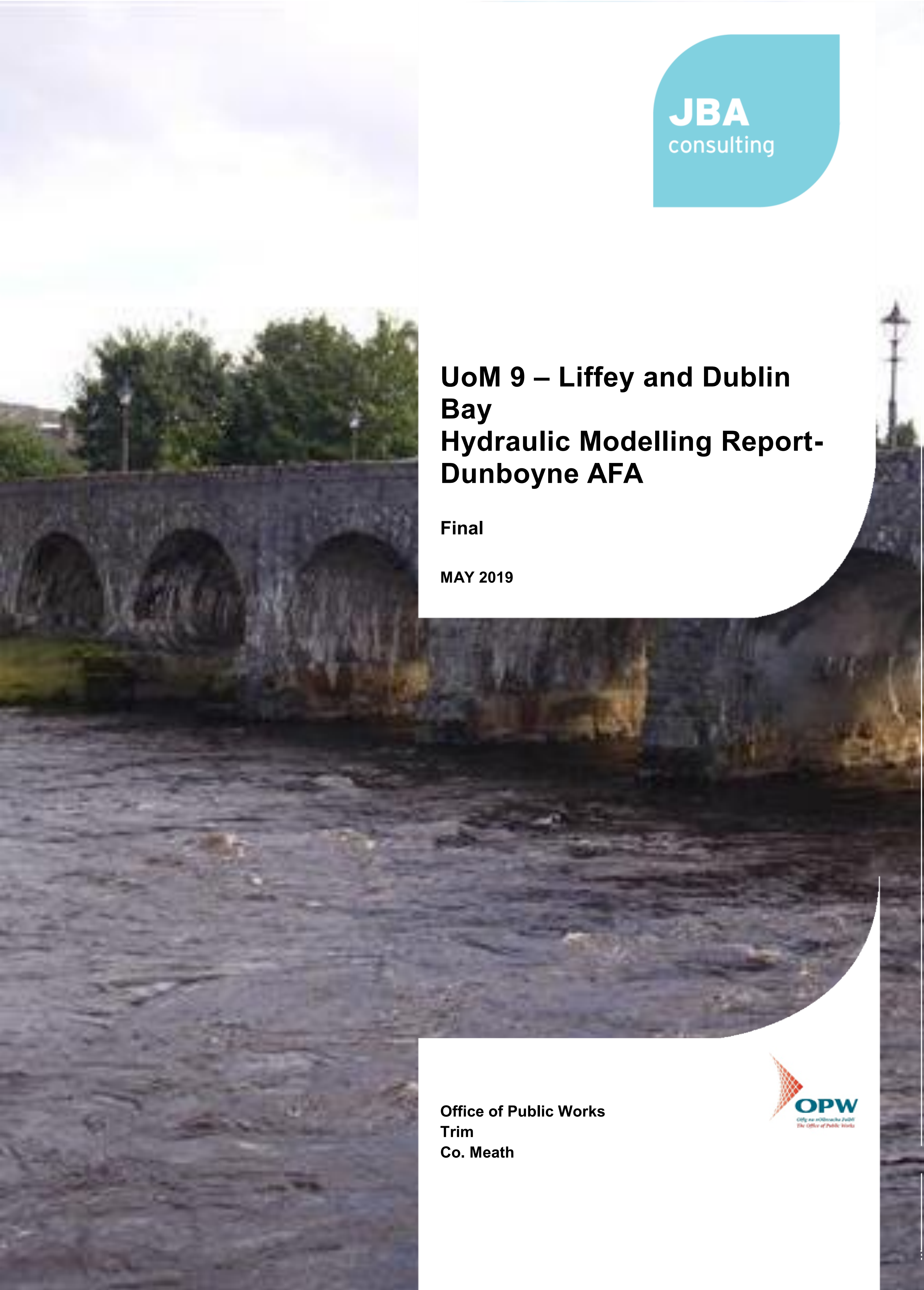

JBA consulting

UoM 9 – Liffey and Dublin Bay Hydraulic Modelling Report- Dunboyne AFA

Final

MAY 2019

Office of Public Works
Trim
Co. Meath

OPW
Oifig na nOibreacha Poiblí
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Revision History

Revision ref / Date issued	Amendments	Issued to
Version 1 / 15 May 2018		Gavin Poole, OPW.
Version 2 / February 2019		Gavin Poole, OPW
Version 3 / March 2019	Minor edits	Gavin Poole, OPW
Version 4 / April 2019	Minor edits	Gavin Poole, OPW
Version 5 / May 2019	FINAL	Gavin Poole, OPW

Contract

This report describes work commissioned by the Office of Public Works, by an email dated (07/11/2017). The Office of Public Works' representative for the contract was Gavin Poole. Joanne Cullinane and Tim Cooke of JBA Consulting carried out this work.

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Purpose

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Abbreviations

AEP................................ Annual exceedence probability
AFA .... Area for further assessment
AMAX............................. Annual maximum
CFRAM .... Catchment flood risk assessment and management
DAD .... Defence asset database
DAS................................ Defence asset survey
DEM .... Digital elevation model (Includes surfaces of structures, vegetation)
DTM .... Digital terrain model (‘bare earth’ model)
ESTRY .... One-dimensional model from the TUFLOW suite
FRISM .... Flood risk metrics (a flood risk tool developed by JBA)
FRMP............................. Flood risk management plan
FRR................................ Flood risk review
FSR .... Flood studies report
FSU .... Flood studies update
GIS................................. Geographical information system
HEFS .... High-end future scenario
HEP................................ Hydrological estimation point
HPW............................... High priority watercourse
HWA............................... Hydrograph width analysis
IBIDEM........................... Interactive bridge invoking the design event method
ICPSS .... Irish coastal protection strategy study
ISIS .... One-dimensional hydraulic modelling software
LA................................... Local authority
LIDAR .... Light detection and ranging
mOD............................... Metres above Ordnance datum (Malin datum)
MPW .... Medium priority watercourse
MRFS............................. Mid-range future scenario
NDHM .... National digital height model (a DTM by Intermap)
OSi .... Ordnance Survey Ireland
PFRA .... Preliminary flood risk assessment
Q(T)................................ Flow for a given return period
QMED .... Median annual flood, used in FSU methods
SAAR .... Standard annual average rainfall
SoP .... Standard of protection (in relation to flood defences)
Tp................................... Time to peak
TUFLOW......................... Two-dimensional hydraulic modelling software
UoM .... Unit of Management

* Asterisks at the end of a cross section label denotes interpolated model cross sections

1 Introduction

1.1 Study Background

The national Catchment Flood Risk Assessment and Management (CFRAM) programme commenced in Ireland in 2011. The intention of this programme was to provide a medium to long-term strategy for the identification and management of flood risk in Ireland. Dunboyne was identified as an Area for Further Assessment (AFA), but due to the existence of a previous study, the region was not originally commissioned for progression to hydraulic modelling. Subsequently, due to the significant changes in the catchment since the previous study, this study has now assessed the Dunboyne River and Castle Stream, both of which have been identified as High Priority Watercourse (HPW) for inclusion into the CFRAM AFA deliverables of mapping. This report is a standalone document concluding the modelling undertaken and conclusions reached.

1.2 Scope of report

This report summarises the hydraulic modelling work for the Dunboyne Area for Further Assessment (AFA) High Priority Watercourse (HPW) hydraulic model.

The report covers the overall hydraulic modelling process from model build through to the development of design runs with the aim of providing a detailed understanding of the hydraulic controls and flood mechanisms identified throughout the study.

The report is not a user manual for the hydraulic model itself, full details of which are provided in the model handover check files accompanying the hydraulic model.

1.3 Model and report overview

The Dunboyne AFA catchment consists of two large modelled watercourses, the Tolka River and the Castle Stream. A number of small tributaries join these watercourses throughout the AFA which have also been modelled, including the Clonee Stream. All watercourses have been included in the same linked 1D-2D Estry-Tuflow model.

The River Tolka had a history of flooding following heavy rainfall, which has been well documented after major flooding events in 1954, 1986, 2000 and 2002. Between 2002-2013 the Tolka Flood Relief Scheme was constructed which provides significant protection to areas of Dunboyne Town.

1.4 Watercourse and catchment overview

The River Tolka is the main watercourse in the area, which flows in a north-westerly to south-easterly direction, running on the western side of the M3 motorway. From Dunboyne, the River Tolka flows through western and northern Dublin City before discharging into Dublin Bay. The Tolka, and its tributaries can be seen in Figure 1-1. Upstream of the M3 Parkway two branches of the Tolka combine and are joined by a smaller tributary.

The key hydraulic structures on this watercourse are a local access road culvert (R157), three railway crossings, Navan Road Bridge and two culverts under the R147. Upstream of the confluence with the Castle Stream is the Loughsallagh Bridge, that conveys the Tolka under the Dublin Road. Point source inflows at the upstream extents of the model were placed upstream of structures, so that any constriction on flows is represented in the model prior to flow entering Dunboyne. The Tolka catchment upstream of the confluence with the Castle is mainly rural, with some rural properties.

Downstream of Loughsallagh Bridge the Tolka is joined by the Castle Stream. Prior to the construction of the Tolka Flood Relief Scheme (completed in 2009), the Castle Stream was the main source of flood risk in the town. The Castle Stream flows in a west to east direction through Dunboyne. The key hydraulic structures on this reach of watercourse are the Newtown Bridge, Maynooth Road Bridge, Rooske Bridge and a railway bridge.

The Castle Stream and River Tolka combine downstream of Dunboyne but upstream of Clonee. In this reach there is a history of significant out of bank flooding with formalised defences built as part of the Tolka Flood Relief Scheme. Clonee Bridge and the M3 culvert are key hydraulic structures along this reach. All significant hydraulic structures and modelled reaches are shown in Figure 1-2.

Figure 1-1: Catchment Overview

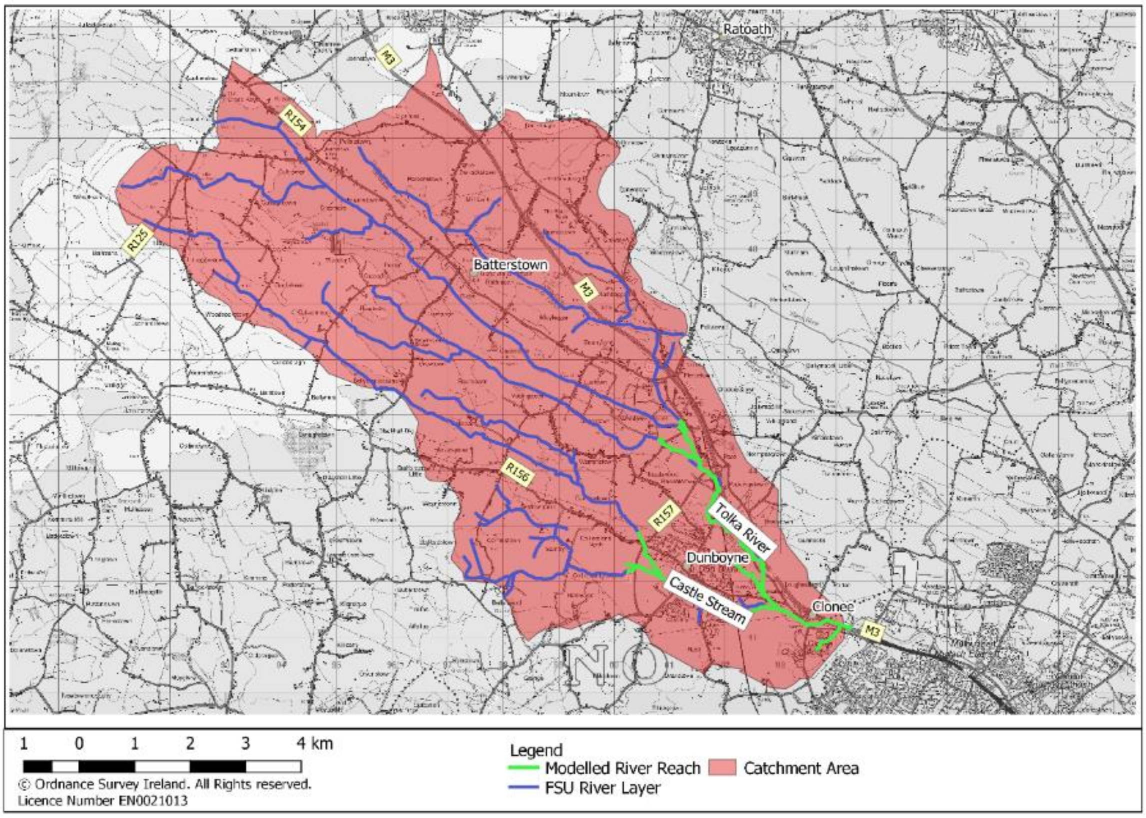
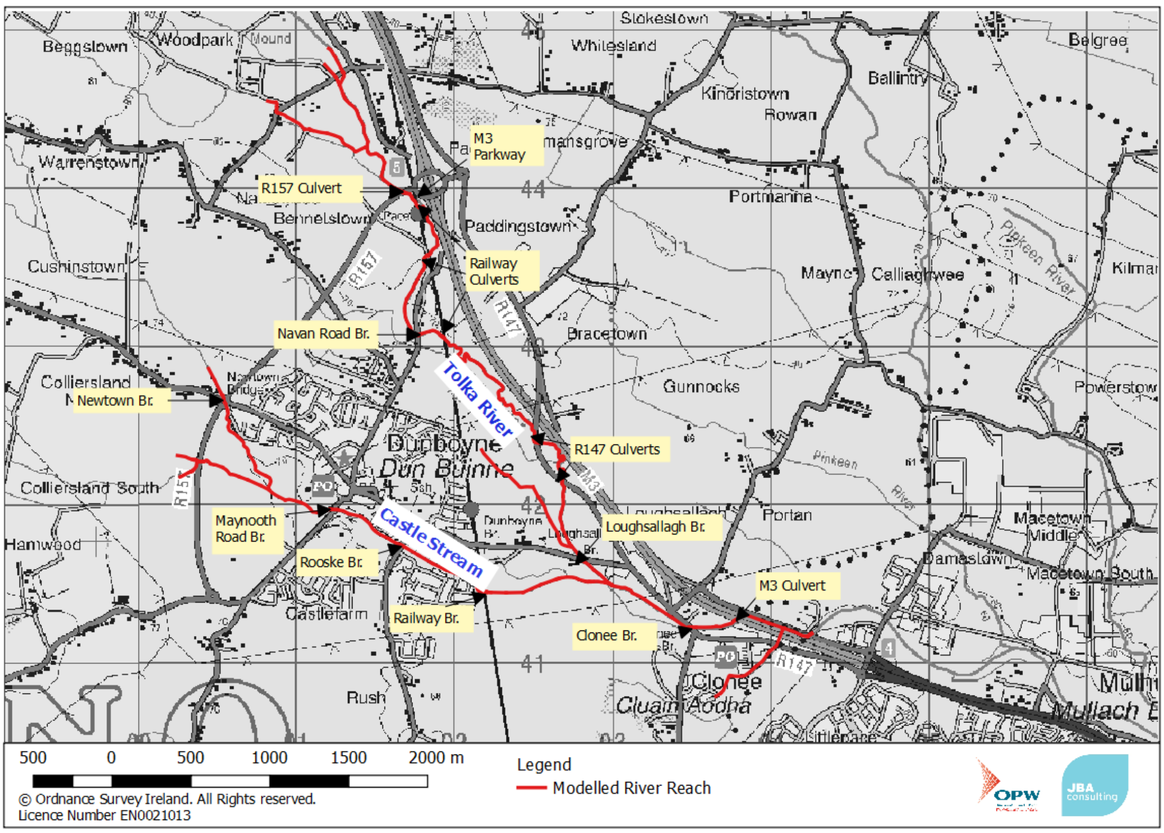


Figure 1-2: Dunboyne Local Area



1.5 Available data

1.5.1 Survey data

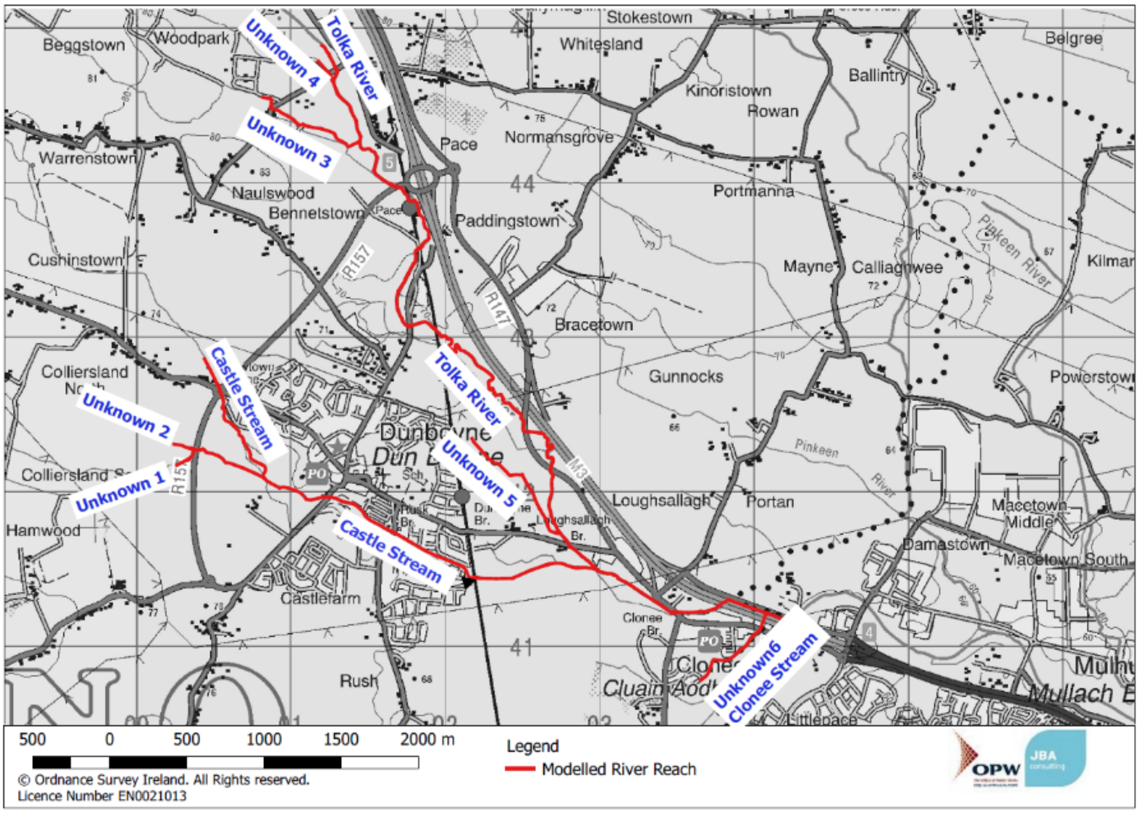
Due to the construction of the Tolka Flood Relief Scheme it was necessary to obtain new up to date cross-sectional data. Cross sectional survey was collected by Cyient / Six-West between July and October 2017 and was delivered in December 2017.

The abbreviated version of each watercourse name as represented in the hydraulic models are detailed in Table 1-1 and are shown in Figure 1-3.

Table 1-1: Abbreviated watercourse names

Reference	Description
TOLK	River Tolka
CAST	Castle Stream
UNK 1	Unnamed Tributary
UNK 2	Unnamed Tributary
UNK 3	Unnamed Tributary
UNK 4	Unnamed Tributary
UNK 5	Unnamed Tributary
UNK 6	Clonee Stream

Figure 1-3: Modelled Watercourses



LIDAR data has been commissioned by the OPW for use in the model. Data has been provided in both its filtered formats in a 2m grid resolution. The LIDAR was flown between November 2011 and February 2012.

A comparison of LIDAR levels against the surveyed cross sections was completed as part of the survey review process. This compared spot levels collected on roads or in open spaces and found an average difference between the two of 0.065m, therefore no adjustment to the LIDAR was required to match the survey data.

1.5.2 Hydrometric data

A summary of hydrometric data within the AFA is provided in Table 1-2.

Table 1-2: Hydrometric gauging stations in the vicinity of the AFA

Gauge reference	Type	Use in calibration
09003 - Clonee	Inactive flow site. Spot flow levels only.	Due to the construction of the Tolka Scheme it is not be possible use the Clonee gauge to calibrate the model given the in-channel changes that occurred during the scheme and the record ceasing in 1991

2 Flood history

2.1 Flood history

The River Tolka has a long history of flooding, reflected in the fact that it's Gaelic name "An Tulca" means The Flood. Significant flood events occurred in November 2000, 1954 and 1880 after long periods of prolonged rainfall.

Prior to November 2000, the 1954 and 1880 were the two major floods on record. The flood of 6th November 2000 was an event of similar magnitude to the historical events of 1954 and 1880.

However, the largest flood event on record is the November 2002 flood. The flood of 15th November, 2002, followed two days of very heavy rainfall. A previous rainfall event on 8th-10th November had resulted in a very wet antecedent conditions; combined with winter vegetation conditions this resulted in little, if any infiltration/soakage into the ground and high levels of runoff.

Significant over-land flooding occurred within this reach affecting low-lying areas of Dunboyne, flooding a large number of residential properties and impacting on the village itself. The floodplain mapping for the 2002 flood for the area by RPS (see Section 2,2) is based on substantial flood level records and anecdotal evidence of areas inundated. Figure 2-1, Figure 2-2 and Figure 2-3 illustrates predicted flood extents from this study at key locations within the AFA. It shows significant inundation of residential areas in both Dunboyne and Clonee. The flood mapping demonstrates that the N3 culvert provided a large restriction to flow. The flood resulted in inundation of the properties in the floodplain at Dunboyne, including flooding of Dunboyne village area directly from the Castle stream, with the combined Tolka River and Castle Stream flows inundating Clonee village.

Figure 2-1: Flooding of Dunboyne Village Commercial area (source River Tolka Flooding Study - Final Report)

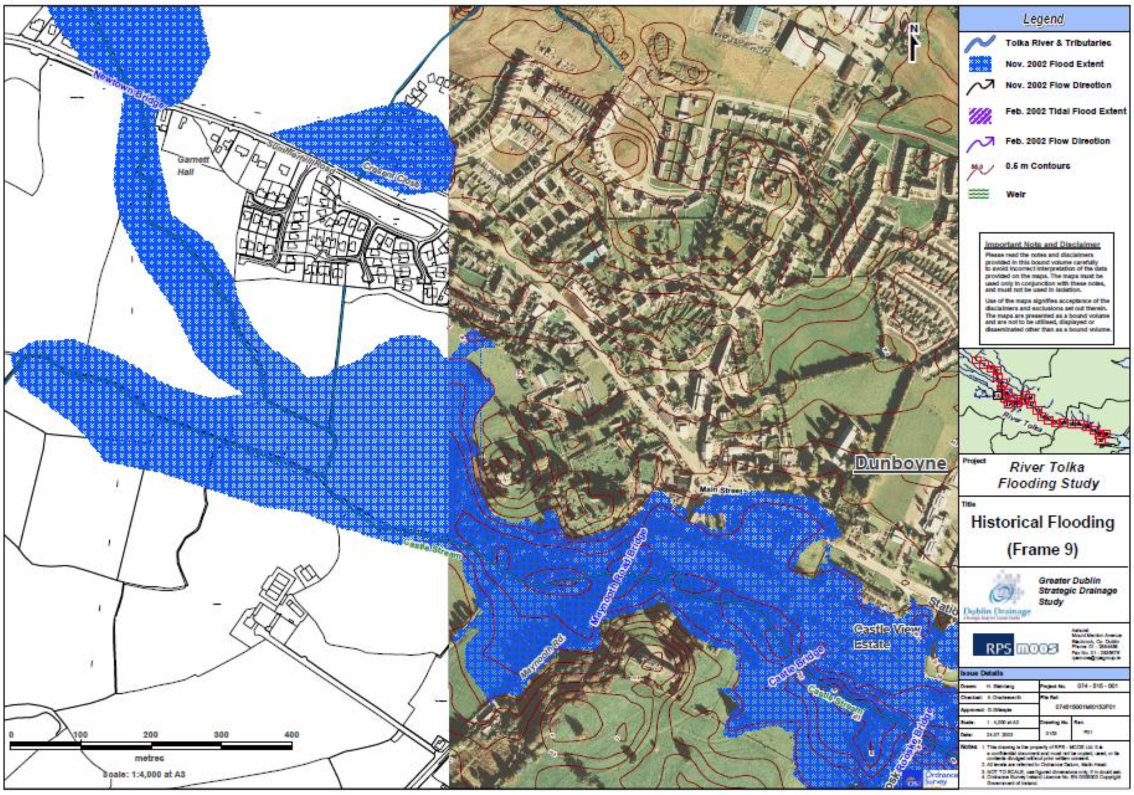


Figure 2-2: Dunboyne East – Clonee area (source River Tolka Flooding Study - Final Report)

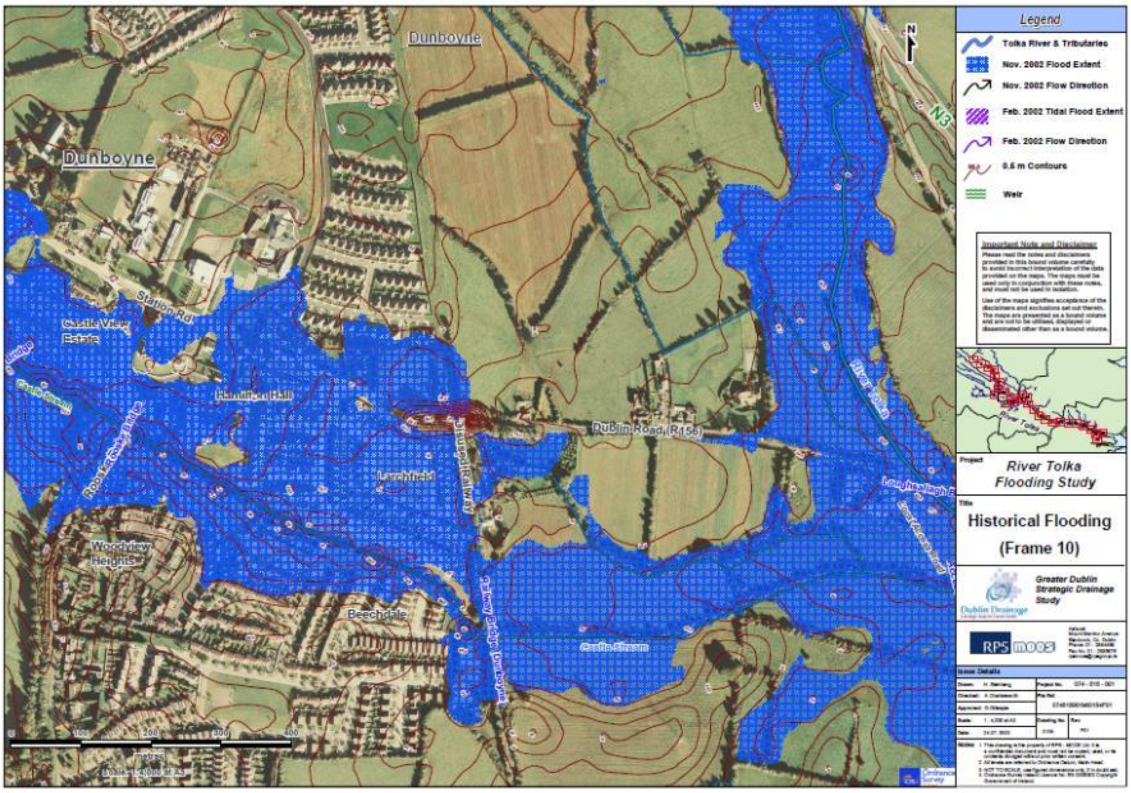
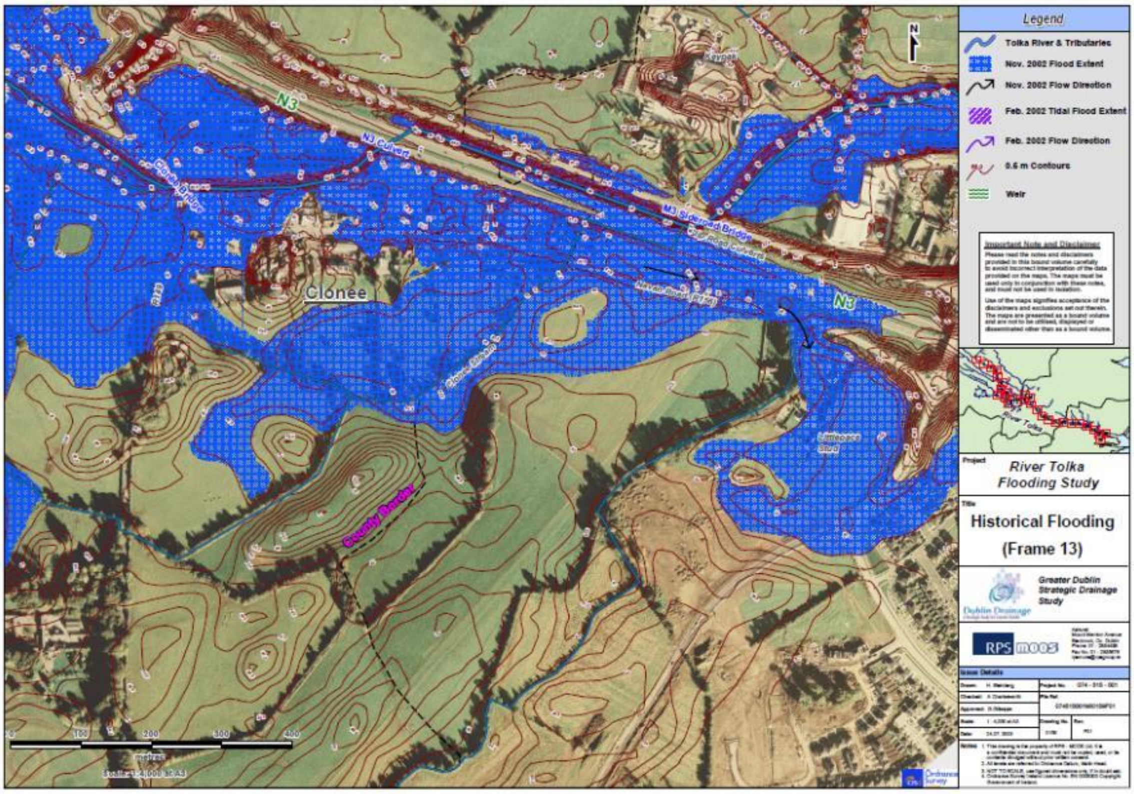


Figure 2-3: Clonee Area (source River Tolka Flooding Study - Final Report)



2.2 Tolka Flood Relief Scheme

In 2002, following the significant flood in November 2000, Dublin City Council commissioned the "River Tolka Flooding Study", in association with Fingal County Council, Meath County Council and the Office of Public Works. The study was carried out by M.C. O'Sullivan & Co. Ltd. (MCOS), now RPS Consulting Engineers.

Following on from the River Tolka Flooding Study, approximately 7km of flood walls and embankments were constructed between 2003 and 2009 in Dublin City, Fingal, and Meath.

The works carried out in the Dunboyne area included:

- Road Bridge replacement and repairs,
- Railway Bridge underpinning
- Stream upgrade
- Embankments and Walls
- General channel maintenance

The flood event of November 2002 occurred during the Study and this event was estimated to be within the range of a 1% AEP event in Dunboyne. The mapping output from the hydraulic modelling for the River Tolka Flooding Study was well matched to the flood extents observed during this flood event.

The works carried out since 2003 have significantly altered the flow regime in the area and since the Scheme was completed there have been no reports of flooding from the River Tolka in these areas.

The construction of the M3 motorway also altered the topography of the area and a section of river channel was realigned to run parallel with the new motorway and the R156 near Clonee.

3 Hydraulic modelling

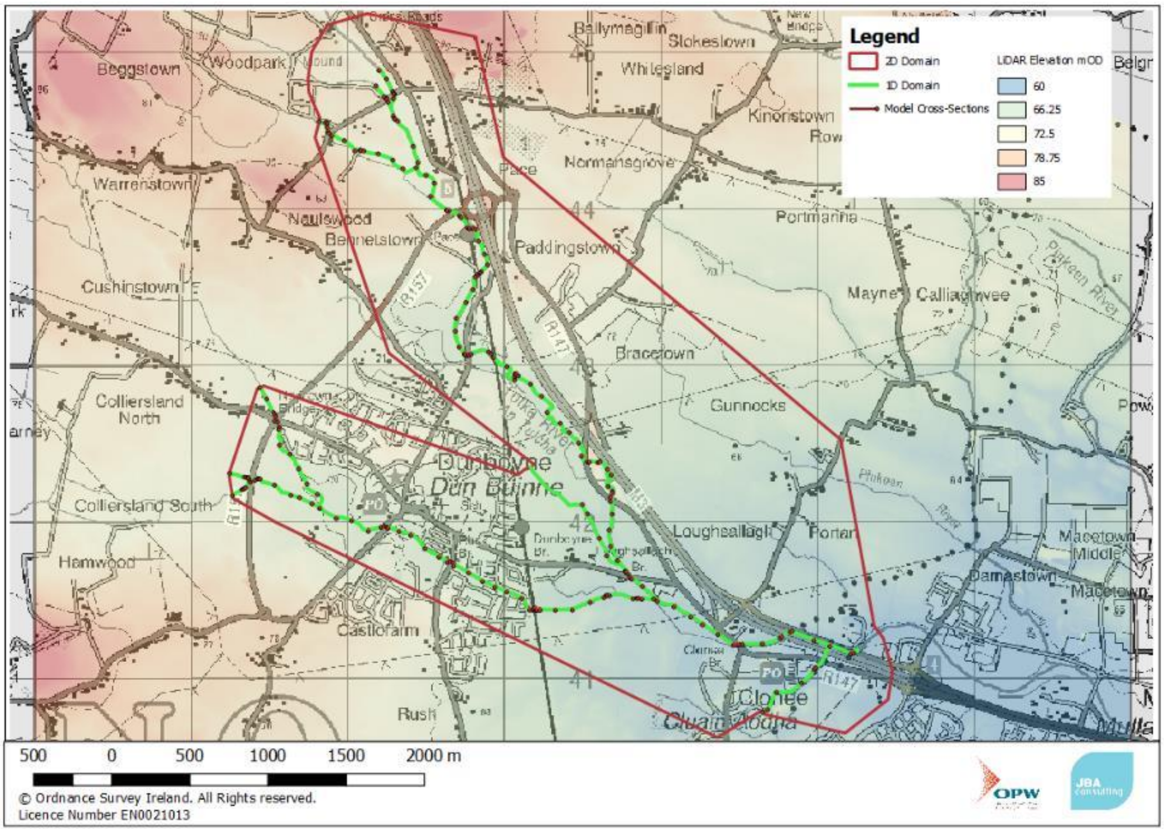
3.1 Context

To provide robust information on the nature of flood risk from the watercourses through Dunboyne a model was built to enable the simulation of fluvial events of different magnitude. An ESTRY-TUFLOW model was built for the reach. The purpose of this section is to describe the modelling approach and the key hydraulic structures.

3.2 Model schematisation and domain

Figure 3-1 shows an overview of the model schematisation. The overview covers the model extents (1D and 2D domain), underlying LiDAR elevations, surveyed cross-sections and modelled river centre line.

Figure 3-1: Model Schematisation



3.3 Key hydraulic structures

There are a considerable number of structures including bridges, multi-span arched bridges and culverts within the Dunboyne AFA model. Key hydraulic structures which dictate water levels and flow routes in the vicinity of key flood risk areas are identified in Figure 1-2 and are summarised in Table 3-1. Further information for additional structures are provided in the hydraulic model check file technical document accompanying delivery of the final model.

Table 3-1: Key hydraulic structures

Structure Name	Description	Photograph
Local Access Road (R157) at M3 parkway (09TOLK22868)	Modelled as a two regular box culverts. Significant scour immediately downstream causing supercritical flow in low flows.	
First railway crossing located adjacent to M3 and M3 Parkway (09TOLK22687)	Modelled as two Irregular culverts. Significant channel vegetation growth.	
Railway crossing and local access bridge immediately downstream (09TOLK22302)	The bridges are located approximately 2m apart. Both bridges restrict flow through them and cause a backwater effect upstream. This results in out of bank flooding upstream.	
Navan Road Bridge - (09TOLK21731I)	This bridge was upgraded as part of the construction of the M3 motorway and replaces a former structure. The height of the parapet means the structure is unlikely to be bypassed.	

Structure Name	Description	Photograph
Railway Culvert	Twin Box Culvert that restricts flow with a headloss of 150mm across the structure. This leads to out of bank flooding on the right bank upstream.	
Loughsallagh Bridge 09TOLK19341D	Previous structure replaced as part of the Tolka Flood Relief scheme, along with embankments on the left and right bank. There is now no modelled flooding caused by this culvert and it is a significant contributing factor to alleviating flood risk in this area.	
Clonee Bridge 09TOLK18502	A multi-span arch bridge with a headloss of 150mm across the bridge in the 1% AEP event. Results in flooding of the floodplain (agricultural land) upstream of the bridge. Key receptors protected by effective flood defences in the form of earthen embankments.	

Structure Name	Description	Photograph
M3 Culvert – 09TOLK18200	Previously the N3 culvert caused a significant afflux and flooding of the Clonee area. This has been replaced by three rectangular culverts. Out of bank flooding occurs immediately upstream of the culvert however is contained within flood defences for the 1% AEP event.	
Clonee Stream M3 Culvert - 09UKN60000	Located in the built up area of Clonee. Upstream reach of the channel is heavily overgrown and significant risk of blockage. Significant culvert length and potential flood risk of properties in the vicinity if becomes blocked.	
Maynooth Road Bridge – 09CAST01911	Upgraded as part of the Tolka Flood Relief scheme and has now the capacity to convey the 0.1% AEP flow. Some out of bank flooding upstream due to low-lying banks.	

Structure Name	Description	Photograph
Rooske Bridge - CAST01438D	Upgraded as part of the Tolka Flood Relief scheme and has now the capacity to convey 0.1% AEP flow.	
Railway and local access bridge - 09CAST0079	Railway bridge with a local bridge immediately downstream. Large parapet on railway bridge and steep banks so bypassing unlikely. Land access bridge replaced as part of the Tolka Flood Relief Scheme.	

3.4 Hydraulic roughness

The hydraulic roughness within the 1D model has been appraised over three panels across the channel as follows:

- Left bank – from left bank top (or end of model left bank section) to a typical water level
- Channel bed – typically inundated part of cross section
- Right bank – from right bank top (or end of model right bank section) to a typical water level

The determination of initial suitable hydraulic roughness values for each watercourse was based upon a combination of survey photographs, notes on survey drawings and observations from site visits. The majority of critical storms are expected to be winter storm and high roughness values based on summer vegetation in these instances are not considered to be appropriate. The assessment has therefore focused on the more permanent vegetation on banks, e.g. bushes and trees, when determining values. The typical Manning's 'n' values applied to the 1D channel are shown in Table 3-2.

Manning's 'n' values were applied as follows:

Table 3-2: 1D channel Manning's 'n'

Channel Type	Manning's 'n' value
In-channel	0.04
Grassy banks	0.04
Long Weeds	0.045
Dense Scrub	0.05
Bushes	0.06
Trees – flood level not reaching branches	0.07
Trees – flood level reaching branches	0.15

3.5 1D-2D boundary

The hydraulic boundary between the 1D and 2D models has been situated along the crest of the river banks. Crest levels, and hence the point at which water transfers from the 1D to the 2D domain have been determined in one of three ways. In order of accuracy (and therefore preference) these are:

- Surveyed top of bank levels.
- Linear interpolation between surveyed cross sections – where cross sections were at sufficiently close intervals and crest level is relatively consistent between cross sections.
- Extraction of bank heights from LIDAR data - where there are data gaps between cross sections and the LIDAR data gives sufficient detail to determine bank crest elevation.

3.6 Defences and walls

3.6.1 Defences

Raised structures adjacent to watercourses will play a significant part in determining if the land behind these structures is shown as at flood risk in the final flood maps. Removing these structures when, in reality, they prevent flooding would overestimate flood risk and reduce public confidence in the quality of the flood maps produced. Conversely, including structures when they are not constructed to a sufficient standard to withstand elevated water levels would result in a false sense of security amongst residents, and result in them being underprepared and at greater risk should the structure fail.

In Dunboyne there are a number of formal flood defences that have been constructed as part of the Tolka Flood Relief Scheme and have been included as effective defences in the hydraulic model.

'Effective' structures are continuous and tie into high ground or other defences. Failure of these structures occurs via overtopping or in the event of a breach. Within the hydraulic model these structures have been represented as surveyed, i.e. the crest level of the defence has been included in the model. These structures have been removed for the purposes of the defended area and flood zone mapping. The locations of these flood defences is shown in Figure 3-2 and Figure 3-3 below.

Figure 3-2: Navan Road Embankment

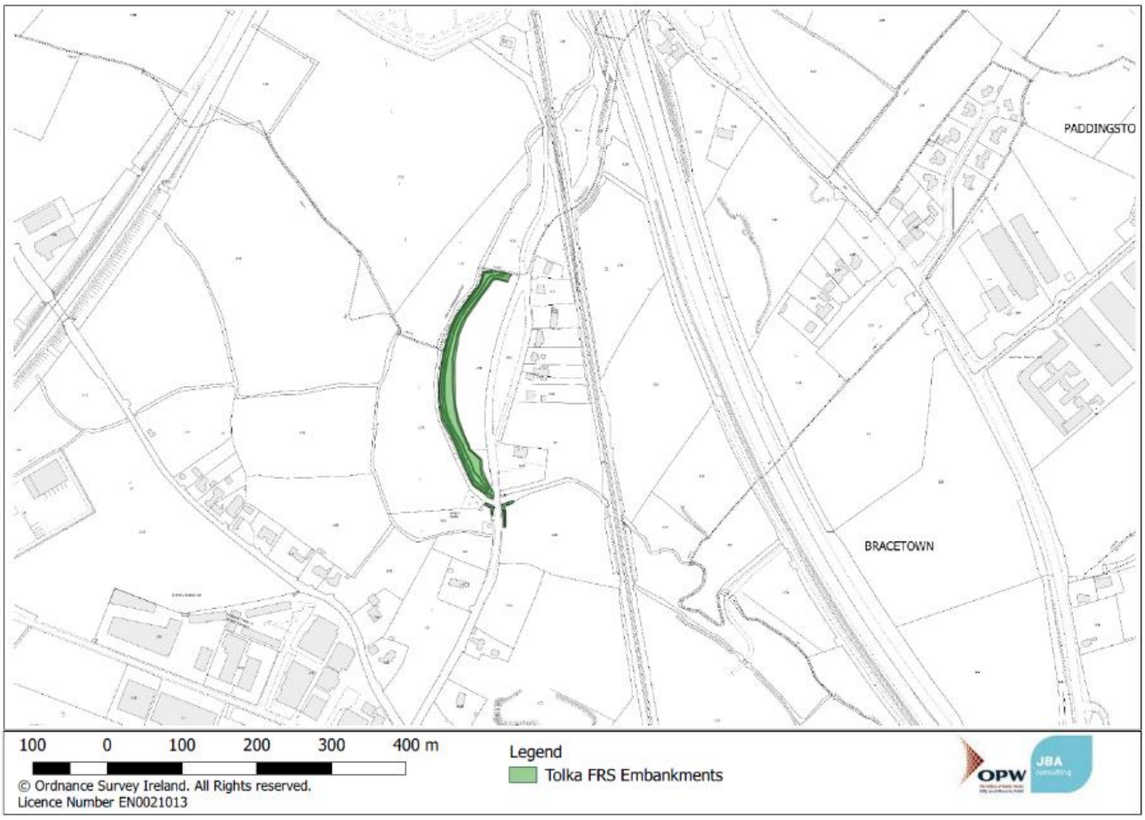
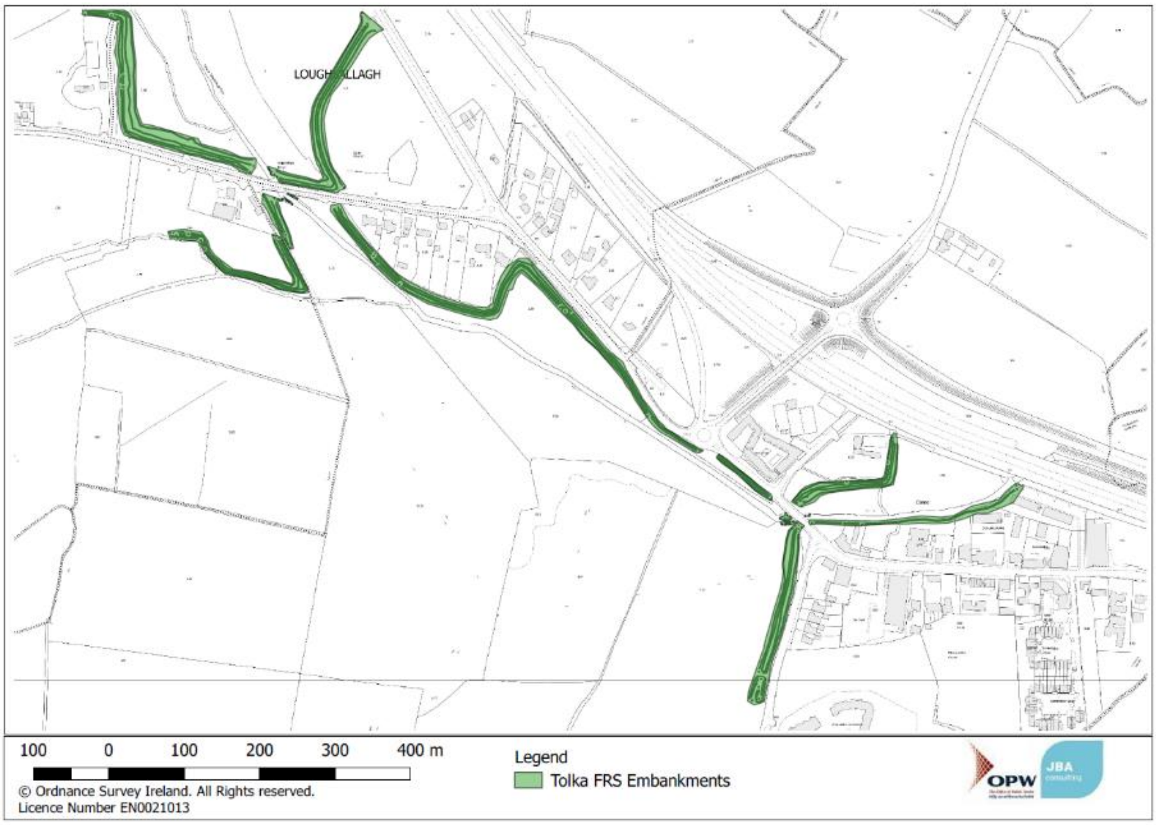


Figure 3-3: Loughsallagh Bridge and Clonee Embankments



3.7 Floodplain

3.7.1 Cellsize

The 2D model floodplain is represented as a ground level grid and has been constructed from the filtered LIDAR data. An appropriate grid resolution of 4m has been determined considering the size of the watercourse, floodplain complexity and model run times. This is reflective of the wide, hydraulically uncomplicated floodplain and large model domain which would otherwise take a long time to run. As a cell size greater than 2m (OPW default standard) has been used, and there is the potential for complex flow paths to develop, the implications have been considered as part of the sensitivity testing. (See Section 7).

To allow flow under the M3, any culverts picked up in the river survey have been incorporated in the model as a 1D ESTRY unit into the 2D-domain. Four culverts were identified, with their locations shown within Figure 3-4

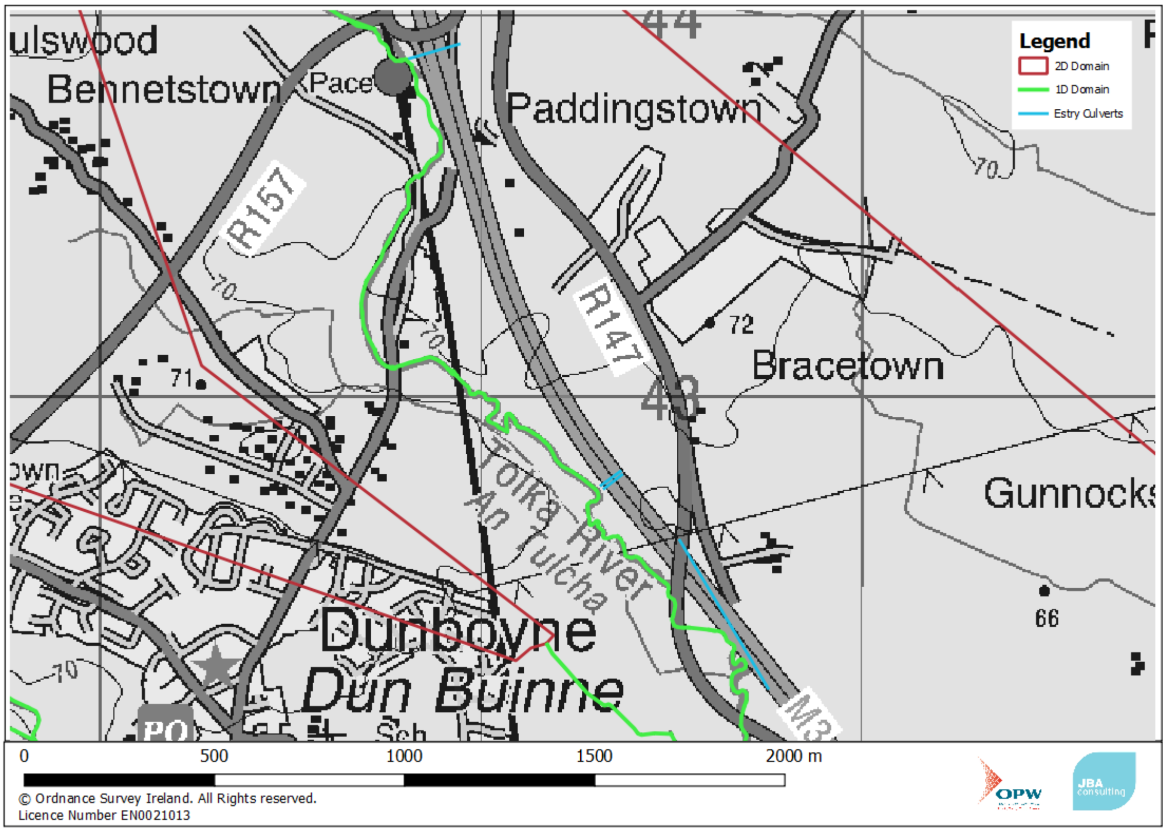


Figure 3-4 Locations of 1D Estry Culverts under the M3 Motorway

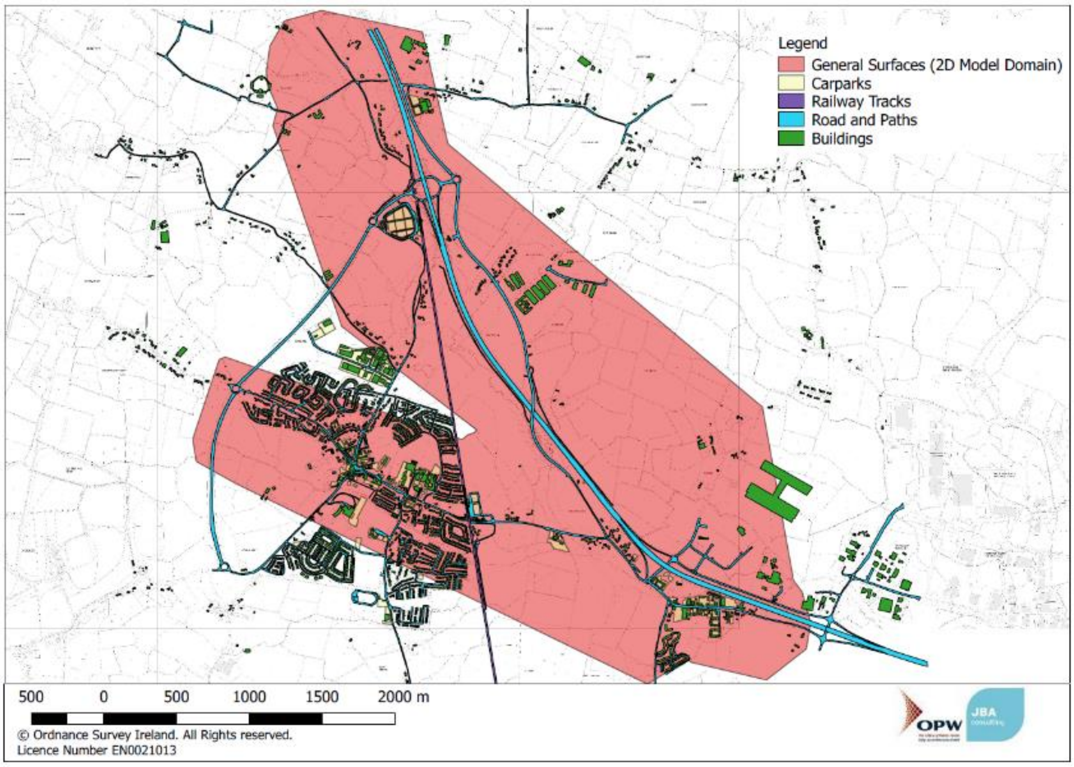
3.7.2 Floodplain roughness

The complexity of the floodplain itself has been represented using a varying hydraulic roughness to represent the different surfaces apparent within the floodplain, Table 3-3. The different surface types have been derived from OSi NTF data. The data has been incorporated into the 2D model in the order listed so that coarse, wide ranging surfaces, such as woodland, do not overwrite more complex surfaces, such as roads. There are a number of different ways to represent buildings within 2D models, ranging from removing them from the floodplain entirely to allowing flow to pass through the building with reduced hydraulic efficiency, represented through Manning's 'n', and as applied to in this model. The Manning's 'n' values applied in the 2D domain are shown in Figure 3-5.

Table 3-3: 2D model floodplain roughness values

Land use type	Manning's 'n' value
Grassland / Open Space	0.04
Road, Paths and Carparks	0.025
Buildings	0.3
Forestry, Dense Scrub	0.075
Railway Track	0.05

Figure 3-5: 2D roughness values



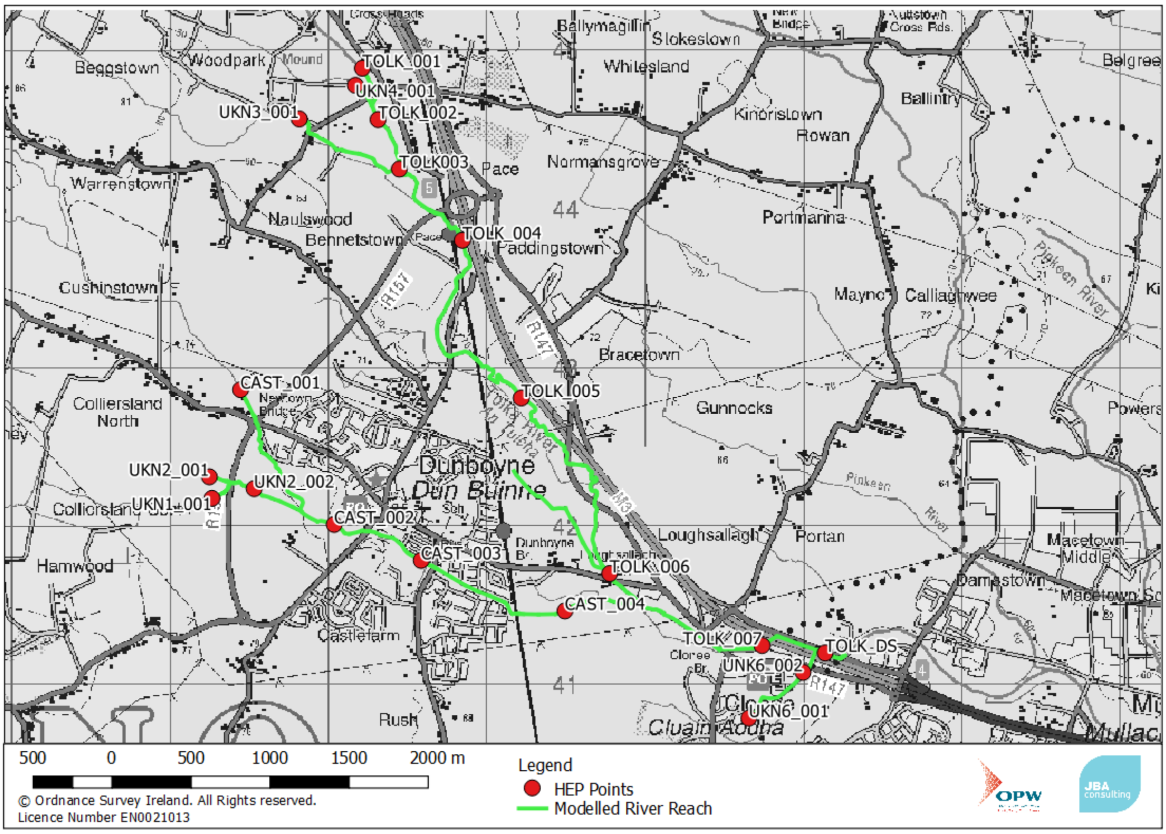
4 Application of hydrology

A summary of the application of hydrologically determined flows into the hydraulic mode are discussed within this section. Additional supporting information is provided with Appendix A : Hydrology Check File.

4.1 Hydrological estimation points

Design flows have been developed at a series of Hydrological Estimation Points (HEPs) throughout the catchment. The locations and names of all the HEPs within the Dunboyne AFA are presented in Figure 4-1.

Figure 4-1: Dunboyne AFA HEP locations



4.2 Calculation of Inflows

4.2.1 Calculation of the Index Flow

Design flows were estimated for each of the HEPs. HEP locations at the upstream extents of the AFA are used as inputs into the model whilst the HEPs mid watercourse were used as model check flows. The catchment area for each inflow is shown in Figure 4-2.

At all HEPs the relevant ungauged catchment descriptors from the FSR and FSU dataset have been used to derive estimates of Qmed. Estimates were carried out for the following methods:

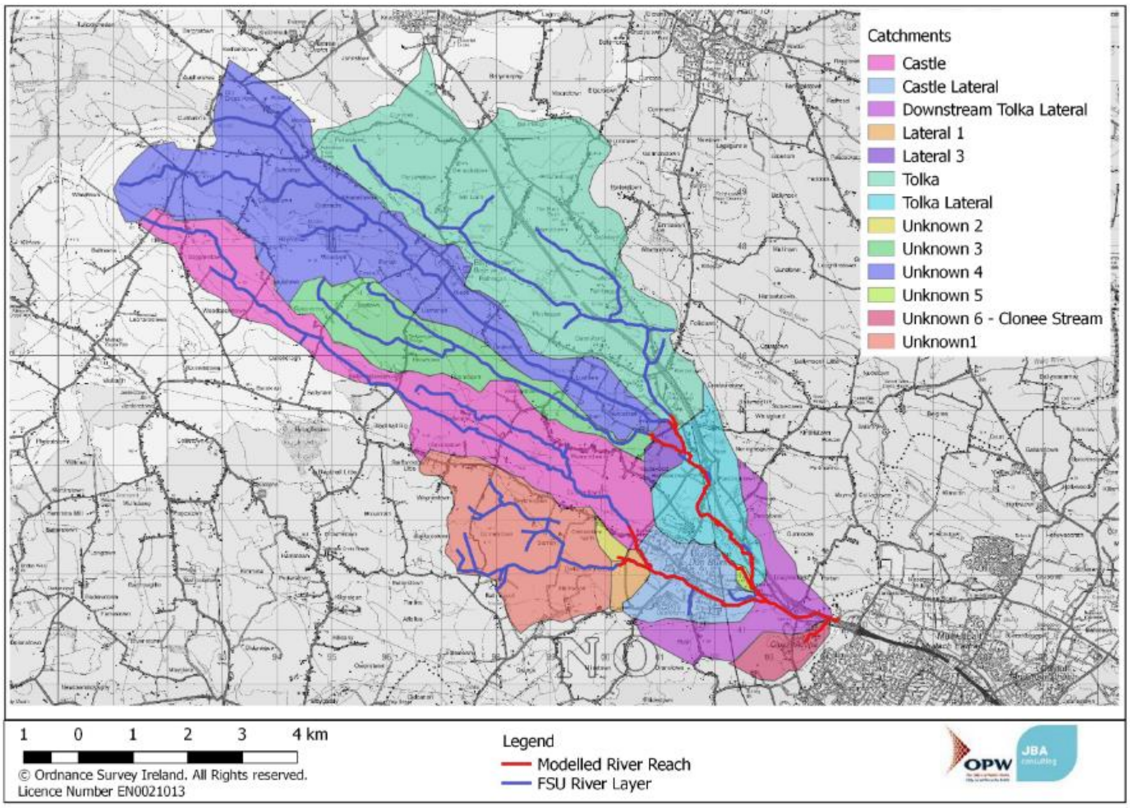
- FSU regression equation and using data transfer from a donor gauge
- FSR Rainfall Runoff Method taking into account FSSR 16
- Institute of Hydrology (IH) Report 124 – Flood Estimation on Small Catchments

The preferred methodology for each HEP was dependent on catchment size as follows:

FSU WP 2.3 'Flood Estimation in Ungauged Catchments' has been used for all catchments with an area more than 15km².

Institute of Hydrology Report No. 124 (Marshall & Bayliss) 'Flood Estimation for Small Catchments' has been used for all catchments with an area less than 15km² although the FSU method above has also been retained for comparative purposes. The exception being that the design estimates for UKN 2 and UKN5 (which were derived from first principles as there was no FSU node data available) did not have estimates derived from the FSU regression equation. Due to the small nature of the catchment only the FSR Rainfall Runoff and IoH124 flow estimates were derived.

Figure 4-2: Sub-catchment delineation



4.2.2 Selection of Donor Gauge

To improve the initial estimate of QMED within the FSU estimation method, a data transfer process is used from a relevant donor gauge with an appropriate data record and similar catchment characteristics.

Two donor gauges are recommended within the FSU Web Portal for determination of flows within the Dunboyne AFA. These gauges are located at Ashbourne (08007) and Fieldstown (08003). There is no significant difference between the catchment attributes of either donor gauge with respect to the inflow catchments. However, significant variation in the resulting Qmed estimate is observed depending on which pivotal (donor) site is applied.

Further review of the catchment area and selection of relevant pivotal site identifies the junction of the Castle Stream and Tolka River as the point within the catchment at which the FSU recommended pivotal site changes from Ashbourne to Fieldstown. This appears to largely be influence by the dramatic increase in overall catchment size through the junction of both watercourses.

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 was found to be 0.8 for Ashbourne and 1.301 for Fieldstown. This factor was then used to adjust the initial estimate of QMED. In the terminology of the FSU research reports, the gauging station where the adjustment factor is calculated is referred to as a donor site.

However, due to the significant variation in Qmed resulting from the use of either pivotal site, JBA Consulting have subsequently undertaken further review of the relevant gauges to provide insight into the applicability of both gauges.

Table 4-1: Donor Gauge Summary

Gauge Name	Gauge Number	Operator	Status	Catchment Area (km^2)	Operating Records	Qmed stats	Notes	Pivotal Adjustment Factor
Ashbourne	08007	EPA	Inactive	37.9	1977 to 1998. 15yrs of flows (not full 21yr length)	8.24	No notes on FSU class or rating	0.8
Fieldstown	08003	EPA	Inactive	83.6	1976 to 1998. 18yrs of flows.	22.55	No notes on FSU class or rating	1.301

On the basis of the gauge review, there is no reason to suggest either pivotal site as a preference for adoption.

- Limitations of the data recorded exists using either Ashbourne or Fieldstown as a pivotal site
- EPA gauge rating focus will be for low flows and limited for high flows
- There are no significant inflows or remarkable change in catchment shape between the two gauges which are very close.
- Neither have any current data and a review of hydrology would need to look fully into the stage-discharge rating.
- The stats Qmed is not based on the full duration of the gauge operation (flows between 1994 and 1998 not included).

Due to the limitations of the data record for both the Ashbourne and Fieldstown pivotal sites, consideration has been given to make use of the data record at the Botanic Gardens gauge. Whilst this gauge is not included in the FSU Web Portal and use of this gauge has its own limitations, it is seen as a reliable dataset with which to proceed.

The Botanic Gardens gauge was installed in 1999 and is still active. At the time of development, the gauge history was too short for FSU inclusion, however as of 2018 there are 18 years of decent well calibrated data. If FSU development criteria had been applied today, Botanic Gardens would be included, and the website would have forced the selection of it based on the encoded rules of a downstream site. Though the Botanic Gardens is another EPA gauge, several significant flood events have occurred through its operating period and is therefore believed to have greater certainty in the stage-discharge curve for high flows. The gauge is located in the lower reaches of the Tolka River but remains free of any tidal influence.

Concerns remain over the increased urban extent within the lower catchment, however this can be addressed through the adoption of an urban adjustment factor developed from the catchment descriptors to the now inactive Clonee Gauge (09003). This adjustment can be applied to the gauged Qmed to remove the urban influence downstream of Clonee. The revised adjustment factor for the Botanic Gardens gauge was 1.401. This is closer to, and more conservative than the Fieldstown gauge.

On the basis of the dramatic increase in overall catchment area downstream of the River Tolka – Castle Stream confluence, the Ashbourne donor gauge is considered the most appropriate upstream of this location and the Botanic Gardens downstream of the junction.

4.2.3 Growth Factor Application

The preferred methodology for deriving the growth factor for each HEP was dependent on catchment size. A large degree of research has been carried out on growth factors for the Liffey Catchment under the Eastern CFRAM. It found that for catchment <10km^2 a medium growth curve should be applied. The applied growth curve for small catchments is presented in Table 4-2.

Table 4-2: Medium Growth Curve for catchments less than 10km²

	Q2	Q5	Q10	Q20	Q50	Q100	Q200	Q1000
Medium Growth Curve	1.00	1.452	1.797	2.18	2.78	3.323	4.04	6.04

For catchments greater than 10km² and less than 200km² an individual growth curve should be derived based on FSU pooling analysis. This methodology has been applied to this study. The growth curves for HEP's with a catchment area greater than 10km² were calculated using the FSU portal. The pooling group for HEP was based on an euclidian dataset.

Consideration was given to the use of the gauge record on the Tolka River at Clonee (09003) for development of growth curve factors, however the gauge was a staff gauge only, therefore records are only available when someone was present measuring flow. It was an EPA gauge in operation from 1976 to 1991. This period is too short of a record to get a reasonable frequency curve that you would be more confident of than a pooled growth curve. Therefore, the Medium Growth Curve estimation method has been applied in preference to the Clonee Gauge.

4.2.4 Lateral Catchments

Flows derived from contributing catchments downstream of the upper model extents were applied as distributed lateral flows across the 1D domain. The applied lateral catchments are shown in Figure 4-2. Lateral catchment flow is expected to respond quicker due to the smaller catchment area and shorter drainage distance to the main watercourse. Therefore, the UKN3 hydrograph shape was used and peak flow scaled based on the top-up flows required to match at HEPs downstream. Where possible, the model results were checked against HEP determined flows downstream to ensure they were within an acceptable range. There are a number of complex hydraulic effects within the model (there are numerous locations of out of bank flow and cross-catchment flow) which makes the process of anchoring the model flows to hydrological estimates difficult.

4.2.5 Catchment Inflows

The catchment inflows provided at all upstream reaches of the model are included in Table 4-3. Top up flows applied from lateral catchments are in Table 4-4.

Table 4-3: Catchment Inflows

HEP	Area	FSU Node	Method	Distribution	Pivotal Site	Q2	Q5	Q10	Q20	Q50	Q100	Q200	Q1000
CAST_001	9.84	09_1487_4	IoH124	n/a	n/a	2.18	3.17	3.92	4.75	6.06	7.24	8.81	13.17
UKN1_001	6.58	09_1654_3	IoH124	n/a	n/a	0.99	1.44	1.78	2.16	2.75	3.29	4.00	5.98
UKN2_001	0.25	n/a	IoH124	n/a	n/a	0.05	0.07	0.09	0.11	0.14	0.17	0.20	0.30
UNK5_001	0.13	n/a	IoH124	n/a	n/a	0.03	0.04	0.05	0.07	0.08	0.10	0.12	0.18
TOLK_001	18.58	09_109_4	FSU	GLO	Ashbourne	2.32	3.26	3.97	4.77	6.00	7.11	8.42	12.44
UKN4_001	15.35	09_549_15	FSU	GLO	Ashbourne	2.27	3.27	4.05	4.94	6.37	7.70	9.29	14.37
UKN3_001	4.93	09_439_10	IoH124	n/a	n/a	1.34	1.95	2.41	2.92	3.73	4.45	5.41	8.09
UKN6_001	1.03	09_1486_1	IoH124	n/a	n/a	0.04	0.06	0.07	0.09	0.11	0.13	0.16	0.24

Table 4-4: Lateral Inflows

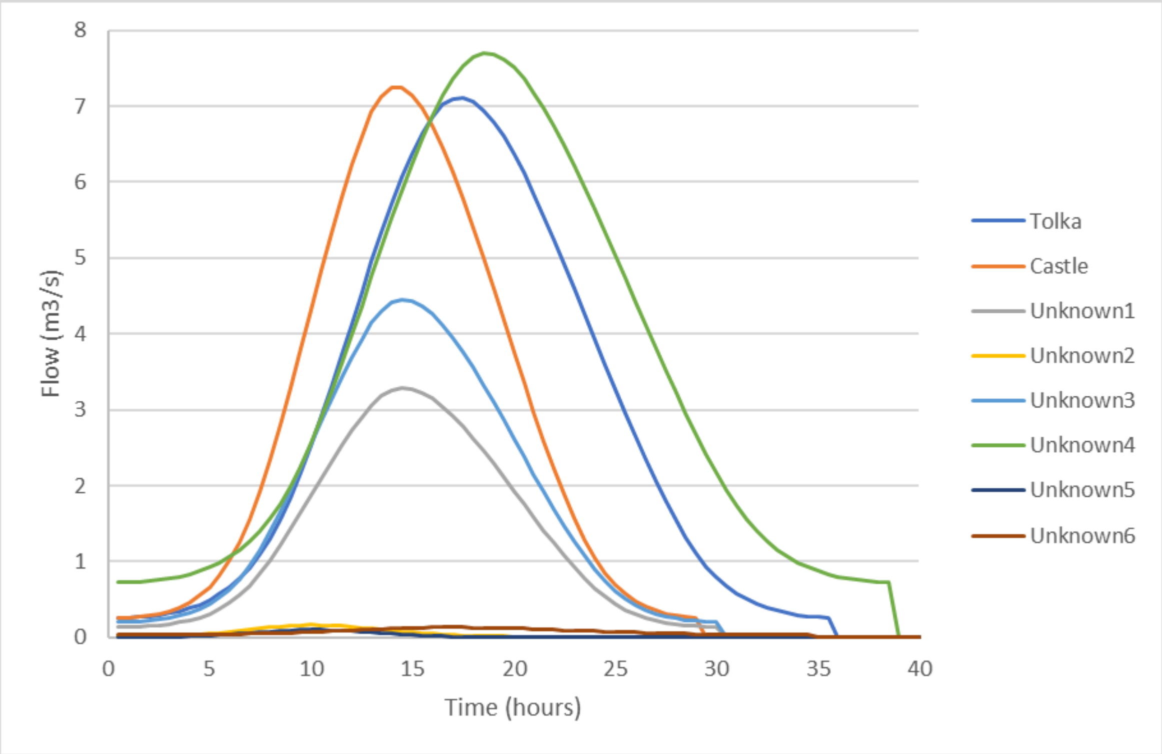
HEP	Q2	Q5	Q10	Q20	Q50	Q100	Q200	Q1000
Tolka Lateral	3.8	4.9	5.4	5.41	5.42	5.43	5.44	5.45
Tolka Lateral Downstream	3.6	3.7	3.8	4.26	4.27	4.275	4.28	4.285
Castle Lateral	2.8	3.8	5	5.4	5.45	5.48	5.49	5.5

4.2.6 Hydrograph shapes

Inflow hydrograph shapes for the Tolka, Castle Stream and the unnamed watercourses have been developed from the Flood Studies Report (FSR) rainfall runoff method. This approach has been tested and, with the exception of a few gauges, FSR approach is generally found to provide the best fit against gauge data. In the absence of gauge data in this location, the rainfall runoff method is appropriate. Inflows are located at the upstream limit of each watercourse.

The FSR method, applied using a uniform design storm for all sub-catchments within a model, imposes a structure on the model inflows with realistic relative timings of the hydrographs. This avoids the need to apply the FSU regression model for relative timings of hydrographs at a confluence; an approach which is associated with a large standard error. Because the FSR method is being used only to control the shape of the hydrographs rather than the magnitude of the peak flows (which are based on the HEPs), there is no benefit to identifying a critical storm duration, i.e. one that results in the highest peak flow or water level. The hydrograph shapes applied on each watercourses are shown in Figure 4-3.

Figure 4-3: Hydrograph Shapes (1% AEP)



4.3 Downstream Boundary

For the River Tolka, the downstream limit to the hydraulic model was chosen downstream of the triple culvert rectangular culvert conveying the River Tolka under the R156, downstream of the M3 culvert. The downstream boundary is therefore located a sufficient distance downstream such that water levels do not impact on levels within the AFA. This is applied as a stage-discharge (HQ) boundary, which incorporates the relationship between water levels and flow, based on the slope of the approaching water surface level.

4.4 Hydraulic Model Validation

Where possible the model results were checked against HEP determined flows downstream to ensure they were within an acceptable range. There are a number of complex hydraulic effects within the model (there are numerous locations of out of bank flow and cross-catchment flow) which makes the process of anchoring the model flows to hydrological estimates difficult.

The hydraulic model flows extracted from the model for each of the HEPS are shown in Table 4-5. As is consistent with the hydrology method, flows within the model transition from use of the Ashbourne pivotal gauge on both the Castle Stream and the Tolka River upstream of the confluence to match the flows determined from the Botanic Gardens Gauge downstream of the confluence.

Check flows at HEPs using the Ashbourne gauge as the donor site is presented in Table 4-6, whilst flows estimated using the Botanic Gardens Gauge are in Table 4-7.

The hydraulic model results compare well with the estimated HEP flows, matching well with flows using the Ashbourne donor gauge in the upper catchments and matching well with flows estimated from the Botanic Gardens gauge in lower reaches of the AFA.

Table 4-5: Hydraulic Model Flows

HEP	Q2	Q5	Q10	Q20	Q50	Q100	Q200	Q1000
CAST_002	3.5	5.5	7.3	9.0	11.6	13.6	16.0	21.7
CAST_003	4.3	6.2	7.7	9.0	11.0	12.7	15.3	21.6
CAST_004	5.7	8.0	10.2	11.6	13.7	15.4	18.0	24.3
TOLK_002	4.6	6.5	7.8	9.6	12.2	14.7	17.5	26.6
TOLK_003	6.2	8.7	10.5	12.4	15.8	18.9	22.4	33.7
TOLK_004	6.3	8.9	10.7	12.5	16.0	19.3	23.0	34.7
TOLK_005	9.2	12.0	13.7	15.3	18.6	21.9	25.7	35.0
TOLK_006	8.9	12.3	14.2	15.7	19.1	22.4	25.7	35.1
TOLK_007	15.9	21.8	26.1	29.5	33.8	38.8	44.6	57.6

Table 4-6: HEP Check Flows - ASHBOURNE Pivotal Site (08007)

HEP	Area	FSU Node	Method	Distribution	Q2	Q5	Q10	Q20	Q50	Q100	Q200	Q1000
CAST_002	17.73	09_469_1	FSU	GEV	3.2	4.78	5.96	7.2	8.98	10.47	12.08	16.41
CAST_003	18.89	09_469_3	FSU	GEV	3.39	4.96	6.12	7.33	9.06	10.48	12.02	16.10
CAST_004	19.63	09_490_3	FSU	GEV	3.59	5.25	6.47	7.75	9.58	11.08	12.71	17.03
TOLK_002	34.02	09_121_1	FSU	GLO	4.61	6.31	7.55	8.88	10.86	12.6	14.57	20.31
TOLK_003	39.93	09_128_1	FSU	GLO	5.75	7.97	9.6	11.37	14.06	16.43	19.16	27.25
TOLK_004	40.81	09_128_3	FSU	GLO	5.85	8.11	9.77	11.57	14.3	16.72	19.5	27.73
TOLK_005	42.20	09_128_5	FSU	GLO	5.98	8.28	9.97	11.82	14.61	17.07	19.91	28.32
TOLK_006	43.15	09_226_2	FSU	GLO	6.13	8.44	10.13	11.97	14.76	17.23	20.06	28.45
TOLK_007	65.94	09_1414_2	FSU	GEV	8.95	12.53	15.01	17.47	20.8	23.39	26.06	32.61

Table 4-7: HEP Check Flows - Botanic Gardens Pivotal Site

HEP	Area	FSU Node	Method	Distribution	Q2	Q5	Q10	Q20	Q50	Q100	Q200	Q1000
CAST_002	17.73	09_469_1	FSU	GEV	5.60	8.35	10.42	12.61	15.74	18.32	21.12	28.69
CAST_003	18.89	09_469_3	FSU	GEV	5.94	8.67	10.68	12.82	15.85	18.34	21.01	28.13
CAST_004	19.63	09_490_3	FSU	GEV	6.29	9.18	11.31	13.58	16.78	19.42	22.25	29.79
TOLK_002	34.02	09_121_1	FSU	GLO	8.07	11.06	13.24	15.58	19.05	22.03	25.51	35.59
TOLK_003	39.93	09_128_1	FSU	GLO	10.07	13.99	16.81	19.93	24.56	28.79	33.52	47.72
TOLK_004	40.81	09_128_3	FSU	GLO	10.24	14.24	17.10	20.28	24.99	29.29	34.11	48.55
TOLK_005	42.20	09_128_5	FSU	GLO	10.47	14.55	17.48	20.73	25.55	29.94	34.86	49.63
TOLK_006	43.15	09_226_2	FSU	GLO	10.73	14.81	17.71	20.93	25.87	30.16	35.10	49.80
TOLK_007	65.94	09_1414_2	FSU	GEV	15.67	21.94	26.33	30.56	36.35	40.90	45.60	57.04

5 Model results

5.1 Model Runs

The model has been run for a present day and two future scenarios, a Mid-Range Future Scenario (MRFS) and a High-End Future Scenario, which consider the potential impact of climate change.

The following return periods were assessed for the present day and MRFS fluvial scenarios: 50%, 10%, 5%, 2%, 1%, 0.5% and 0.1% AEP design events. Only the 10%, 1% and 0.1% AEP design events have been run for the HEFS scenario.

Table 5-1, Table 5-2 and Table 5-3 present the predicted flows from the hydraulic model at various locations throughout the AFA for the current conditions, MRFS and HEFS scenarios respectively.

Table 5-1: Peak flows

HEP reference	Predicted Peak Flows (m3/s)		
	10% AEP	1% AEP	0.1% AEP
09CAST0076	9.8	15.0	23.9
09CAST0180	7.3	12.3	21.2
09CAST0302	4.1	7.5	13.4
09UKN10451	1.8	3.4	6.2
09TOLK1786	27.6	39.9	54.9
09TOLK1863	26.2	38.5	53.6
09TOLK1896	26.1	38.8	57.6
09TOLK2153	11.3	19.4	32.6
09TOLK2279	10.5	18.9	33.7
09TOLK2376	7.8	14.7	26.6
09TOLK1934	14.2	22.4	35.1
09TOLK1820	27.6	39.7	54.7
09UKN60484	0.1	0.1	0.2
09UKN30558	2.4	4.5	8.0
09TOLK2173	11.2	19.4	32.9
09TOLK2233	10.9	18.1	31.1
09UKN50475	0.1	0.1	0.5
09TOLK1987	13.9	21.9	35.0

Table 5-2: Peak flows for the Mid-Range Future Scenario

HEP reference	Predicted Peak Flows for the MRFS (m3/s)		
	10% AEP	1% AEP	0.1% AEP
09CAST0076	11.7	18.2	28.6
09CAST0180	8.7	15.0	25.3
09CAST0302	4.9	8.9	15.9
09UKN10451	2.2	4.1	7.4
09TOLK1786	32.0	47.4	59.5
09TOLK1863	30.4	45.8	62.2
09TOLK1896	31.1	46.6	68.4
09TOLK2153	13.2	23.1	38.6
09TOLK2279	12.4	22.6	40.3
09TOLK2376	9.7	17.6	31.9
09TOLK1934	16.6	26.5	41.4
09TOLK1820	31.9	47.2	58.3
09UKN60484	0.1	0.2	0.3
09UKN30558	2.9	5.4	9.6
09TOLK2173	13.2	23.1	38.7
09TOLK2233	12.7	21.6	37.1
09UKN50475	0.1	0.1	1.3
09TOLK1987	16.2	25.9	39.4

Table 5-3: Peak flows for the High-End Future Scenario

HEP reference	Predicted Peak Flows for the HEFS (m3/s)		
	10% AEP	1% AEP	0.1% AEP
09CAST0076	12.6	20.0	30.9
09CAST0180	9.4	16.5	27.4
09CAST0302	5.3	9.7	17.3
09UKN10451	2.4	4.4	8.0
09TOLK1786	34.1	50.6	60.4
09TOLK1863	32.6	48.9	66.0
09TOLK1896	33.5	50.5	72.2
09TOLK2153	14.5	25.0	41.9
09TOLK2279	13.6	24.5	43.6
09TOLK2376	10.5	19.1	34.5
09TOLK1934	17.9	28.3	45.0
09TOLK1820	34.0	50.5	58.8
09UKN60484	0.1	0.2	0.7
09UKN30558	3.2	5.8	10.4
09TOLK2173	14.4	24.9	41.9
09TOLK2233	13.7	23.0	38.4
09UKN50475	0.1	0.1	1.9
09TOLK1987	17.5	27.9	42.2

5.2 Flood Extent Mapping

Flood extent maps for the predicted flood extents in the 10%, 1% AEP and 0.1% AEP current scenario, MRFS and HEFS have been produced to accompany this report.

6 Model calibration and sensibility checking

Where a recording flow gauge is located in or near the site and this data is accompanied by historical data from a flood event (such as flood extents, or spot levels), then it is possible to undertake calibration of the model. However, in Dunboyne the gauge at Clonee was decommissioned in 1991. The nearest active gauge is located at the Botanic Gardens and this is too far downstream, with a large variance in catchment size and type (too heavily influenced by urban runoff for an adequate hydrological comparison) to be used in this study to reliably apply a stage-discharge relationship.

The construction of the Tolka Flood Relief Scheme and the upgrade of the M3 motorway have significantly changed the flow regime in the area. The flood alleviation scheme was carried by 2009 to address these flood risk issues making most of the historical records of limited use in verifying the model.

Whilst anecdotal information and available data has been used to the best extent possible, overall there is little or poor data to calibrate the model to and observation of more events would be necessary to reduce the uncertainty in model results.

6.1 Comparison of hydraulic models

The hydraulic modelling carried in 2003 as part of the River Tolka Flooding Study was undertaken prior to construction of the M3 Motorway and the Tolka Flood Relief Scheme. Mapping output from this modelling was well matched to observed flood extents during the 2002 flood event and was estimated to be within the range of a 1% AEP event in Dunboyne. The underlying hydrology within this model was a rainfall-runoff model calibrated to the Botanic Gardens gauge, with no other flow gauges closer to the AFA available.

In the time since completion of this modelling, not only have there been significant changes within the topography and hydraulic environment of the AFA, there have also been considerable advanced in modelling methodology and approaches.

It is noted in the following that there are severe limitations in comparing the two methodologies and hydraulic models:

- Significant uncertainty remains when using rainfall data across large areas, requiring spatial interpolation of limited observed data
- The 2003 rainfall runoff model was calibrated to Botanic Gardens – The Tolka River to Dunboyne is less than 50% of this catchment and a demonstrates a significant change in catchment characteristics between the two locations.
- Application of FSU methodology and the reliance on donor gauges at pivotal sites can produce substantially different flow estimates.
- 1D modelling limitations. The 2003 hydraulic model was a 1-Dimensional model completed with Infoworks-RS, a now outdated software package that has been replaced by ICM. Within this model are observed constraints including glass-walling and the lack of detailed representation of 2-Dimensional flow behaviour within the floodplains. The revised modelling has been undertaken using a dynamically linked 1D-2D hydraulic modelling allowing explicit modelling of flow behaviour out of channel.
- Outdated and coarse resolution DTM. Significant inaccuracies are noted in the DTM used within the 2003 modelling. 33% of OSi Spot Levels used to validate the previous DTM recorded elevation differences in excess of 200mm. 1m resolution Lidar flown in 2011/2012 was used in the revised model, with a vertical accuracy of +/-150mm. Comparison of this Lidar against survey commissioned by the OPW in 2017 yielded an average variance in elevation levels of 65mm. Up to +/- 500mm differences in elevation are observed between the two DEM datasets.

6.2 Comparison of predicted flood extents

Due to the significant changes within the AFA following the previous mapping, it is very difficult to make any meaningful comparison between model extents.

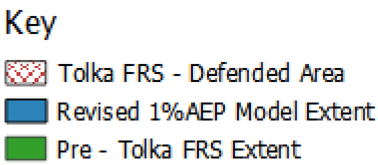
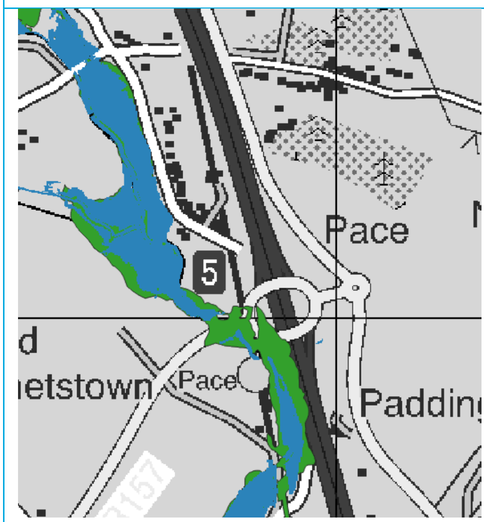
Subsequent to the 2002 flood event the Tolka Flood Relief Scheme included the following works:

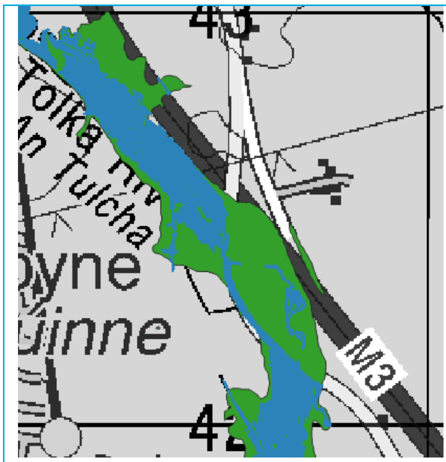
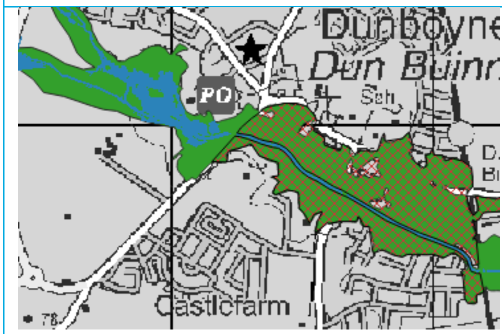
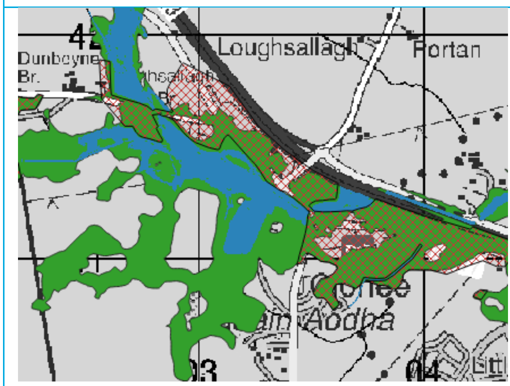
- Road Bridge replacement and repairs,
- Railway Bridge underpinning,
- Stream conveyance upgrades,
- Construction of flood defence embankments and walls,
- General channel maintenance.

These works significantly altered the flow regime in the area. Since the Scheme was completed there have been no reports of flooding from the River Tolka in these areas. The construction of the M3 motorway also altered the topography of the area and significantly improved conveyance though the structure under the motorway at Clonee.

Table 6-1 presents five areas where significant changes to flood extents are predicted following the completion of the M3 and the Tolka Flood Relief Scheme.

Table 6-1: Comparison of Revised 1%AEP extents with Pre- Tolka FRS mapped extents

	
	**M3 Parkway** Similar flood extents are modelled on the River Tolka upstream of the M3 Parkway, however topographic modifications from the M3 and improved conveyance through structures has decreased flood extents downstream of the Parkway.
	**Bennetstown** Flood extents have been reduced on the left back following construction of the Tolka FRS embankments. There is a significant difference in flood extents on the right bank. Pre – Tolka FRS extent mapping includes a small tributary inflow with ponding occurring behind the road. This flooding is not extended from the River Tolka and is not included within the revised hydraulic model

	**M3** Topographic modifications from the M3 and improved conveyance through structures has decreased flood extents adjacent to the M3.
	**Castle Stream** The revised model extent of the Castle Stream through Dunboyne identifies the significant benefits of the Tolka FRS. Significant dredging and improved conveyance of the Castle Stream has dramatically reduced the modelled flood extents.
	**Clonee** Topographic modifications from the M3 and improved conveyance through structures has decreased flood extents adjacent to the M3, particularly the significant increase in culvert size under the M3. Construction of Tolka FRS embankments has also significantly altered the flood extents throughout the area. Flood extents out of the right bank are sensitive to minor increases in flood levels due to the very flat nature of the topography.

7 Sensitivity testing

7.1 Screening of sensitivity tests

The application of the sensitivity tests has been an iterative process which allowed certain criteria to be screened out. Table 7-1 summarises the full suite of potential sensitivity tests, and highlights those which have are not applicable, and those which have been screened out. Further details of these criteria are provided in the following sections.

Table 7-1: Sensitivity test summary

Sensitivity test	
Peak flow	Tested (10% AEP, 1% AEP)
Flow volume	Tested (10% AEP, 1% AEP)
Roughness	Tested (10% AEP, 1% AEP)
Building representation	Screened out
Afflux / headloss at key structures	Tested (1% AEP)
Water level boundaries and joint probability	Tested (10% AEP, 1% AEP)
Timing of tributaries	Screened out
Timing of fluvial and tidal peaks	Not applicable
Cell size	Tested (1% AEP)

7.1.1 Peak Flow

Table 7-2 provides a scoring mechanism through which each watercourse has been attributed a score from each row of the table, reflecting the level of confidence in the hydrology. The resulting scores have been summed to provide an overall indication of uncertainty and used to look up in Table 7-3 the uncertainty weighting to apply for the sensitivity test. For Dunboyne the hydrological estimates score 29 as highlighted below.

The uncertainty in QMED was assessed using the equations for Standard Error and Factorial Standard Error provided in the FSU WP2.2 report. These were applied to estimates derived from catchment descriptors, which will give a scaling factor of 1.37. Where additional data is available at gauge sites typically a lower scaling factor can be used. This reflects the uncertainty in the index flood but does not reflect the uncertainty in the growth curve, for this reason an additional multiplication factor is included for the 1% AEP event.

For Dunboyne, the watercourses with flows estimated using the FSU regression equation have an Qmed uncertainty of 1.2, whilst the smaller watercourses whose hydrological estimates have been calculated using the IoH124 have a Qmed uncertainty of 1.37.

Table 7-2: Flow sensitivity test scoring mechanism

Scoring parameter	Score of 1	Score of 3	Score of 5	Score of 7
Is there a local recording gauge that has been used as a donor for the hydrology?	Within 5km of the AFA and on the same watercourse with no significant other inflows between the gauge and the AFA OR Upstream and downstream of the AFA with no significant other inflows between and routing of flows supports the hydrology	Within 5km of the AFA but not on the same watercourse or with significant other inflows between the gauge and the AFA	Beyond 5km or with significant other inflows between the gauge and the AFA	No useable gauge
What is the length of record of the local gauge?	Greater than 40 years	Between 20 and 40 years	Between 2 and 20 years.	No useable gauge
What quality is the record from the gauge?	Rating review carried out, high confidence	Rating review carried out, moderate confidence or no rating review carried out but gauge is FSU class A	All other sites.	N/A.
What unusual features are there in the catchment hydrology?	None – a rural catchment typical of many in the gauged datasets	Some lakes (0.99>FARL>0.9) or urbanisation (0.05<URBEXT< 0.15)	Some karst or extensive lakes (FARL<0.9) or urbanisation (URBEXT>0.15) or arterial drainage	N/A
What is the size of the catchment?	N/A	N/A	<25km	N/A

Table 7-3: Flow sensitivity scaling factors

Return period of event	Score up to 6	Score of between 7 and 14	Score of between 15 and 22	Score above 23
10%	No sensitivity test required.	Use QMED uncertainty	Use QMED uncertainty	Use QMED uncertainty
1%*	Use QMED uncertainty then apply adjustment factor of 1.1	Use QMED uncertainty then apply adjustment factor of 1.2	Use QMED uncertainty then apply adjustment factor of 1.3	Use QMED uncertainty then apply adjustment factor of 1.5.
* Where extensive areas of karst with connections to the surface water system is present then use QMED uncertainty then multiply flows by 2.0 to reflect the uncertainty in the 1% event flow.				

7.1.2 Flow Volume

The sensitivity to the hydrograph duration has been assessed where design storm hydrographs have been developed from limited data. Where observed data from significant flood events is available, it is considered a reasonable approximation of the flood duration has been made and no sensitivity test has been required. This is not the case in Dunboyne. Table 7-4 details a range of flood duration multipliers reflecting the basis for the development of the design event hydrographs. A flow multiplier of 2 was found to be applicable for Dunboyne.

Table 7-4: Flood duration multipliers for flow volume sensitivity test

Description of site	Sensitivity multiplier applied to flood duration
Flood duration has been developed from a single observed event data or multiple events below the 10% AEP.	1.2
Flood duration has been developed from catchment descriptors and there are few or no lakes in the upstream catchment (FARL>0.9)	2
Flood duration has been developed from catchment descriptors and there are extensive lakes in the upstream catchment (FARL<0.9)	9

7.1.3 Roughness

The specific maintenance regime undertaken by the Office of Public Works is not known, but site inspection shows the channel through the town to be well maintained. The Tolka and tributaries are mainly rural and do not look to be maintained to the same degree as the Castle Stream. This indicates that although channel and bank roughness (i.e. vegetation growth) may increase, it will probably be within reasonable bounds.

Based on the assessment of typical vegetation cover completed as part of the hydraulic modelling, and an understanding of the general maintenance regime carried out by the local authorities and OPW, high and low end roughness values have been determined for each channel.

Table 7-5 through to Table 7-7 expand upon the quoted values detailed in Section 2 and provide upper and lower bound values for a variety of surfaces.

Table 7-5: Roughness bounds for river channels

Channel substrate	Roughness values (Manning's 'n')		
	Lower Bound Value	Typical Value	Upper Bound Value
Coarse gravel	0.03	0.035	0.04
Clear Stoney	0.033	0.04	0.045
Slightly vegetated	0.04	0.045	0.055
Heavily Overgrown	0.045	0.05	0.06
Dense Vegetation	0.045	0.055	0.065
Very Weedy reaches, channel unclear from banks	0.05	0.06	0.07

Table 7-6: Roughness bounds for river banks

Bank material	Roughness values (Manning's 'n')		
	Lower Bound Value	Typical Value	Upper Bound Value
Grassy banks	0.03*	0.04	0.06*
Long Weeds	0.04	0.045	0.05
Dense Scrub	0.045	0.05	0.07
Bushes	0.04*	0.06	0.08*
Trees – flood level not reaching branches	0.05	0.07	0.13
Trees – flood level reaching branches	0.1	0.15	0.2

Table 7-7: Roughness bounds for floodplain surfaces

Floodplain material	Roughness values (Manning's 'n')		
	Lower Bound Value	Typical Value	Upper Bound Value
Grassland / Open Space	0.033	0.04	0.05
Road, Paths and Carparks	0.02	0.025	0.03
Buildings	0.1	0.3	1
Forestry, Dense Scrub	0.06	0.075	0.1
Railway Track	0.04	0.05	0.07

7.1.4 Building representation

The current flood risk extents in the 1% AEP event show no inundation of properties so no test related to the representation of buildings in the 2D domain was required.

7.1.5 Afflux at key structures

Key structures identified for this sensitivity test are those that have a controlling influence on local water levels and the resulting influence may be expected to cause flooding to local receptors. These structures have been identified by examination of the long section water level plot through the structure, a review of nearby receptors at risk and an assessment of likely flow routes around the structure.

A number of key structures were identified for review as part of this sensitivity test; the M3 culvert, a main road culvert adjacent a number of properties in the Clonee Area. To review the head losses associated with the M3 culvert (modelled as a rectangular culvert) on the River Tolka, inlet losses were increased by 20%. A similar increase was applied at Loughsallagh Bridge due to receptors in close proximity.

Clonee bridge is modelled as a BB Bridge in Estry. No pier losses were applied as it was modelled as three individual arches. As a sensitivity test pier losses were added calculated due to velocity and headloss across the structure.

7.1.6 Water level boundaries

The downstream boundary is an HQ (head flow) boundary. It is located downstream of the M3 culvert and deemed far enough beyond the area of risk to impact levels. A sensitivity test of the HQ on both an increased and decreased HQ slope was completed.

7.1.7 Timing of tributaries

Adjustments to the timing of the River Tolka peak flows could result in higher levels in all of the tributaries, if this was to coincide with peak flows in the tributaries. This test is only recommended when there is good confidence in the hydrology and the increase in flows resulting from the shift in timing would exceed the increase in flows investigated as part of the flow sensitivity tests described in Section 7.1.1. The increases in flows on the River Tolka from a shift in timing of the tributaries and Castle Stream is negligible compared to the increase in flows on the River Tolka in the flow sensitivity test. As such no investigation of the timing of the tributaries has been completed.

7.1.8 Cell-size

As a cell size greater than 2m has been used, where there are complex flow routes (such as around buildings), the model was sensitivity checked with a 2m grid resolution. This will allow the potential for development of additional flow paths to be identified.

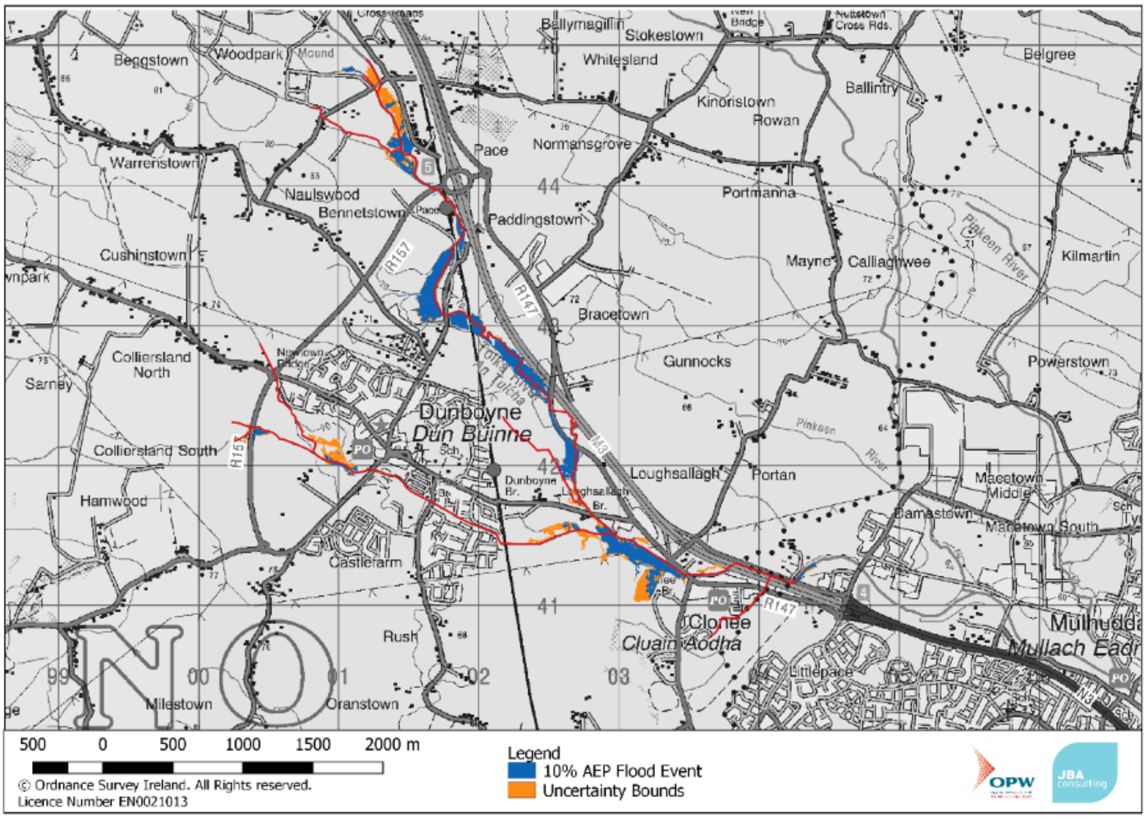
7.2 Sensitivity Testing Results

The results of the sensitivity tests have been used to inform the uncertainty bounds. The uncertainty bound in effect presents the most sensitive hydraulic parameter/s as assessed within the bounds identified in Section 7.1 at all locations along the modelled reach.

To simplify the presentation of the sensitivity tests, only the uncertainty bounds for the 10% AEP and 1% AEP events has been presented.

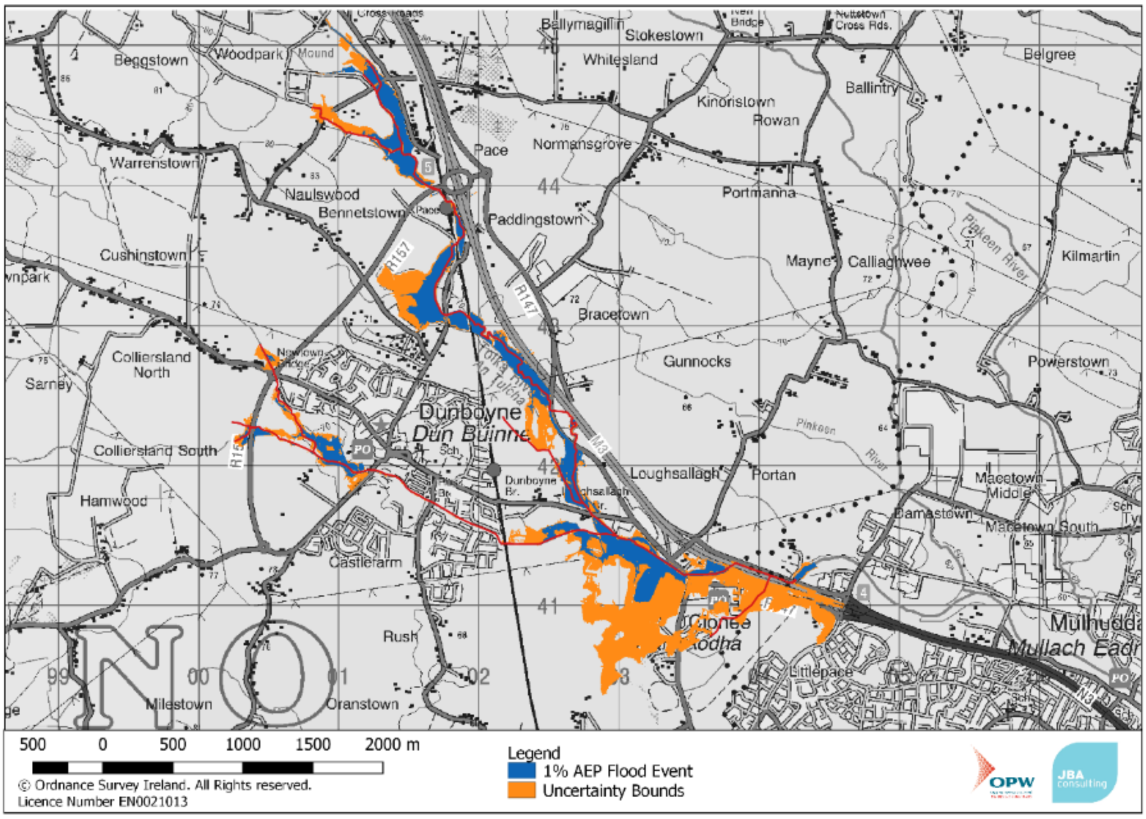
The 10% AEP uncertainty bound is compared to the equivalent predicted flood extent for the Dunboyne AFA in Figure 7-1. There is additional out of bank flooding upstream of Dunboyne Park and Ride, on the Castle Stream upstream of Newtown Bridge and between Loughsallagh Bridge and Clonee Bridge, upstream of Clonee. Primarily the increased flood extent and uncertainty bound is from sensitivity to increased peak flow as described in Section 7.1.1.

Figure 7-1: 10% AEP event uncertainty bounds



The 1% AEP uncertainty bound is compared to the equivalent predicted flood extent for the Dunboyne AFA in Figure 7-2. The sensitivity results indicate the model is particularly sensitive to peak flow and to some extent higher roughness parameters. There is a substantial increase in flood risk in the Clonee area with receptors impacted. There was no considerable difference in flood extents for any of the other sensitivity tests.

Figure 7-2: 1% AEP event uncertainty bounds



8 Model limitations

8.1 Channel blockage and maintenance

Blockage of culverts and small span bridges has the potential to increase flood risk on any watercourse. In Dunboyne, the smaller unnamed tributaries may be prone to blockage due to the small size of each of the openings, particularly UKN60000 which is located in a built-up area with no potential bypass routes. Water would back up and possibly overtop the left bank causing flood risk to the adjacent properties. A number of structures on the Tolka have had gates/fences constructed in channel to prevent access, reducing the flow area and raising the risk of blockage. Blockage has not been investigated in more detail in this model, but it is possible that blockage of structures would exacerbate flood risk to a number of properties. In addition to blockage, the model does not take into account the condition of a channel and channel maintenance.

8.2 Historical data and calibration

As discussed in Section 6, the construction of the Tolka Flood Relief Scheme and the M3 motorway have substantially altered the flood behaviour within the modelled area. Consequently, significant differences have been noted within the results of the modelling from this study and the flood mapping preceding the Scheme and M3. The changes within the catchment significantly limit the ability to reasonably compare the two modelling approaches.

Historical calibration is also limited as no observed flood events have occurred following construction of the M3 motorway and the Scheme. Additionally, the previously existing Clonee gauge was deactivated in 1991 and therefore no flow data is available for this site from this time.

As such, limited comparison can be made to previous studies and no calibration of the model to observed records is possible with existing catchment conditions.

The methods undertaken within this assessment have utilised the best available information at the time of modelling, including both hydrological determination of flows and hydraulic modelling approaches. However, as limited information is available for calibration, significant uncertainty remains inherent within the outcomes of this study. Sensitivity of flood extent mapping (Figure 7-1 and Figure 7-2) to identified uncertainties listed within Section 7, clearly illustrates significant potential changes within the predicted flood extents resulting from a 10% increase in peak flow, particularly within the Clonee area.

It is therefore recognised that the results and mapping produced from this study are subject to change if additional information becomes available through future observed flood events or the re-installation of a recording gauge within the catchment, with such changes potentially resulting in either the increase or decrease in predicted flood extents and standard of protection of flood defences.

It is strongly recommended that a flow and level monitor be installed at a sensible location within the mid-catchment area as part of any monitoring regime or to support any future works.

8.3 Model Cell Size

A cell size of 4m has been selected for the 2D grid. This cell size enables areas of interest to be modelled in sufficient detail, whilst retaining good computational performance of the model.

8.4 Model Instabilities

No negative depths are recorded within the model and Mass Error is contained within the accepted threshold of ± 1%

Appendix A : Hydrology Check File

A.1 Site Details

Site Name	Dunboyne
Site Description	Dunboyne AFA
Watercourse Catchment	Tolka
Watercourse Name	Tolka, Castle, Clonee Stream and its unnamed tributaries

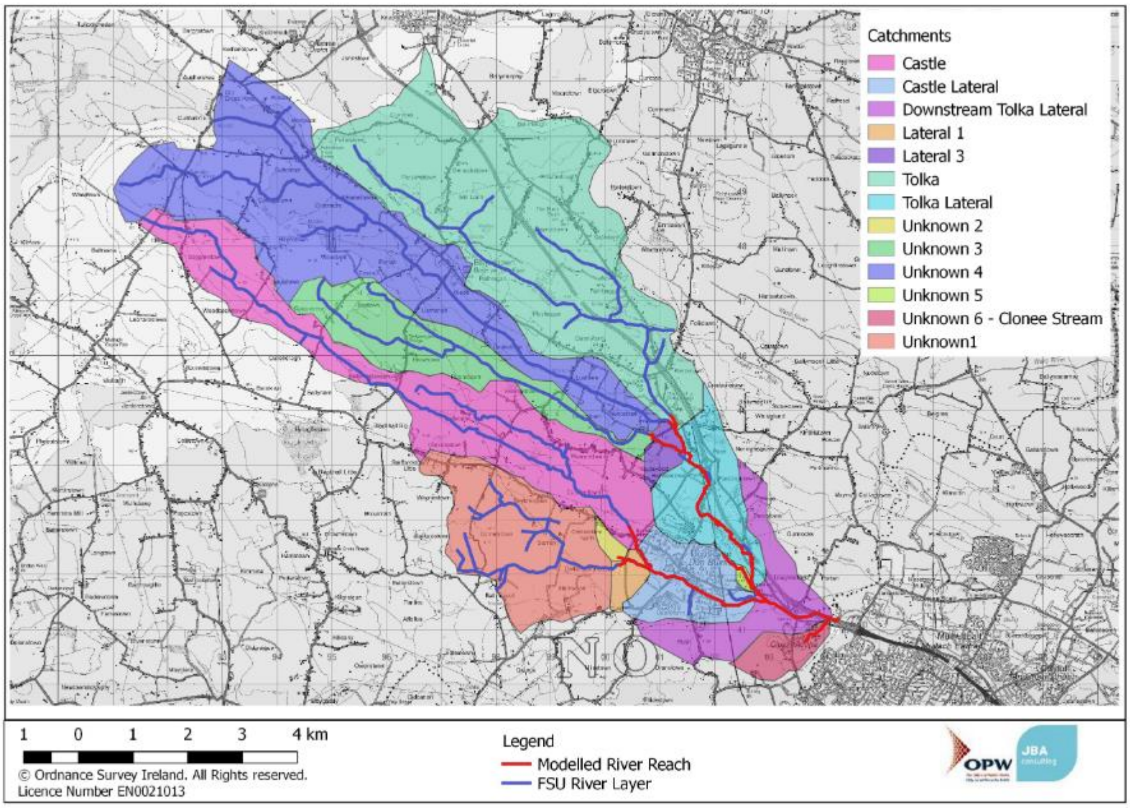


Figure A-1: Model Catchment Inflows

A.2 QMed Estimation Methodology

For the development of the design flows have been estimated for each of the HEPs. The inflow HEP are used as inputs into the model whilst the HEPs mid watercourse were used as model check flows.

At all HEPs the relevant ungauged catchment descriptors from the FSR and FSU dataset have been used to derive estimates of Qmed. Estimates were carried out for the following methods:

- FSU regression equation and using data transfer from a local gauge
- FSR Rainfall Runoff Method taking into account FSSR 16
- Institute of Hydrology (IH) Report 124 – Flood Estimation on Small Catchments

The preferred methodology for each HEP was dependent on catchment size as follows:

- FSU WP 2.3 'Flood Estimation in Ungauged Catchments' has been used for all catchments with an area more than 15km².
- Institute of Hydrology Report No. 124 (Marshall & Bayliss) 'Flood Estimation for Small Catchments' has been used for all catchments with an area less than 15km² although the FSU method above has also been retained for comparative purposes. The exception being that the design estimates for UKN 2 and UKN5 (which were derived from first principles as there was no FSU node data available) did not have estimates derived from the FSU regression equation. Due to the small nature of the catchment only the FSR Rainfall Runoff and IoH124 flow estimates were derived.

A.3 Inflow Catchment Design Flow Estimation

Figure A-1 shows the modelled network and the inflow boundaries to the scheme. The main inflow boundaries are as follows:

Table A-1 Inflow Locations Summary

Model Inflow	HEP Reference	FSU_node	Area
Tolka	TOLK_001	09_109_4	18.58
Castle	CAST_001	09_1487_4	9.84
Unknown 1	UNK1_001	09_1654_3	6.58
Unknown 2	UNK2_001	Derived from first principles	0.25
Unknown 3	UNK3_001	09_439_10	4.93
Unknown 4	UNK4_001	09_549_15	15.35
Unknown 5	UNK5_001	Derived from first principles	0.13
Unknown 6 (Clonee Stream)	UNK6_001	09_1486_1	1.03

In additional to the key inflows described above, lateral inflows are provided distributed along the stream length within the model area. The following laterals are applied:

A.3.1 Catchment Characteristics

Table A-2: Catchment Characteristics

Descriptor	Tolka	Castle	Unknown 1	Unknown 2	Unknown 3	Unknown 4	Unknown 5	Unknown 6	Pivotal Site Ashbourne 08007	Pivotal Site Fieldstown 08003
AREA	18.582	9.84	6.58	0.251	4.972	15.353	0.125	1.028	37.93	83.59
SAAR	837.05	818.34	793.28	793.28	822.44	838	831.8	773.75	845.02	826
FARL	1	1	1		1	1		1	1	1
BFIsoil	0.4426	0.4483	0.4311		0.4438	0.4586		0.6611	0.3985	0.466
URBEXT	0.0259	0.0661	0.0169		0.0158	0.0068			0.06	0.0456
MSL	8.935	11.558	3.603	0.751	7.952	12.618	0.479	1.386		
S1085	2.9029	4.4815	2.902		3.618	3.362		1.177	3.84	3.90
DrainD	1.703	1.649	1.401		2.019	1.116		1.772	0.98	1.098
ArtDrain2	0	0	0		0	0		0	0.78	0.56
SOIL1								1	-	-
SOIL2	0.75	0.6	1	1	0.45	0.6	1		-	-
SOIL3									-	-
SOIL4	0.25	0.4	0	0	0.55	0.4	0		-	-
SOIL5									-	-
SOIL	0.338	0.36	0.3	0.3	0.383	0.36	0.3	0.15	-	-
M5-2day	56.3	43.8	43.8	43.8	55.3	56.3	56.3	57.9	-	-
r	0.325	0.325	0.325	0.325	0.325	0.325	0.325	0.325	-	-

The flood study update carried out by the OPW in Ireland delineated descriptors for flood estimation through the country. There are approximately 134,000 such descriptor nodes on the river network, and specific parameters for each of these have been pre-calculated.

A.3.2 FSU Estimation Qmed

The Flood Studies Update (FSU) method to estimate Q_{med} as described in research reports produced from FSU work packages 2.2 and 2.3, has been used. Q_{med} 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 Q_{med} to a set of catchment descriptors. The catchment descriptors can be used to determine Q_{med}.

$$QMED_{rural}=1.237x10\text{-}5AREA^{0.937}BFIsoils^{-0.922}SAAR^{1.306}FARL^{2.21}DRAIND^{0.341}S1085^{0.185}(1+ARTDRAIN2)^{0.408}$$

Where:

AREA is the catchment area (km^2).

BFI_{soils} 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

Donor Gauge Summary

To improve the initial estimate of QMED, a data transfer process is used from a relevant donor gauge with an appropriate data record and similar catchment characteristics.

Two donor gauges are recommended within the FSU Web Portal for determination of flows within the Dunboyne AFA. These gauges are located at Ashbourne (08007) and Fieldstown (08003). The location and catchment of each gauge is shown in Figure 2 and Figure 3 respectively. Catchment descriptors for these gauges are included within Table A-1 along with catchment characteristics of the inflow boundaries. There is no significant difference between the catchment attributes of either donor gauge with respect to the inflow catchments. However, significant variation in the resulting Qmed estimate is observed depending on which pivotal (donor) site is applied.

Further review of the catchment area and selection of relevant pivotal site identifies the junction of the Castle Stream and Tolka River as the point within the catchment at which the FSU recommended pivotal site changes from Ashbourne to Fieldstown.

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 was found to be 0.8 for Ashbourne and 1.301 for Fieldstown. This factor is then used to adjust the initial estimate of QMED. In the terminology of the FSU research reports, the gauging station where the adjustment factor is calculated is referred to as a donor site.

However, due to the significant variation in Qmed resulting from the use of either pivotal site, JBA Consulting have subsequently undertaken further review of the relevant gauges to provide insight into the applicability of both gauges. Table A-2 presents a summary of the available data for each gauge.

Table A-3: Gauge Summary

Gauge Name	Gauge Number	Operator	Status	Catchment Area (km^2)	Operating Records	Qmed stats	Notes	Pivotal Adjustment Factor
Ashbourne	08007	EPA	Inactive	37.9	1977 to 1998. 15yrs of flows (not full 21yr length)	8.24	No notes on FSU class or rating	0.8
Fieldstown	08003	EPA	Inactive	83.6	1976 to 1998. 18yrs of flows.	22.55	No notes on FSU class or rating	1.301

On the basis of the gauge review, there is no reason to suggest either pivotal site as a preference for adoption.

- Limitations of the data recorded exists using either Ashbourne or Fieldstown as a pivotal site
- EPA gauge rating focus will be for low flows and limited for high flows
- There are no significant inflows or remarkable change in catchment shape between the two gauges which are very close.
- Neither haave any current data and a review of hydrology would need to look fully into the stage-discharge rating.
- The stats Qmed is not based on the full duration of the gauge operation (flows between 1994 and 1998 not included).

Due to the limitations of the data record for both the Ashbourne and Fieldstown pivotal sites, consideration has been given to make use of the data record at the Botanic Gardens gauge. Whilst this gauge is not included in the FSU Web Portal and use of this gauge has its own limitations, it is seen as a reliable dataset with which to proceed.

The Botanic Gardens gauge was installed in 1999 and is still active. At the time of development, the gauge history was too short for FSU inclusion, but now in 2018 there are 18 years of decent well calibrated data. If FSU development criteria had been applied today, Botanic Gardens would be included, and the website would have forced the selection of it based on the encoded rules of a downstream site. Though the Botanic Gardens is another EPA gauge, several significant flood events have occurred through its operating period and is therefore believed to have greater certainty in the stage-discharge curve for high flows. The gauge is located in the lower reaches of the Tolka River but remains free of any tidal influence.

Concerns remain over the increased urban extent within the lower catchment, however this can be addressed through the adoption of an urban adjustment factor developed from the catchment descriptors to the now inactive Clonee Gauge. This adjustment can be applied to the gauged Qmed to remove the urban influence downstream of Clonee.

Table A-4 presents the catchment descriptors for the Clonee and Botanic Gardens gauges including PCD estimates.

Table A-4: Tolka River Gauge Catchment Descriptors

Botanic Gardens		Clonee	
Location Number	09_1868_3	Location Number	09_1414_2
Contributing Catchment Area	137.909 km2	Contributing Catchment Area	65.941 km2
BFISOIL	0.4871	BFISOIL	0.4705
SAAR	791.92 mm	SAAR	821.49 mm
FARL	1	FARL	1
DRAIND	1.048 km/km2	DRAIND	1.262 km/km2
S1085	2.7267 m/km	S1085	2.5973 m/km
ARTDRAIN2	0	ARTDRAIN2	0
URBEXT	0.2091	URBEXT	0.0513
Centroid distance	18.2216 km	Centroid distance	807.2291 km
Coordinates	[-698598.5059, 7052657.9863]	Coordinates	[-716574.3241, 7059454.2881]
QMED values		QMED values	
PCD estimate	18.1299m3/s	PCD estimate	10.386m3/s
PCD urban estimate	24.0217m3/s	PCD urban estimate	11.1853m3/s

The following calculations have been used to determine a pivotal factor for the Botanic Gardens Gauge based on the Urban Adjustment Factor (UAF) from the Clonee Gauge. The PCD urban estimate for Botanic Gardens is adjusted

Table A-5: Adjustment of Botanic Gardens Gauge UAF

	Calculation	Botanic Gardens	Clonee
Urban Adjustment Factor (UAF)	$\frac{PCD\ Urban\ Estimate}{PCD\ Estimate}$	1.325	1.077
Adjusted PCD Urban estimate	$UAF(Clonee) * PCD\ Estimate(Botanic\ Gardens)$	19.525	
AMAX Qmed	$Gauge\ data\ record$	33.65	
Adjusted AMAX Qmed	$AMAX\ Qmed\ / UAF(Botanic\ Gardems) * UAF(Clonee)$	27.351	
Pivotal Factor	$Adjusted\ AMAX\ Qmed\ / Adjusted\ PCD\ Urban\ Estimate$	1.401	

Only catchments more than 10km2 used the FSU methodology for the determination of flows.

Table A-6: FSU Qmed estimate

Descriptor	Tolka	Castle	Unknown 1	Unknown 2	Unknown 3	Unknown 4	Unknown 5	Unknown 6
Qmed	2.84	1.94	1.08	-	1.0	2.91	-	0.11

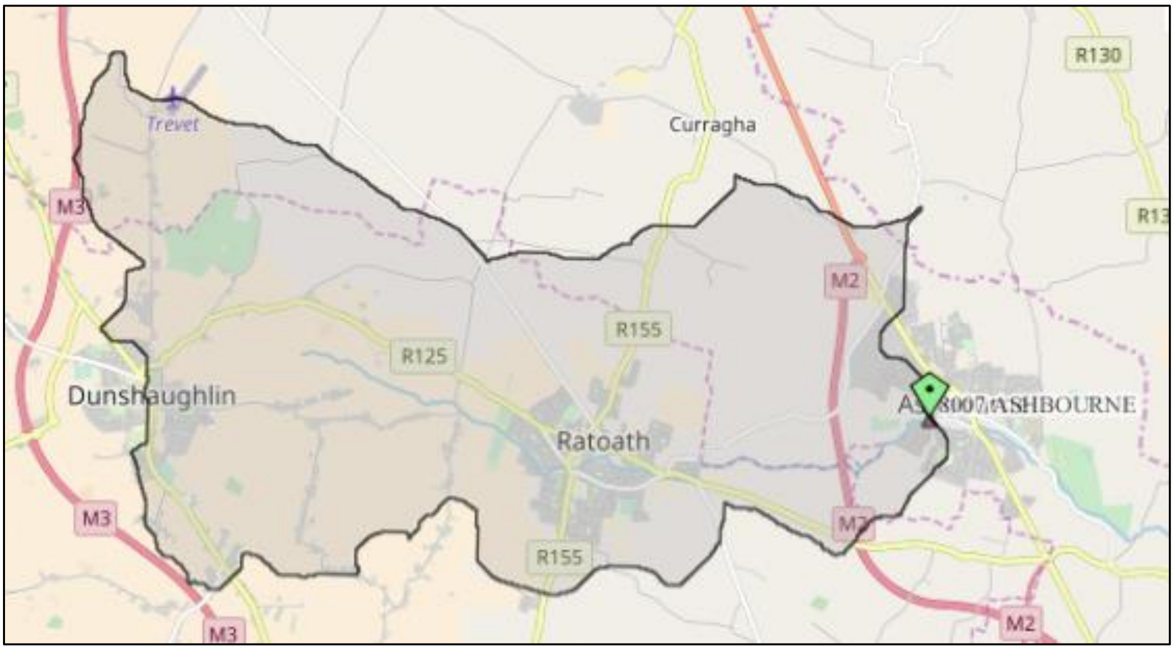


Figure A-2: Ashbourne Pivotal Gauge (08007)

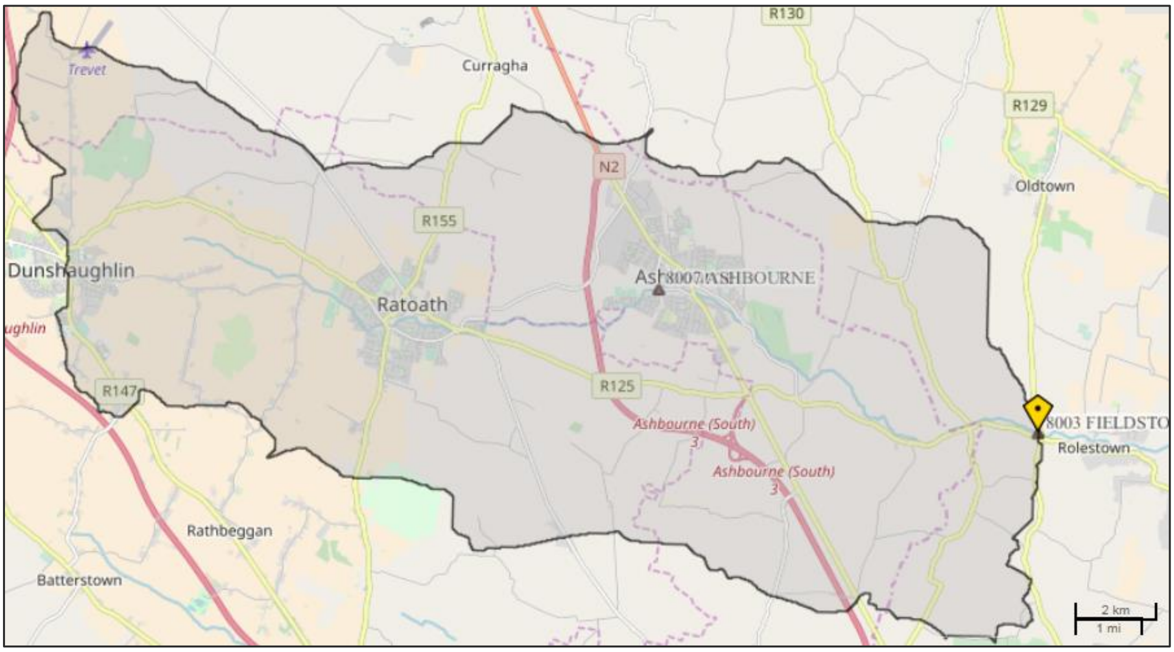


Figure A-3: Fieldstown Pivotal Gauge (08003)

A.4.3 FSR Rainfall Runoff Method

The FSR Statistical method most 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 500km^2. 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/100km^2 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

Table A-7: FSR Rainfall Runoff Results

Descriptor	Tolka	Castle	Unknown 1	Unknown 2	Unknown 3	Unknown 4	Unknown 5	Unknown 6
Qmed	4.45	2.29	1.17	0.04	0.82	2.29	0.04	0.07

A.5.4 Institute of Hydrology Report 124 Method

The IH 124 Report examined the response of small catchments, less than $25km^2$, 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 AREA0.89 SAAR1.17 SOIL2.17 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)

QBAR has an estimated return period of 2.33 years. 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 Qbar was calculated as $1.38m^3/s$ for this catchment.

Table A-7 shows the results from the calculation of design flows from the different catchment-based methods of the design flow estimation.

Table A-8: IH124 Results

Descriptor	Tolka	Castle	Unknown 1	Unknown 2	Unknown 3	Unknown 4	Unknown 5	Unknown 6
Qmed	3.68	2.18	0.99	0.05	1.34	2.18	0.03	0.04

A.7 Growth Curve Estimation

The preferred methodology for each HEP was again dependent on catchment size. A large degree of research has been carried out on growth factors for the Liffey Catchment under the Eastern CFRAM. It found that for catchment <10km^2 a medium growth curve should be applied. Details of this growth curve are shown in Table A-8.

Table A-9: Medium Growth Curve for Catchment area less than 10km2

	Q2	Q5	Q10	Q20	Q50	Q100	Q200	Q1000
Medium Growth Curve	1.00	1.452	1.797	2.18	2.78	3.323	4.04	6.04

For catchments greater than 10km^2 and less than 200km^2 an individual growth curve should be derived based on FSU pooling analysis. The growth for HEP's with a catchment area greater than 10km^2 were calculated using the FSU portal and details of the distribution selected are shown below. The pooling group for HEP was based on an euclidian dataset.

Consideration was given to the use of the gauge record on the Tolka River at Clonee (09003) for development of growth curve factors, however the gauge was a staff gauge only, which means records are only available when someone was there measuring flow. It was an EPA gauge in operation from 1976 to 1991. This period is too short of a record to get a reasonable frequency curve that you would be more confident of than a pooled growth curve.

Therefore the Medium Growth Curve estimation method has been applied in preference to the Clonee Gauge.

A.8 Hydrograph Shape

Inflow hydrograph shapes for the Tolka, Castle Stream and the unnamed watercourses have been developed from the Flood Studies Report (FSR) rainfall runoff method. This approach has been tested and, with the exception of a few gauges, this found the FSR approach to provide the best fit against gauge data, with the exception of a few gauges across the WCFRAM area. In the absence of gauge data in this location, the rainfall runoff method is appropriate. Inflows are located at the upstream limit of each watercourse.

The FSR method, applied using a uniform design storm for all sub-catchments within a model, imposes a structure on the model inflows with realistic relative timings of the hydrographs. This avoids the need to apply the FSU regression model for relative timings of hydrographs at a confluence; an approach which is associated with a large standard error. Because the FSR method is being used only to control the shape of the hydrographs rather than the magnitude of the peak flows (which are based on the HEPs), there is no benefit to identifying a critical storm duration, i.e. one that results in the highest peak flow or water level. The hydrograph shapes applied on each watercourses are shown in Figure A-4.

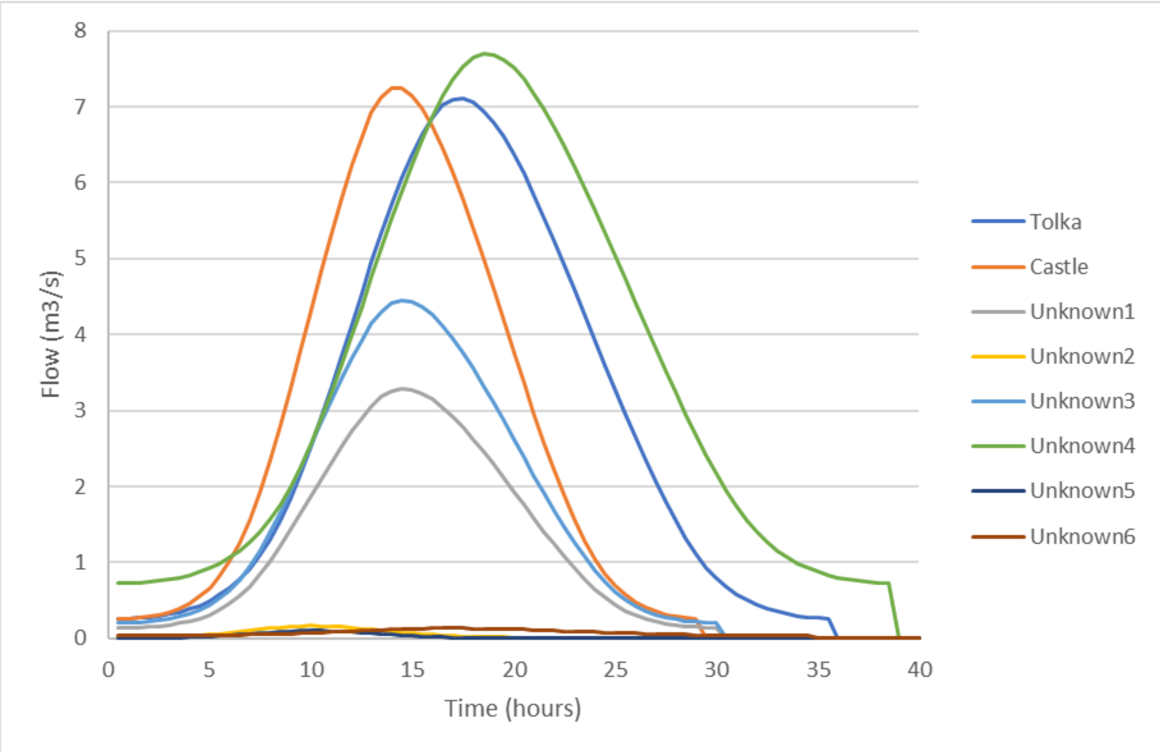


Figure A-4: Inflow Hydrograph Profiles

A.9 Lateral Catchments

Lateral catchment flow is expected to respond quicker and the UKN3 hydrograph shape has been scaled based on the top-up flows required to match at HEPs downstream.

A.10 Summary of proposed hydrology method

As agreed with the OPW for catchments greater than 10km^2, the proposed hydrology method is to apply the pivotal factor for the Ashbourne Gauge to inflows and HEPs upstream of the Tolka River and Castle Stream confluence. The pivotal factor for the Botanical Gardens, adjusted to reduce urban extent, is applied downstream of the confluence. Catchments less than 10 km^2 will continue to be developed from IoH124 methodology.

Pooled growth curves are to be applied for all inflows based on catchment size. Catchments greater than 10km^2 and less than 200km^2 will have an individual growth curve developed using the FSU portal. For catchments smaller than 10km^2 a medium growth curve will be applied.

Table A-10 summarises the catchment inflows provided within the model and Table A-11 the lateral inflows. Table A-12 and Table A-13 present the HEP check flows using the Ashbourne and Botanic Gardens gauge respectively. Note, the only HEP located downstream of the Tolka River - Castle Stream Confluence is TOLK_007.

A.11 HEP Summary Flows - Current Scenario

Table A-10: Catchment Inflows

HEP	Area	FSU Node	Method	Distribution	Pivotal Site	Q2	Q5	Q10	Q20	Q50	Q100	Q200	Q1000
CAST_001	9.84	09_1487_4	IoH124	n/a	n/a	2.18	3.17	3.92	4.75	6.06	7.24	8.81	13.17
UKN1_001	6.58	09_1654_3	IoH124	n/a	n/a	0.99	1.44	1.78	2.16	2.75	3.29	4.00	5.98
UKN2_001	0.25	n/a	IoH124	n/a	n/a	0.05	0.07	0.09	0.11	0.14	0.17	0.20	0.30
UNK5_001	0.13	n/a	IoH124	n/a	n/a	0.03	0.04	0.05	0.07	0.08	0.10	0.12	0.18
TOLK_001	18.58	09_109_4	FSU	GLO	Ashbourne	2.32	3.26	3.97	4.77	6.00	7.11	8.42	12.44
UKN4_001	15.35	09_549_15	FSU	GLO	Ashbourne	2.27	3.27	4.05	4.94	6.37	7.70	9.29	14.37
UKN3_001	4.93	09_439_10	IoH124	n/a	n/a	1.34	1.95	2.41	2.92	3.73	4.45	5.41	8.09
UKN6_001	1.03	09_1486_1	IoH124	n/a	n/a	0.04	0.06	0.07	0.09	0.11	0.13	0.16	0.24

Table A-11: Lateral Inflows

HEP	Q2	Q5	Q10	Q20	Q50	Q100	Q200	Q1000
Tolka Lateral	3.8	4.9	5.4	5.41	5.42	5.43	5.44	5.45
Tolka Lateral Downstream	3.6	3.7	3.8	4.26	4.27	4.275	4.28	4.285
Castle Lateral	2.8	3.8	5	5.4	5.45	5.48	5.49	5.5

Table A-12 HEP Check Flows - ASHBOURNE Pivotal Site (08007)

HEP	Area	FSU Node	Method	Distribution	Q2	Q5	Q10	Q20	Q50	Q100	Q200	Q1000
UKN1_002	7.16	09_1654_4	IoH124	n/a	1.02	1.48	1.83	2.22	2.84	3.39	4.12	6.16
CAST_002	17.73	09_469_1	FSU	GEV	3.2	4.78	5.96	7.2	8.98	10.47	12.08	16.41
CAST_003	18.89	09_469_3	FSU	GEV	3.39	4.96	6.12	7.33	9.06	10.48	12.02	16.10
CAST_004	19.63	09_490_3	FSU	GEV	3.59	5.25	6.47	7.75	9.58	11.08	12.71	17.03
TOLK_002	34.02	09_121_1	FSU	GLO	4.61	6.31	7.55	8.88	10.86	12.6	14.57	20.31
TOLK_003	39.93	09_128_1	FSU	GLO	5.75	7.97	9.6	11.37	14.06	16.43	19.16	27.25
TOLK_004	40.81	09_128_3	FSU	GLO	5.85	8.11	9.77	11.57	14.3	16.72	19.5	27.73
TOLK_005	42.20	09_128_5	FSU	GLO	5.98	8.28	9.97	11.82	14.61	17.07	19.91	28.32
TOLK_006	43.15	09_226_2	FSU	GLO	6.13	8.44	10.13	11.97	14.76	17.23	20.06	28.45
TOLK_007	65.94	09_1414_2	FSU	GEV	8.95	12.53	15.01	17.47	20.8	23.39	26.06	32.61

Table A-13: HEP Check Flows - Botanic Gardens Pivotal Site ()

HEP	Area	FSU Node	Method	Distribution	Q2	Q5	Q10	Q20	Q50	Q100	Q200	Q1000
UKN1_002	7.16	09_1654_4	IoH124	n/a	1.02	1.48	1.83	2.22	2.84	3.39	4.12	6.16
CAST_002	17.73	09_469_1	FSU	GEV	5.60	8.35	10.42	12.61	15.74	18.32	21.12	28.69
CAST_003	18.89	09_469_3	FSU	GEV	5.94	8.67	10.68	12.82	15.85	18.34	21.01	28.13
CAST_004	19.63	09_490_3	FSU	GEV	6.29	9.18	11.31	13.58	16.78	19.42	22.25	29.79
TOLK_002	34.02	09_121_1	FSU	GLO	8.07	11.06	13.24	15.58	19.05	22.03	25.51	35.59
TOLK_003	39.93	09_128_1	FSU	GLO	10.07	13.99	16.81	19.93	24.56	28.79	33.52	47.72
TOLK_004	40.81	09_128_3	FSU	GLO	10.24	14.24	17.10	20.28	24.99	29.29	34.11	48.55
TOLK_005	42.20	09_128_5	FSU	GLO	10.47	14.55	17.48	20.73	25.55	29.94	34.86	49.63
TOLK_006	43.15	09_226_2	FSU	GLO	10.73	14.81	17.71	20.93	25.87	30.16	35.10	49.80
TOLK_007	65.94	09_1414_2	FSU	GEV	15.67	21.94	26.33	30.56	36.35	40.90	45.60	57.04

A.12 Hydraulic Model Validation

Where possible the model results were checked against HEP determined flows downstream to ensure they were within an acceptable range. There are a number of complex hydraulic effects within the model (there are numerous locations of out of bank flow and cross-catchment flow) which makes the process of anchoring the model flows to hydrological estimates difficult.

The hydraulic model flows extracted from the model for each of the HEPS are shown in Table A-14. As is consistent with the hydrology method, flows within the model transition from use of the Ashbourne pivotal gauge on both the Castle Stream and the Tolka River upstream of the confluence to match the flows determined from the Botanic Gardens Gauge downstream of the conflunce.

Table A-14 Hydraulic Model Flows

HEP	Q2	Q5	Q10	Q20	Q50	Q100	Q200	Q1000
CAST_002	3.5	5.5	7.3	9.0	11.6	13.6	16.0	21.7
CAST_003	4.3	6.2	7.7	9.0	11.0	12.7	15.3	21.6
CAST_004	5.7	8.0	10.2	11.6	13.7	15.4	18.0	24.3
TOLK_002	4.6	6.5	7.8	9.6	12.2	14.7	17.5	26.6
TOLK_003	6.2	8.7	10.5	12.4	15.8	18.9	22.4	33.7
TOLK_004	6.3	8.9	10.7	12.5	16.0	19.3	23.0	34.7
TOLK_005	9.2	12.0	13.7	15.3	18.6	21.9	25.7	35.0
TOLK_006	8.9	12.3	14.2	15.7	19.1	22.4	25.7	35.1
TOLK_007	15.9	21.8	26.1	29.5	33.8	38.8	44.6	57.6

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