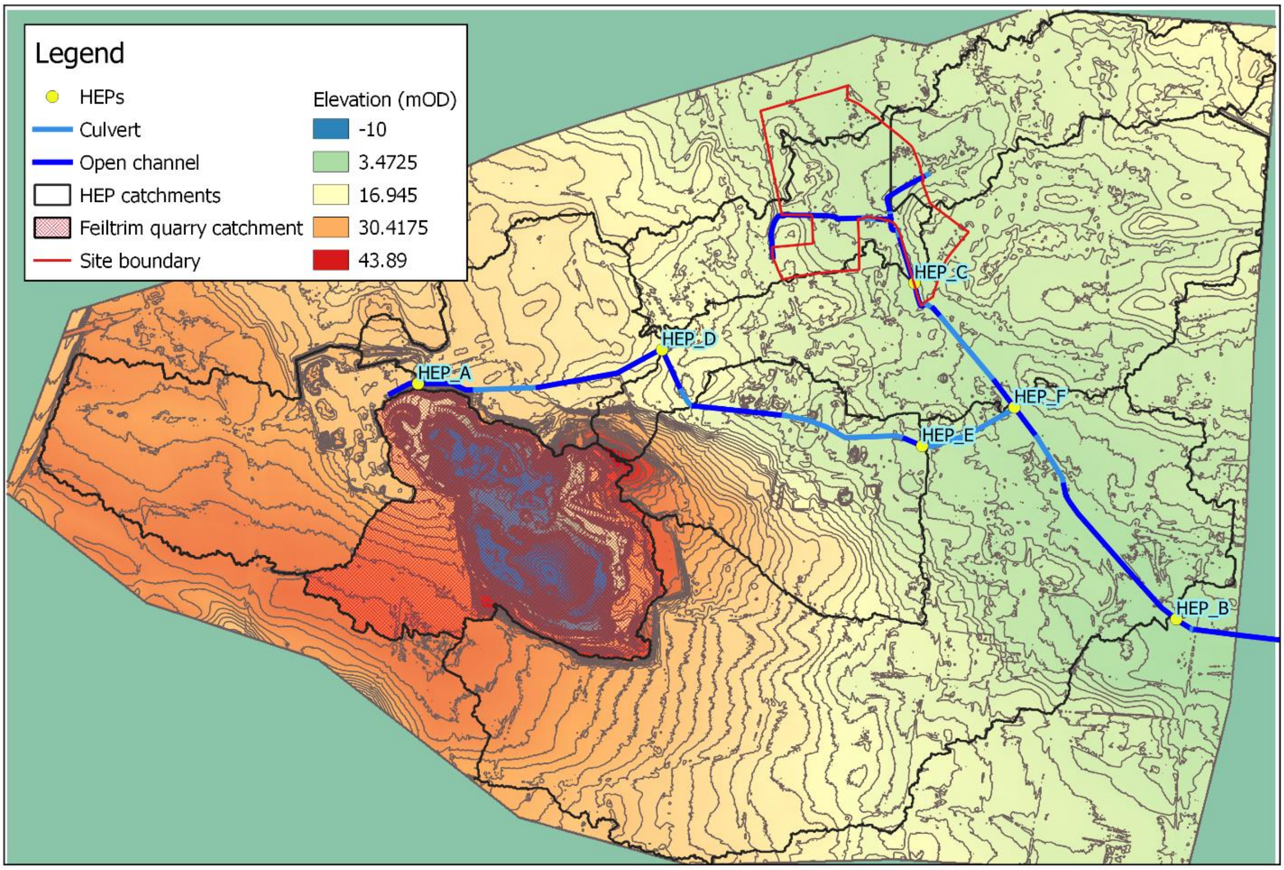
A.3 Consequences of Flooding

Consequences of flooding depend on the hazards caused by flooding (depth of water, speed of flow, rate of onset, duration, wave-action effects, water quality) and the vulnerability of receptors (type of development, nature, e.g. age-structure, of the population, presence and reliability of mitigation measures etc.).

The 'Planning System and Flood Risk Management' provides three vulnerability categories, based on the type of development, which are detailed in Table 3.1 of the Guidelines, and are summarised as:

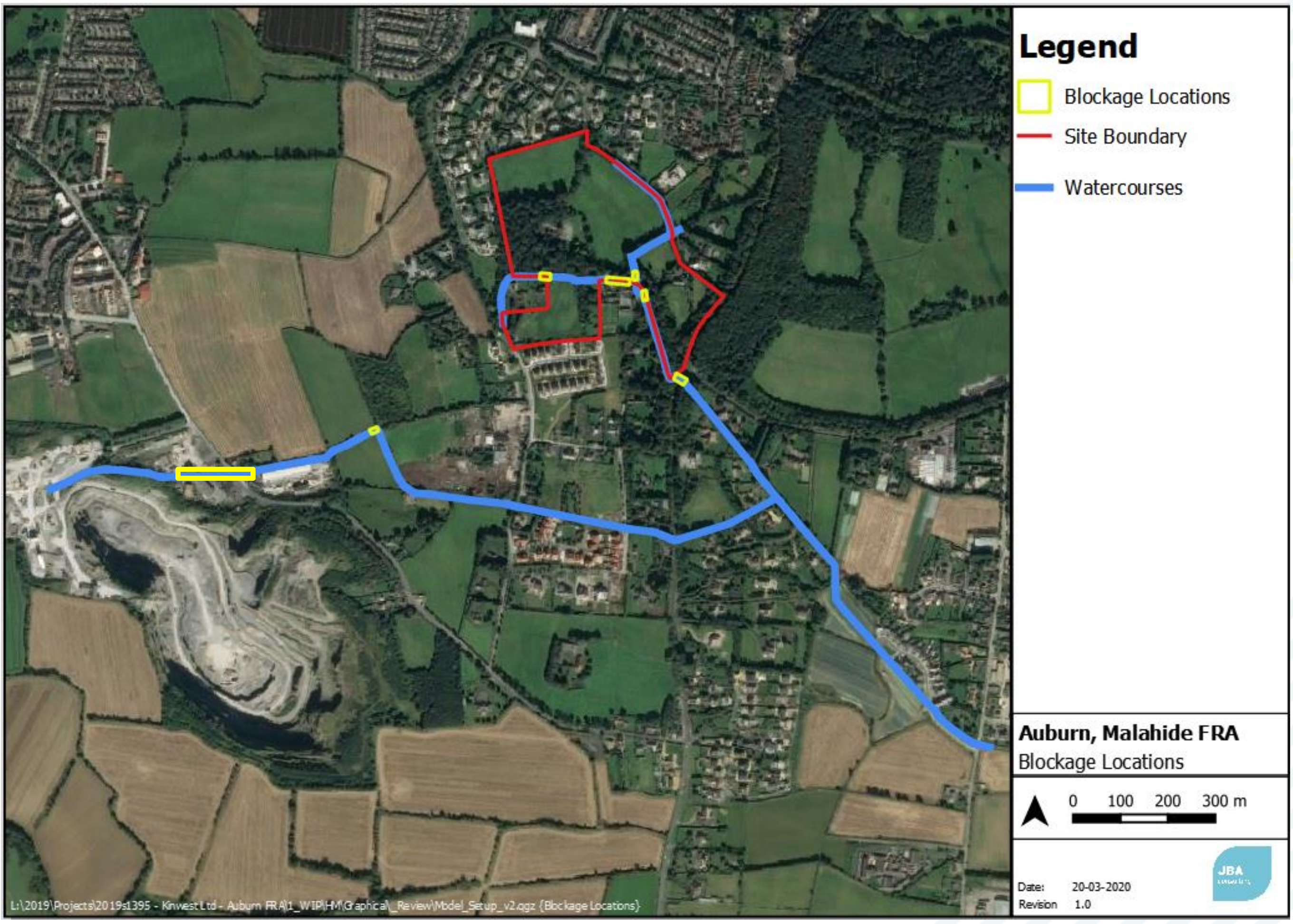
- **Highly vulnerable**, including residential properties, essential infrastructure and emergency service facilities;
- **Less vulnerable**, such as retail and commercial and local transport infrastructure;
- **Water compatible**, including open space, outdoor recreation and associated essential infrastructure, such as changing rooms.

B Catchment Map

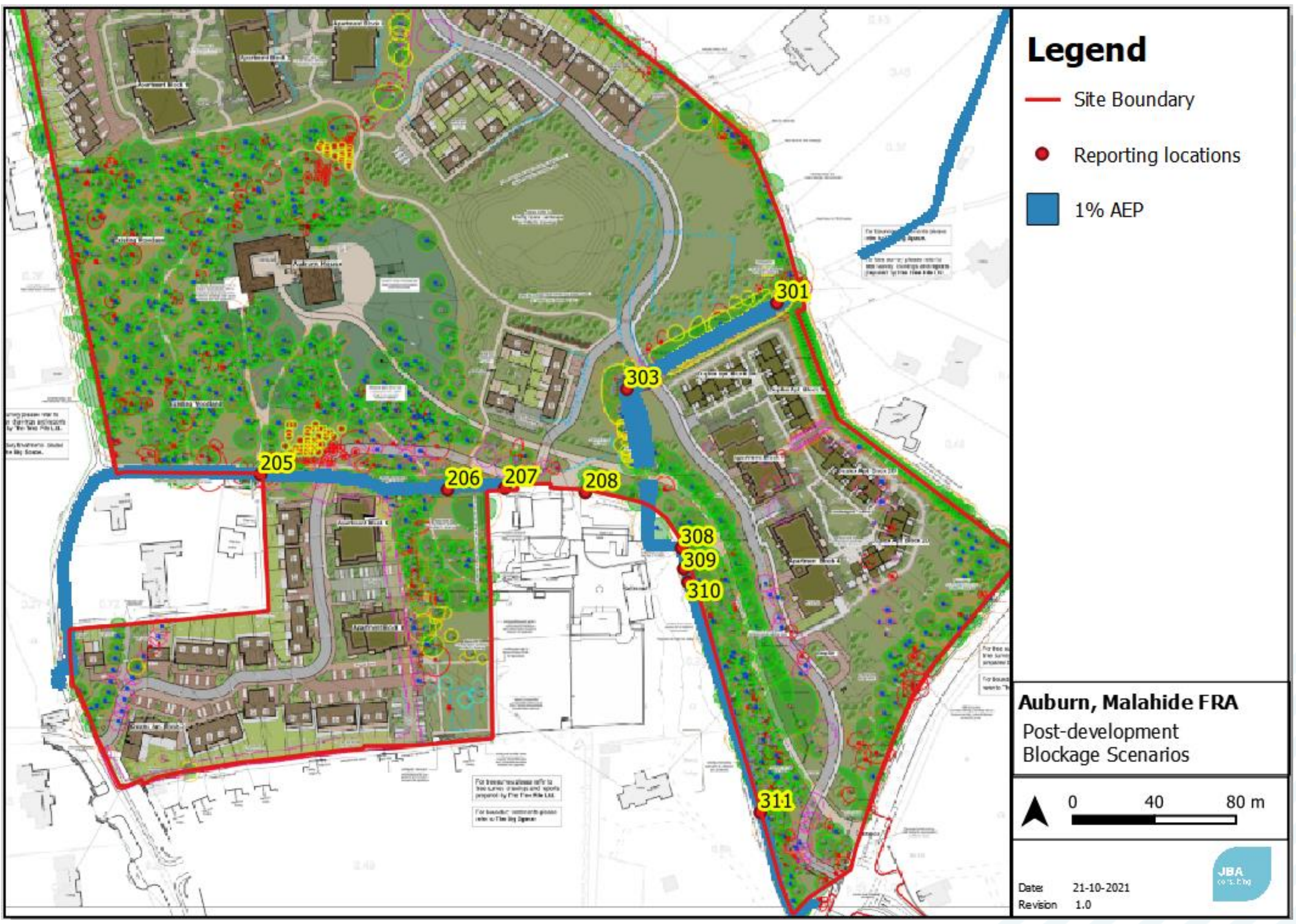


Catchment areas and topography

C Residual Risk – Post Development- Blockage Flood Extents



Blockage Flood Extents



D Impact Tables

Baseline (current) - Model Results

Model Node	1% AEP			0.1% AEP		
	Pre-Development	Post-Development	Impact	Pre-Development	Post-Development	Impact
205	9.71	9.71	0	9.85	9.86	0.01
206	9.23	9.23	0	9.32	9.17	-0.15
207	7.93	7.93	0	9.11	9.16	0.05
301	7.83	7.83	0	8.95	8.8	-0.15
303	7.81	7.81	0	8.82	8.8	-0.02
308	7.79	7.79	0	8.81	8.79	-0.02
311	7.65	7.65	0	8.65	8.64	-0.01
111	7.26	7.26	0	8.38	8.37	-0.01
113	6.54	6.54	0	6.66	6.65	-0.01
119	6.44	6.44	0	6.48	6.48	0

Climate Change (HEFS) - Model Results

Model Node	1% AEP			0.1% AEP		
	Pre-Development	Post-Development	Impact	Pre-Development	Post-Development	Impact
205	9.75	9.75	0	9.91	9.92	0.01
206	9.25	9.25	0	9.39	9.41	0.02
207	8.23	8.24	0.01	9.21	9.4	0.19
301	8.17	8.17	0	9.04	9.09	0.05
303	8.16	8.17	0.01	9.04	9.09	0.05
308	8.16	8.16	0	9.03	9.08	0.05
311	8.08	8.09	0.01	8.82	8.85	0.03
111	7.93	7.93	0	8.42	8.42	0
113	6.6	6.6	0	6.71	6.7	-0.01
119	6.46	6.46	0	6.5	6.5	0

E Hydrology Check File

Flood estimation report: 2019s1395 Aubrun Malahide FRA – Hazelbrook Stream

Approval

	Name and qualifications	Date
Method statement prepared by:	Hannah Moore BA MSc	06/02/2020
Method statement reviewed by:	Tom Sampson BSc MSc FRGS C.WEM MCIWEM	
Calculations prepared by:	Hannah Moore BA MSc	06/02/2020
Calculations reviewed by:	Tom Sampson BSc MSc FRGS C.WEM MCIWEM	

Revision History

Revision Ref/Date	Amendments	Issued to
P01.01/06/02/2020	First draft	Tom Sampson
P01.05/20/02/2020	Division of Catchment HEP C	Tom Sampson
P01.06/23/03/2020	Revision of flows and rewording of document	Tom Sampson

Contents

Abbreviations

AMAX ....Annual Maximum

AREA ....Catchment area (km^2)

BFI ....Base Flow Index

BFISoil ....Base Flow Index derived using soil classification

CFMP ....Catchment Flood Management Plan

EPA...........................Environmental Protection Agency

FARL.........................FEH index of flood attenuation due to reservoirs and lakes

FEH ....Flood Estimation Handbook

FSR ....Flood Studies Report

QMED ....Median Annual Flood (with return period 2 years)

ReFH.........................Revitalised Flood Hydrograph method

SAAR ....Standard Average Annual Rainfall (mm)

SPR ....Standard percentage runoff

Tp(0) ....Time to peak of the instantaneous unit hydrograph

URBAN ....Flood Studies Report index of fractional urban extent

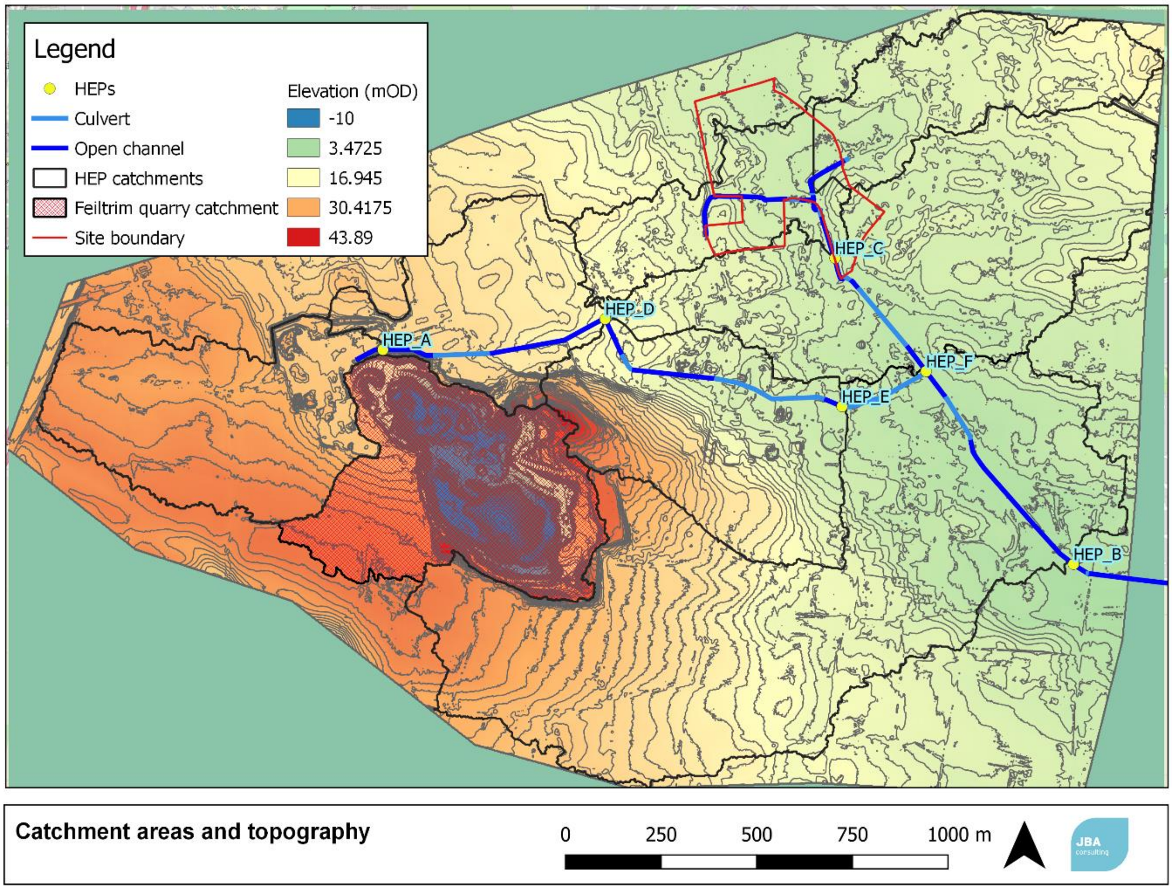
1 Method statement

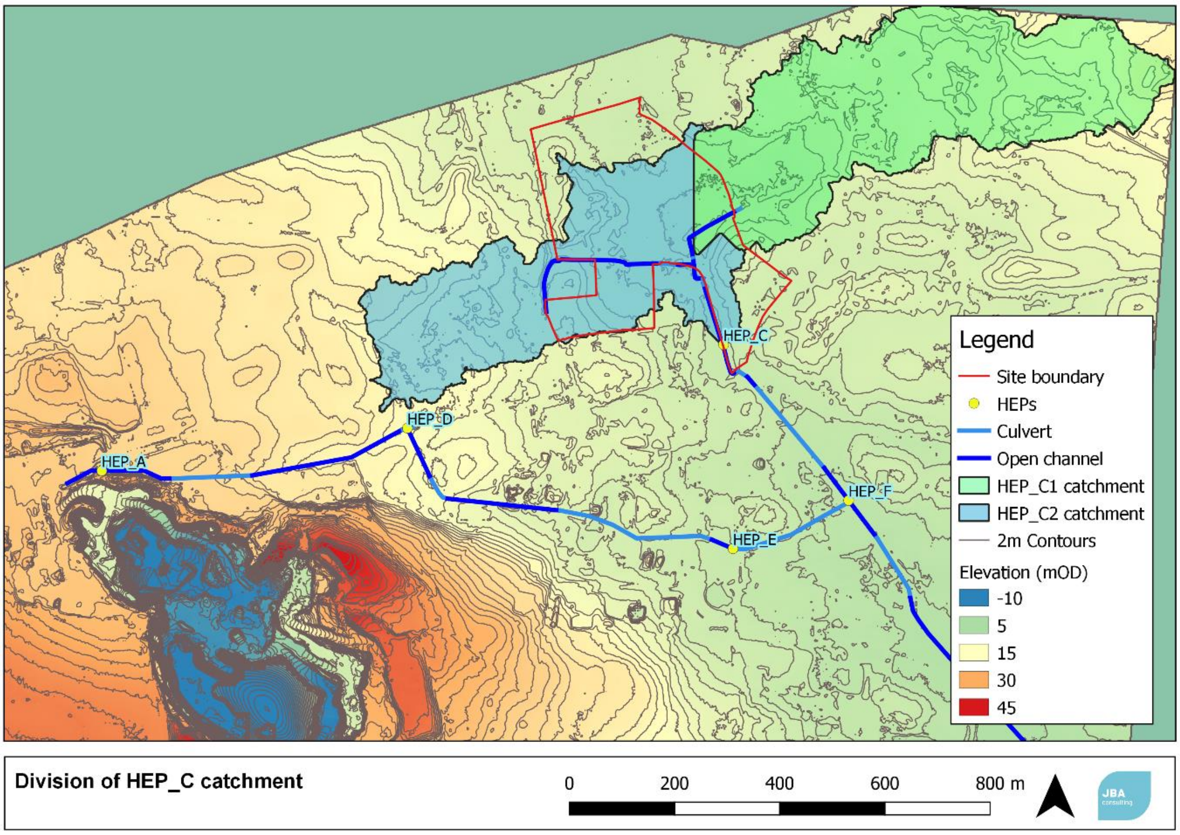
1.1 Requirements for flood estimates

Overview • Purpose of study • Point or catchment flood estimates? • Peak flows or hydrographs? • Range of return periods	- Flow estimates required for a flood risk assessment for a private development site. Flow estimation to relevant HEPs required to carry out FRA. - Peak flows and hydrographs required for study for the critical events (1% and 0.1% AEP). Additional AEP event hydrographs may also be derived depending on whether they are deemed necessary.
Project context	- The updated CFRAM mapping of the area generated a new flow path that effects the site which was not previously on any mapping, the FRA is investigating this flow path and doing a site specific model to look into it.

1.2 The catchment

Map (Include river network, catchment boundary and gauging stations)





Description Include topography, climate, geology, soils, land use and any unusual features that may affect the flood hydrology.	- Main watercourse: The Hazelbook stream originates to the west near Feltrim quarry flowing in an easterly direction. It joins the Sluice River west of the study site location. The watercourse is split into two flow paths much of which are culverted. The two watercourse sections are reconnected to the south of the study site. - Catchment topography: Land is generally sloping towards the south east with higher ground in the west and north. This is reflected in the flow direction and pathway of the Hazelbrook Stream. Total catchment area considered: 3.21km2 - Geology and soils: Catchment bedrock is limestone conglomerate and the quaternary sediments are identified as Limestone till and alluvium. The subsoil permeability in the catchment is variable but predominantly classified as low. Interaction with groundwater is not considered to be of importance in this catchment. - Land use: Catchment land use is a mixture of arable, green field, and urban residential land uses. - Unusual features: There is a gravel quarry located at the upper catchment extent which influences the total flow entering the watercourse.

1.3 Gauging stations (flow or level)

Watercourse is ungauged Kinsaley Hall gauge is located 1km from the lower catchment extent.

Water-course	Station name	Gauging authority number	Gauging Authority	Catchment area (km²)	Type (rated / ultrasonic / level…)	Start of record and end if station closed	Notes
Sluice River	Kinsaley Hall	09105	EPA	9.20	Level gauge	1977-2001	Nearest gauge, not located on watercourse and has been closed for 19 years.

1.4 Other data available and how it has been obtained

Type of data	Data relevant to this study?	Data available?	Source of data	Details
Check flow gaugings (if planned to review ratings)	NA	NA		
Historic flood data Include chronology and interpretation of flood history in Annex or separate report.	Yes	Yes	Flood info	Records of flooding occurring within the area around the site
			Internet search	Records of flooding occurring within the area around the site
Flow or river level data for events	NA	NA		
Rainfall data for events	NA	NA		
CFRAM study method & outputs	Yes	Yes	OPW	FEM FRAMS documentation and Streamstown report (updated flood mapping
Results from other previous studies	Yes	Yes	OPW	FEM FRAMS
			OPW	Streamstown report
Other data or information (e.g. groundwater, tides, channel widths, low flow statistics)	Yes	Yes	Fingal Co Co	Planning application for the Feltrim quarry in the upper catchment with propose discharge rates and measures

1.5 Hydrological understanding of catchment

Hydrological interpretation Catchment processes, response time, propagation of flood, contributions from tributaries	Key factors that influence the hydrological response are the impact of the Feltrim quarry and the channel constrictions caused by the culverts along the watercourse.

Outline the conceptual model, addressing questions such as: • Where are the main sites of interest? • What is likely to cause flooding at those locations? (peak flows, flood volumes, combinations of peaks, groundwater, snowmelt, tides…) • Might those locations flood from runoff generated on part of the catchment only, e.g. downstream of a reservoir? • Is there a need to consider temporary debris dams that could collapse?	- Sites of interest: Feltrim quarry – refer to section 1.6 for more detailed investigation of its impact and consideration in the hydrological estimation for the catchment. - Potential causes of flooding: Under-sizing of culverts along the watercourse resulting in backing up of water upstream and out of bank spill in extreme events. - Other considerations: Blockage scenario is recommended as residual risk test in hydraulic modelling.

1.6 Further research into Feltrim Quarry

Feltrim quarry began operations in 1964 excavating limestone gravel for use in construction. The quarry size was expanded following granting of planning permission for extension of works in 2016 (planning reference F15/0291). The quarry is located at the upstream extent of the Hazelbrook Stream and any surface water and groundwater pumping from the quarry is discharged into this watercourse. Within the 2016 planning application for following points in terms of surface water discharge and flood risk are noted:

- Approximately 1449m3 per day (constant flow of 0.017m3/s) will be pumped from the quarry into the watercourse.
- In times of red rainfall weather warnings pumping won't occur during the period where there are high flows along the Hazelbrook stream. The additional storm water will be stored on site and discharged when flows are reduced.
- A staff gauge along the Hazelbrook stream at the quarry outfall was proposed to measure the discharge from the quarry (it is unknown whether this gauge is currently in place).

Given that the planning application was granted in 2016 these points are assumed to be currently acted upon in the day to day operation of the quarry. As the quarry is an isolated entity within the catchment with a set discharge it is proposed to remove the catchment area which flows into and includes the quarry area from the flow calculations and apply the stated discharge rate as a constant point inflow if needed. Refer to Figure 1-1 for the contributing catchment area to be excluded (total area removed: 0.34km2).

In terms of the overall project purpose it is important to note that the quarry will not be discharging during extreme events. Therefore, the discharge from the quarry does not have to be considered within the estimation of the 1 and 0.1% AEP event peak flows and the quarry is essentially removed from hydrological consideration. This approach differs to the one taken in the Streamstown modelling update study in which the quarry discharge was included in the hydrological peak flow estimation as base flow for all AEP events. There is no mention of the cessation of discharging during storm events discussed in the Streamstown report in relation to the quarry.

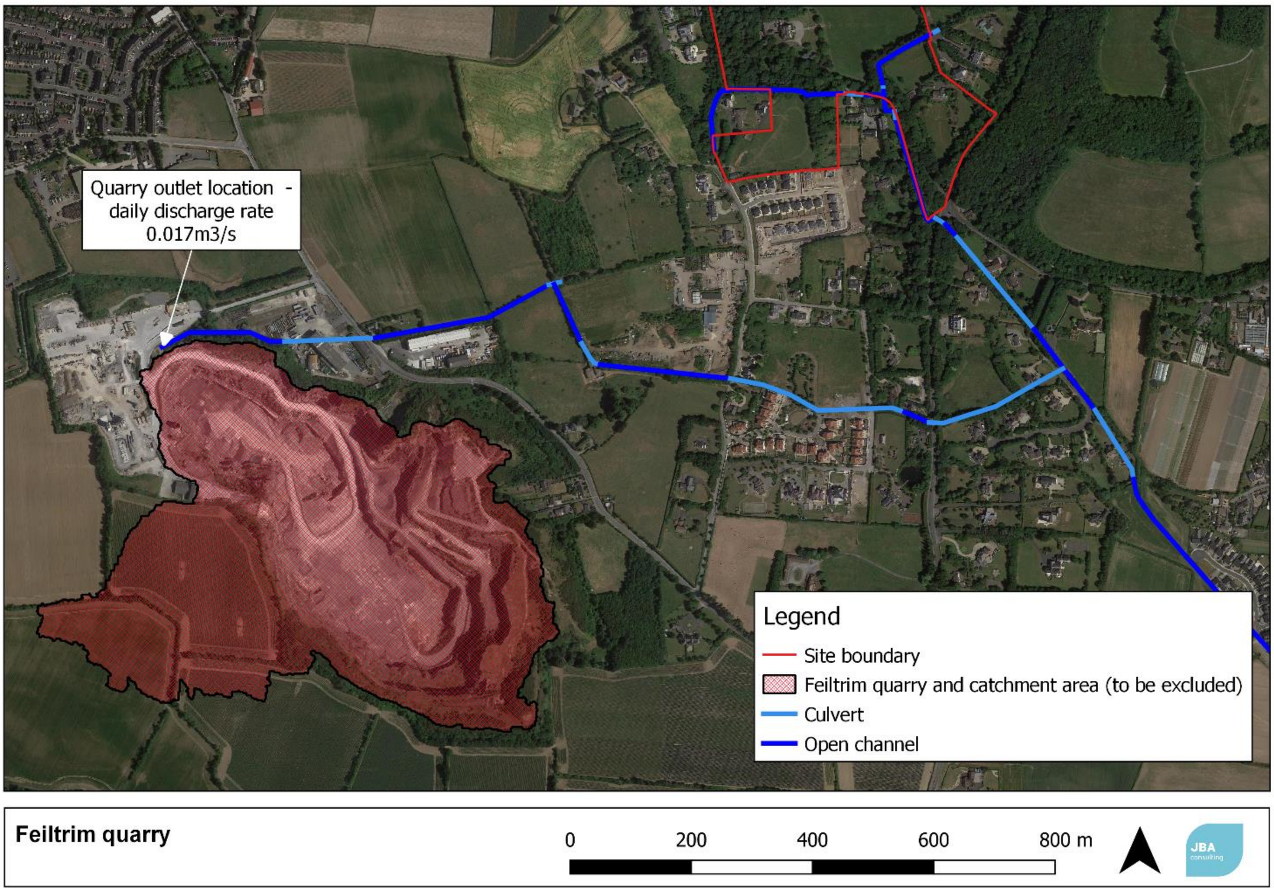


Figure 1-1: Feiltrim quarry

1.7 Initial choice of approach

Is FSU appropriate? (it may not be for extremely heavily urbanised or complex catchments) If not, describe other methods to be used.	FSU is not considered appropriate in this case due to the size of the catchments considered. FSU is designed for catchments of areas greater than 25km2. The catchments in this study are therefore too small for this method to be used
Initial choice of method(s) and reasons How will hydrograph shapes be derived if needed? Will the catchment be split into sub-catchments? If so, how?	As the overall catchment areas considered are small the FSU small catchments,IH124 and FSR RR are considered as the initial approach to Qmed estimation. Higher AEP flows will be estimated using a suitable growth curve. It is thought that hydrograph shape will be sourced from the FSSR RR method. 6 HEP points will be considered for flow estimation
Software to be used (with version numbers)	JSpeed /JBA's Flood Estimation Software (JFes) v.7

2 Locations where flood estimates required

The table below lists the locations of subject sites. The site codes listed below are used in all subsequent tables to save space.

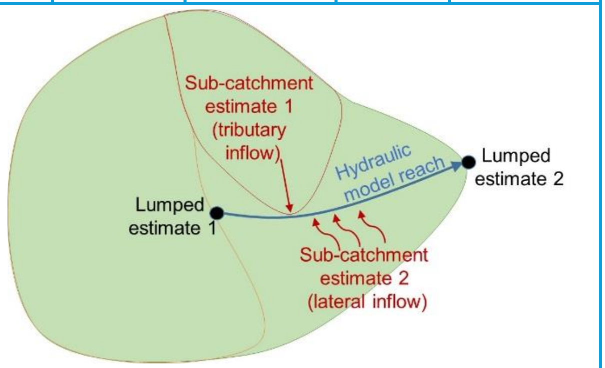
2.1 Summary of subject sites

Site code	Type of estimate L: lumped catchment S: Sub-catchment	Watercourse	Name or description of site	Easting	Northing	AREA (km^2)	Revised AREA if altered
HEP_A	s	Hazelbrook Stream	Estimation point at upstream extent of watercourse			0.67	0.33km2 (Quarry area removed)
HEP_B	l	Hazelbrook Stream	Estimation point at downstream extent of watercourse			2.87	
HEP_C1	s	Hazelbrook Stream	Estimation point at site boundary			0.23	
HEP_C2	s	Hazelbrook Stream	Estimation point at site boundary			0.18	
HEP_D	l	Hazelbrook Stream	Interim estimation point			0.56	
HEP_E	l	Hazelbrook Stream	Interim estimation point			0.81	
HEP_F	l	Hazelbrook Stream	Interim estimation point			0.97	

Note: Lumped catchments (L) are complete catchments draining to points at which design flows are required.

Sub-catchments (S) are catchments or intervening areas that are being used as inputs to a semi-distributed model of the river system. There is no need to report any design flows for sub-catchments, as they are not relevant: the relevant result is the hydrograph that the sub-catchment is expected to contribute to a design flood event at a point further downstream in the river system. This will be recorded within the hydraulic model output files. However, catchment descriptors and ReFH model parameters should be recorded for sub-catchments so that the results can be reproduced.

The schematic diagram illustrates the distinction between lumped and sub-catchment estimates.



For clarity throughout this report results tables are divided into Sub catchment and lumped catchments

2.2 Important catchment descriptors at each subject site (incorporating any changes made)

Descriptor	HEP_A*	HEP_B	HEP_C1*	HEP_C2*	HEP_D	HEP_E	HEP_F
Area	0.33	2.87	0.23	0.18	0.56	0.81	0.97
SAAR	703.08	703.08	703.08	703.08	703.08	703.08	703.08
FARL	1.00	1.00	1.00	1.00	1.00	1.00	1.00
BFI Soil	0.57	0.57	0.57	0.57	0.57	0.57	0.57
Urban area	0.05	0.27	0.09	0.00	0.02	0.05	0.14
URBEXT	0.15	0.09	0.04	0.00	0.06	0.16	0.09
MSL	0.64	3.76	1.51	0.95	1.42	0.90	3.06
S1085	10.5	7.05	9.66	8.42	10.87	18.05	7.77
DrainD	0.12	0.12	0.12	0.12	0.12	0.12	0.12
ArtDrain2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Soil (number)	2.00	2.00	2.00	2.00	2.00	2.00	2.00
SMDBAR	7.00	7.00	7.00	7.00	7.00	7.00	7.00
M5-2day	56.30	56.30	56.30	56.30	56.30	56.30	56.30
M5-1day	47.60	47.60	47.60	47.60	47.60	47.60	47.60
r	30	30	30	30	30	30	30
* denotes sub catchment							

2.3 Checking catchment descriptors

Record how catchment boundary was checked and describe any changes (add maps if needed)	Catchment boundaries were derived using QGIS tools and then adjusted where necessary using LIDAR data.
Record how other catchment descriptors were checked and describe any changes. Include before/after table if necessary.	There are no FSU ungauged nodes located along the Hazelbrook Stream watercourse. Catchment descriptors have been sourced from FSU ungauged node 09_1523_2 which is located 1.25km downstream of HEP_B along the same watercourse. It is assumed that the relevant descriptors at this location reflect the catchment area upstream. Descriptors such as area, MSL and S1085 have been derived manually.
Source of URBEXT	URBEXT values calculated via urban-rural area ratio. Urban area determined using satellite imagery and polygons drawn around urbanised areas.

3 FSU Pivotal gauge evaluation

3.1 Data transfer for QMED estimation

Table 3-1. Pivotal gauge options

	Kinsaley Hall	Fieldstown	Balheary	Ballyboghil	Broadmeadow
Number	08005	08003	08009	08012	08008
FSU gauge quality ranking	A2		A1	B	A2
Catchment area (km2)	9.17	83.6	61.644	25.95	107.92
Qmed gauged m3/s	1.31	16.23	10.29	4.18	19.97
Qmed(rural) m3/s	08005	08003	08009	08012	08008
On same watercourse as subject site (Y/N)	No	No	No	No	No
In same catchment as subject site (Y/N)	No	No	No	No	No
Hydrological similarity to ungauged location	0.25	2.07	1.54	1.064	2.14
Gauge type	Level	Level	Level	Level	Level
Operator	EPA	EPA	EPA	EPA	EPA
Status	Inactive			Inactive	Active
Reasons for choosing or dismissing	Close to the ungauged location, and therefore has a catchment size and hydrological parameters very similar with that of the ungauged location	Larger catchment and hydrological similarity >2	Kinsaley Hall gauge preferred due to proximity	B ranked gauge	Larger catchment and hydrological similarity >2

3.1.1 Kinsaley Hall AMAX review

The Kinsaley Hall was an active gauge between 1977 and 2001, two AMAX records for the gauge are available - one from the OPW FSU site (1983-2000) and the second from the EPA hydronet website (1977-2001). With regards to the EPA data although the record is longer there were several changes to the gauge (e.g. weir removal) that occurred prior to 1983. To ensure consistency within the gauge records and rating curve applied it is recommended that the data prior to 1983 not be used in analysis.

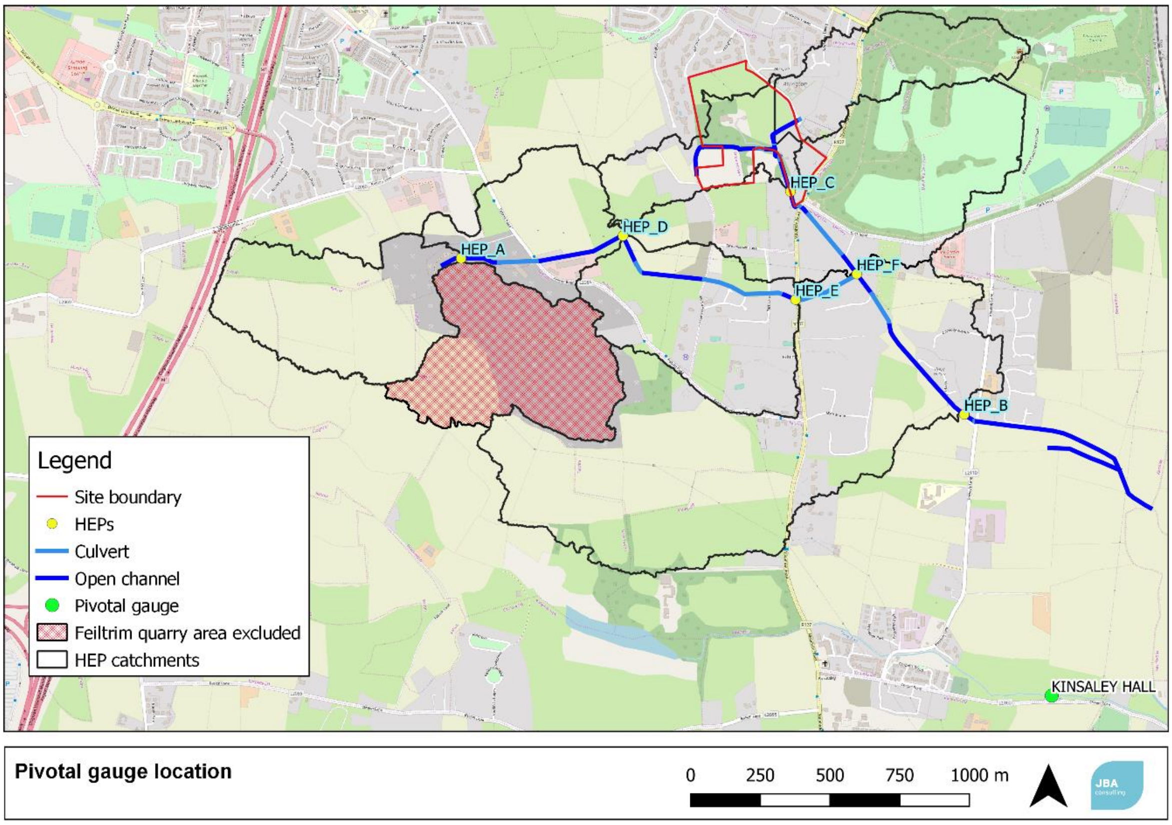


Figure 3-1: Pivotal gauge location

Figure 3-2 compares the two AMAX records available. There are notable differences in the peak flows recorded from both data sets. Review of the data sets revealed that different rating curves must have been applied to the recorded water levels. There are no records of any rating review or the actual rating curve used in the OPW FSU data. It was also noted that the AMAX recorded of water levels recorded differed for each data set, there is no information as to why the water levels recorded differ.

It was decided that the EPA AMAX from 1983-2001 be used for analysis because:

- The EPA oversaw the gauge when it was operational;
- There is no information as to how the OPW data was sourced or the rating curve applied to the data;
- The rating curve and full data record is available from the EPA and a clear trail of data collection and application can be seen through the AMAX series and is therefore considered a more reliable data source;
- The EPA data was used in the FEM FRAM study which is the most up to date assessment of the watercourse and flood risk for the area.

The AMAX analysis worksheet can be found within the project folder.

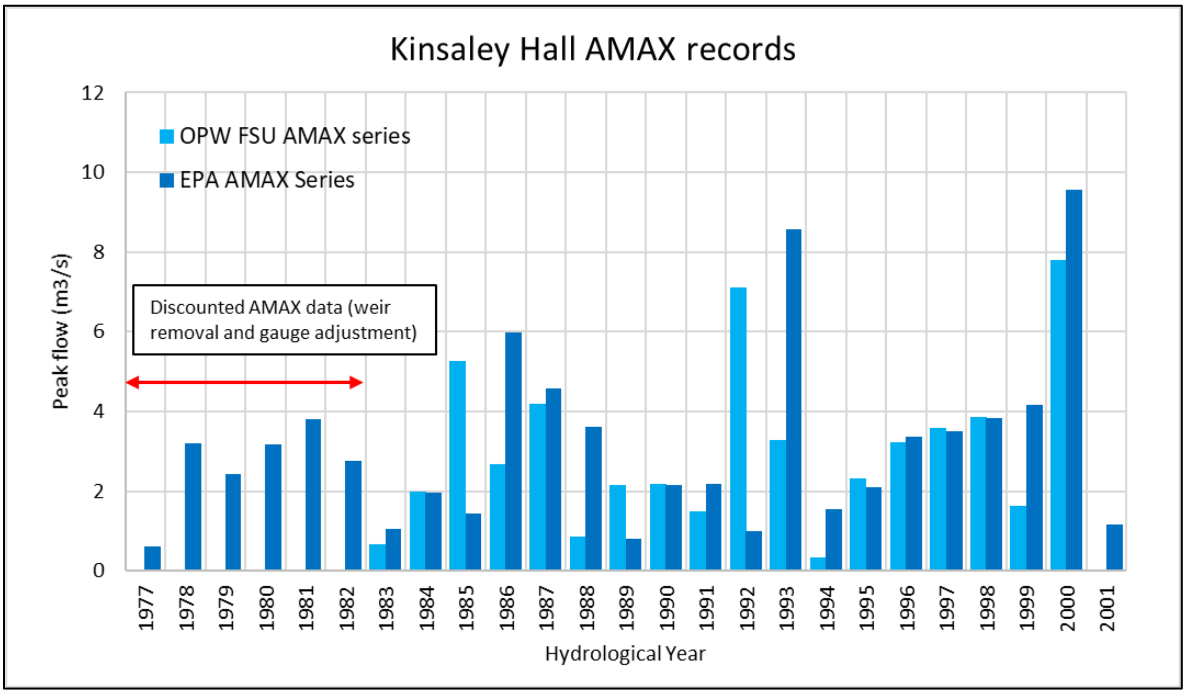


Figure 3-2: Kinsaley hall AMAX records

The gauged Qmed value from the Kinsaley Hall EPA is recorded as 2.76m3/s while the AMAX Qmed (Qmed Stat) for the data set is 1.62m3/s. The gauged Qmed value from the OPW AMAX data was 2.50m3/s.

Table 3-2. Pivotal sites chosen and QMED adjustment factors

Descriptor	Pivotal site
Area	9.17 km2
SAAR	710
FARL	1
BFI Soil	0.52
URBEXT	0.25
S1085	6.90 m/km
DrainD	0.91 km/km2
ArtDrain2	0.00
Soil (number)	0.30
SMDBAR	7.00
M5-2day	56.30
M5-1day	47.60
r	0.30
FSU Gauge ranking	A2
Hydrological similarity	-
FSU record	1983-2000 (full AMAX 1977- 2000)
Qmed(rural) m3/s	1.62
Qmed (URBEXT) m3/s	2.76
Qmed(gauged) m3/s	1.31
Qmed stat	2.52

3.2 Growth Curves

As the catchments are less than 5km2 no representative pooling group using the FSU database can be derived. Therefore, two growth curves are considered:

- Single site analysis using Kinsaley Hall gauge;
- ECFRAM small catchment (10km2) growth curve;

3.2.1 Single site growth curve analysis – Kinsaley Hall

Growth curve analysis was carried out using JSpeed (in house software) for the Kinsaley Hall gauge – the pivotal gauge for the catchment areas. A Log-normal 3-parameter distribution was selected as to use a generalised distribution does not reflect the site specific data available. Table 3-3 shows the growth factors produced and Figure 3-3 shows the single site growth curve.

Table 3-3: Kinsaley hall single site growth curve

AEP%	Growth Factor
50%	1.00
10%	2.75
1%	5.82
0.1%	9.82

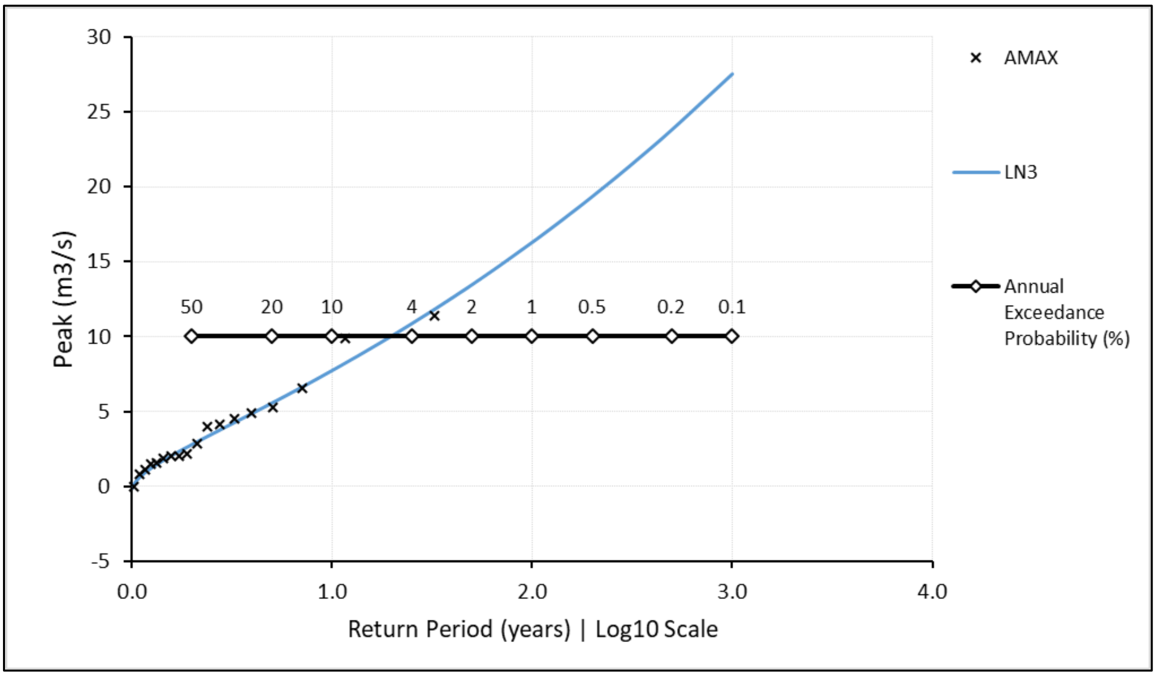


Figure 3-3: Kinsaley hall growth curve

3.2.2 ECFRAM growth curve

As part of the ECFRAM study growth curves were derived for 6 different catchment area ranges. Table 3-4 shows the ECFRAM small catchments growth curve which was applied for all catchments less than 10km2. The pooling group used to develop this growth curve included small upland catchments located in the Dublin mountains.

Table 3-4: ECFRAM small catchments growth curve

AEP%	Growth Factor
50%	1.00
10%	1.79
1%	3.32
0.1%	5.92

3.2.3 FSR RR growth curves

The FSR RR method generates a growth curve for each catchment under assessment based on rainfall values and catchment properties. Table 3-5 shows the range of growth curve values estimated for the HEP catchments considered in this study.

Table 3-5: FSR RR growth curve

AEP%	Growth Factor
50%	1.00
10%	1.24 – 1.80
1%	2.24 – 3.20
0.1%	3.63 – 5.00

3.2.4 Discussion on growth curves

Table 3-6 compares the growth curves. The single site growth curve is too steep to be used as the growth factors for the higher HEP events would result in excessive peak flow estimates which would not match the expected catchment responses given their S1085 values and their size. Therefore, the ECFRAM small catchments growth curve will be applied to estimate higher peak flows for the FSU SC and IH124 methods and the FSR RR growth curves be used for the FSR RR peak flow estimates in this study.

Table 3-6: Growth curve comparison

AEP%	Kinsaley hall single site growth curve	ECFRAM small catchments growth curve	FSR RR growth curve (range)
50%	1.00	1.00	1.00
10%	2.75	1.79	2.24 – 3.20
1%	5.82	3.32	1.24 – 1.80
0.1%	9.82	5.92	2.24 – 3.20

Offices at

Dublin
Limerick

Registered Office
24 Grove Island
Corbally
Limerick
Ireland

+353(0)61 345463
info@jbaconsulting.ie
www.jbaconsulting.ie
Follow us:

4 FSU small catchments

Table 4-1 shows the peak flows estimated using the FSU small catchment method (FSU SC), the ECFRAM growth curve for catchments less than 10km2 has been applied.

Table 4-2 shows the peak flow estimates after Qmed adjustment using the Kinsaley Hall pivotal gauge (adjustment factor of 0.58). It is felt that the adjusted values are significantly lower than those expected for the catchments therefore it is recommended that the unadjusted values be considered for final flow selection.

Table 4-1: FSU SC peak flow estimates for the HEPs (no Qmed adjustment)

AEP%	HEP_A	HEP_C1	HEP_C2
50%	0.04	0.02	0.01
10%	0.06	0.04	0.02
1%	0.12	0.07	0.03
0.1%	0.21	0.13	0.06

AEP%	HEP_B	HEP_D	HEP_E	HEP_F
50%	0.26	0.05	0.07	0.09
10%	0.47	0.09	0.13	0.17
1%	0.87	0.16	0.24	0.31
0.1%	1.56	0.29	0.42	0.56

Table 4-2: FSU SC peak flow estimates for the HEPs (Qmed adjustment)

AEP%	HEP_A	HEP_C1	HEP_C2
50%	0.02	0.01	0.02
10%	0.04	0.02	0.03
1%	0.07	0.04	0.06
0.1%	0.12	0.08	0.10

AEP%	HEP_B	HEP_D	HEP_E	HEP_F
50%	0.15	0.03	0.04	0.05
10%	0.27	0.05	0.07	0.10
1%	0.51	0.10	0.14	0.18
0.1%	0.91	0.17	0.24	0.32

5 IH124

QBAR has an estimated return period of 2.33 years. The estimated QBAR is then multiplied by the growth factors estimate design flows for specified return periods. In this case Qmed estimates have been multiplied by growth factors from the ECFRAM small catchments growth curve. To further refine the flow estimation a Qmed adjustment factor of 0.56 has been applied to the Qmed values estimated. The Qmed adjustment factor is based on the pivotal gauged catchment Kinasley hall.

Table 5-1 and Table 5-2 show the peak flows estimated using the IH124 method and Figure A.4 shows the IH124 growth curves generated. Table 5-3 shows the flow estimates for the pivotal gauged catchment and the calculated adjustment factor applied to the final flow estimates. It is felt that the adjusted values are significantly lower than those expected for the catchments therefore it is recommended that the unadjusted values be considered for final flow selection.

Table 5-1: IH124 peak flow estimates for the HEPs (no Qmed adjustment)

AEP%	HEP_A	HEP_C1	HEP_C2
50%	0.09	0.05	0.03
10%	0.16	0.09	0.05
1%	0.30	0.17	0.10
0.1%	0.53	0.30	0.18

AEP%	HEP_B	HEP_D	HEP_E	HEP_F
50%	0.54	0.12	0.21	0.22
10%	0.96	0.21	0.37	0.40
1%	1.79	0.40	0.70	0.73
0.1%	3.19	0.71	1.24	1.30

Table 5-2: IH124 peak flow estimates for the HEPs (Qmed adjustment)

AEP%	HEP_A	HEP_C1	HEP_C2
50%	0.05	0.03	0.02
10%	0.09	0.05	0.03
1%	0.17	0.09	0.06
0.1%	0.30	0.17	0.10

AEP%	HEP_B	HEP_D	HEP_E	HEP_F
50%	0.30	0.07	0.12	0.12
10%	0.54	0.12	0.21	0.22
1%	1.00	0.22	0.39	0.41
0.1%	1.79	0.40	0.70	0.73

Table 5-3: IH124 Qmed adjustment factor

Descriptor	Value
Kinsaley Hall gauged Qmed (50% AEP flow)	1.31m3/s
Kinsaley Hall IH124 rural Qmed from descriptors only	1.17m3/s
Kinsaley Hall IH12 urban Qmed from descriptors only	2.34m3/s
IH124 Qmed Adjustment Factor	0.56

6 FSR RR

The default rainfall depth duration data within the Jfes software has been updated with the Met Eireann values for each catchment, linearly interpolated to match the storm duration suggested by the software for each HEP. The 0.1% AEP rainfall depths which are not provided within the MET Eireann data were determined by applying the ratio between the 1% and 0.1% AEP FSR rainfall depths to the 1% AEP MET Eireann values

Table A.3-1 shows the calculated growth curves for each of the sub catchments and Figure A.3 shows the corresponding flow hydrographs. FSR RR is not a statistical method therefore no Qmed adjustment using the pivotal gauge is applied.

Table 6-1: FSR RR peak flow estimates for the HEPs (FSR RR growth curves applied)

AEP%	HEP_A	HEP_C1	HEP_C2
50%	0.13	0.07	0.05
10%	0.21	0.11	0.08
1%	0.39	0.19	0.14
0.1%	0.62	0.30	0.22

AEP%	HEP_B	HEP_D	HEP_E	HEP_F
50%	0.75	0.17	0.40	0.27
10%	1.08	0.29	0.60	0.46
1%	2.18	0.50	1.02	0.77
0.1%	3.42	0.79	1.82	1.22

7 Comparison of flow estimates

Table 7-1 compares the peak flows estimated by the two methods considered. The ECFRAM small catchments growth curve has been applied to both flow estimates. As discussed in the previous sections the pivotal gauge adjusted values have been discounted due to the low flows generated which are not considered representative.

Comparing the values those generated using the FSU SC method are lower for all HEPs. The FSU SC method is recommended for catchments between 1 and 25km2 and so many of the catchments considered in this study are not within the recommended range for the method. Given that the flow estimates are so low, and the method is not recommended for the catchment sizes the FSU SC method has been discounted.

Of the two remaining methods the FSR RR produces the highest peak flows. The individual catchment growth curves applied in the method are similar to the ECFRAM growth curve values. This method was designed for steep upland catchments with areas greater than 1km2. As the catchments considered in this study do not match this description it is recommended that the IH124 flow estimates be used. The IH124 method is designed for smaller catchments and therefore using these values ensures that an appropriate method is used, and conservative flows that are still representative of the catchment are applied.

Table 7-1: Comparison of peak flow estimates (flow in m3/s)

	HEP_A	HEP_C1	HEP_C2
	50% AEP		
FSU SC	0.04	0.02	0.01
IH124	0.09	0.05	0.03

FSR RR	0.13	0.07	0.05
	10%AEP		
FSU SC	0.06	0.04	0.02
IH124	0.16	0.09	0.05
FSR RR	0.21	0.11	0.08
	1% AEP		
FSU SC	0.12	0.07	0.03
IH124	0.30	0.17	0.10
FSR RR	0.39	0.19	0.14
	0.1% AEP		
FSU SC	0.21	0.13	0.06
IH124	0.53	0.30	0.18
FSR RR	0.62	0.30	0.22

	HEP_B	HEP_D	HEP_E	HEP_F
	50% AEP			
FSU SC	0.26	0.05	0.07	0.09
IH124	0.54	0.12	0.21	0.22
FSR RR	0.75	0.17	0.40	0.27
	10%AEP			
FSU SC	0.47	0.09	0.13	0.17
IH124	0.96	0.21	0.37	0.40
FSR RR	1.08	0.29	0.60	0.46
	1% AEP			
FSU SC	0.87	0.16	0.24	0.31
IH124	1.79	0.40	0.70	0.73
FSR RR	2.18	0.50	1.02	0.77
	0.1% AEP			
FSU SC	0.156	0.29	0.42	0.31
IH124	3.19	0.71	1.24	1.30
FSR RR	3.42	0.79	1.82	1.22

8 Hydrograph Shapes

The FSR RR method has been selected for the generation of storm hydrographs. The FSR RR hydrographs are based of the unit hydrograph. As there are no reservoirs or lakes influencing the catchments the FSR RR hydrograph shape is suitable for use in the catchment.

9 Storm Duration

As the overall catchment area is small it is reasonable to assume that the same storm event would occur over the entire study area. Therefore, a single storm duration will be applied. The FSR RR method provides a recommended storm duration for each HEP catchment based on catchment descriptors. Table 9-1 shows the different recommended storm durations. The larger catchments have the longest recommended storm duration which is to be expected. Given the variety of the recommended durations it is proposed that two storm durations are run – a 3- and 8-hour storm and sensitivity analysis be run by increasing and decreasing the hydrograph length by 20%. The use of the two durations allows testing as to whether the catchment is more likely to flood in shorter or longer events.

Table 9-1: Recommended storm durations using FSR RR

HEP	Catchment area	Storm duration
HEP_A	0.33	3.75
HEP_B	2.87 (whole catchment)	7.75
HEP_C	0.40	8.25
HEP_D	0.48	5.75
HEP_E	0.30	3.30
HEP_F	1.55	7.25

10 Downstream Boundary

As the Hazelbrook stream continues on past the site and study area a normal Q-h boundary is recommended for the downstream boundary to represent the continuation of the watercourse past the model domain.

11 CFRAM & other study Comparison

Two previous detailed flood mapping studies have been carried out in the area – the FEM FRAM study and the Streamstown mapping update (SMU).

Following the release of the FEMFRAMS flood maps in 2010 public consultation regarding the Streamstown area flood map in 2015 raised several objections including:

- Claims that the route of the modelled watercourse was incorrect;
- Flood extents did not match the lack of evidence/absence of flood events recorded in the area;

Further investigation of the area and claims in 2016 found the wrong river centreline had been surveyed, and a portion of culverted stream to the south had not been included in the original FEMFRAMS modelling. To address this, the OPW commissioned a flood map update study, remodelling the watercourse to include the correct river route and the dual watercourses.

The study produced a more accurate schematisation of the water course and completed a new hydrologic estimation of peak flows used as inputs into the hydraulic model. The SMU outputs have now replaced the FEMFRAMS flood mapping extents. Therefore, only the methods and outputs from the SMU study are considered in this section.

11.1 Streamstown mapping update study

For the Streamstown report catchment boundaries for the area were reviewed. Updated catchment areas for five Hydrological Estimation Points (HEPs) were defined by analysing available LIDAR DTM data and drainage maps. Figure 11-1 shows the SMU catchment boundaries. Further detail about catchment characteristics is not provided in the report. It is stated that “Physical catchment descriptors representing each HEP/catchment were derived using various GIS datasets and, where considered representative, were borrowed from nearby adjacent FSU defined catchments.” There is no way to review these descriptors to see whether those used are appropriate.

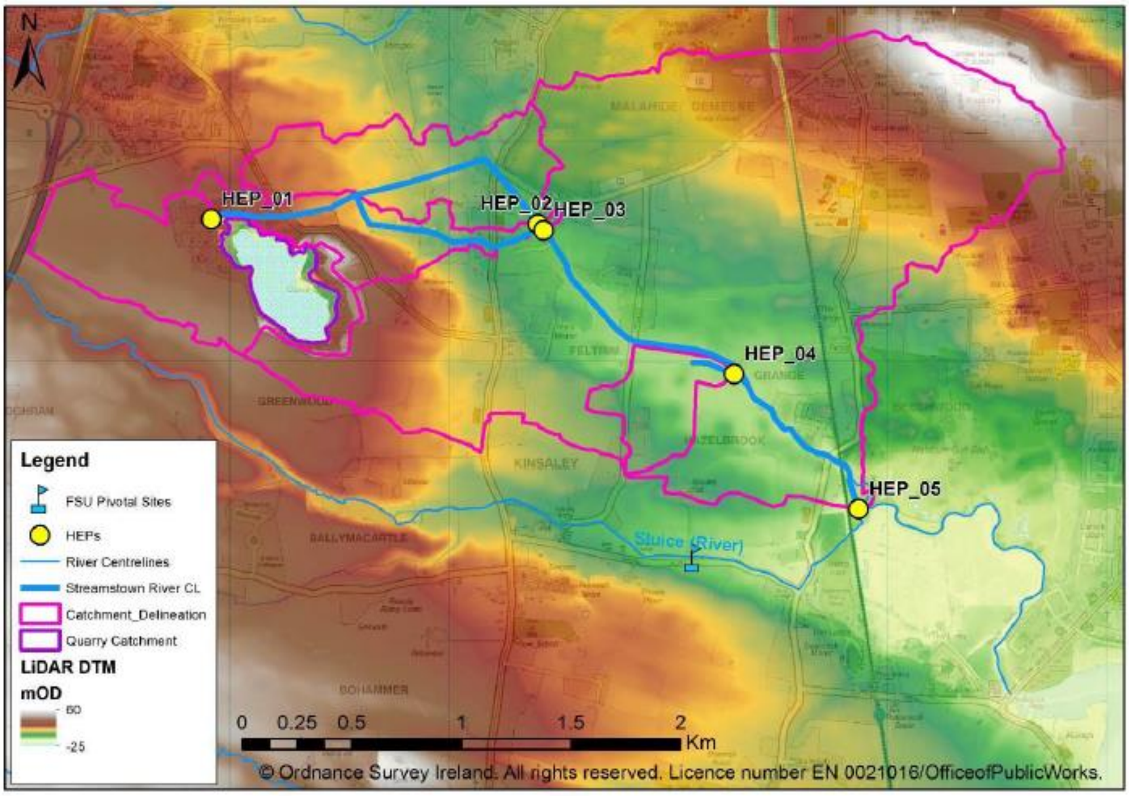


Figure 11-1: SMU catchment boundaries and HEPs (source: Streamstown mapping update study report)

The FSU catchment descriptor equation was used to estimate Qmed for all HEPs. The Kinsaley Hall gauge (08005) was used as a pivotal gauged site in the estimations. This gauge was selected as it is the closest to the watercourse and is hydrologically similar. An adjustment factor of 1.36 was applied to all HEP Qmed values. It is highlighted that the FSU method was designed for catchments greater than 25km2 and is not recommended for catchments below this size. The largest catchment considered in the study is just over 5km2 and therefore the FSU method is not appropriate. The Eastern CFRAM growth curve for catchments less than 10km2 was used to generate peak flow estimates for higher return period events. Table 11-1 compares the peak flow estimates from the SMU and those calculated in this report for HEPs at the same locations.

The peak flows estimated in this check file at HEP_A are considerably less than those reported in the SMU. This is largely due to the difference in HEP catchment size. In the SMU only the actual quarry and not the area contributing flows to it was removed from the HEP_01 catchment area resulting in the size difference. The flow estimates at HEP_03 and HEP_F also differ due to the comparative catchment sizes as the CFRAM HEP_03 includes sections of the JBA HEP_D and E within its catchment area. It is noted that the SMU flow estimates at HEP_03 higher due to the FSU adjustment factor of 1.36 is applied (e.g. 10% flow = 0.52 without adjustment factor).

Overall it is felt that the flow values estimated in this report are more representative of the catchments considered. The impact of Feiltrim quarry is more clearly addressed in this check file and considers the operation of the quarry in storm events as described in the planning permission documents (refer to section 1.6). There is also greater confidence in using the flow values as the catchment descriptors used in the estimations have been clearly stated unlike in the SMU study and the method applied is considered more appropriate for small catchments.

Table 11-1: Comparison of CFRAM and estimated flows (SMU flows taken from SMU report)

	HEP_01 (CFRAM)	HEP_A (JBA)	HEP_03 (CFRAM)	HEP_F (total flows to HEP_F) (JBA)
Area (km2)	0.71	0.33	1.52	0.97
AEP	Peak flow (m3/s)			
10%	0.26	0.16	0.69	0.12
1%	0.46	0.30	1.28	0.22
0.1%	0.79	0.53	2.28	0.41

It is also noted in the SMU report the 1% AEP design hydrographs are extremely long (between 10-30hours). This is considered unusual given the size of the total catchment area considered. The hydrograph shape and length were derived using the OPW FSU hydrograph shape generator. It is recorded in the SMU report that "*Two small catchment pivotal sites remote from Streamstown were used as pivotal sites, 22009 and 26022, as they were deemed to be hydrologically similar*." These two gauges catchments have areas of 35.39 and 61.88km2 respectively which are significantly larger than the catchments considered and may be why such a long storm hydrograph was generated. Given the mismatch between storm hydrograph length and the catchment area it is recommended that the hydrographs generated in this check file be used as they are considered more representative of the expected catchment response.

12 Discussion and summary of results

12.1 Final choice of method

Choice of method and reasons Include reference to type of study, nature of catchment and type of data available.	Comparing the values those generated using the IH214 method are higher for all HEPs. The FSU SC method is recommended for catchments between 1 and 25km2 and so many of the catchments considered in this study are not within the recommended range for the method. The IH124 method is designed for smaller catchments and therefore the values from this method are recommended for use. This ensures that an appropriate method is used, and conservative flows that are still representative of the catchment are applied. Adjustment factors have not been applied but found to be insignificant in relation to the estimates made.
Climate change allowance	+20% flow increase under the OPW Medium range forecast scenario (MRFS)
How will the flows be applied to a hydraulic model? If relevant. Will model inflows be adjusted to achieve a match with lumped flow estimates, or will the model be allowed to route inflows?	HEP_A = Point inflow HEP C_1 = Point inflow HEP C_2 = Point inflow All others = lateral inflows
Recommended sensitivity tests for hydraulic model e.g. peak flow, volume, hydrograph shape, downstream boundary, bankfull	- Flow routing through the hydraulic model to test flow estimates are appropriate and that storage or hydraulic aspects in the system that may affect flow estimates. - Two storm durations tested to look at affect also sensitivity +/-20% hydrograph length. - Test 1% AEP event with and without constant discharge from Feiltrim quarry. - Test of Qh relationship at downstream boundary

12.2 Assumptions, limitations and uncertainty

List the main assumptions made (specific to this study)	- Feltrim quarry and its representation - Ungauged catchment – no calibration/validation possible - No FSU catchment descriptor equation nodes along watercourse, relevant descriptors sourced from nodes on nearby watercourses. - All catchments are extremely small and are at or below the lower limit of the range at which the methods used should be applied.
Discuss any particular limitations, e.g. applying methods outside the range of catchment types or return	NA

periods for which they were developed.	
Give what information you can on uncertainty in the results, e.g. confidence limits from Kjeldsen (2014).	NA
Comment on the suitability of the results for future studies, e.g. at nearby locations or for different purposes.	- Hydrology estimations suitable for further use within the same catchment area but review of their suitability would be needed prior to use. These flows have been estimated for the purposes of an FRA and therefore may not be appropriate for different study types.
Give any other comments on the study, e.g. suggestions for additional work.	- Ensure hydrology is updated following flow routing and storm duration testing within the hydraulic modelling process.

12.3 Checks

Are the results consistent, for example at confluences?	NA
Has joint probability been considered?	No – single watercourse, not applicable
Have adjustments to catchment descriptor methods or gauge data been applied?	Yes
Is storm duration important?	Potentially – storm duration testing recommended
What do the results imply regarding the return periods of floods during the period of record?	No flood records recorded. No comparisons to be made.
What is the range of 100-year growth factors? Is this realistic?	3.32 – considered appropriate given catchment slopes.
If 1000-year flows have been derived, what is the range of ratios for 1000-year flow over 100-year flow?	Ratios range between 1.76 – 1.80
How do the results compare with those of other studies? Explain any differences and conclude which results should be preferred.	Differences discussed in Section11.
Are the results compatible with the longer-term flood history?	NA
Describe any other checks on the results	Sensitivity checks recommended for hydraulic modeller to test.
Location of calculation sheets, data and records.	"L:\2019\Projects\2019s1395 - Kinwest Ltd - Auburn FRA\1_WIP\HO\Non_Graphical_Review" JFes – search for project code 2019s1395

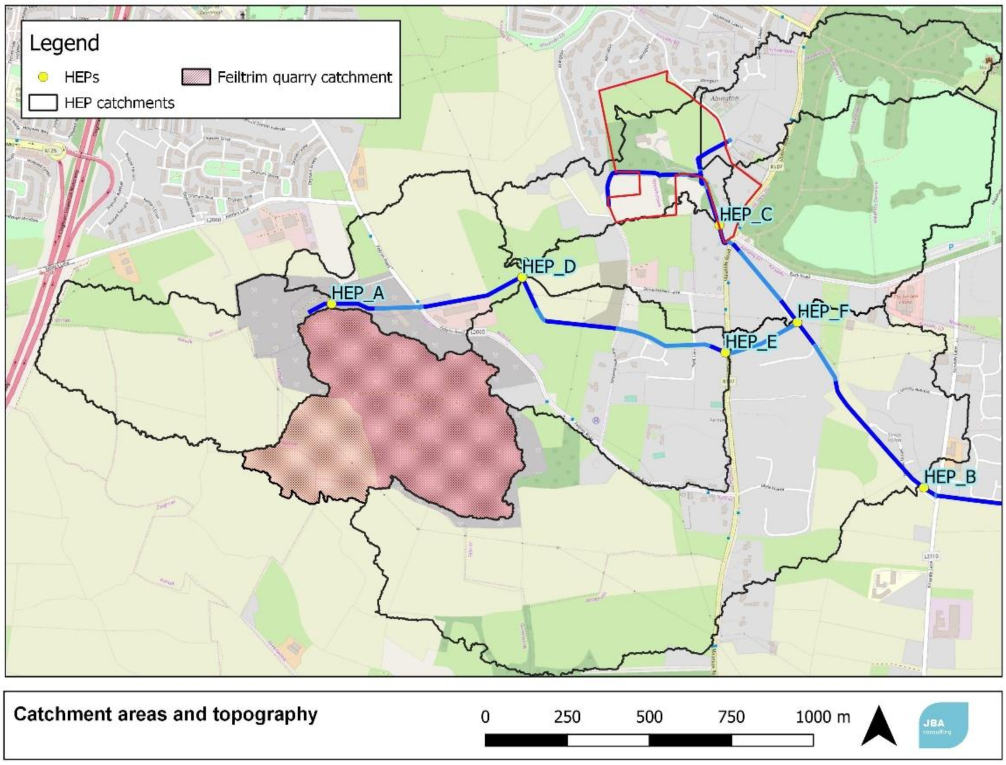
12.4 Final results

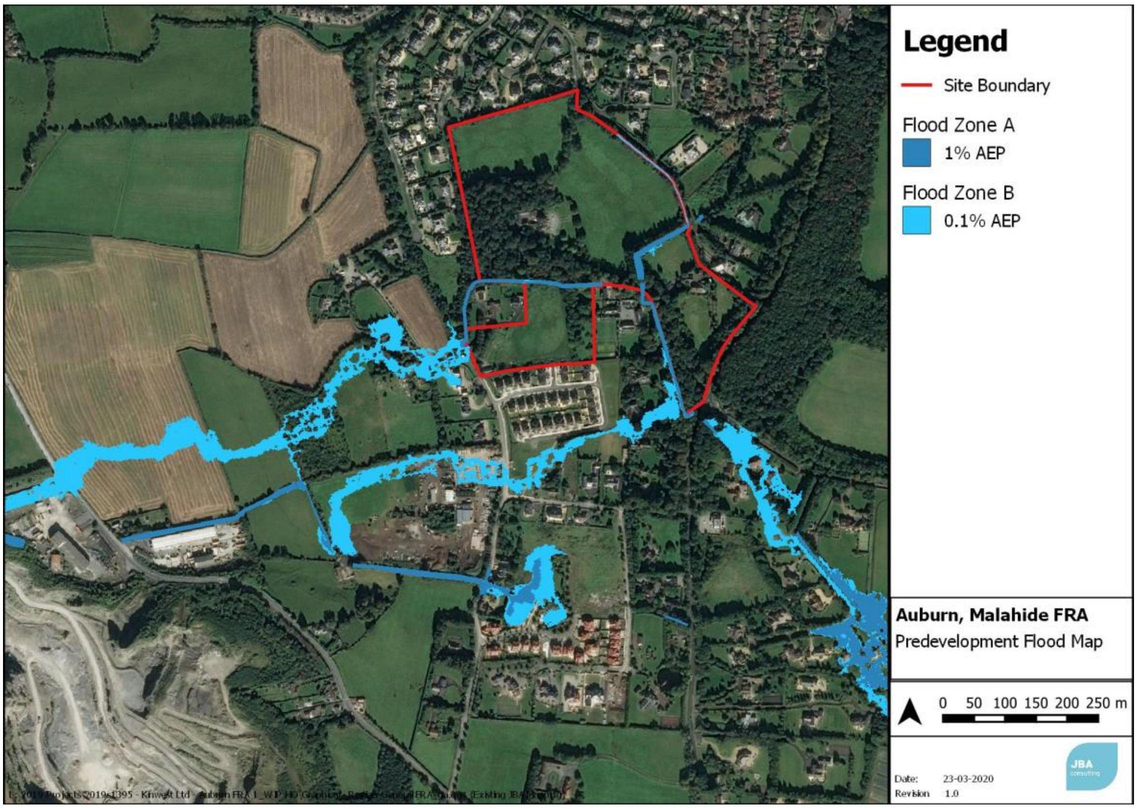
AEP%	HEP_A	HEP_C1	HEP_C2
50%	0.09	0.05	0.03
10%	0.16	0.09	0.05
1%	0.30	0.17	0.10
0.1%	0.53	0.30	0.18

AEP%	HEP_B	HEP_D	HEP_E	HEP_F
50%	0.54	0.12	0.21	0.22
10%	0.96	0.21	0.37	0.40
1%	1.79	0.40	0.70	0.73
0.1%	3.19	0.71	1.24	1.30

12.5 Model Comparison

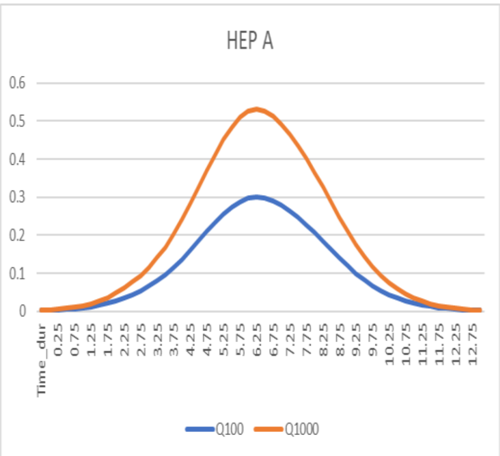
In this section a comparison will be made between the estimated HEP flows and the actual flows modelled. The catchment maps is provided below for reference which provides the location of each HEP. Extracts are provided from the model for each of the HEP's that have been compared to the estimated flows with discussions on the results. For reference, 1% AEP and 0.1% AEP flood extents are provide displaying the overland flow pathways.

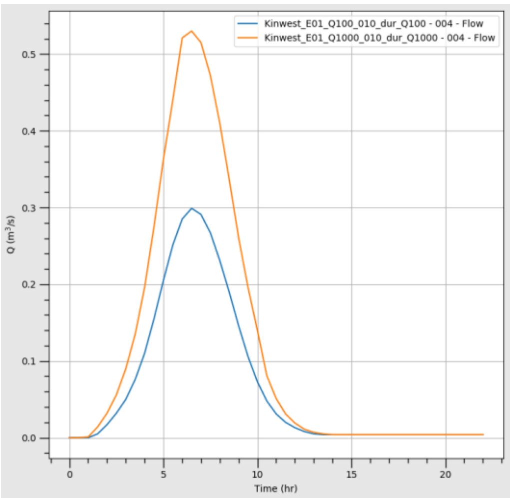




12.5.1 HEP A

This has been applied as a point source at the upstream boundary. Review of the figures below show a good comparison between the inflows data and model application.





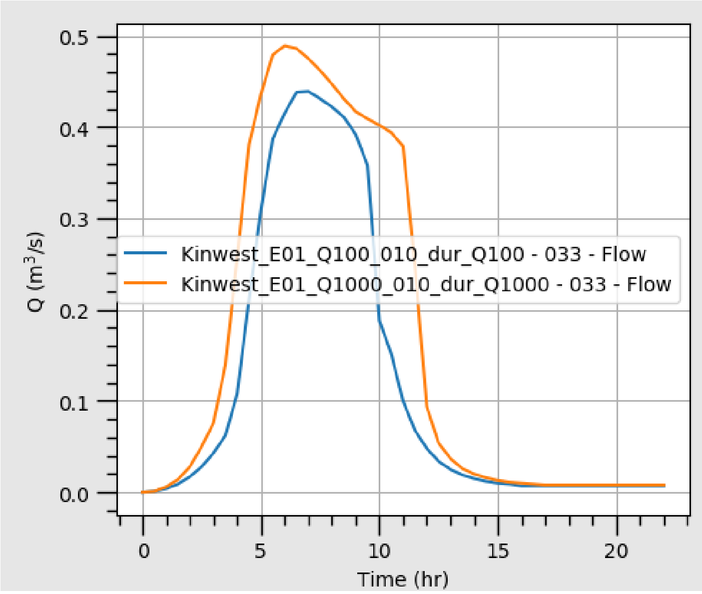
Model Inflow Input

Model Result

12.5.2 HEP D

This HEP is located just downstream of HEP A and has been applied as a lateral inflow. The table below provides the peak flow estimation and the lateral inflow in brackets. The results show a good comparison for 1% AEP event. However, this does not extent to the 0.1% AEP event, with the modelled flows coming in 0.22m3/s below the estimated flows. Likely down to the impacts of the small upstream culverts. During the 0.1% AEP event there is bank overtopping upstream of the culvert that transfers flows to the east towards the site. This does not re-enter this tributary.

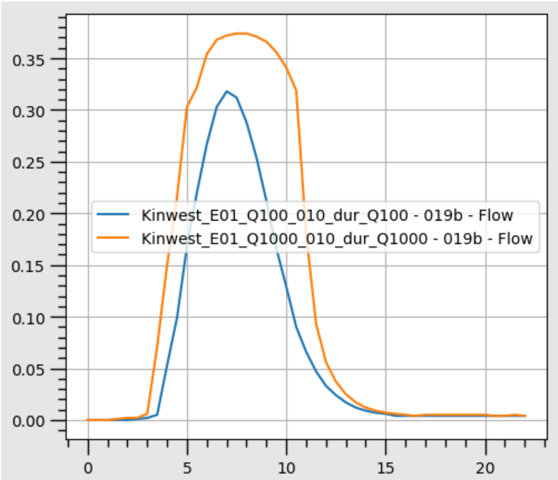
AEP%	HEP_D
1%	0.40 (0.1)
0.1%	0.71 (0.16)



12.5.3 HEP E

This HEP is located just downstream of HEP D and has been applied as a lateral inflow. The table below provides the peak flow estimation and the lateral inflow in brackets. The results not show a good comparison for both the 1% and 0.1% AEP events. The 1% AEP event is approx. 0.4m3/s lower, while the 0.1% AEP event is 0.88m3/s lower

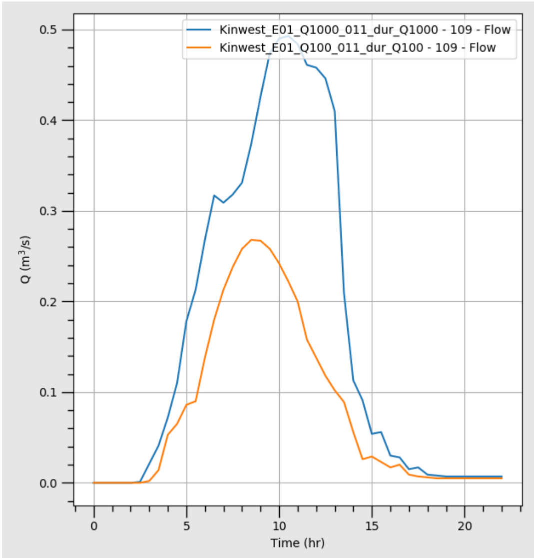
AEP%	HEP_E
1%	0.70
0.1%	1.24



12.5.4 HEP C

This has been applied as two point sources, C1 & C2 at the site. The results have been obtained at the HEP C point downstream of the site. Review of the results show the 1% AEP event as modelled is coming in 0.1m3/s lower than the estimate values while there is a good match for the 0.1% AEP event. The impact is likely down to the culverts onsite that overtop during the 0.1% AEP event.

AEP%	HEP_C
1%	0.37
0.1%	0.48



12.5.5 HEP F

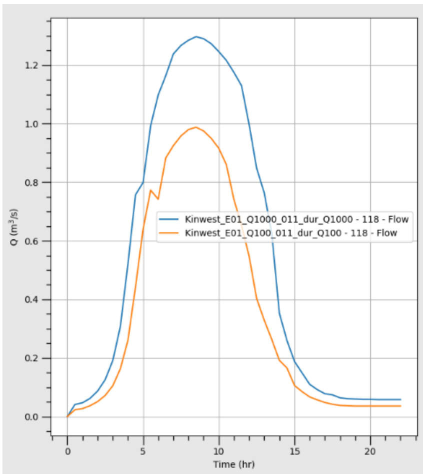
This HEP is located downstream of the site and at juncture of the two tributaries. The estimate peak flows are presented in the table below and the graph provides the modelled flows. Review of the data

shows that the model is showing higher flows (approx. 0.26m3/s) during 1% AEP event while the model is showing a good comparison for the 0.1% AEP event.

Estimated Flows

Modelled Flows

AEP%	HEP_F
1%	0.73
0.1%	1.30



12.5.6 Summary

Regarding the site, HEP A and HEP C are the critical HEP's concerning flood risk at the site. HEP C is applied directly onsite, while at HEP A, there is bank overtopping that flow easterly and enters the stream watercourse at the site. The model is showing a good match for both these HEP's.

Regarding HEP D and E, there is a relatively poor convergences. At HEP D the 1% AEP event there is a match but not for the 0.1% AEP event. This is likely due to the bank overtopping upstream of this HEP during the 0.1% AEP event. There is poor match at HEP E which is likely due to number of culverts in this area.

At the convergence of the two tributaries the model is showing higher flows during the 1% AEP event but a good match for the 0.1% AEP event.

Given the heavily culverted and small catchment areas, there is a satisfactory representation of the flows through the model. The only exception is HEP E but this is located downstream of the site on a separate tributary and does not have an impact on flood levels at the site. On the next adjoining downstream HEP from HEP E, at HEP F the model is showing a good match.

12.5.7 Sensitivity Assessment

A number of sensitivity assessment have been undertaken, which are as follows:

- Storm Duration Increase (20%)
- Mannings Increase (+20%)

The results from the above sensitivity analysis show <5mm increase in flood levels onsite. This is likely down to the location of the site on the upstream reach of a small stream watercourse.

Appendices

A Methods

A.1 The FSU method

The Flood Studies Update (FSU) method to estimate Qmed as described in research reports produced from FSU work packages 2.2 and 2.3, has been used. Qmed can be estimated using a regression equation based on seven different physical catchment descriptors, in conjunction with an urban adjustment, developed in FSU work package 2.3.

The multivariate regression equation was developed on the basis of data from 199 gauged catchments, linking Qmed to a set of catchment descriptors.

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

Where:

- AREA is the catchment area (km2).
- BFIsoils is the base flow index derived from soils data
- SAAR is long-term mean annual rainfall amount in mm
- FARL is the flood attenuation by reservoir and lake
- DRAIND is the drainage density
- S1085 is the slope of the main channel between 10% and 85% of its length measured from the catchment outlet (m/km).
- ARTDRAIN2 is the percentage of the catchment river network included in the Drainage

The urban extent can be taken into account using the following equation:

$$Q_{MEDfinal} = Qmed\,(1 + URBEXT)^{1.482}$$

Where URBEXT is the percentage of the catchment covered by urban land use.

Following the calculation of QMED the calculated adjustment factor and a growth curve are applied to generate the peak flows for AEP events. In this case the growth curve produced by the FSU pooling group for the ungauged catchment has been applied.

The catchment descriptors can be used to determine Qmed. In order to improve on this initial estimate of QMED, the data transfer process can be used. In the terminology of the FSU research reports, the gauging station where the adjustment factor is calculated is referred to as a donor site. An adjustment factor for QMED is calculated as the ratio of the gauged to the ungauged estimate of QMED at the gauging station. This factor is then used to adjust the initial estimate of QMED at the hydrological estimation point.

The growth factors for this site are also calculated from the FSU using pooling groups.

For pooled analysis within the FSU, gauges are chosen on the basis of their similarity with the subject catchment according to three catchment descriptors, i.e. AREA, SAAR and BFIsoil. The report on FSU WP 2.2 presents two alternative equations for calculating the similarity of catchments according to these three descriptors. For this study, equal weight was given to each of these variables, applying the similarity distance formula given as Equation 10.2 in the report on FSU WP 2.2.

Not all gauges in Ireland were considered for use in pooling, because the analysis required to fit a flood growth curve makes use of the magnitude of each annual maximum flow, and thus it is necessary that even the highest flows are reliably measured. This excludes gauges where there is significant uncertainty in the high flow rating.

Although there is some evidence from research on UK data that flood growth curves are affected by additional catchment descriptors such as FARL, the FSU research found that FARL was not a useful variable for selection of pooling groups (uncertainty was greater when FARL was included than when it was excluded) and therefore no attempt was made to allow for the presence of lakes in the composition of pooling groups. Similarly, no allowance was made for arterial drainage in selecting pooling groups.

For pooled growth curves, WP 2.2 recommends considering 3-parameter distributions, because the extra data provided by the pooling group ensures that the standard error is lower than it would be for single-site analysis. The report states that either the generalised extreme value (GEV) or generalised logistic (GL) distributions are worth considering. For this study, GEV has been fitted for the pooled analysis.

A.2 The FSU Small Catchments Method

The FSU small catchments method was created as part of FSU working package 4 and is discussed in 'Work Package 4.2 - Flood Estimation in Small and Urbanised Catchments'.

The FSU small catchment equation is a 5 variable regression equation that was developed after the examination of multiple small catchments equations and regression analysis of multiple catchment descriptors. The FSU small catchment equation for QMED is:

$$Qmed = (2.0951*10^{-5})*(AREA^{0.9245})*(SAAR^{1.2695})*(BFI^{-0.9030})*(FARL^{2.3163})*(S1085^{0.2513})$$

Where:

- AREA is the catchment area (km2)
- SAAR is long-term mean annual rainfall amount in mm
- BFISoil is the base flow within the catchment soil
- FARL is the percentage of the catchment covered by lakes or reservoirs
- S1085 is the slope of the main channel between 10% and 85% of its length measured from the catchment outlet (m/km)

The urban extent can be taken into account using the same method as above for the FSU standard method.

A.3 FSR Rainfall-Runoff

The FSR Statistical method is widely used in Ireland and the UK for ungauged catchments is the FSR triangular unit hydrograph and design storm method. This method estimates the design flood hydrograph, describing the timing and magnitude of flood peak and flood volume (area beneath hydrograph). This method requires the catchment response characteristics (time to peak, tp), design rainstorm characteristics (return period, storm duration, rainfall depth and profile) and runoff / loss characteristics (percentage runoff and baseflow).

The UK Natural Environmental Research Council (1975) carried out a comprehensive flood study involving a large number of catchments from throughout Britain including many Irish catchments. The unit hydrograph prediction equation was derived from 1,631 events from 143 gauged catchments (the hydrograph method only included one Irish catchment) ranging in size from 3.5 to 500km2. The result was a triangular Unit Hydrograph described by the time to peak Tp of the catchment derived from catchment characteristics. The instantaneous triangular unit hydrograph is defined by a time to peak Tp, a peak flow in cumecs/100km2 Qp = 220/Tp and a base length TB = 2.52Tp.

The FSR rainfall-runoff method relies on rainfall frequency statistics to provide inputs to a model that converts rainfall to runoff. The rainfall-runoff model separates a flood hydrograph into a baseflow component and a rapid runoff component. The rapid runoff is found by estimating the component of rainfall that contributes to runoff (the effective rainfall) and converting the effective rainfall to flow by use of a unit hydrograph. The unit hydrograph describes the theoretical response of the catchment to an input of a unit depth of rainfall over a unit of time.

The steps in the model are:

- Determine the parameters of the unit hydrograph, either from flood event data or from catchment characteristics;
- Determine the percentage runoff to convert total rainfall to effective rainfall;
- Construct the design storm by determining its duration, depth and profile;

- Combine the effective rainfall profile with the unit hydrograph by convolution to give the flood hydrograph;
- Add baseflow to the flood hydrograph

A.4 IH124

The IH 124 Report examined the response of small catchments, less than 25km2, to rainfall and derived an improved flood estimation equation (Marshall & Bayliss, 1994). A total of 87 sites were used to develop the method. The report developed a new equation to estimate the mean annual flood, QBAR (in m3/s), for small rural and urban catchments.

QBARrural = 0.00108 $AREA^{0.89}$ $SAAR^{1.17}$ $SOIL^{2.17}$ and

QBARurban = QBARrural $(1 + URBAN)^{2NC}$ [1 +URBAN{(21/CIND) - 0.31]

Where: NC is "rainfall continenality factor".
NC = 0.92 – 0.00024SAAR, for 500 _ SAAR _ 1100mm,
NC = 0.74 – 0.000082SAAR, for 1100 _ SAAR _ 3000mm, and
CIND is a catchment index defined as a function of SOIL and catchment wetness index (CWI), both as in FSR (1975)

The estimated QBAR is then multiplied by the growth factors derived by the FSR to estimate design flows for specified return periods. For example, QBAR is multiplied by 1.96 to get the 100-year peak flow.

The FSR method uses a regional growth curve for estimating design event peak flows.

Table 12-1: FSR Regional Growth Curve for Ireland

Annual Exceedance Probability (%)	Growth curve
50% (2yr)	0.95
20% (5yr)	1.20
10% (10yr)	1.37
5% (20yr)	1.54
2% (50yr)	1.77
1% (100yr)	1.96
0.1% (1000yr)	2.60