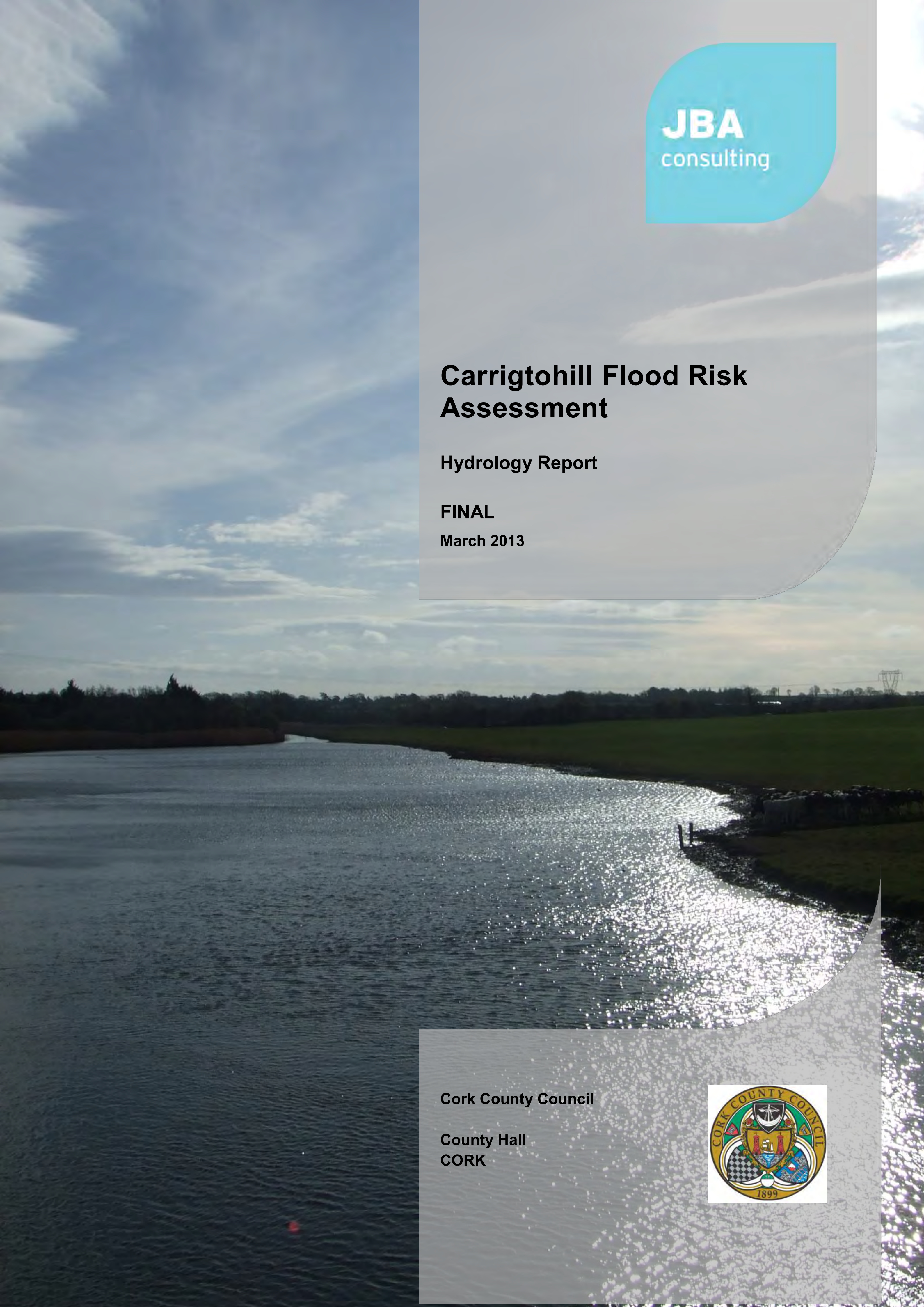

Carrigtohill Flood Risk Assessment

Hydrology Report

FINAL

March 2013

Cork County Council

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CORK

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This report describes work commissioned by Cork County Council under the terms of the Contract signed on 24th January 2012. Cork County Council's representative for the contract was Charles Brannigan. Rosalie Scanlon of JBA Consulting carried out this work.

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Purpose

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Abbreviations

1D	One Dimensional (modelling)
AEP	Annual Exceedance Probability
ALTBAR	Mean catchment altitude (m above sea level)
AMAX	Annual Maximum
BFI	Base Flow Index
CFRAM	Catchment Flood Risk Assessment and Management
CFRAMS	Catchment Flood Risk Assessment and Management Study
DTM	Digital Terrain Model
EPA	Environmental Protection Agency
FARL	Index of flood attenuation due to reservoirs and lakes
FEH	Flood Estimation Handbook (UK)
FRA	Flood Risk Assessment
FSR	Flood Studies Report
FSU	Flood Studies Update
GEV	General Extreme Value Distribution
GL	General Logistic Distribution
HEP	Hydrological Estimation Point
ID	Identifier
IH	Institute of Hydrology
MSL	Mean sea level
OPW	Office of Public Works
Q100	Flow at the 100-year return period
Q1000	Flow at the 1000-year return period
Qmed	Median Annual Flood (with return period 2 years)
SAAR	Standard Average Annual Rainfall (mm)
URBEXT	FEH index of fractional urban extent
WINFAP-FEH	Windows Frequency Analysis Package - FEH version

1 Introduction

1.1 Commission

Cork County Council appointed JBA Consulting to undertake a flood risk assessment study at Carrigtohill, Co. Cork, under the terms of the Contract signed on 24th January 2012.

Under the EU Floods Directive, a national Catchment Flood Risk Assessment and Management (CFRAM) programme has been rolled out to review flood risk across the country and produce flood hazard mapping and flood risk management plans. The Lee CFRAMS was the first pilot study and a Catchment Flood Risk Management Plan (CFRAMP) was published in February 2010. One of the recommendations of this plan stated that ''*More detailed assessment is required in Carrigtohill due to the nature of the watercourses, on-going development and work recently undertaken by Cork County Council.''*

This study is also important in terms of planning and development management and will be used to inform decision making for the Carrigtohill Masterplan and Midleton Local Area Plan.

This study consists of a Detailed Flood Risk Assessment, analysing flood risk for a range of scenarios but does not include a Flood Risk Management Plan.

1.2 Study Context

Carrigtohill is a commuter town located 11km east of Cork City on the main Cork to Waterford N25 national route (as shown in Figure 1-1). The town has experienced extensive development in recent years, in part supported by the re-opening of the rail line with a new station in Carrigtohill.

The study area of Carrigtohill is located adjacent to Cork Harbour and the flood risk assessment will consider the risk from fluvial and tidal sources as well as appraising the risk associated with other local features such as the recently constructed Slatty pumping station, tidal gates at Slatty Bridge, flow siphons at the rail line and other culverts and bridges in the village.

The purpose of this report is to detail the hydrology assessment undertaken for Carrigtohill and present the design flows to be used as inputs to the hydraulic modelling. The impact of local development on surface water runoff and flow in the receiving watercourses is also considered.

The report will review existing data relating to flooding, including previous studies and local reports, historical flood records and anecdotal evidence from local landowners and residents.

This report does not intend to replicate the work undertaken as part of the Lee CFRAM, but will review and update where necessary, based on recent updates to the FSU research and other data made available since the finalisation of the Lee Hydrology Report in 2008.

The hydrological analysis in this Carrigtohill FRA study will consider additional local watercourses not covered under the Lee CFRAMS and in addition, due to a strong groundwater influence, a hydro-geological analysis has been undertaken. The hydrogeology is reported on separately and a copy is included as an Appendix to the Main Report.

Figure 1-1 Location Map

2 Data Review

2.1 Previous Studies

The Lee CFRAMS was the first pilot study, for the national CFRAM programme and Halcrow Group Ltd. were appointed as lead consultants in August 2006. The Lee CFRAMS covered the River Lee catchment and included the Owenacurra, Glashaboy and Owenboy river catchments to the east. An extract from the Lee CFRAMS, showing the areas included in the hydraulic modelling is reproduced in Figure 2-1 below.

Under the Lee CFRAMS, a series of reports were completed documenting the work undertaken at the various stages of the study and the methodology applied. These reports are available for download on the internet at www.leecframs.ie. The Lee CFRAMS Hydrology Report was finalised in April 2008.

2.2 Flood History and Local Information

The OPW hosts a National Flood Hazard Mapping website[1] that makes available information on areas potentially at risk from flooding. This website provides information on historical flood events across the country. Information is provided in the form of reports and newspaper articles which generally relate to rare and extreme events. It is envisaged that any reports of significant flooding in future years will be captured on this website.

While significant flooding was reported in the Lee Catchment in 2009, based on the information collated on the website there are no reports of significant flooding in Carrigtohill. It is however noted that the website may not hold all the relevant information as it relies on information being supplied to the OPW for inclusion. The website indicates the presence of Turloughs in the Ballyadam area.

From other data sources, there is evidence of flooding in Carrigtohill. RPS prepared a report on the flooding that occurred on the Castlelake site in November 2009 and the Community Council made a submission to the Council in regard to the issue of flood risk in 2010.

Consultation was held with Cork County Council Local Area Engineers, OPW regional engineers, member of the Carrigtohill Community Council and a number of local landowners. The consultation identified areas that have experienced flooding in past and provided some information, in the form of photos and anecdotal evidence, to help quantify the extent of the flooding.

2.3 LIDAR

LIDAR data flown as part of Lee CFRAMS in June 2005 / 2006 was provided for the study. However consultation with the OSi revealed that for the majority of the area LIDAR was flown as recently as March 2011. Due to the recent extensive development in Carrigtohill it was recommended to Cork County Council that the more recent data was obtained for the study. The LIDAR was used to help determine the physical catchment descriptors for the catchment and is also a major component of the 2D hydraulic modelling. (The hydraulic modelling is detailed in a separate report).

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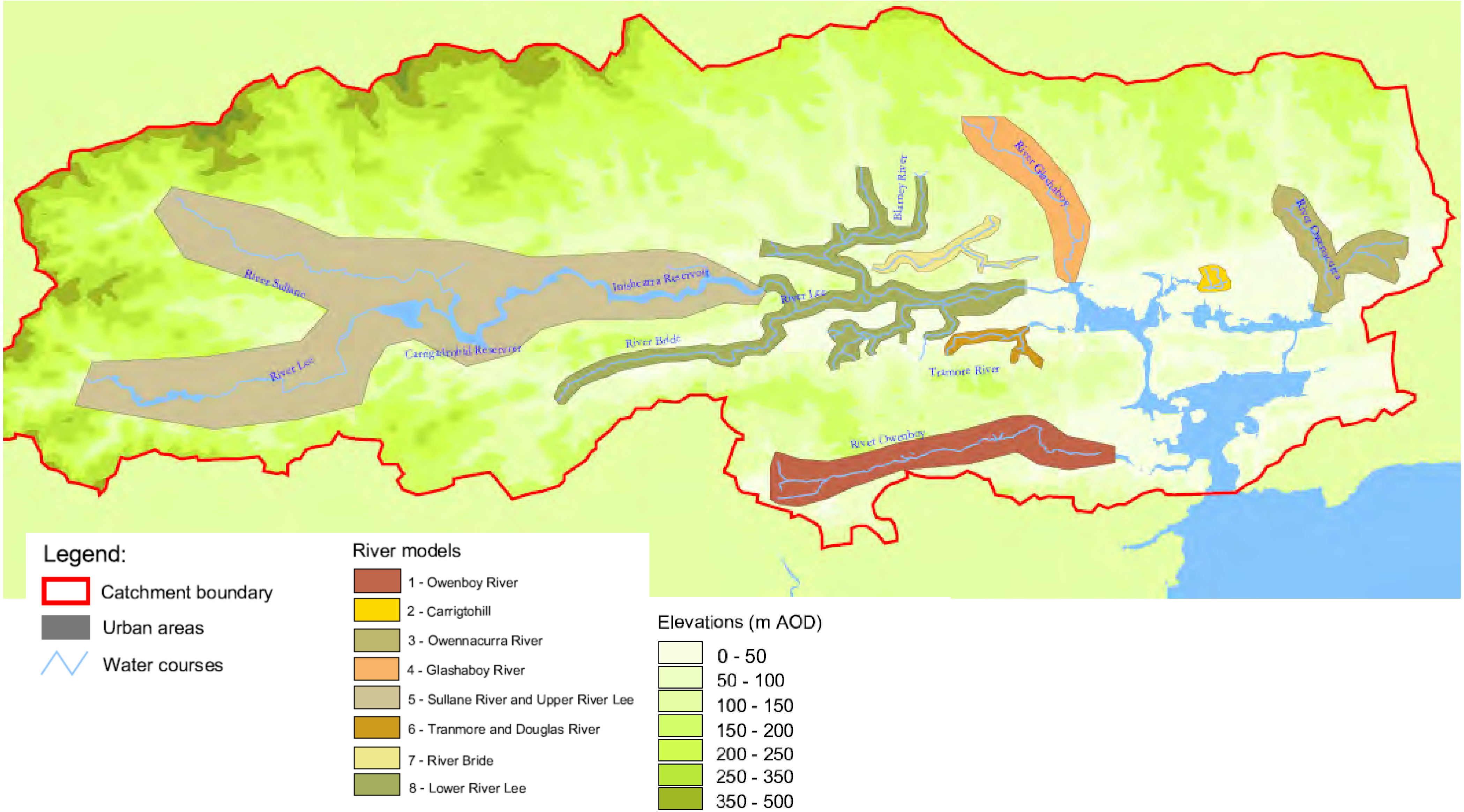
[1] www.floodmaps.ie

Figure 2-1 Lee CFRAMS Study Area (extract taken from Lee CFRAMS report)



3 Hydrometric & Meteorological Analysis

3.1 FSU Work Package

The meteorological analysis undertaken for the Lee CFRAMS followed the methodology included in the Flood Studies Report (FSR) Volume II Meteorological Studies approach.

Since the publication of the Lee CFRAMS hydrology report, Work Package 1.2 (WP1.2) of the Flood Studies Update has been completed. This research undertaken by Met Éireann produced a grid of parameters that summarise the rainfall depth-duration-frequency relationship, allowing point estimation of point rainfall frequencies for a range of durations for any location in Ireland.

3.2 Approach for this Study

The Lee CFRAMS rainfall growth curve was developed from available rainfall records from 29 meteorological stations with records of more than 10 years, and compared with FSR growth curves. This was also compared with preliminary results of the FSU and the Lee CFRAMS recommended the use of FSU rainfall data based on their findings. In line with the Lee CFRAMS, the Carrigtohill FRA hydrology uses the rainfall grid data developed by Met Éireann as part of the FSU research.

The Lee CFRAMS completed a rating review for eleven river gauges in the Lee catchment. Where improved ratings were recommended under the Lee CFRAMS these were reviewed and are discussed in Section 3.3 below. This scope of this study did not include a rating review of gauged sites.

There are no rainfall or hydrometric river gauges in the Carrigtohill catchment and therefore further analysis of rainfall and hydrometric data was not undertaken as part of this study.

3.3 Rating Improvements

The Lee CFRAMS carried out a rating review for eleven gauges and two of these gauges have been identified in the FSU pooling group for the hydrology of the Carrigtohill catchment (see Section 5.2). These are:

- **19020 Ballyedmond** - The gauge is located at an open channel section, at the interchange between a steep sided valley and open flat floodplains. The rating produced as part of the Lee CFRAMS correlated well with the established EPA rating. Applying the Lee CFRAMS rating to the most recent years of data (2009, 2010) resulted in less than 2% difference in the estimated flows compared with EPA AMAX flows.
- **19001 Ballea Bridge Upper** - This gauge consists of a crump weir located approximately 3km downstream of Ballea Bridge. The OPW have confirmed that there is some uncertainty in flow estimation at this location and the OPW rating is currently under review by the OPW. Bypassing of the channel occurs during high flows, and water backs up at the bridge. The Lee CFRAMS revised rating shows a significant departure from the OPW rating at high flows.

Since the publication of the Lee CFRAMS hydrology report, the Lee Catchment experienced significant flooding in November 2009. The water levels recorded at Ballyedmond and Ballea Bridge did not exceed the highest levels on record for previous years and so do not have an impact on the rating curve and the statistical analysis confirms that the recent AMAX values do not have a significant impact on the estimation of Qmed.

A rating is dynamic and physical changes in the channel will have an impact on the stage - flow relationship. Ballyedmond is located at an open river channel section, and it is possible that the rating developed for the current scenario would not be appropriate for the gauged site 20 years ago, for example. Where a gauge station is located at a flow control structure there can be more confidence that the rating will remain unchanged over time. However, at Ballea Bridge gauge, which is located at a crump weir, both the OPW and the Lee CFRAMS note that there is uncertainty over the rating. This may be attributed to backing up at the bridge and bypassing of the channel in high flows.

4 Index Flood Estimation

4.1 Overview

The Flood Studies Report (FSR) was published by the National Environmental Research Council in the UK in 1975 and has been used extensively for flood flow estimation across Ireland since then. However, the methodology is currently being updated by the Flood Studies Update research programme.

This section will outline the methodology applied to calculate the design flows for the Carrigtohill catchment for use in the hydraulic modelling.

The Flood Studies Update method has been used to determine the design flood flows. However, the flow estimates from other older methods are listed for comparison. (These are presented in Section 4.4).

4.2 FSU Index Flood Estimation

Under the FSU research, Work Package 2.3 (WP2.3) investigated procedures for Flood Estimation in Ungauged Catchments and this research updates the methodologies outlined in Flood Studies Report (FSR), Flood Studies Supplementary Report (FSSR), Institute of Hydrology (IH) 124 and others.

At ungauged sites, the value of Qmed can be obtained from catchment descriptor data through the application of a regression model. As part of the FSU, a multivariate regression equation was developed on the basis of data from 199 gauged catchments, linking Qmed to a set of catchment descriptors.

$$\text{Qmed} = 1.237 \times 10^{-5}\, \text{AREA}^{0.937}\, \text{BFIsoils}^{-0.922}\, \text{SAAR}^{1.306}\, \text{FARL}^{2.21}\, \text{DRAIND}^{0.341}\, \text{S1085}^{0.185}\, (1+\text{ARTDRAIN2})^{0.408}$$

Where:

- AREA is the catchment area (km^2).
- 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 Schemes
- The Factorial Standard Error (FSE) of $\text{QMED}_{\text{rural}}$ in the above equation is 1.36.

4.2.1 Hydrological Estimation Points

Hydrological estimation points (HEPs) essentially are points at intervals along a watercourse at which flow estimates are derived, based on catchment descriptors. These flow estimates are used to calibrate the model to ensure that the flow is represented along the watercourse. This works well in natural catchments where flow estimation using catchment characteristics is reliable. Flow estimates are calculated at a number of locations along a watercourse. Runoff from land within the modelled reach which will contribute to flow in the main watercourse must be taken into account. For natural catchments with little human influence, flow estimation based on catchment descriptors works well and flow estimation using catchment characteristics is reliable. The location of each flow estimate is known as a hydrological estimation points (HEPs).

In Carrigtohill there are a number of areas where flow is diverted from one sub-catchment to another, either through man-made or geological processes, and therefore flow estimation based on catchment descriptors alone is not appropriate. These are annotated on the map presented in Figure 4-1.

Hydrological estimation points have been selected at a number of locations. Four of these (HEP 01 to 04) will be used as a direct flow input at the upstream extent of the area to be modelled. A map showing the location of the hydrological estimation points is shown below in Figure 4-1. Other points of interest in terms of flow estimation have been identified and are also highlighted on the map. Flows at these locations will be confirmed during the hydraulic modelling phase of the study.

4.2.2 FSU Catchment Descriptors

Catchment descriptors are used to estimate the index flood and this is then scaled upwards to determine flood flows for various annual exceedance probability (return period) scenarios.

As part of Work Package 5.3 of the Flood Studies Update, catchment descriptors were generated at 500m intervals or less, on watercourses across the country.

In the eastern area of the Carrigtohill, due to the relatively small size of the catchment and associated watercourses, catchment descriptors were not automatically generated as part of the FSU work for HEP 03 and 04. These have been calculated manually for this study using the digital terrain model (DTM), ground cover and other information. For these HEPs (HEP 03 and 04), only the catchment descriptors that are a function of the FSU index flood equation have been calculated. These are AREA, BFIsoils, SAAR, FARL, DRAIND, S1085, ARTDRAIN2.

The catchment descriptors at each hydrological estimation points (HEP) are summarised in Table 4-3 and Table 4-4.

4.2.3 Catchment Boundaries

The catchment boundaries for the HEP 01 to 04 have been digitised based on the available mapping and DTM data and are indicated in

Figure 4-2.

4.3 Summary of Index Flood FSU Estimates

The FSU methodology allows consideration of urbanisation in a catchment by applying an urban factor. For the calculation of the flows at each HEP the urban factor is zero as the catchment upstream is rural.

Within the town and development plan area, account will be taken of the urban extent when considering the inflows to the hydraulic model. This will address the impact of extensive development in Carrigtohill area in recent years. The calculation of surface water runoff flows and inclusion in the hydraulic modelling is covered in Section 7.

The index flood (Qmed) for each of the HEPs, as derived from the FSU catchment characteristic method, (equation provided in Section 4.2), is presented in Table 4-1 below.

Table 4-1 Summary of Index Flows

HEP_Ref	HEP 01	HEP 02	HEP 03	HEP04	HEP 05	HEP 06	HEP 07	HEP08
Qmed (m^3/s)	0.75	1.37	1.33	0.75	1.02	1.51	0.76	1.32

4.4 Summary of Other Methods

The Flood Studies Update, as detailed above, is a new method that has been developed to incorporate more Irish catchments and more years of recorded data to develop a flow estimation method with a higher degree of empirical support than the alternatives. The FSU also incorporates catchment descriptors derived from DTM and thematic datasets.

The FSU includes a basic method to derive hydrograph shape. However there are concerns due to the absence of a catchment size or stream length in this FSU approach. These issues have been highlighted at National Technical Coordination Group (NTCG) workshops for the National CFRAM programme. Therefore the FSR Rainfall Runoff methodology has been applied to derive hydrograph shapes for the Carrigtohill study area.

The alternatives to FSU that are included for comparison of Qmed include methods outlined in the Flood Studies Report Report. The Flood Studies Report was issued by the National Environmental Research Council (NERC) in 1975 and aimed to develop standardised methods to estimate flood flows at ungauged locations anywhere in Ireland and the UK. It was the result of seven years of applied research and presented flow estimation techniques derived using real data from a hydrologic network of rivers.

Two basic analytical methods were derived; a regional statistical flood estimation procedure and a rainfall-runoff procedure. The regional statistical approach (incorporating single site analysis) is based on the estimation of an index flood, and uses information from geographically similar sites for flood frequency analysis. The rainfall-runoff method is a conceptual unit hydrograph-based model, which derives flood frequency curves from rainfall characteristics.

Three methods, FSR regional statistical method, Institute of Hydrology (IH) Report 124 equations and the FSR rainfall runoff (unit hydrograph) method have been applied to allow a comparison of flow estimates. These are detailed below.

4.4.1 The FSR Regional Statistical Method

The FSR regional Statistical approach first estimates an index flood; namely the mean annual flood (QBAR) and then multiplies the index flood by an appropriate growth curve factor for the target return period. The index flood can be estimated using catchment characteristics, but it is preferable, where possible to improve this estimate using local data or data from a hydrologically similar but more distant analogue site.

The FSR six parameter equation is best for catchments with AREA > 25km2. However, it has been presented here for comparison:

$$\text{QBAR} = \text{C Area}^{0.94}\ \text{StrmFq}^{0.27}\ \text{SOIL}^{1.23}\ \text{RSMD}^{1.03}\ (1+\text{LAKE})^{-0.85}\ S_{1085}^{\ 0.16}$$

Where C = 0.0172 for Ireland.

The StrmFq parameter represents the characteristics of most uncertainty. Due to the size and nature of the watercourses in this catchment, not all watercourse are depicted on the OS mapping. A review of the number of channel elements provided in the FSU digital catchment descriptors were not considered appropriate for this calculation and gave unusually high values of flow. The StrmFq was re-calculated but caution is advised.

For the six parameter FSR equation the standard error is 0.168 and the factorial standard error is 1.47. This gives a 68% confidence interval. A factorial standard error of 2.17 is applied to the estimate of QBAR for a 95% confidence interval.

4.4.2 The Institute of Hydrology Report 124

The Institute of Hydrology Report No.124 published in June 1994, aimed to provide a more accurate estimation of flood flows for small, lowland catchment and part-urban catchments in particular. The equation for QBAR detailed in this report is as follows:

$$\text{QBAR, rural} = 0.00108 \times \text{AREA}^{0.89} \times \text{SAAR}^{1.17} \times \text{SOIL}^{2.17}$$

The Institute of Hydrology Report No. 124 indicates the three parameter equation has a standard factorial error of 1.65. A factor of 2.73 gives a 95% confidence interval.

4.4.3 The Rainfall Runoff Method

The FSR Rainfall-Runoff method relies on rainfall frequency statistics to provide inputs to a model, which 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.

Where possible, the shape of the unit hydrograph and response of the catchment is determined from the analysis of recorded data in the catchment. If, as in this case, recorded data is unavailable then the necessary parameters to carry out the Rainfall-Runoff method are estimated using catchment characteristics.

The unit hydrograph method was tested on 36 Irish catchments and was found to overestimate flood flows. For the 25 year flood flow this method was found to overestimate 26 out of 36 catchments by a mean value of 164% (Bree et al.)

4.4.4 Summary

The estimates for the index flood for each method are presented below in TABLE XX. With the exception of the rainfall runoff method (which is known to overestimate flows) the FSU flow estimates compare well and for 3 of the 4 HEPs giving more conservative flows than the alternatives.

Table 4-2 Summary of Flow from Various Methods

HEP	FSR Statistical	IH 124	FSR RR*	***FSU***
01	0.68	0.60	1.44	***0.75***
02	1.28	1.30	2.81	***1.37***
03	0.89	0.92	2.73	***0.99***
04	1.02	0.70	1.44	***0.82***
	**** Note: FSR RR is known to overestimate flows***			

4.5 Conclusion

The flow estimation method used in this study to derive the index flood is the recently researched Flood Studies Update. This method when compared with similar empirical methods gives slightly higher results (with the exception of the Rainfall Runoff method which is known to overestimate flows).

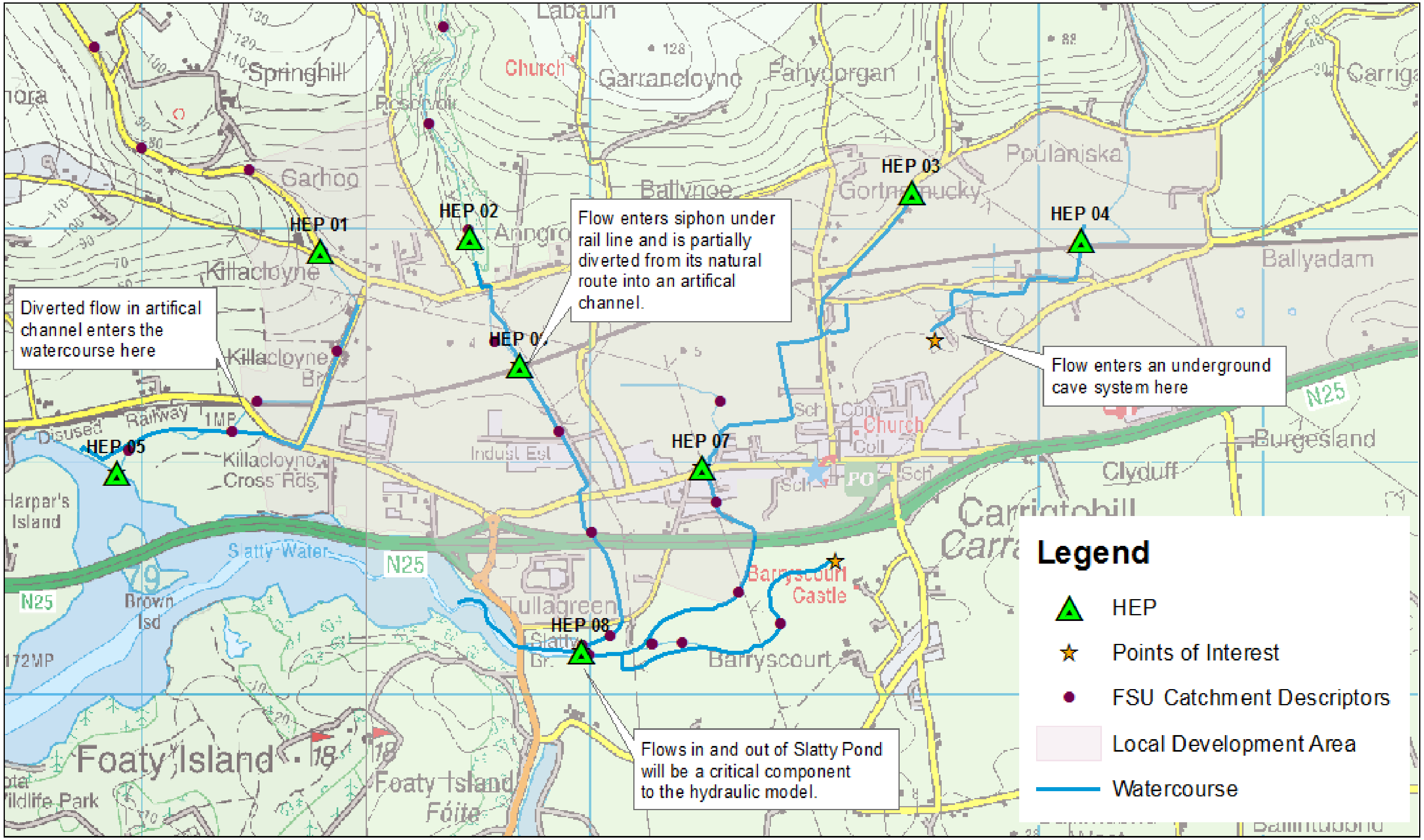
Table 4-3 Catchment Descriptors for HEP 01 to 04

	HEP 01	HEP 02	HEP 03	HEP 04	Description	Unit
NODE_ID	19_1554_4	19_1733_3	N/A	N/A	FSU node identifier	
NODE_EAST	179,806	180,280	182,433	183,188	Easting of node in Irish National Grid	m
NODE_NORTH	73,904	74,455	74,159	73,958	Northing of node in Irish National Grid	m
DTM_AREA	2.279	5.71	4.043	2.981	Catchment area from DTM	km^2
MSL	2.14	3.611	1.1	2.84	Main Stream Length	km
NETLEN	2.142	4.77	-	-	Length of entire stream network in catchment	km
STMFRQ	1	5	-	-	Number of discrete channel elements	
DRAIND	0.94	0.835	1	0.87	Drainage density; relates to the length stream network and catchment area (NETLEN/AREA)	
S1085	38.965	27.320	75	21	Main stream slope (as per FSR)	m/km
TAYSLO	30.805	28.302	-	-	Taylor Schwartz slope; alternative slope term	
ARTDRAIN2	0	0	0	0	Percent of catchment river network benefitting from arterial drainage schemes	%
ARTDR_LEN	0	0	-	-	Length of stream network included	%
FARL	1	0.967	1	1	Flood attenuation from lakes and reservoirs (range 0 - 1)	
CENTE	178910	180310	-	-	Easting of catchment centroid	m
CENTN	74870	76150	-	-	Northing of catchment centroid	m
ALTBAR	104.6	124.5	-	-	Main elevation	m
ALT_MIN	19.6	0	-	-	Minimum elevation	m
ALT_MAX	155.2	190.7	-	-	Maximum elevation	m
SAAR	1078.2	1088.5	1080	1080	Standard annual average rainfall	mm
SAAPE	538.69	532.4	-	-	Standard annual average potential evaporation	mm
FORMWET	0.64	0.64	-	-	Average catchment wetness index	
URBEXT	0	0	-	-	Urban extent from CORINE data	%
PEAT	0	0	-	-	Peat cover extent from CORINE data	%
ALLUV	0	0	-	-	Floodplain alluvial extent from national dataset of soil parent material	%
FOREST	1.36	7.94	-	-	Forest cover extent from CORINE data, Coillte Teoranta database and FIPS (Forest Inventory Parcel System)	%
ARTDRAIN	0	0	-	-	Percentage of the catchment that is categorised as benefitting land	%
PASTURE	100	95.01	-	-	Grassland, pasture agricultural cover extent from CORINE data	%
FAI_PROP	0.040	0.035	-	-	Flood attenuation indicator (range 0 - 1)	
BFISOILS	0.66	0.68	0.68	0.68	Baseflow index from soil type (range 0 - 1)	

Table 4-4 Catchment Descriptors for HEP 04 to 08

	HEP 05	HEP 06	HEP 07	HEP 08	Description	Unit
NODE_ID	19_739_3	19_1733_5	19_1647_2	19_1693_2	FSU node identifier	
NODE_EAST	178886	180568	181557	180990	Easting of node in Irish National Grid	m
NODE_NORTH	72952	73515	72824	72172	Northing of node in Irish National Grid	m
DTM_AREA	3.249	6.107	8.285	15.05	Catchment area from DTM	km^2
MSL	3.928	4.612	0.966	2.252	Main Stream Length	km
NETLEN	4.073	5.771	0.968	3.387	Length of entire stream network in catchment	km
STMFRQ	3	5	1	3	Number of discrete channel elements	
DRAIND	1.254	0.945	0.117	0.225	Drainage density; relates to the length stream network and catchment area (NETLEN/AREA)	
S1085	31.81	28.82	4.72	1.70	Main stream slope (as per FSR)	m/km
TAYSLO	14.24	20.76	0.33	0.18	Taylor Schwartz slope; alternative slope term	
ARTDRAIN2	0	0	0	0	Percent of catchment river network benefitting from arterial drainage schemes	%
ARTDR_LEN	0	0	0	0	Length of stream network included	%
FARL	1	0.969	1	1	Flood attenuation from lakes and reservoirs (range 0 - 1)	
CENTE	179120	180310	182220	182850	Easting of catchment centroid	m
CENTN	74380	75710	74860	74190	Northing of catchment centroid	m
ALTBAR	77.5	118.8	75	53	Main elevation	m
ALT_MIN	0	0	2	0	Minimum elevation	m
ALT_MAX	155.2	190.7	164.7	164.7	Maximum elevation	m
SAAR	1072.5	1087.8	1080.7	1070.1	Standard annual average rainfall	mm
SAAPE	540.2	533.1	541.9	546.0	Standard annual average potential evaporation	mm
FORMWET	0.64	0.64	0.63	0.63	Average catchment wetness index	
URBEXT	2.18	0	2.69	4.42	Urban extent from CORINE data	%
PEAT	0	0	0	0	Peat cover extent from CORINE data	%
ALLUV	0	0	0.01	5.97	Floodplain alluvial extent from national dataset of soil parent material	%
FOREST	1.04	9.58	1.81	1.19	Forest cover extent from CORINE data, Coillte Teoranta database and FIPS (Forest Inventory Parcel System)	%
ARTDRAIN	0	0	0	0	Percentage of the catchment that is categorised as benefitting land	%
PASTURE	97.78	93.56	97.31	93.81	Grassland, pasture agricultural cover extent from CORINE data	%
FAI_PROP	0.200	0.051	0.013	0.051	Flood attenuation indicator (range 0 - 1)	
BFISOILS	0.66	0.68	0.67	0.69	Baseflow index from soil type (range 0 - 1)	

Figure 4-1 HEPs and Other Flow Points of Interest



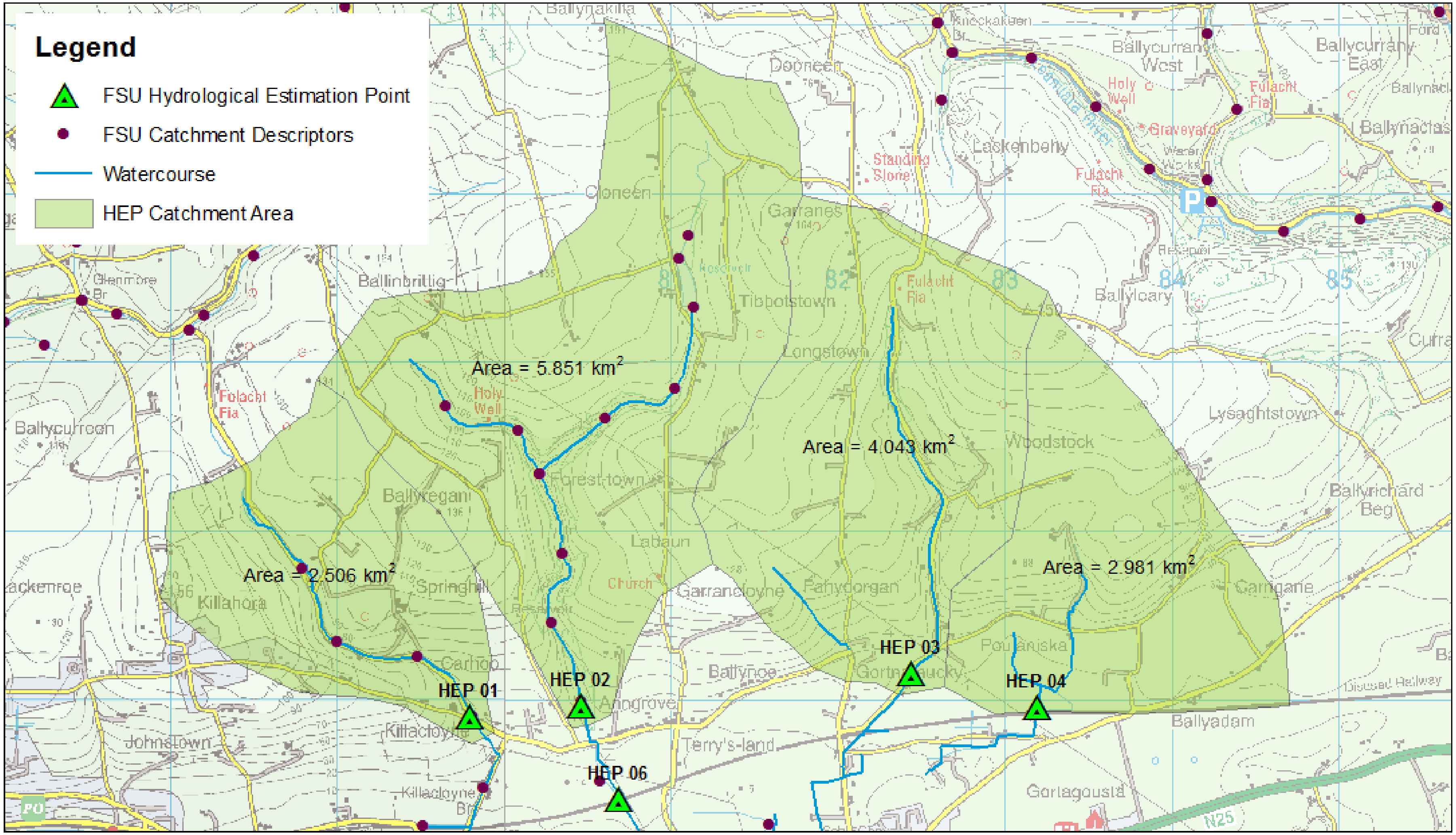
Diverted flow in artifical channel enters the watercourse here

Flow enters siphon under rail line and is partially diverted from its natural route into an artifical channel.

Flow enters an underground cave system here

Flows in and out of Slatty Pond will be a critical component to the hydraulic model.

Figure 4-2 Catchment Areas



4.6 FSU Data Transfer / Pivotal Site Analysis

The FSU recommends use of donor catchment or pivotal gauges to improve estimates of the index flood at ungauged sites. Based on the methodology of the FSU the catchment characteristics-based estimate of Qmed at each subject site is scaled by the ratio of observed and estimated Qmed values at the donor site.

$$\text{Qmed}_A = \text{Qmed}_{(\text{estimated})A} \times \frac{\text{Qmed}_{(\text{measured})B}}{\text{Qmed}_{(\text{estimated})B}}$$

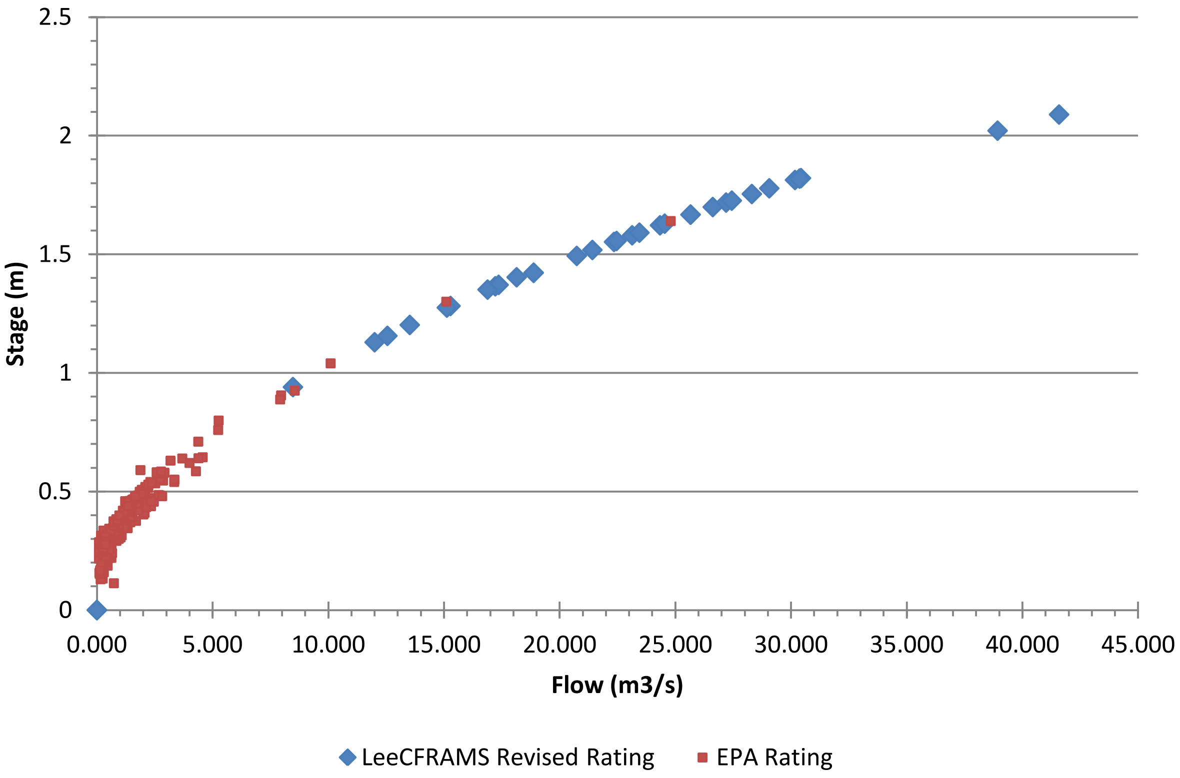
Where QmedA is the index flood at A, the ungauged site and subscript B refers to the donor site.

The pivotal gauge for the Carrigtohill catchment was selected from the nearby FSU gauging stations in Class A that are similar in characteristics and are within the FSU pooled group for the Carrigothill catchment (see Section 5.2). The FSU classification is as follows:

- Class A (including A1 and A2) - suitable for flood frequency analysis up to 2 times Qmed;
- Class B - suitable for flow estimation up to Qmed;
- Class C - possible to extrapolate.

Of the nearby gauges, two potential pivotal gauges are identified; 19001 Ballea Bridge and 19020 Ballyedmond. As detailed in Section 3.3 above, the OPW confirmed that there is some uncertainty in flow estimation at Ballea Bridge. Based on this information, Ballyedmond has been selected as the most suitable gauge for transfer of data. This gauge is located in the Owencurra River catchment and has 28 years of data. The location of Ballyedmond gauge in relation to the Carrigothill study area is indicated in Figure 4-4 and the Rating Curve for Ballyedmond is presented in Figure 4-3 below.

Figure 4-3 19020 Rating Curve



The index flood at Ballyedmond is presented in Table 4-5 below. The adjustment factor based on the observed flow using the EPA rating is 1.44 and using the Lee CFRAM rating is 1.42.

Table 4-5 Index Flood at Donor Site

	EPA (measured)	Lee CFRAM (measured)	FSU Equation (estimated)	Adjustment Factor	
				EPA	Lee CFRAMS
Qmed (m3/s)	23.157	22.797	16.035	1.44	1.42

The adjustment factors were applied to the Qmed FSU estimates and the adjusted flows at all the HEPs are presented below.

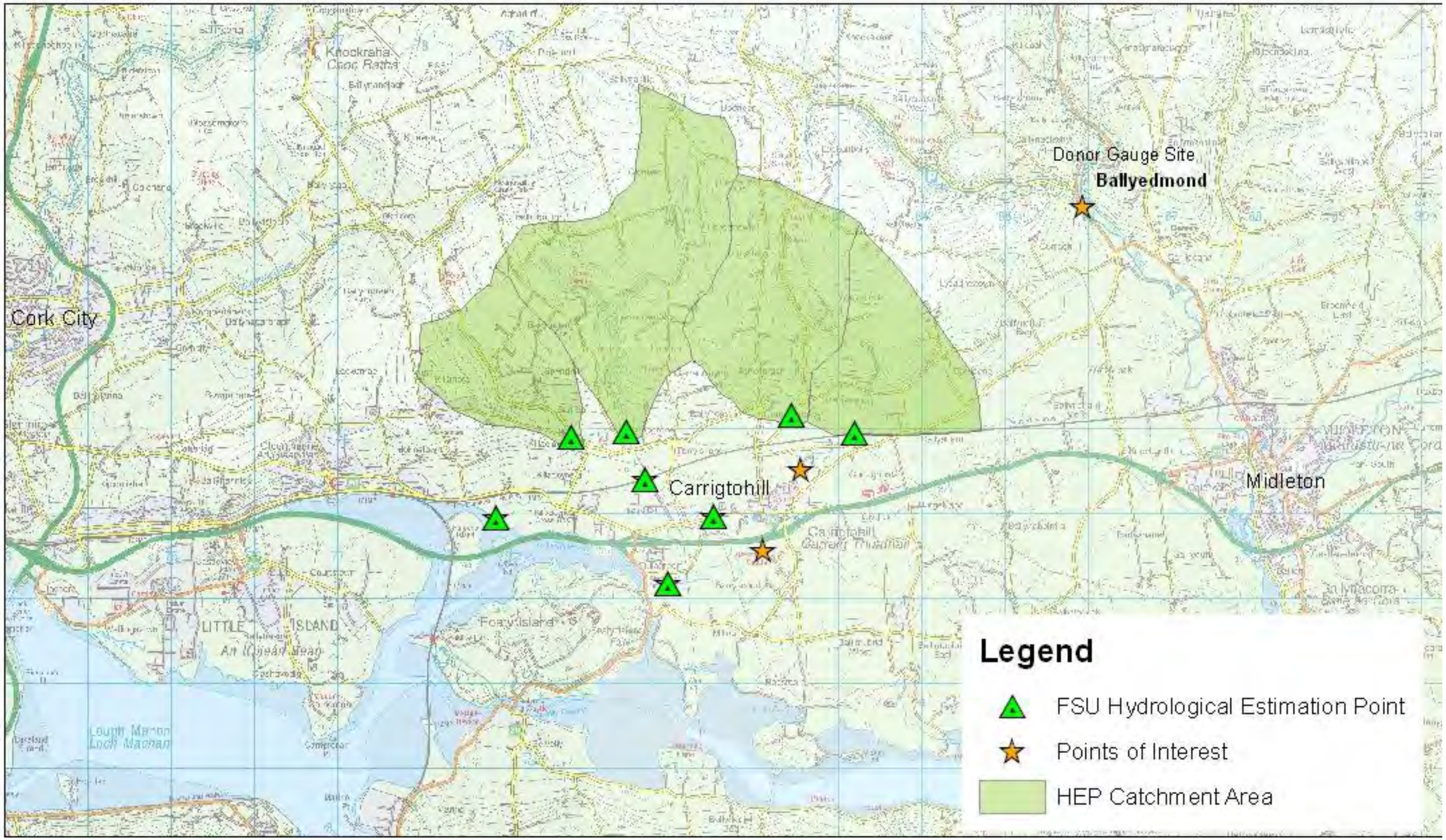
Table 4-6 Comparison of Estimated and Adjusted Qmed at HEPs

HEP_Ref	HEP 01	HEP 02	HEP 03	HEP 04	HEP 05	HEP 06	HEP 07	HEP 08
Qmed estimated	0.8	1.4	1.3	0.8	1.0	1.5	0.8	1.3
Qmed adjusted (Lee CFRAMS)	1.1	2.0	1.9	1.1	1.4	2.1	1.1	1.9
Qmed adjusted (EPA)	1.1	2.0	1.9	1.1	1.5	2.2	1.1	1.9

As can be seen from the results there is a marginal difference between the calculated flows. The flows selected for use in the study are the flows generated based on the Qmed measured from the EPA rating as this gives a slightly more conservative result.

An increase in Qmed in this part of the country matches FSU Work Package 2.3 findings.

Figure 4-4 Donor Gauge Site Location



5 Flood Frequency Analysis

The aim of flood frequency analysis is to derive a growth factor, which can be used to multiply Qmed to give flows for a required design event.

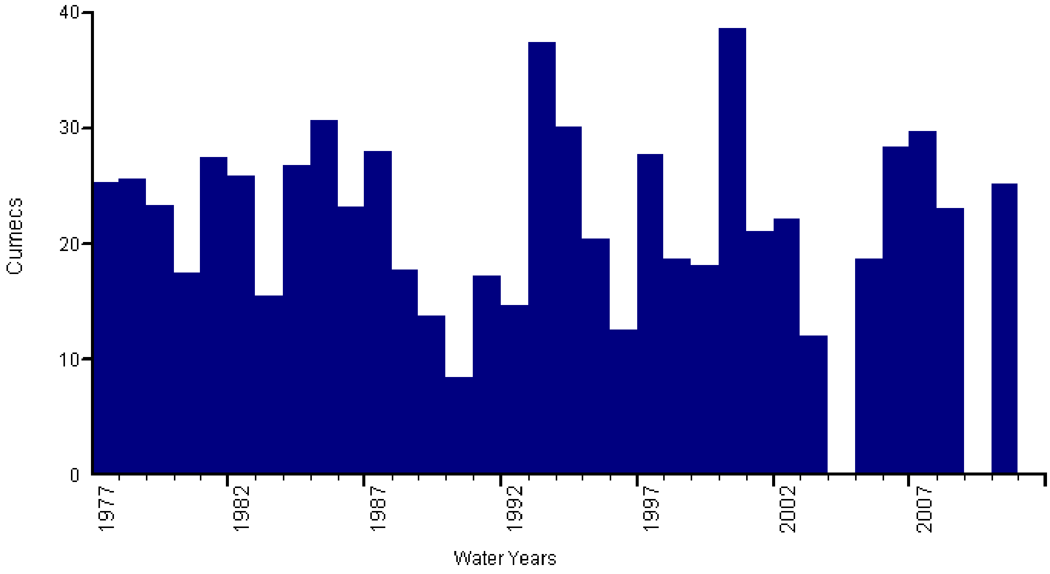
The Qmed estimate is multiplied by a growth factor derived either from the national, regional or pooled growth curve to arrive at the design flood estimate for a particular annual exceedance probability (AEP) or return period flood event.

Work Package 2.2 of the FSU research is based on the analysis of annual maximum flow records at approximately 200 gauging stations throughout Ireland to determine growth factors. Guidance on flood frequency analysis is provided at both gauged and ungauged catchments and the use of growth curves based on regional pooling of data with the use of suitable 3 parameter distributions is recommended for most applications.

5.1 Single Site Analysis

A single site analysis was carried out using the data from the gauge at Ballyedmond for comparison purposes. This gauge is the nearest suitable gauge with a data record of 28 years. The AMAX data for this gauge is presented in Figure 5-1.

Figure 5-1 AMAX Data at Ballyedmond 19020



The software package WINFAP-FEH was used to analyse the data, applying a number of typical statistical distribution methods. The results indicate that the GEV distribution is the best fit.

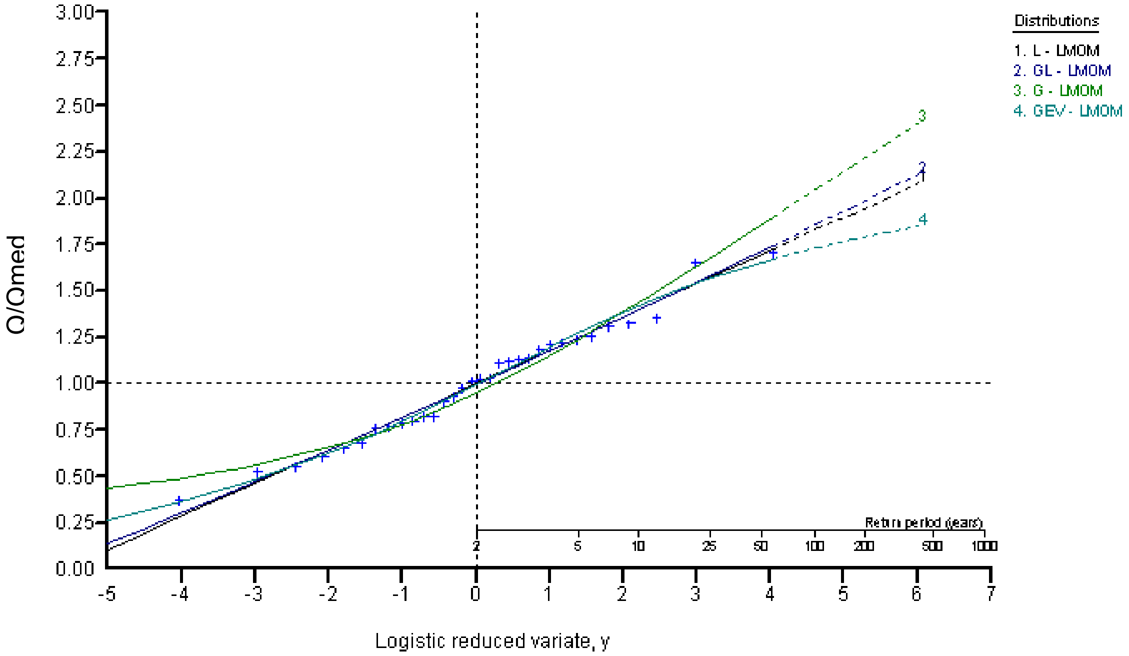
Single site analysis is appropriate where there the single gauge site lies within the study catchment; the analysis has been included for comparison only. In Carrigtohill there are no hydrometric gauges in the study catchment and therefore a pooled group analysis is more appropriate and will consider data from a wider spread of hydrologically similar gauged catchments.

The pooled analysis is discussed in detail in Section 5.2.

Table 5-1 Single Site Analysis Growth Curve Values

Return Period	GEV	GL	Gumbel	Logistic
2	0.993	0.995	0.945	1
5	1.273	1.246	1.239	1.249
10	1.418	1.396	1.433	1.394
25	1.567	1.581	1.678	1.57
* 50	1.657	1.717	1.86	1.698
* 100	1.731	1.853	2.041	1.824
* 200	1.793	1.989	2.221	1.949
* 500	1.86	2.172	2.458	2.114
* 1000	1.902	2.311	2.638	2.238
* Return Period exceeds record length and should be treated with caution.				

Figure 5-2 Single Site Analysis Growth Curve Graph



5.2 Pooling Group Analysis

Following the methods of the FSU Work Package 2.2 (WP2.2), a pooling group analysis was undertaken based on the AREA, SAAR and BFISOILS catchment descriptors for the Carrigtohill catchment.

The distance measure, dij, was applied to identify a suitable pooling group. This distance measure considers the similarity between catchment descriptors (AREA, SAAR and BFISOILS) rather than a geographic distance. Using the 5T rule, the length of the pooling group should be five times the length of the design flood. A data record of more than 500 years was obtained from 14 gauging stations. One common pooling group was used in the analysis for all HEPs across the catchment.

The gauging stations used in the analysis were selected from those rated as A1 and A2 as part of the FSU WP2.2.

Annual maximum (AMAX) data for each gauge was obtained from the OPW and EPA (on behalf of the local authorities) hydrometric stations. Details of the pooling group are presented in Table 5-2. All members of the pooling group are outside the Carrigtohill Catchment.

Table 5-2 Pooling Group Details

Station No	AM Record (years)	AREA (km2)	Source of AMAX	Station Name	Record Available
25034	24	10.77	Westmeath County Council	ROCHFORT	1975 to 2012
25040	20	28.02	North Tipperary County Council	ROSCREA	1960 to 2012
10022	18	12.94	Dun Laoghaire -Rathdown Council	CARRICKMINES	1980 to 2005
6031	18	46.17	Louth County Council	CURRALHIR	1975 to 1991
24022	20	41.21	Limerick County Council	HOSPITAL	1984 to 2012
10021	24	32.51	Dun Laoghaire -Rathdown Council	COMMON'S ROAD	1980 to 2012
19020	28	73.95	Cork County Council	BALLYEDMOND	1977 to 2012
8002	20	33.43	Fingal County Council	NAUL	1977 to 2001
26022	33	61.88	Office of Public Works	KILMORE	1972 to 2009
8005	0	9.17	Fingal County Council	KINSALEY HALL	not on hydronet
16005	30	84	Office of Public Works	AUGHNAGROS S	1976 to 2009
9002	24	34.95	South Dublin County Council	LUCAN	1977 to 2002
25044	33	92.55	North Tipperary County Council	COOLE	1961 to 2012
19001	48	103.28	Office of Public Works	BALLEA	1957 to 2009
14009	25	68.35	Office of Public Works	CUSHINA	1980 to 2009
25027	43	118.87	Office of Public Works	GOURDEEN	1962 to 2009
9010	19	94.26	Dublin City Council	WALDRON'S BRIDGE	1986 to 2012
26018	49	119.48	Office of Public Works	BELLAVAHAN	1956 to 2009

A statistical analysis of the AMAX data was carried out using WINFAP-FEH software package.

The results indicate the pooling group is strongly heterogeneous and so a further review of the group was carried out. This did not highlight any reasons to amend the pooling group.

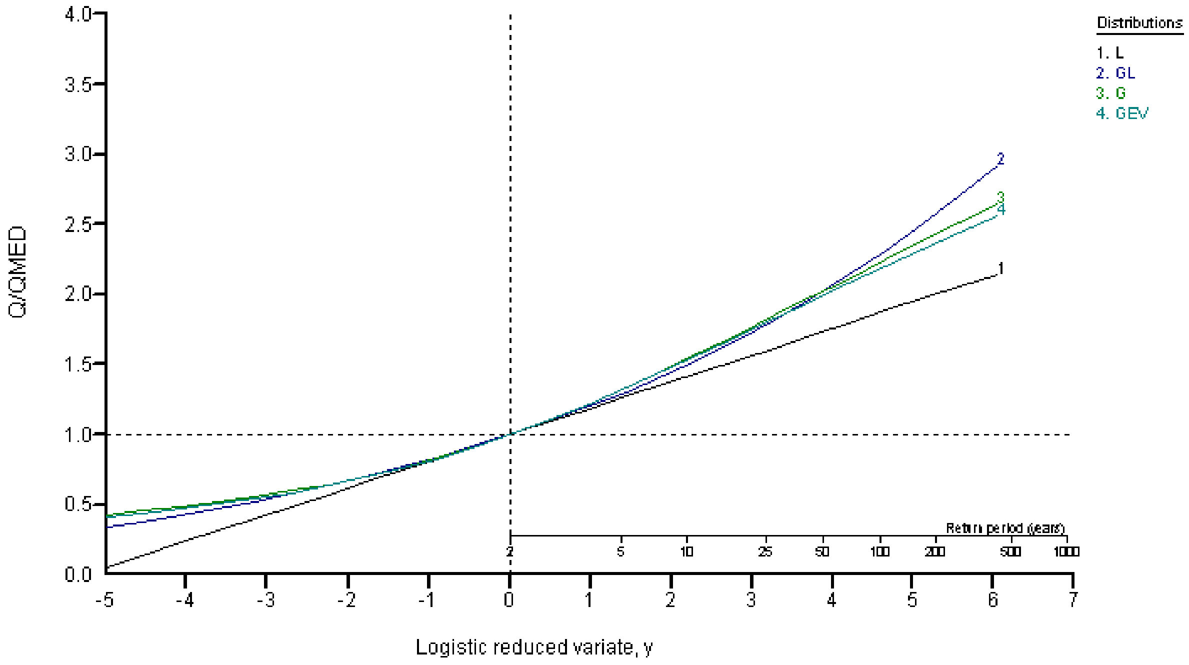
The goodness of fit test shows that the Generalised Extreme Value (GEV) distribution is the best fit.

The growth factors from the GEV statistical distribution of the FSU pooling group correlate well with the growth factors applied in the Lee CFRAMS. The Lee CFRAMS adopted the FEH methodology as the FSU research on pooled analysis was not finalised at the time. The Lee CFRAMS growth curve was based on the GEV distribution of the FEH pooled group for flow less than 50 years and on the FSR standard growth curve for flows greater than a 50 year return period.

Table 5-3 Pooled Analysis Growth Curve Values

Return Period	L	GL	G	**GEV**
2	1	1	1	**1**
5	1.263	1.296	1.329	**1.327**
10	1.416	1.501	1.546	**1.54**
25	1.602	1.788	1.821	**1.804**
50	1.737	2.025	2.025	**1.996**
100	1.871	2.287	2.228	**2.185**
200	2.003	2.577	2.43	**2.37**
500	2.177	3.011	2.696	**2.61**
1000	2.309	3.382	2.897	**2.789**

Figure 5-3 Pooled Analysis Growth Curve



5.3 Design Peak Flows

Based on the results of the statistical analysis, it is recommended to adopt the GEV distribution from the pooled analysis for determining the design flows. These are highlighted in bold in Table 5-3. The final design flows are presented in Table 5-4 below. These are the peak design flows for a return period of 5, 10, 25, 50, 100, 200, 500 and 1,000 years respectively.

Table 5-4 Design Peak Flows (m^3/s)

HEP Ref.	Qmed	Q5	Q10	Q25	Q50	Q100	Q200	Q1000
01	1.1	1.4	1.7	2.0	2.2	2.4	2.6	3.0
02	2.0	2.6	3.1	3.6	4.0	4.3	4.7	5.5
03	1.4	1.9	2.2	2.6	2.9	3.1	3.4	4.0
04	1.2	1.6	1.8	2.1	2.4	2.6	2.8	3.3
05	1.0	1.3	1.6	1.8	2.0	2.2	2.4	2.8
06	1.5	2.0	2.3	2.7	3.0	3.3	3.6	4.2
07	0.8	1.0	1.2	1.4	1.5	1.7	1.8	2.1
08	1.3	1.8	2.0	2.4	2.6	2.9	3.1	3.7

6 Flow Hydrograph Analysis

The previous section of this report details the methods used to derive the peak design flows for the HEPs within the study area. Design flow hydrographs detailing the volumes and timings of the flood flows are necessary to route flood flows through the hydraulic model. The following section describes the approach taken to develop the design flow hydrographs for Carrigtohill.

6.1 Flood Studies Report - Rainfall Runoff

The unit hydrograph method estimates the design flood hydrograph, describing the timing and magnitude of flood peak and flood volume. The method requires the catchment response characteristics, design rainstorm characteristics and runoff / loss characteristics to be input.

The unit hydrograph describes the theoretical response of the catchment to an input of a unit depth of rainfall over a unit of time.

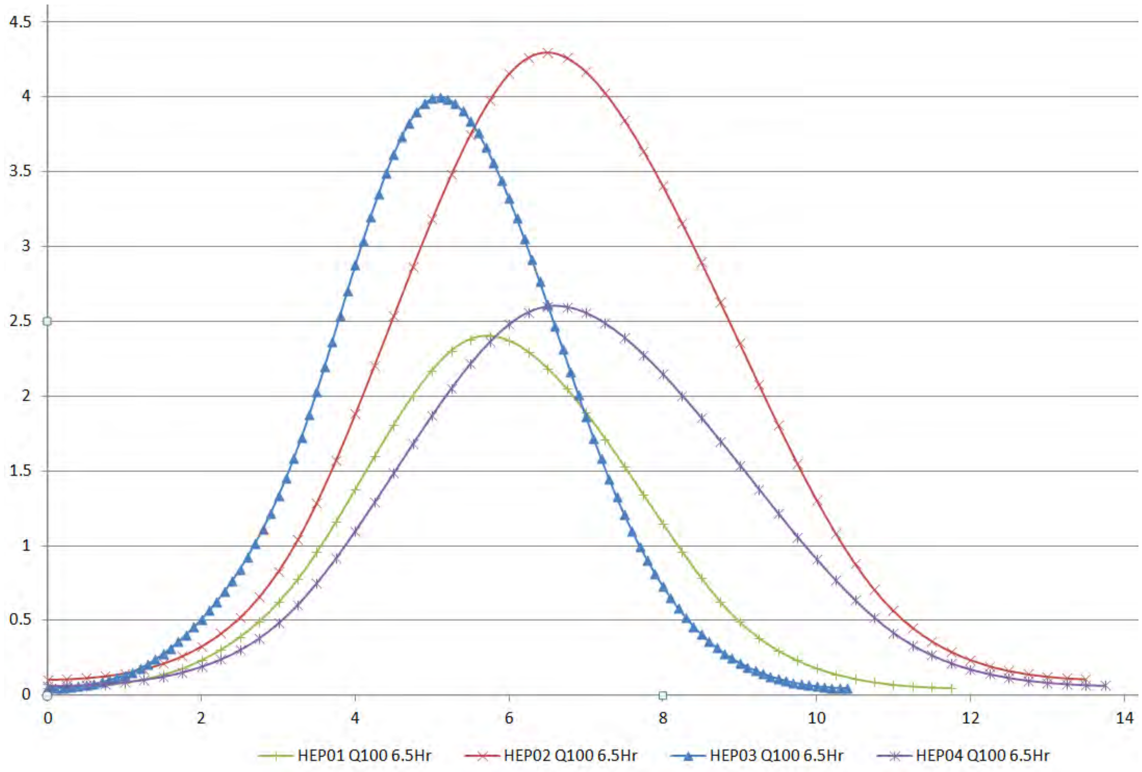
The rainfall runoff method as detailed in the Flood Studies Report has been used to generate flow hydrographs for the Carrigtohill catchment. JBA's web based Flood Estimation Software (FES) was used to generate the hydrograph shape that is characteristic of the catchment, based on the FSR Rainfall Runoff methodology. This hydrograph is then scaled to match the derived peak design flows based on the FSU methodology, that are discussed in Section 5.

6.2 Design Flow Hydrographs

At gauged sites flow records can be used to calibrate the hydrograph shape. Carrigtohill is an ungauged catchment with no site specific data records. The Lee CFRAMS adopted the FSR unit hydrograph approach and made refinements where site data was available. In general in the Lee catchment most sub-catchments are small and rural in nature and are characterised by FSR as low runoff material. From the assessment of the area for this study, this holds true in the Carrigtohill catchment.

The hydrographs generated for the 1% AEP event for each HEP (based on a 6.5 hour storm duration) are shown below in Figure 6-1. For detail on the design flow hydrographs for each HEP refer to Appendix A.

Figure 6-1 1% AEP Design Flow Hydrographs



6.3 Varying Strom Duration

Based on catchment characteristics and hydrological analysis of the natural catchment the critical storm is taken as 6.5 hours for the overall catchment.

Due to the nature of the catchment, in particular the presence of Slatty Pond and the Pump Station at the downstream end of the reach, storms of varying duration have been considered. A longer rain storm characteristically will be of less intensity and can result in more total rainfall. A longer duration rain storm will generally result in a longer duration runoff hydrograph with a lower peak value and possibly greater volume of flow.

The runoff hydrographs for each duration for each HEP are presented in Figure 6-2 to Figure 6-5 below.

Figure 6-2 1% AEP Flow Hydrographs for Varying Durations at HEP01

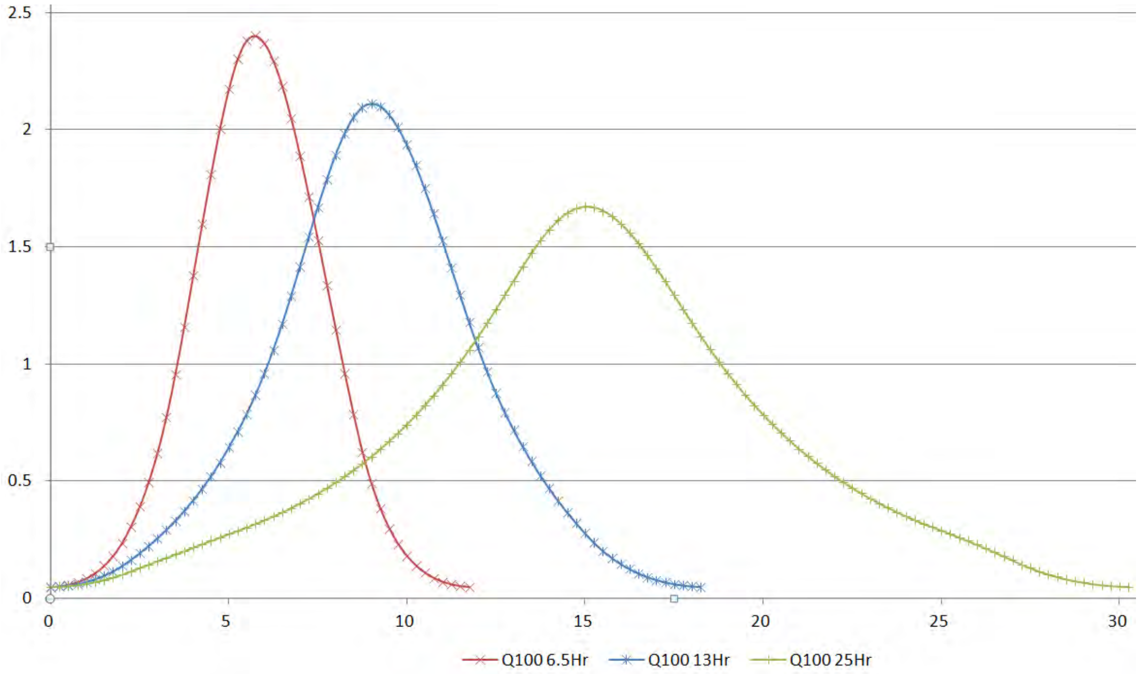


Figure 6-3 1%AEP Flow Hydrograph for Varying Durations at HEP02

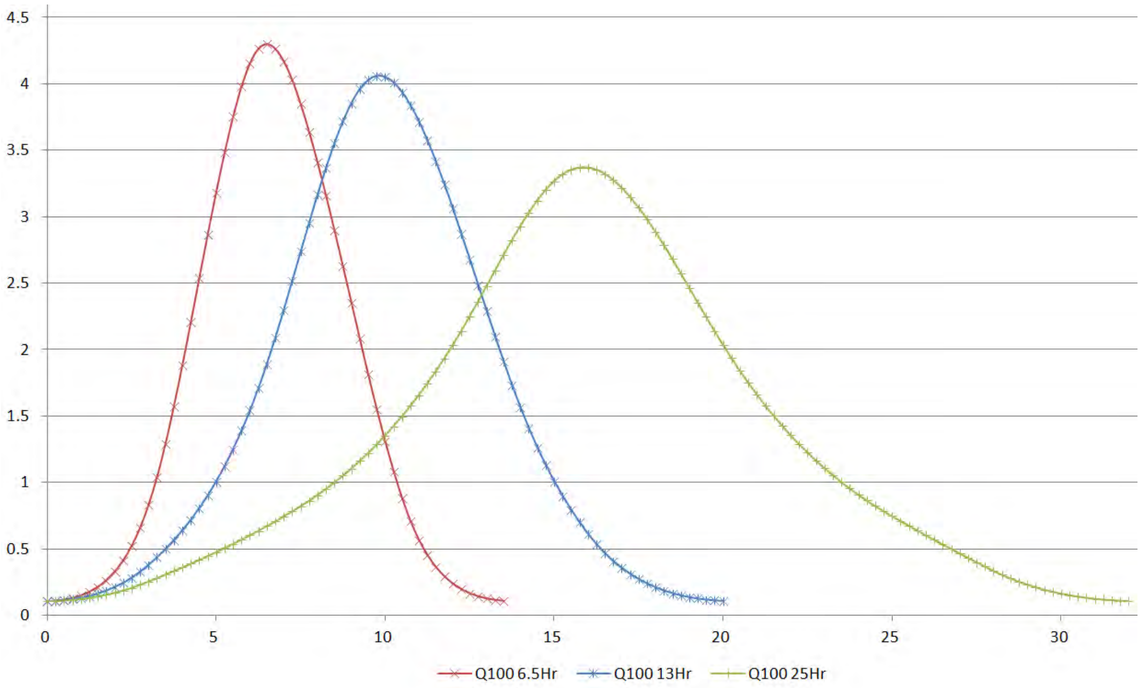


Figure 6-4 1%AEP Flow Hydrograph for Varying Durations at HEP03

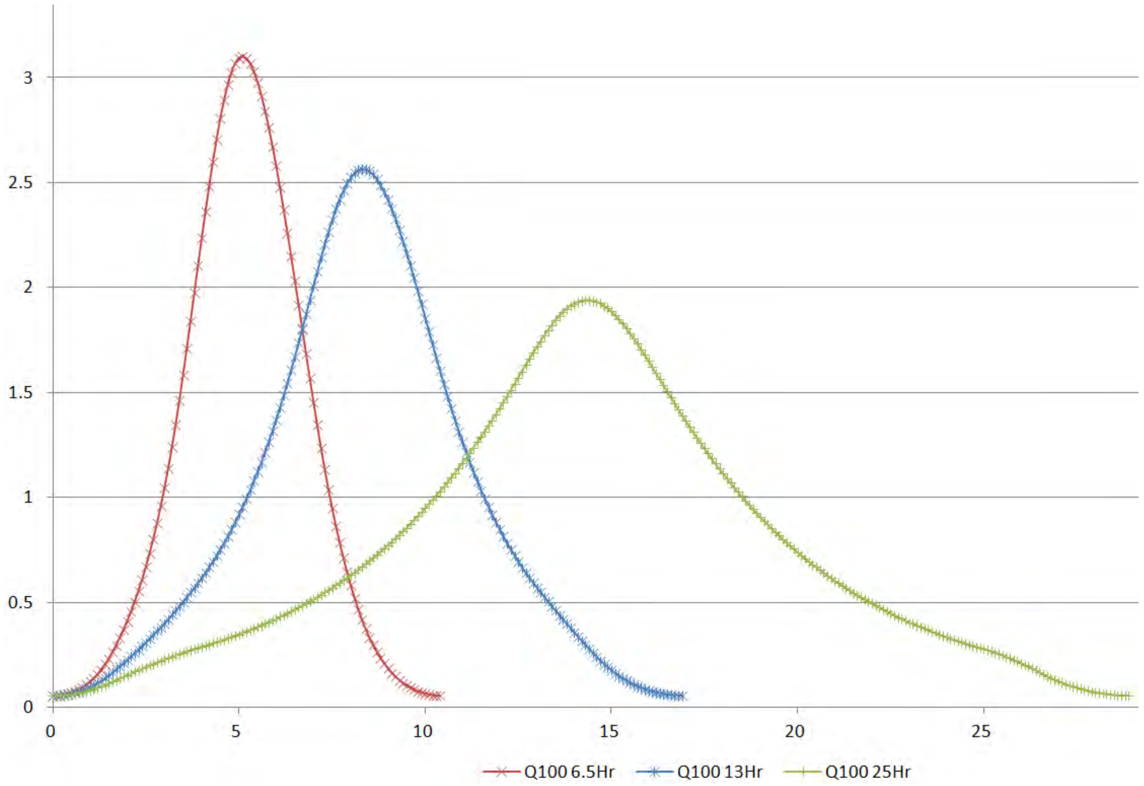
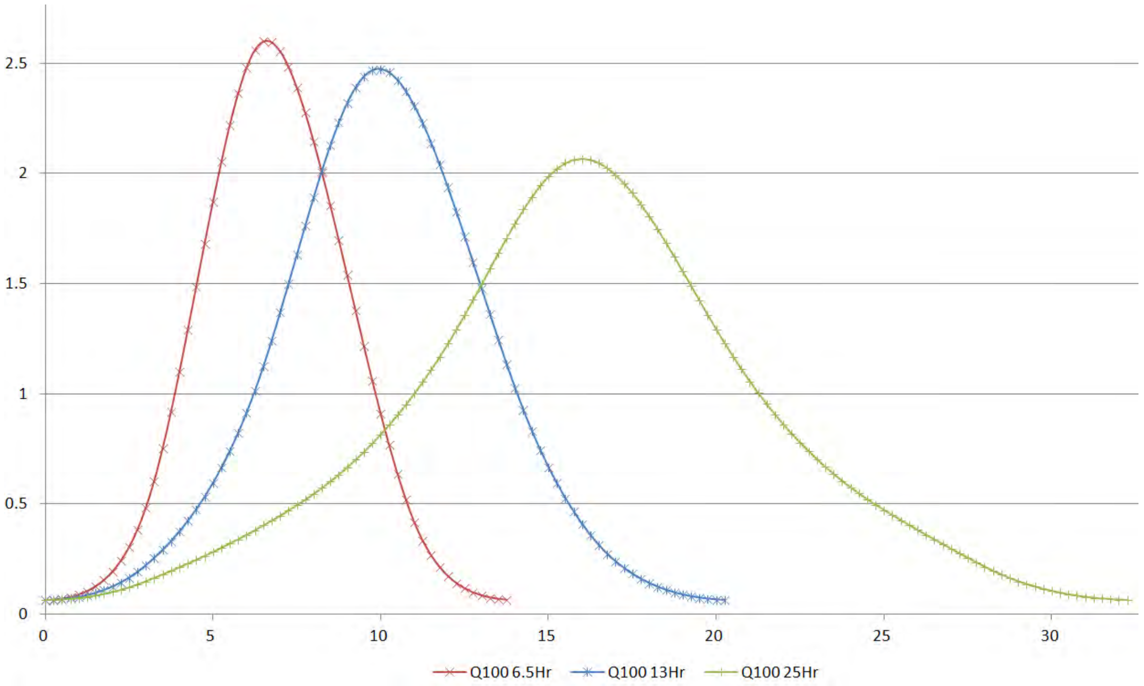


Figure 6-5 1%AEP Flow Hydrograph for Varying Durations at HEP04



To test the model sensitivity to storm duration the runoff hydrograph for the 6.5, 13 and 25 hour storms have been generated and used as inflows in the sensitivity analysis completed in the hydraulic modelling phase. The findings of this analysis are detailed in the Model Check File and Hydraulics Report.

7 Surface Water

Surface water piped flows and surface water overland flows within the model domain area is accounted for in the hydraulic modelling stage.

Lateral inflows are added to the hydraulic model at points along the watercourse. The surface water piped outfall points are indicated on Figure 7-2. The map also indicates the areas that drain to these outfalls.

7.1.1 Greenfield runoff

Surface water runoff from undeveloped sites or permeable unpaved catchments is based on the flow estimation method adopted for the larger fluvial catchments, namely the Flood Studies Update (FSU). This method was also applied for developed sites that have provided attenuation as part of the surface water drainage design. The overland surface water runoff is included as lateral inflows to the appropriate length of the watercourse based on the topography of the land. A limitation to this approach is the representation of the time to peak. However, this is a conservative approach with the peak times of surface water runoff closer to that of the overall fluvial catchment flows.

7.1.2 Developed land

Surface water runoff from developed sites that is collected in a piped network and discharges to natural watercourses was determined based on the Rational Method. The design rainfall was extracted from Met Éireann DDF (depth duration frequency) data and a rainfall hyetograph was developed for a 6.5, 13 and 25 hour storm. Corresponding runoff hydrographs based on the impermeable area was calculated for each sub-catchment. Generally a 70:30 split for permeable and impermeable area was assumed. Runoff from permeable areas is based on the FSU methodology and runoff from impermeable areas is calculated using Rational Method. This calculation applies to un-attenated flows into the modelled watercourses. The location of the surface water network outfalls were determined based on data collated from Cork County Council, TJ O'Connor (who completed the Carrigtohill Sewerage Improvement Scheme), local developers, survey data and site walkovers.

The assumptions and considerations applied to some specific areas are outlined below:

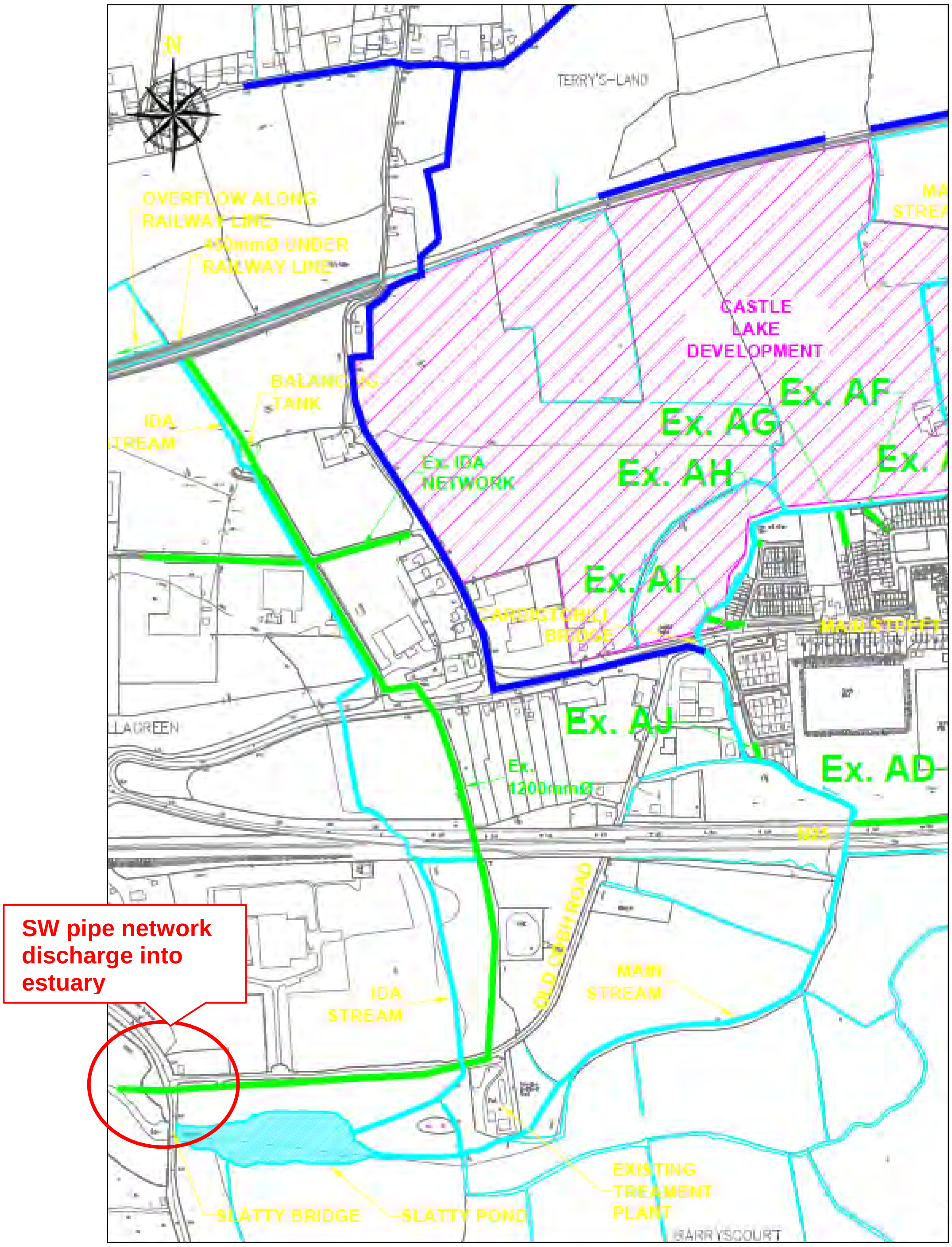
IDA lands in the west of the catchment and south of the rail line: Based on the information available and the work carried out by TJ O'Connor for the Carrigtohill Sewerage Improvement Scheme the surface water runoff flow is assumed to discharge directly into the tidal estuary. This flow therefore is not included in the model. (see figure below, which is an extract from Figure 7.2 of the Carrigtohill Sewerage Improvement Scheme Preliminary Report).

IDA lands north of the rail line: This developed area drains into the IDA surface water pipe network and passes under the rail line to a balancing tank via the IDA siphon. As noted in the model build this tank was observed to be flowing full and therefore does not provide any attenuation function. The surface water runoff in this area has been calculated using Rational Method and it has been assumed to contribute to flows in the stream.

Castlelake Development: Surface water runoff flows from this developed site are attenuated by a large open attenuation pond on site. The flow from this site is assumed to be at Greenfield rates and discharges to the modelled watercourse just upstream of Carrigtohill Bridge.

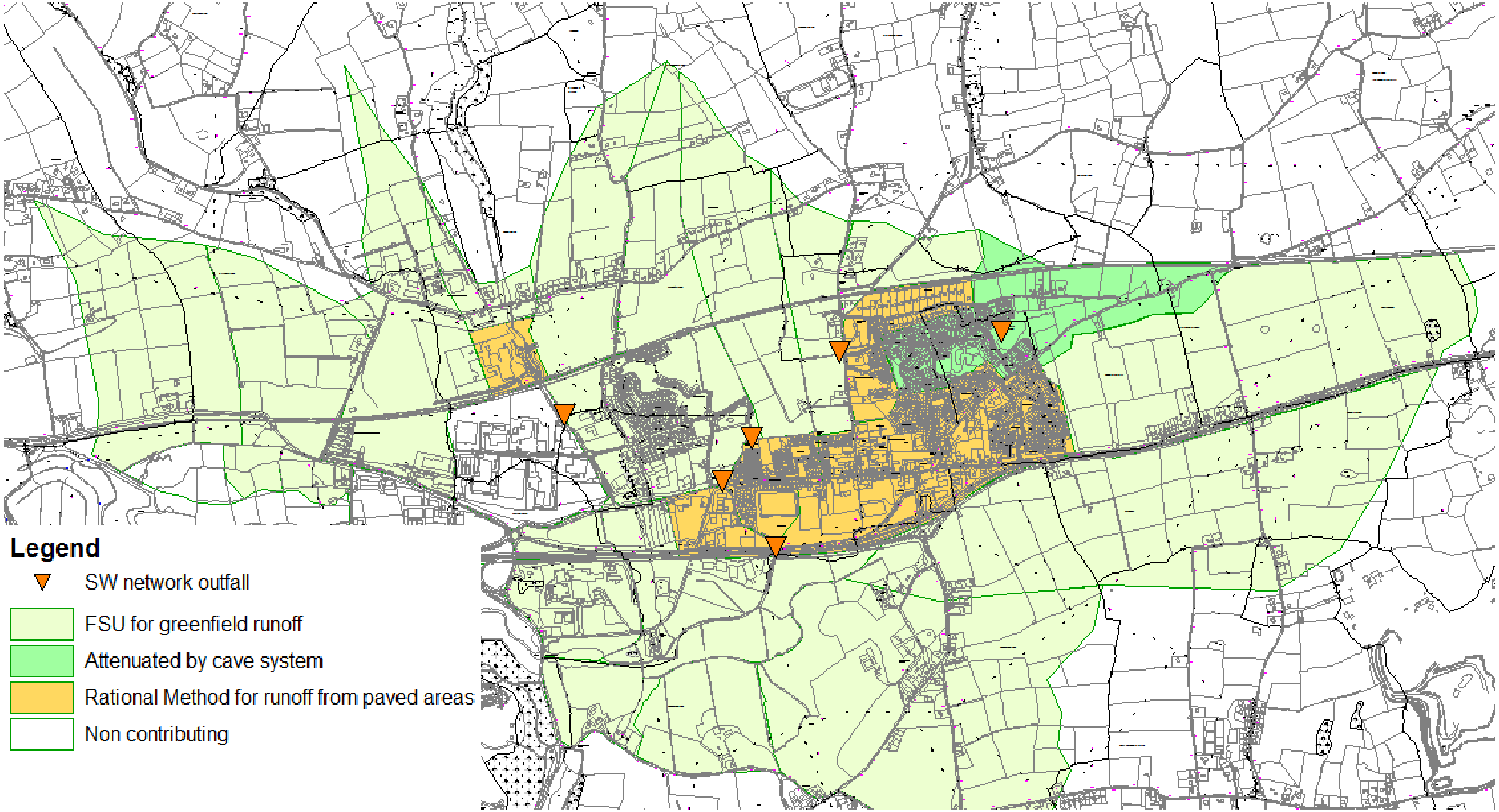
Cúl Ard Housing Estate: The surface water runoff from this area drains into the cave system.

Figure 7-1 Drainage from IDA Lands



SW pipe network discharge into estuary

Figure 7-2 Surface Water Runoff



8 Tidal Data and Combined Probabilities

Due to the proximity of the study area to Cork harbour, tidal water will have an important influence on flood flow regime. Tidal gates are located at Slatty Bridge preventing high tide backing up the river system. In addition, a recently constructed pump station partially controls water levels in Slatty Pond. The operation of these level controls are taken into account in the hydraulic model. The assessment will consider defended and undefended scenarios, with the undefended scenario considering tidal inundation if the pumps fail but with the tidal non-return valves operating normally. The defended and undefended scenarios are represented by a combination of 1D-2D models and a 2D only model for more extreme tidal events as the area is fully inundated..

Tide level data is used in the hydraulic model to define the downstream boundary conditions.

Previous work has been carried out to develop a hydraulic model of Cork harbour. This work was undertaken initially under the MODESTIS project by MarCon Computations International and more recently under the LEE CFRAMS. The tidal data that is available from the Lee CFRAMS will be utilised directly in this study for Carrigtohill. The tidal peaks taken from the Lee CFRAMS model of the Carrigtohill area are summarised in Table 8-1, (level are metres Above Datum Malin).

Table 8-1 Peak Tide Levels

Tidal AEP	Tidal Return Period	Peak Tide Level (mAD)
50%	2	2.309
20%	5	2.422
10%	10	2.496
4%	25	2.585
2%	50	2.658
1%	100	2.728
0.5%	200	2.796
0.1%	1000	2.951

8.1 Joint Probability – Tidal and Fluvial

As part of the National CFRAM programme, the topic of joint probability has been debated and best practice guidance has been established for the purpose of the CFRAM programme. While Carrigtohill FRA is a separate study it will feed into the overall CFRAM deliverables for the South West region. The following discusses the issue of joint probability in the context of the Carrigtohill catchment and the nature of the various hydraulic influences present i.e. pump station, sluices.

The chance / probability of an extreme tide and an extreme fluvial event occurring at the same time is generally considered to be very low and a joint probability (JP) analysis can be carried out to assess this. For this situation to require a detailed JP analysis, the outcome i.e. flooding must depend on the combined occurrence of these conditions and the dependence between the two conditions must be non-trivial i.e. neither independent nor fully dependent.

In this case, under a current scenario (i.e. existing defended) the flood risk generated from an extreme fluvial event is largely independent of the tide. The presence of tidal flap valves and the pump station mean that the tide does not have a significant influence. The tidal flap valves prevent the tide propagating up the fluvial channel and also prevent flow from the river discharging to the estuary when tides are high (higher that the outfall invert). Even though flow through the flap valves is restricted, flow also discharges from the fluvial system through the pump station. The pumps operate on a minimum level in Slatty Pond (-0.9mAD) regardless of the tide. The flapped outfall soffit levels (ranging from-1.39 to 0.01mAD) are well below the 50% AEP tide 2.309mAD

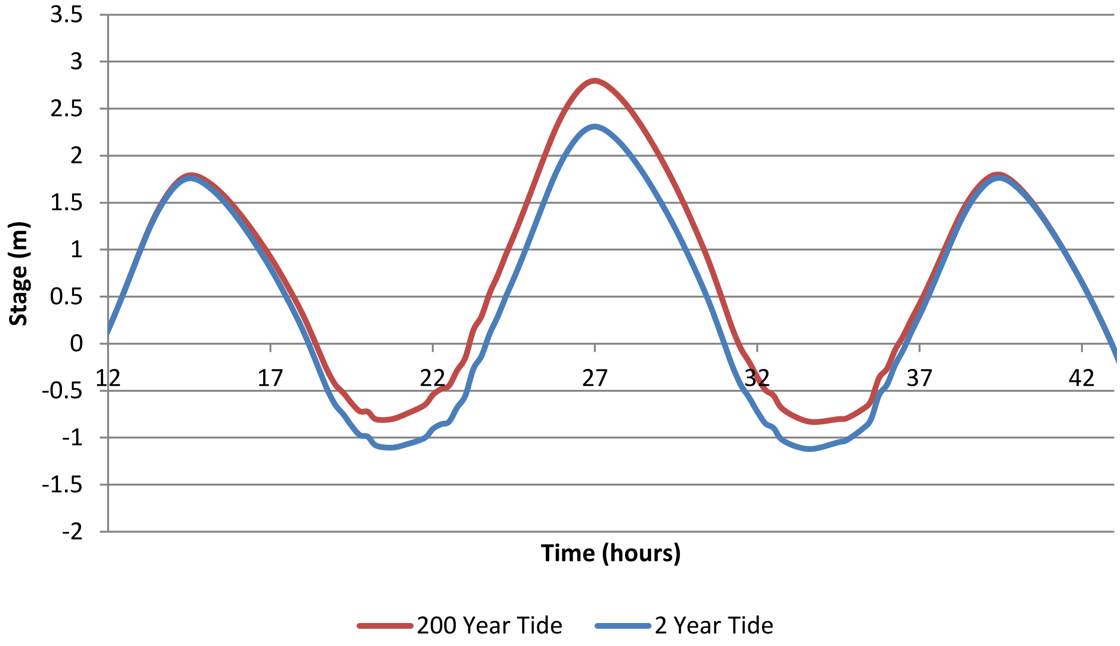
Once tidal overtopping of the R624 road occurs during extreme or future events, tide levels will influence flood risk in the fluvial system. Based on the available survey and LIDAR levels limited overtopping will occur during a 0.5% AEP (200 year) tidal event. For extreme tidal inundation (> 200 year event) it is assumed that the pumps will fail and these extreme tidal events are modelled using a 2D only model.

The assumption on independence presented here is tested in the hydraulic modelling stage and development of the model. The results from this sensitivity testing are presented in the Hydraulic Model Check File.

Therefore, in summary, the catchment has both a fluvial and tidal influence. However, under the current scenario, with Slatty pump station operating and the tidal flap valves functioning as normal, flood risk in the catchment is influenced by the magnitude of the fluvial event (provided that the tide does not overtop the N25 and R624 road). Once tidal inundation occurs, flood risk in the lower end of the catchment is likely to be dominated by the tide. During extreme tidal inundation, it is assumed that the pumps will fail. These extreme tidal scenarios are modelled using a 2D only model and map the predicted flood extent along the whole shoreline of the study catchment.

The tidal stage graphs for the 0.5% AEP (200 Year) event and the 50% AEP (2 year) event are shown in Figure 8-1 below. For details on the tidal stage for all return periods refer to Appendix B.

Figure 8-1 Design Tidal Stage Graph



9 Allowance for Climate Change

It is anticipated that climate change effects will lead to a rise in sea levels and a change in rainfall intensities that may lead to increased flood risk in many areas. Both nationally and internationally, a significant amount of research has been undertaken and is ongoing on the subject of climate change.

Two climate change scenarios are considered based on Draft OPW guidance[2]. These are the Mid-Range Future Scenario (MRFS) and the High-End Future Scenario (HEFS). Based on these two scenarios the recommended allowances for climate change are given in the table below.

Table 9-1 OPW Recommendations for Climate Change Allowances

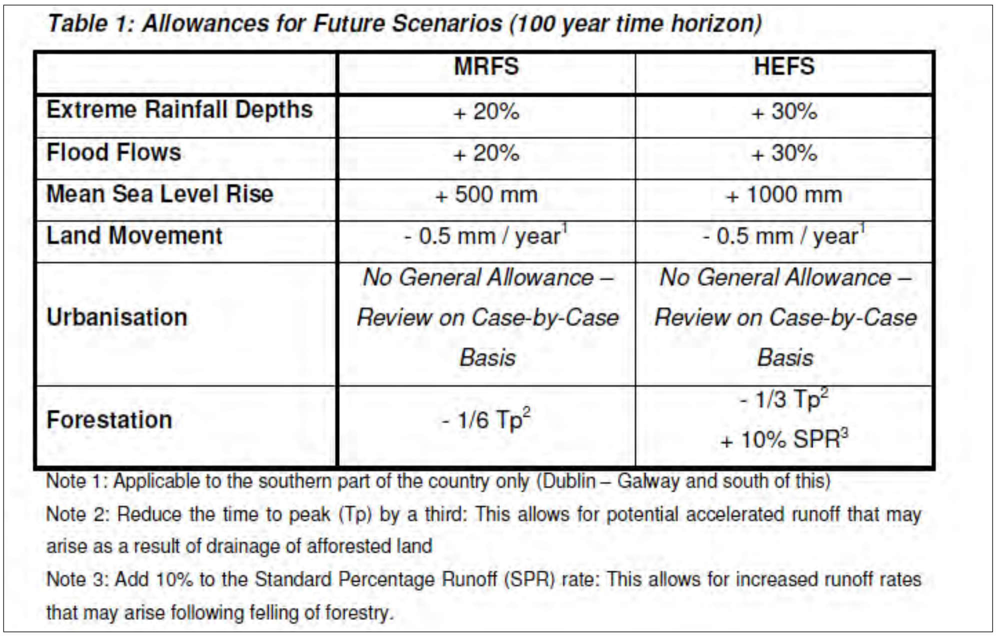


Table 1: Allowances for Future Scenarios (100 year time horizon)

	MRFS	HEFS
Extreme Rainfall Depths	+ 20%	+ 30%
Flood Flows	+ 20%	+ 30%
Mean Sea Level Rise	+ 500 mm	+ 1000 mm
Land Movement	- 0.5 mm / year[1]	- 0.5 mm / year[1]
Urbanisation	*No General Allowance – Review on Case-by-Case Basis*	*No General Allowance – Review on Case-by-Case Basis*
Forestation	- 1/6 Tp[2]	- 1/3 Tp[2] + 10% SPR[3]

Note 1: Applicable to the southern part of the country only (Dublin – Galway and south of this)

Note 2: Reduce the time to peak (Tp) by a third: This allows for potential accelerated runoff that may arise as a result of drainage of afforested land

Note 3: Add 10% to the Standard Percentage Runoff (SPR) rate: This allows for increased runoff rates that may arise following felling of forestry.

Taking into account sea level rise and land movement, the total climate change allowance for tide levels is 0.55m for the MRFS and 1.05m for the HEFS. For fluvial flows, climate change flows are increased by 20% and 30% for MRFS and HEFS respectively. The tide and fluvial flow with climate change allowance are presented in Table 9-3 and Table 9-3 below.

Table 9-2 Climate Change Tide Levels

		+0.55m	+1.05m
Tidal AEP	Design Tide Level	MRFS Tide Level	HEFS Tide Level
50%	2.309	2.859	3.359
20%	2.422	2.972	3.472
10%	2.496	3.046	3.546
4%	2.585	3.135	3.635
2%	2.658	3.208	3.708
1%	2.728	3.278	3.778
0.50%	2.796	3.346	3.846
0.10%	2.951	3.501	4.001

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[2] Reference: OPW, Assessment of Potential Future Scenarios for Flood Risk Management, Draft Guidance, 2009

Table 9-3 Climate Change Fluvial Flows (HEP01 to 04)

Design Peak Flows

HEP Ref.	Qmed	Q5	Q10	Q25	Q50	Q100	Q200	Q1000
01	1.1	1.4	1.7	2.0	2.2	2.4	2.6	3.0
02	2.0	2.6	3.1	3.6	4.0	4.3	4.7	5.5
03	1.4	1.9	2.2	2.6	2.9	3.1	3.4	4.0
04	1.2	1.6	1.8	2.1	2.4	2.6	2.8	3.3

MRFS Flows **+20%**

HEP Ref.	Qmed	Q5	Q10	Q25	Q50	Q100	Q200	Q1000
01	1.3	1.7	2.0	2.4	2.6	2.9	3.1	3.6
02	2.4	3.2	3.7	4.3	4.8	5.2	5.6	6.6
03	1.7	2.3	2.6	3.1	3.4	3.8	4.1	4.8
04	1.4	1.9	2.2	2.6	2.8	3.1	3.4	4.0

HEFS Flows **+30%**

HEP Ref.	Qmed	Q5	Q10	Q25	Q50	Q100	Q200	Q1000
01	1.4	1.9	2.2	2.6	2.8	3.1	3.4	3.9
02	2.6	3.4	4.0	4.7	5.1	5.6	6.1	7.2
03	1.9	2.5	2.9	3.4	3.7	4.1	4.4	5.2
04	1.5	2.0	2.4	2.8	3.1	3.4	3.6	4.3

Appendices

A Appendix - Design Fluvial Flow Hydrographs

B Appendix - Design Tidal Stage Graphs

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