Carrigtohill Flood Risk Assessment

Main Report (Hydraulics)

FINAL

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Cork County Council

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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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Executive Summary

Cork County Council appointed JBA Consulting to undertake a flood risk assessment study at Carrigtohill, Co. Cork, in January 2012. This study follows on from the recommendations in the Lee Catchment Flood Risk Assessment and Management Study (CFRAMS) that a more detailed assessment of flood risk in Carrigtohill is warranted "due to the nature of the watercourses, on-going development and work recently undertaken by Cork County Council.''

Carrigtohill is a commuter town located 11km east of Cork City and the area has experienced significant growth and development in recent years, supported by the re-opening of the Glounthaune to Midleton rail line with a new station serving Carrigtohill. The flood risk assessment (FRA) will be used to inform decision making for the Carrigtohill Masterplan, Special Local Area Plan and Midleton Local Area Plan, to allow for sustainable development in terms of flood risk.

This study required close working with the client, Cork County Council and liaison with the key stakeholders. A public information day was held, where JBA met with the community chairman, landowners and local authority staff. Developers in the area, including IDA and Irish Rail were also consulted, along with the Office of Public Works.

The hydrological assessment relied on a number of flow estimation methods for ungauged catchments, including the recent Flood Studies Update (FSU) research and involved a statistical analysis based on recorded data from suitable pivotal gauges. The catchment has a strong hydro-geological influence evident by the presence of an extensive underground cave network, turloughs and other karst features.

A review of the catchment indicates that there are a number of areas where the natural drainage pattern has been altered. The hydraulic assessment included a number of complex hydraulic structures namely flow siphons transferring flow under the rail line, man-made diversion channels, in-line weirs and most notably the recently constructed pump station at Slatty Pond.

A review of the hydro-geomorphology of the catchment revealed evidence of sediment deposition and siltation at a number of structures and erosion in other areas. The study included a review, to highlight the areas of concern, that require on-going monitoring and potential maintenance.

As part of the study topographic river survey was collated and a number of site walkovers were conducted to identify and investigate the hydraulic features in the catchment. This data, along with a range of other data, was used to develop the hydraulic models. Two separate models were developed; a linked 1D-2D model to assess fluvial flood risk and a 2D model to assess tidal flood risk.

The analysis of hydraulic results identified a number of key structures where flooding occurs. In some instance due to under sized culverts and in other due to poor maintenance and siltation problems. These areas would benefit from continued monitoring and an investigation into potential flood mitigation and management measures.

Contents

Executive Summary ..... **iii**

1 Introduction **1**

1.1 Commission 1
1.2 Purpose and Scope of Study 1

2 Description of Study Area **2**

2.1 Development Planning Context 2
2.2 Potential Sources of Flood Risk 3
2.3 Watercourses in the Study Area 4

3 Data Review **10**

3.1 Previous Studies 10
3.2 Flood History and Local Information 10
3.3 LIDAR 10
3.4 Topographical River Survey Data 10

4 Hydrology Overview **12**

4.1 Introduction 12
4.2 Estimation of the Index Flood (Qmed) 12
4.3 Flood Frequency Analysis 12
4.4 Flood Hydrograph Analysis 12
4.5 Surface Water Runoff 13
4.6 Joint Probability of Tidal and Fluvial events 13
4.7 Allowance for Climate Change 14

5 Hydrogeology **15**

5.1 Groundwater Catchment 15
5.2 Hydro geological Characteristics 16
5.3 Groundwater Flooding Assessment 16
5.4 Recommendations 17

6 River Survey & Data Collection **18**

6.1 Defence Assets 18
6.2 Trash Screens 18
6.3 Culverts & Bridges 19

7 Hydraulics Overview **21**

7.1 Fluvial Model Development 21
7.2 Tidal Model Development 23
7.3 Key Model Parameters 25
7.4 Model Boundary Conditions 25
7.5 Model Limitations & Uncertainty 26
7.6 Model Sensitivity 27
7.7 Model Design Runs 28

8 Hydro-geomorphology **29**

8.1 Introduction 29
8.2 Historic Morphology 29
8.3 Sources &General Catchment Character 32
8.4 Conveyors - Channel Type & Velocities 32
8.5 Sinks - Hydraulic Controls 35
8.6 Blockage Screening Assessment 42
8.7 Conclusion 44

9 Validation of Model **46**

10 Fluvial Model Results **51**

Contents

10.1 Kilacloyne Stream ... 51
10.2 Slatty Pump Station ... 61
10.3 IDA and Irish Rail Siphon Arrangement ... 66
10.4 Carrigtohill Bridge ... 68

11 Tidal Model Results ... 69

11.1 Slatty Pond Area ... 69
11.2 Kilacloyne Tidal Area ... 71

12 Climate Change Impacts ... 72

13 Flood Mapping ... 74

13.1 Map Types ... 75
13.2 Uncertainty & Confidence Intervals ... 75

14 Summary & Conclusions ... 77

Appendices ... I

A Data Register ... I

B Hydrology Report ... I

C Hydrogeology Report ... I

D Hydraulic Model Check File ... I

E Model Output ... I

F Flood Maps ... I

List of Figures

Figure 2-1 Location Map ... 2

Figure 2-2 Area of Interest ... 3

Photo 2-3 Kilacloyne Stream Typical Channel ... 4

Figure 2-4 Rail Diversion Channel Typical Section ... 5

Photo 2-5 Rail Diversion Channel and Overflow ... 5

Figure 2-6 Tibbotstown Stream (Upper Reach ... 6

Figure 2-8 Poulaniska Stream Flow Route ... 8

Figure 2-9 Slatty Pond ... 9

Figure 3-1 Summary of Anecdotal Evidence ... 11

Figure 4-1 1%AEP Flow Hydrograph for Varying Durations at HEP02 ... 13

Figure 7-1 Fluvial Model Schematic ... 22

Figure 7-2 Tidal Model Schematic ... 24

Figure 8-1 Tibbotstown Stream at IDA lands ... 29

Figure 8-2 Extent of Slatty Pond ... 30

Figure 8-3 Cross Section Location Plan ... 31

Figure 8-4 Cross section plot for 2CAR_327 and ANNA000721 ... 32

Figure 8-5 Kilacloyne Stream ... 33

Figure 8-6 Rail Diversion Channel ... 33

Figure 8-7 Tibbotstown Stream ... 34

Contents

Figure 8-8 Woodstock Stream 35
Figure 8-9 Key Structures & Hydro-Geomorphologic Features........ 36
Table 8-1 Key Structures 37
Figure 8-10 Structure in the Carrigtohill Model Extent 45
Photo 9-1 Flooding at Ryan Aherne Place in 2009 47
Figure 9-2 Summary of Anecdotal Evidence 48
Figure 9-3 Record of Flooding at Bog Road Aug 2012 49
Figure 9-4 Report of Flooding Upstream of Modelled Extent 50
Figure 10-1 Kilacloyne Flood Depth at 5hours during 1% AEP fluvial event 51
Figure 10-2 Kilacloyne Maximum Flood Depth for a 1% AEP Fluvial Event 52
Figure 10-3 Tibbotstown Flood Depth at 3h 45m during a 1% AEP Fluvial Event........ 53
Figure 10-4 Tibbotstown Flood Depth at 4h 15m during a 1% AEP Fluvial Event........ 54
Figure 10-5 Tibbotstown Flood Depth at 7h 30m during a 1% AEP Fluvial Event........ 55
Figure 10-6 Tibbotstown Maximum Flood Depth for a 1% AEP Fluvial Event 56
Figure 10-7 Woodstock Flood Depth at 3h 30m during a 1% AEP Fluvial Event 57
Figure 10-8 Woodstock Flood Depth at 4h during a 1% AEP Fluvial Event 58
Figure 10-9 Woodstock Maximum Flood Depth for a 1% AEP Fluvial Event........ 59
Figure 10-10 Poulaniska Flood Depth at 3h 45m during a 1% AEP Fluvial Event........ 60
Figure 10-11 Poulaniska Maximum Flood Depth for a 1% AEP Fluvial Event........ 60
Figure 10-12 Outfall Cross Section 61
Figure 10-13 Schematic of Outfall Long Section 62
Figure 10-14 Stage at Slatty Pond during a 1% AEP Event........ 63
Figure 10-15 Pumped Flow during a 1% AEP Event 63
Figure 10-16 Gravity Flow during a 1% AEP Fluvial Event 64
Figure 10-17 Pumped Flow during 50% AEP Fluvial Event 65
Figure 10-18 Gravity Flow during 50% AEP Fluvial Event 65
Photo 10-19 3 Way Split Structure 66
Photo 10-20 Irish Rail Cascade........ 67
Figure 10-21 Flows during a 1% AEP Event 67
Photo 10-22 Carrigtohill Bridge 68
Figure 11-1 Tidal Stage Graph for 0.5% AEP Event 69
Figure 11-2 Slatty Pond Flood Depth at 14h 45m 70
Figure 11-3 Slatty Pond Maximum Flood Depth........ 70
Figure 11-4 Kilacloyne Tidal Area Flood Depth at 14h 30m........ 71
Figure 11-5 Kilacloyne Tidal Area Maximum Flood Extent 71
Figure 12-1 Climate Change Impact on Fluvial Extent for High End Future Scenario 72
Figure 12-2 Climate Change Impact on Tidal Extent for High End Future Scenario........ 73

List of Tables

Photo 2-7 Tibbotstown Stream Channel Photos 7

Contents

Table 4-1 Design Peak Flows (m^3/s) ... 12
Table 4-2 Climate Change Tide Levels ... 14
Table 6-1 List of Defence Assets ... 18
Table 6-2 List of Trash Screens ... 19
Table 6-3 List of Culverts & Bridges ... 20
Table 8-2 Screening Assessment Results ... 42
Table 13-1 List of Flood Maps ... 74

Abbreviations

1D	One Dimensional (modelling)
2D	Two Dimensional (modelling)
AEP	Annual Exceedance Probability
AMAX	Annual Maximum
CFRAM	Catchment Flood Risk Assessment and Management
CFRAMS	Catchment Flood Risk Assessment and Management Study
DEFRA	Department of the Environment, Food and Rural Affairs
DTM	Digital Terrain Model
EPA	Environmental Protection Agency
FRA	Flood Risk Assessment
FSU	Flood Studies Update
GEV	General Extreme Value Distribution
GIS	Geographical Information System
GSI	Geological Survey of Ireland
HEFS	High End Future Scenario
HEP	Hydrological Estimation Point
HR	Hydraulic Research, Wallingford
ID	Identifier
IDA	Industrial Development Agency
ISIS	Hydrology and hydraulic modelling software
JFLOW	2-D hydraulic modelling package developed by JBA
MRFS	Medium Range Future Scenario
OPW	Office of Public Works
OS	Ordnance Survey
OSi.	Ordnance Survey Ireland
Q100	Flow at the 100-year return period (1% AEP)
Q1000	Flow at the 1000-year return period (0.1% AEP)
TUFLOW	Two-dimensional Unsteady FLOW (a hydraulic model)

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 Purpose and Scope of Study

The main purpose of the study is to carry out a detailed flood risk assessment and produce flood maps to illustrate predicted flood risk for a range of current and future scenarios.

The key processes involved in the study are:

- Review of data relevant to flooding in the study area and identify key structures and any flood defences assets
- Complete a topographic river survey to collate channel and structure data
- Complete a hydrological analysis including a review of the Lee CFRAMS hydrology
- Develop a 1D-2D linked model of the Carrigothill catchment building on the Lee CFRAMS model
- Complete a hydraulic assessment for a range of AEPs including future climate change and undefended scenarios
- Prepare flood maps for significant events and provide for public consultation.

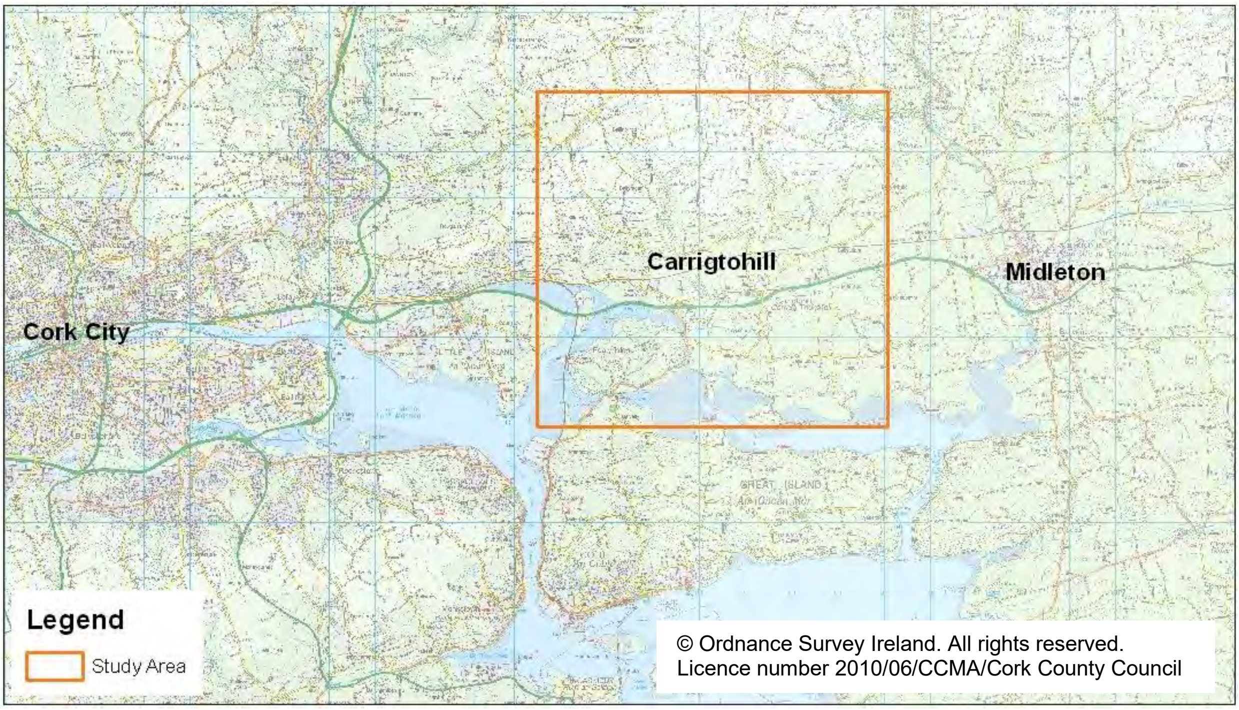
This report acts as a main overarching report, covering all aspects of the study with more technical detail confined to the Appendices. This report concentrates on the findings of the Hydraulic Assessment and discusses flood risk within the study area. A detailed Hydrology Report, Hydrogeology Report and Model Check File are included in the Appendices.

2 Description of Study Area

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 pond pumping station, tidal gates at Slatty Bridge, flow siphons at the rail line and other culverts and bridges in the village.

Figure 2-1 Location Map



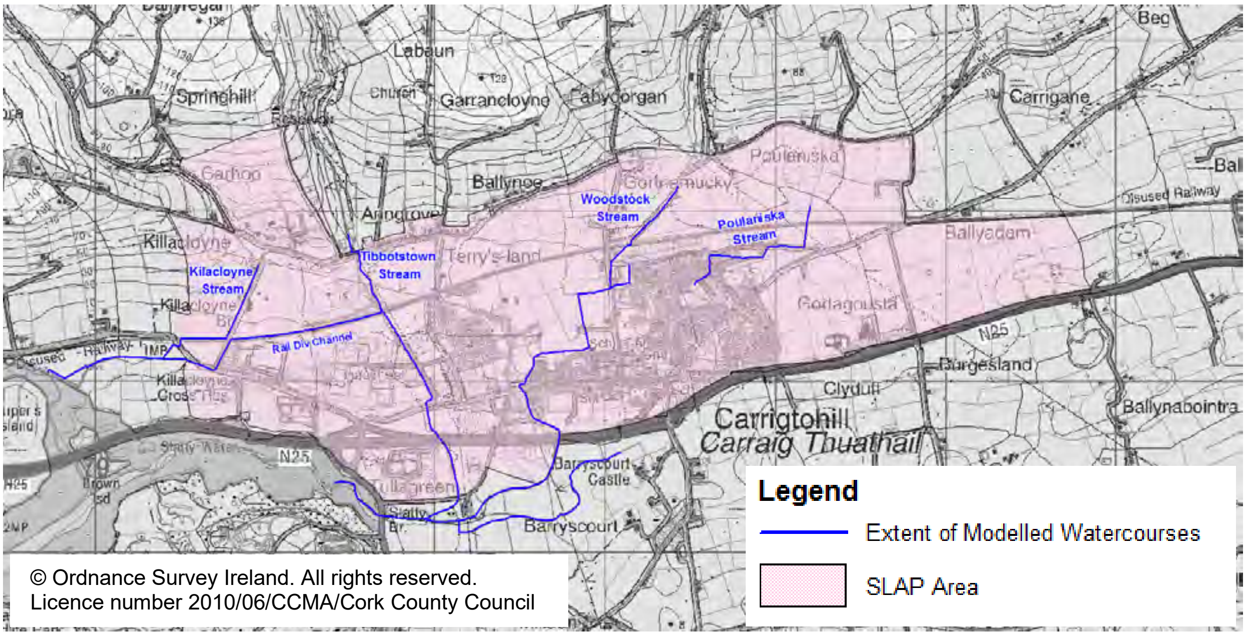
2.1 Development Planning Context

Carrigtohill is governed by the Cork County Development Plan, the Midleton Electoral Area Local Area Plan, and the Carrigtohill Special Local Area Plan (SLAP). There is also a Masterplan for Carrigtohill North.

The extent of the SLAP area is illustrated in Figure 2-2 and this area is the main focus for the preparation of flood maps to update existing flood maps and aid plan making decisions.

The Special Local Area Plan, adopted in 2005 was prepared to allow the establishment of Carrigtohill as a suburban commuter town taking advantage of proposals to re-open the Glounthaune to Midleton rail line.

Figure 2-2 Area of Interest



2.2 Potential Sources of Flood Risk

The potential sources of flood risk in the catchment include river / fluvial, tidal, groundwater and surface water / pluvial.

2.2.1 Fluvial

Four main fluvial watercourses were identified in the study area and these were included in the hydrological and hydraulic assessments. A brief description on each watercourses is included below in Section 2.3.

- Kilacloyne
- Tibbotstown
- Woodstock
- Poulaniska

A hydrological analysis of the individual catchments was carried out to estimate fluvial flows for a range of annual exceedance probability (AEP) flood events. An overview of the hydrology is presented in Section 4 and the full Hydrology Report is included in Appendix B.

2.2.2 Tidal

Tidal risk is identified along the shore between Slatty Water and the study catchment. The topography of the shore is carefully considered in the assessment of tidal flood risk. Tide level data has been abstracted from the Lee CFRAMS and used to define the tidal boundary in the hydraulic modelling assessment.

2.2.3 Groundwater

A review of the catchment geology and flood history highlights groundwater as a potential source of flooding. As part of this study a hydro-geological assessment was completed by an independent hydrogeology expert. An overview of this study is presented in Section 5 and the full report is available in Appendix C.

2.2.4 Surface Water

A pluvial modelling assessment has not been undertaken as part of this study. However, as required by the brief, the contribution of surface water from existing and potential future developments has been taken into account in the fluvial model.

2.3 Watercourses in the Study Area

This section gives an overview of the nature of the watercourses in the study area. More detail on the hydraulics of the channel and how they are represented in the model is included in the Model Check File in Appendix D.

2.3.1 Kilacloyne Stream

The Kilacloyne Stream is a straightened drainage channel that flows along the side of a local third class road, before crossing under the rail line and into the downstream tidal estuary of the Kilacloyne Stream. It joins flows from the rail diversion channel that flows from the east.

The following photos give an indication of the size and nature of this channel. At the upstream extent the channel measures approx 1m wide but along its full length the Kilacloyne reach is typically 2m wide with a depth (to top of bank) of approx 0.6 to 0.7m.

Photo 2-3 Kilacloyne Stream Typical Channel

KILA00004_DOWN

KILA00025_UP

KILA00065I_UP

KILA00068J_DOWN

KILA00077I_UP

KILA00095_UP

2.3.2 Rail Line Diversion Channel

Works associated with the re-opening of the rail line involved the construction of a concrete channel to convey flow along the northern side of the rail line. The rail diversion channel extends for approximately 900m from the location of the IDA / Gilead access road in the east to the Fota Retail Park in the west. The upstream end of the channel is fed by an overflow channel from the Tibbotstown Stream. Construction details were provided by Irish Rail and these were used in the development of the model. The diversion channel measures 1.5m wide with a minimum height of 1.2m. A typical cross section is illustrated below in Figure 2-4 and photos of the rail channel and overflow are also shown below. (More information on these structures and the model build is outlined in the Model Check File in Appendix D).

Figure 2-4 Rail Diversion Channel Typical Section

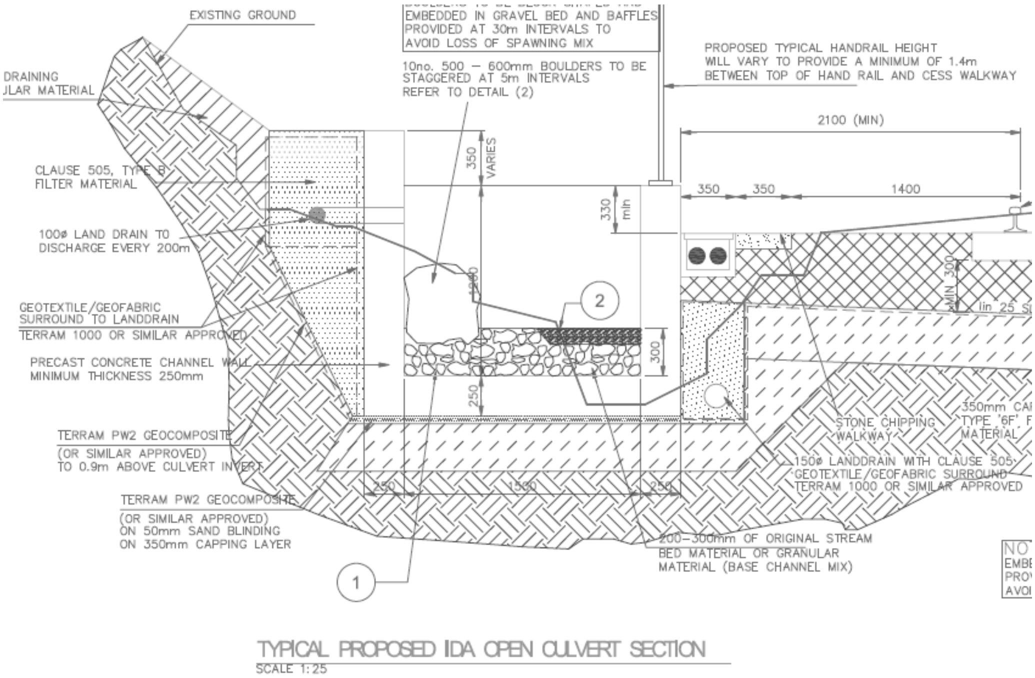


Photo 2-5 Rail Diversion Channel and Overflow

Rail Channel at downstream end

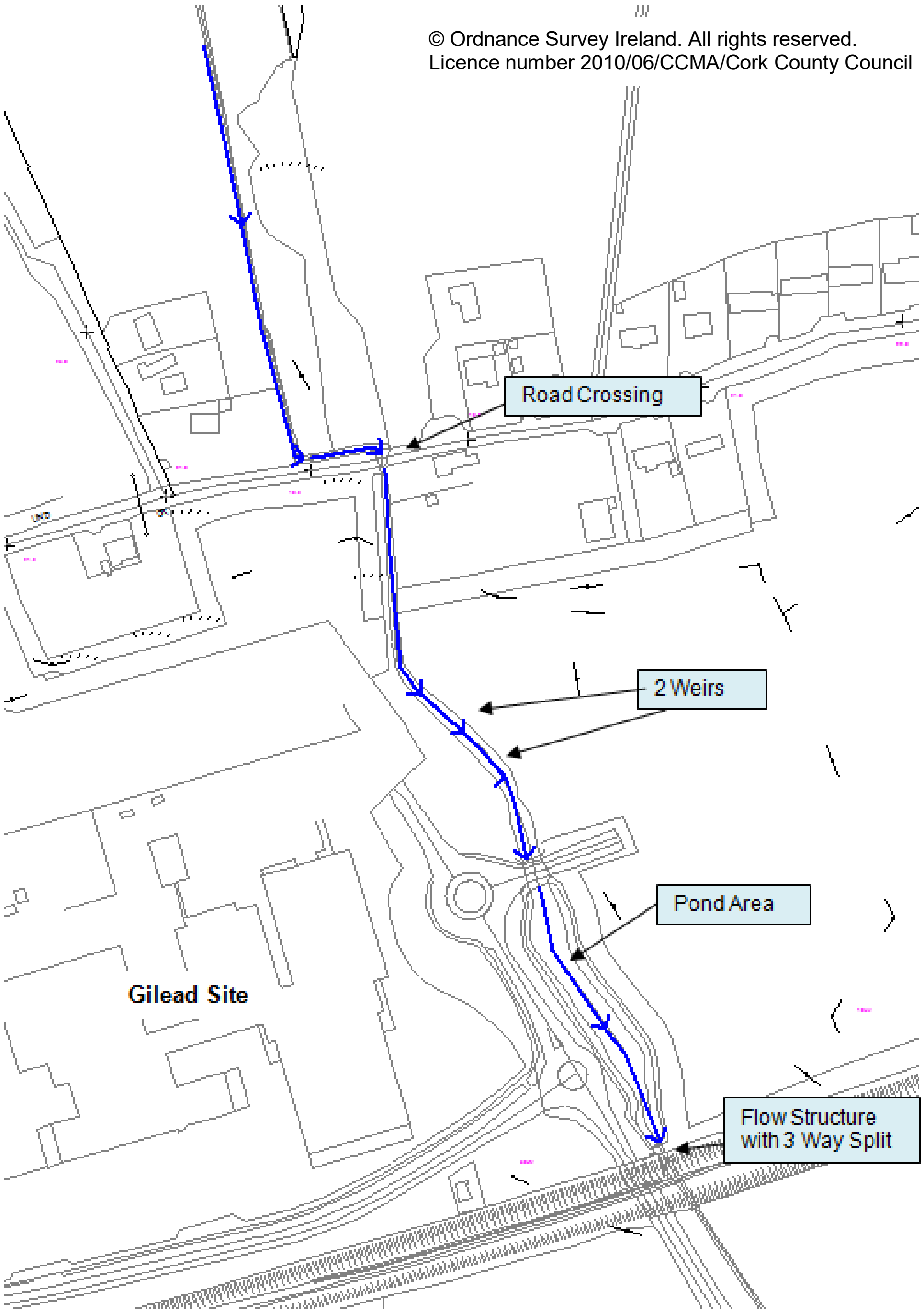
Rail Channel Cascade at upstream end

2.3.3 Tibbotstown Stream

The Tibbotstown Stream flows through IDA lands to the west of Carrigtohill centre. To facilitate on-going development in the area this stream has been subject to modifications i.e. inclusion of weirs, realignment.

The stream flows from North to South crossing under a local third class road upstream of Gilead. From here the stream flows over 2 stone weirs, under an IDA culvert into a localised deep pond section before discharge into a 3 way flow split structure at the rail line. The flow is directed to a siphon under the rail line to continue downstream in an open channel, to a cascade leading into the rail diversion channel and the remainder enters the IDA surface water drainage network and the re-emerges in the open channel further downstream.

Figure 2-6 Tibbotstown Stream (Upper Reach)



Downstream of the rail line the channel flows through a number of culvert and weir structures, passes under the N25 Road and discharges into Slatty Pond. Photos to illustrate the general character of the watercourse are presented below. More information on the structures and how they have been represented in the hydraulic model can be found in the Model Check File in Appendix D.

Photo 2-7 Tibbotstown Stream Channel Photos

Upstream channel section

Weir on the upper reach

Pond area upstream of the rail line

Weirs downstream of the rail line

2.3.4 Woodstock Stream

The Woodstock Stream flows in a south westerly direction alongside a local third class road, under the rail line, through private residential land, into a long culvert at the junction near the railway station and the Bog Road, through private land to Carrigtohill Bridge and on further downstream under the N25 road embankment and into Slatty Pond.

The following photos give an indication of the general size and nature of the Woodstock Stream.

Upstream extent of channel

Adjacent to private residential property

Channel approx 200m upstream of the rail crossing

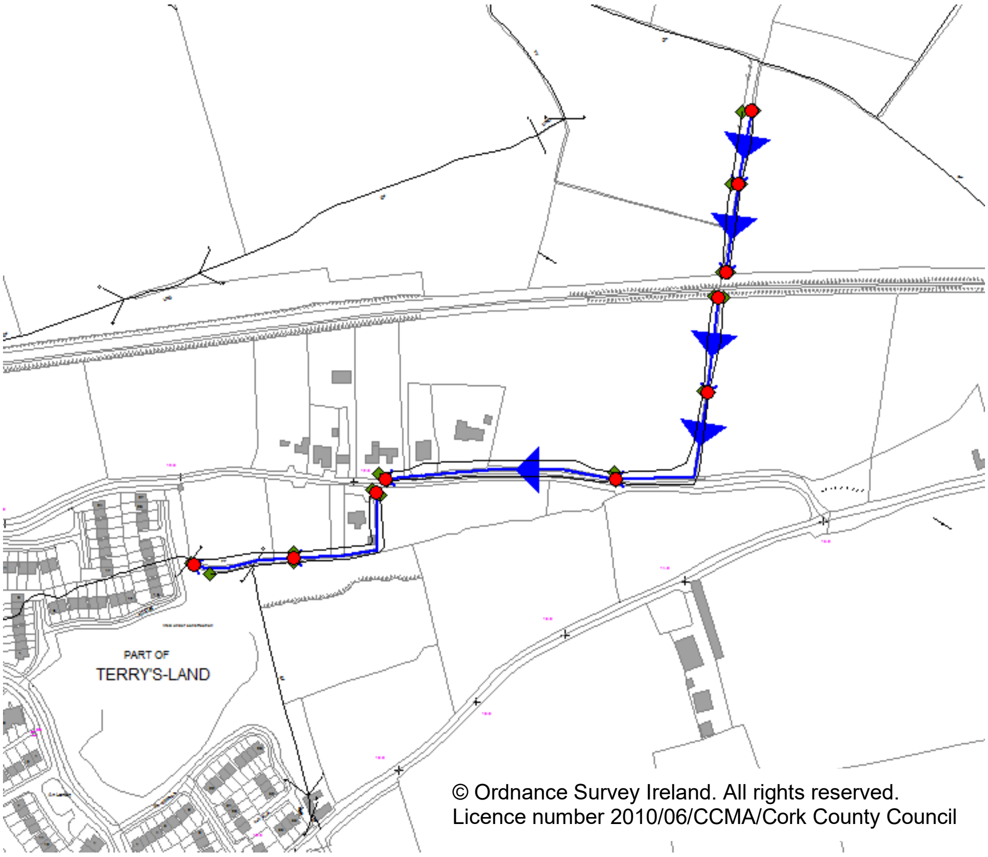
Channel through private undeveloped land

2.3.5 Poulaniska Stream

The Poulaniska Stream discharges into a network of underground caves at Cúl Ard housing estate. From its upstream (modelled) extent the Poulaniska Stream flows in a north south direction to the Bog Road then flows in a westerly direction along the Bog Road, before turning southward and discharging into the underground caves.

Based on the hydrogeological study, it is assumed that this flow re-emerges further downstream, near Slatty Pond.

Figure 2-8 Poulaniska Stream Flow Route

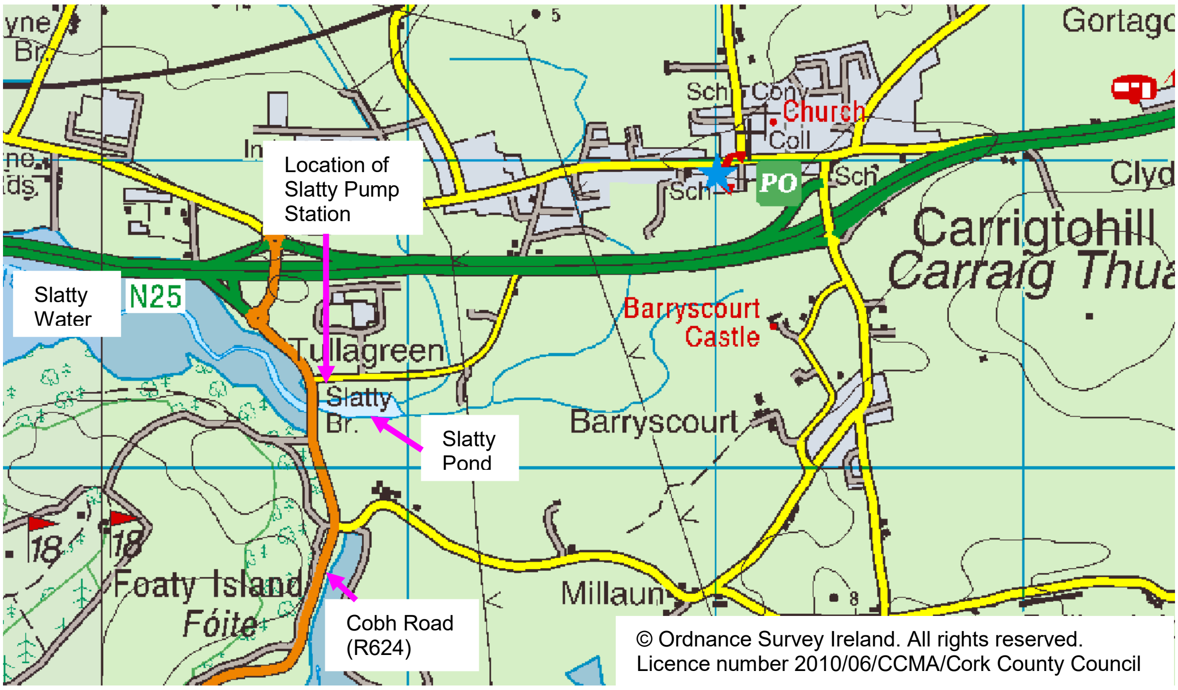


2.3.6 Slatty Pond

Slatty Pond is located at the southern end of the catchment and drains into Slatty Water, as illustrated in Figure 2-9 below. This pond was once part of the larger estuary but since the construction of Slatty Bridge a large portion of land in the vicinity has been reclaimed for agricultural purposes.

Slatty Pump Station was constructed in recent years to address local concerns about rising water levels in the pond. This pump station pumps water from Slatty pond to Slatty Water, the tidal estuary downstream of Slatty Bridge. Water also drains by gravity through 5 non-return valves at Slatty Bridge.

Figure 2-9 Slatty Pond



3 Data Review

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.

3.1 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.

Under the Lee CFRAMS, a series of reports were completed documenting the work undertaken at the varying 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.

3.2 Flood History and Local Information

The OPW hosts a National Flood Hazard Mapping website 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. The anecdotal evidence collated is summarised in Figure 3-1.

3.3 LIDAR

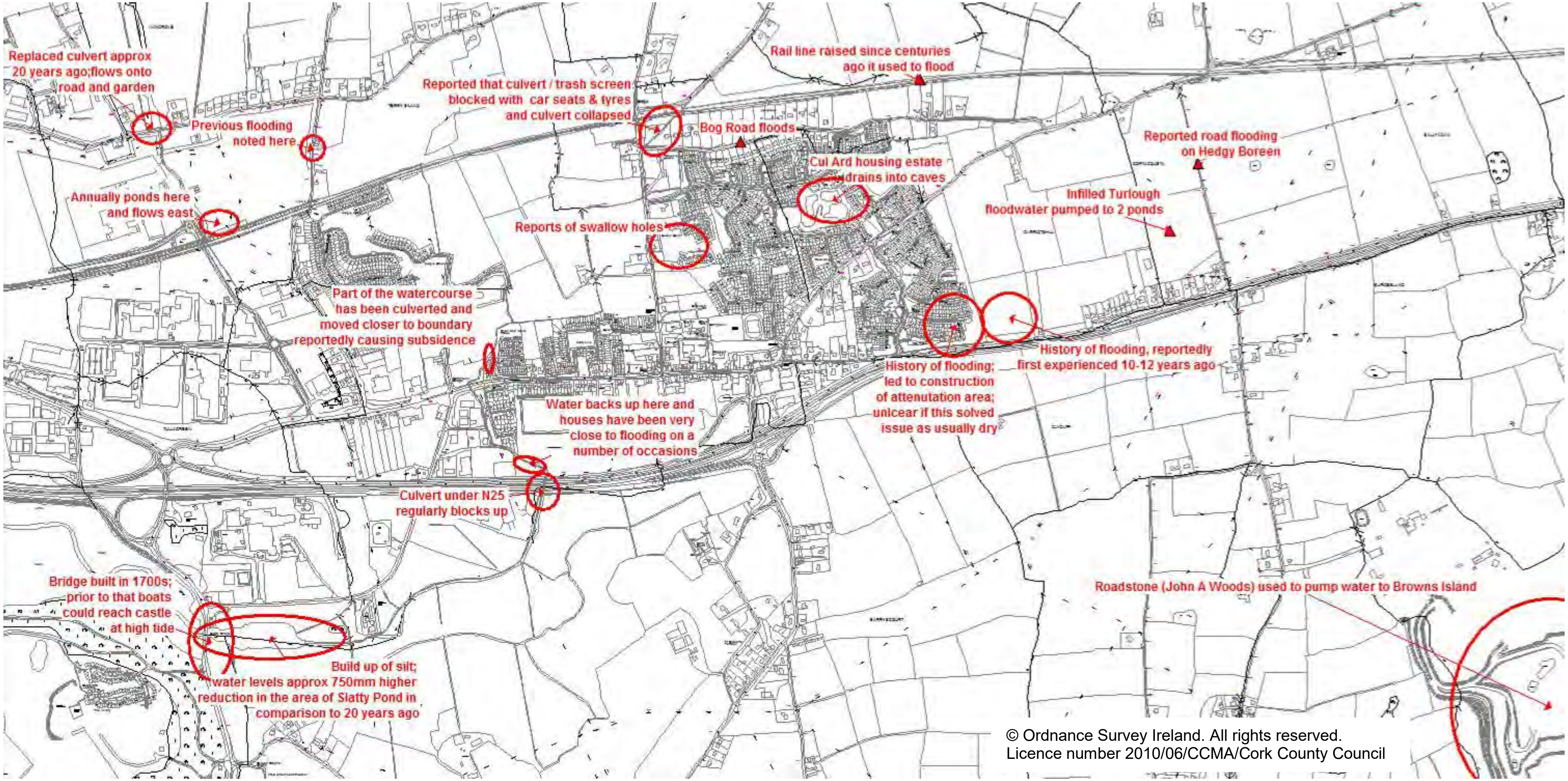
LIDAR (Light Detection And Ranging) is a remote sensing technology that uses laser scanning / radar to collect ground elevation data. LIDAR data flown as part of Lee CFRAMS in June 2005 / 2006 was provided for the study. However consultation with the OSi revealed that for the majority of the area LIDAR 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.

3.4 Topographical River Survey Data

River survey was carried out in June 2007 as part of the Lee CFRAMS. This covered the lower reaches of the watercourses in Carrigtohill.

In 2012, JBA commissioned Murphy Surveys Ltd to carry out further survey to include the upper reaches and also to resurvey areas where notable recent development adjacent to the watercourses had occurred and areas within the original survey extent that would benefit from additional survey points. More detail on the survey information that was collated is presented in Chapter 6.

Figure 3-1 Summary of Anecdotal Evidence



4 Hydrology Overview

4.1 Introduction

The purpose of this Chapter (Chapter 4) is to outline the hydrology assessment undertaken for Carrigtohill and present the design flows to be used as inputs to the hydraulic modelling. The hydrological analysis completed for this study is detailed in the Hydrology Report which can be found in Appendix B of the main report.

The steps taken to carry out the hydrological analysis for Carrigtohill are outlined below.

4.2 Estimation of the Index Flood (Qmed)

Carrigtohill is an ungauged catchment therefore the flow estimation techniques adopted rely on ungauged methods with data transfer (or donor sites) to relate flow estimates to recorded data in neighbouring or similar sites. The index flood was estimated using Flood Studies Update methodology and alternatives methods were investigated for comparison. The Flood Studies Update 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. When compared with the older alternatives the FSU gives slightly more conservative results for this study. (See Hydrology Report).

4.2.1 FSU Data Transfer

The FSU recommends use of donor catchment or pivotal gauges to improve estimates of the index flood at ungauged sites. Ballyedmond Gauging Station was selected as the best available pivotal gauge for data transfer; it is the nearest gauge geographically with a data record of 28 years. The adjustment factor is based on the ratio of observed / measured flow to estimated Qmed flow at the donor site.

4.3 Flood Frequency Analysis

This consists of a statistical analysis of AMAX data for a number of 'pooled' sites to determine flood frequency curve. The pooled group of gauging stations is based on those gauges with good quality data reliable for the estimation of Qmed i.e. A1 and A2 rated gauges. The growth factors applied to Qmed for this study are based on the GEV statistical distribution of the FSU pooling group. The flows for all return periods derived for use in the hydraulic modelling are shown in Table 4-1 below. A map showing the location of the hydrological estimation points (HEPs) can be found in the hydrology report.

Table 4-1 Design Peak Flows (m^3/s)

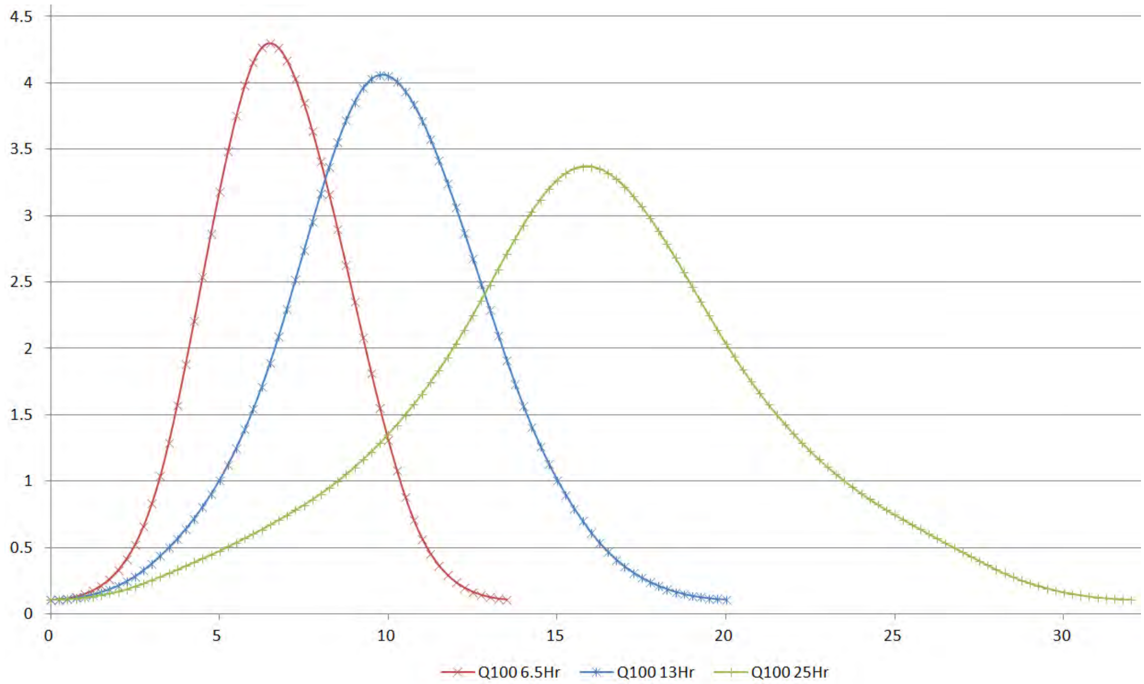
HEP Ref.	Qmed	Q5	Q10	Q25	Q50	Q100	Q200	Q500	Q1000
01	1.1	1.4	1.7	2.0	2.2	2.4	2.6	2.8	3.0
02	2.0	2.6	3.1	3.6	4.0	4.3	4.7	5.2	5.5
03	1.9	2.5	3.0	2.6	3.8	4.2	4.6	5.0	5.4
04	1.1	1.4	1.7	2.1	2.2	2.4	2.6	2.8	3.0

4.4 Flood Hydrograph Analysis

The Flood Studies Report rainfall runoff methodology is used to derive a hydrograph shape and these are then scaled to the FSU flow estimates. 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 and the resultant flow hydrographs developed. Taken HEP02 as an example, Figure 4-1 illustrates how the hydrograph shape differs for storms of varying duration.

A sensitivity analysis was completed to determine the impact of the various durations on flood risk. Based on the results of this the 6.5 hour storm was taken forward for the design model runs.

Figure 4-1 1%AEP Flow Hydrograph for Varying Durations at HEP02



4.5 Surface Water Runoff

Piped and overland surface water flow within the model domain is estimated by applying Rational Method and FSU based approaches. The consideration of surface water takes into account surface water that is diverted to other sub-catchments or outfalls directly to the estuary. To represent surface water runoff lateral inflows are added to the hydraulic model at points along the watercourse. Surface water runoff from undeveloped sites or permeable unpaved catchments is based on the flow estimation method adopted for the larger fluvial catchments. This approach assumes that attenuation to greenfield runoff rates will be required as a minimum for any future development in the catchment.

4.6 Joint Probability of Tidal and Fluvial events

The chance of an extreme tidal and extreme fluvial event occurring simultaneously is considered to be very low and joint probability (JP) analysis can be carried out to assess this assumption. For this situation to be worthy of 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. 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 and these extreme tidal events are modelled using a 2D only model.

Based on this the combined probabilities investigated for Carrigtohill are a nominal tide with all fluvial events. Extreme tidal events are investigated through the development of a 2D only model.

4.7 Allowance for Climate Change

Based on Draft OPW guidance[1], two climate change scenarios are considered, the Mid-Range Future Scenario (MRFS) and the High-End Future Scenario (HEFS). The total climate change allowance for tide levels is 0.55m for the MRFS and 1.05m for the HEFS, as presented below in Table 4-2. For fluvial flows, climate change flows are increased by 20% and 30% for MRFS and HEFS respectively. For more detail and a breakdown of the fluvial flows refer to the full Hydrology Report in Appendix B.

Table 4-2 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. 593
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

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

5 Hydrogeology

Due to a strong groundwater influence, a hydro-geological analysis has also been undertaken by a specialist sub-consultant, Peter Conroy. This study is summarised in this Chapter (Chapter 5) and the full hydrogeology report is presented in Appendix C.

A qualitative assessment of groundwater flood risk has been carried out based on all available data from the statutory databases and local stakeholders. The assessment also takes into account the potential impact of quarry dewatering.

The study involved a comprehensive desk review of hydro geological data available from the following sources:

- Geological Society of Ireland (GSI),
- Environmental Protection Agency (EPA),
- Cork County Council, quarry operators in the area,
- IPCC licence holders,
- Ordnance Survey Ireland (OSi),
- Office of Public works (OPW),
- South Western River Basin District (SWRBD).

Consultation was also held with key stakeholders including developers and the local community, a catchment site visit and drive-over survey was also carried out. This allowed a preliminary hydro-geological assessment to identify groundwater flooding factors such as karst features and groundwater elevation in the study area.

5.1 Groundwater Catchment

The northern two-thirds of the groundwater catchment sits on a sandstone ridge to the north of Carrigtohill and the remaining third sits on a limestone valley. This limestone valley is bounded by parallel east west trending sandstone ridges to the north and south. There are a number of gravel pits and limestone quarries that have significantly altered the natural topography on a local scale.

The GSI karst database indicates the presence of three caves, two swallow holes and two turloughs within the limestone component of the catchment. Two caves and a swallow hole occur at the disused quarry at Cúl Ard and a second swallow hole was also identified here during the site visit.

The two turloughs and swallow hole recorded in the GSI database at Ballyadam, to the east of Carrigtohill, were not identified at the exact recorded location on site. However, it is considered likely that these karst features did occur at a site that has since been partly developed and has undergone significant groundworks. This site has been earmarked by IDA for development of an industrial estate and the groundworks completed at this site included infilling of a "man made lake" (IDA, 2010). Since the groundworks were carried out, frequent flooding was reported by Cork County Council of the adjacent local road (known as the Hedgy Boreen). From the site visit a new swallow hole was identified at the base of an attenuation pond on the site.

Further karst features were identified in the surrounding limestone bedrock (outside the Carrigtohill surface water catchment). See the full Hydrogeology Report in Appendix C for more detail.

GSI maps indicate that the majority of the study area has high groundwater vulnerability with zones of extreme vulnerability.

5.2 Hydro geological Characteristics

The study area is classed as a Regionally Important Aquifer with kartisfied, diffuse flow mechanisms. Generally flow finds its way through "karst conduits" in the aquifer to discharge points at springs and rivers. The karst pathways are typically oriented along east-west and north-south joints and fractures at 1m to 6m intervals, although caving explorations have also identified north-east to south-west trends in caves at Carrigtohill.

Groundwater flow velocities are expected to be high along the karst pathways. Tracer testing in the Regionally Important aquifer suggests flow velocities of up to 30m/hr between swallow holes and the Dower Spring, east of Castlematyr (GSI 2004). Analysis of borehole testing and pumping data indicates a high yield aquifer. This is also supported by the large quarry dewatering volumes in the Carrigtohill area.

Quarry dewatering is a feature (or has been) of all quarries in the area. A saline component was identified at a number of quarries, this indicates the karst pathways in the aquifer are in hydraulic continuity with the estuary to the south.

Quarry	Dewatering Rate (m^3/day)
Readymix Rossmore	1,600 - 2,000
RoadstoneWood Ballyvodock West	18,000 to 25,000
Lagan Cement Milebush in Ballynabointra	1,400 to 6,000

Quarrying of the limestone bedrock has impacted on the physical characteristics of the aquifer with the creation of large voids in the bedrock with depths down to -22mAOD. These voids create large storage reservoirs in what would otherwise be a low storage and highly flashy aquifer. The removal of clay, blasting of rock and exposure of multiple conduits to a large flooded void will increase the transmissivity of the aquifer and create new interconnections between conduits.

The infilling of the Ballyadam Turloughs has also altered the physical characteristics of the aquifer. Infilling of the turlough void space has displaced groundwater flooding of the voids to the adjacent road way to the west, while pumping of the flood waters to the IDA attenuation pond has created a new swallow hole pathway. These physical changes may be diverting groundwater flow from historical flowpaths through the system into new flowpaths. Such changes in the flow volume through parts of the system may change the flooding behaviour of the system compared to what has been observed historically.

Observation of GSI and EPA groundwater records indicate a flashy pattern of groundwater levels which is typical in karst aquifers under the influence of rapid recharge from point sources such as swallow holes. Overall the recorded data does not show a clear dewatering impact on groundwater elevations compared to the pre-dewatering baseline. The data reveals little with respect to potential maximum regional groundwater elevation rebound as the post dewatering scenario is still evolving.

In the Regionally Important aquifer the hydraulic gradient across the study areas is likely to be directed from the sandstone hills to the sea and once post dewatering groundwater levels have stabilised the gradient in the west of the catchment is likely to be directed towards Slatty Water and Rossmore, while in the east it will be directed towards the estuary of the Owenacurra River. At a local scale individual abstractions will generate gradients towards the abstraction point.

The assumed groundwater flow directions are shown in Figure 9 of the full hydro-geology report in Appendix C.

5.3 Groundwater Flooding Assessment

The different mechanisms of groundwater flooding are outlined below. These are described in more detail in the full hydrogeology report.

- Flooding can occur at inputs to the karst system i.e. swallow holes can occur during extreme rainfall events or when the available recharge exceeds the tranmissivity of the saturated groundwater flow system.
- Flooding can also occur at discharge points from the karst system i.e. springs when the spring discharge exceeds the capacity of pond or channel draining out of the spring.
- Flooding can occur at attenuation points i.e. turloughs, enclosed depressions and limestone quarry pits along the karst groundwater flow paths. Such features provide storage for excess groundwater, the absence of this storage would increase the discharge from springs.

Only one area of known groundwater flooding was identified. This is reported at the local road (known as the Hedgy Boreen) adjacent to the western boundary of the IDA site in Ballyadam.

There is no anecdotal evidence from the stakeholders that quarry flooding has had any impact on groundwater flooding occurrences in the study area. As the RoadstoneWood quarry stopped dewatering in the 2010 it is possible that rising water levels in the quarry and its vicinity may have exacerbated the flooding reported in Ballyadam adjacent to the IDA site in 2010.

Overall it appears that to date the cessation of dewatering in the quarries has not led to a significant increase in groundwater flooding at karst features. As the groundwater level has not yet stabilised at the Milebush quarry it cannot be ruled out that flooding of the Milebush and Ballyvodock West quarries could cause or exacerbate groundwater flooding in the future.

5.4 Recommendations

The study concludes with a number of recommendations in order to facilitate monitoring of groundwater levels across the study area and quantitative assessment of groundwater flood risk.

These are summarised below, refer to the full hydrogeology report in Appendix C for more detail.

- A groundwater level monitoring network should be established. This should incorporate existing boreholes and monitoring wells in the catchment. A detailed well and karst survey should be completed to identify any additional bedrock boreholes and karst features and where an insufficient number of boreholes are identified, new boreholes should be drilled at key locations to fill data gaps. A number of other steps to establish a monitoring network are also detailed in the full report.
- Carry out dye tracer testing at swallow holes to identify groundwater flow paths through the karst aquifer.
- Install gauges with continuous monitoring at springs and sinking stream in order to quantify ground water discharge and surface water recharge rates

6 River Survey & Data Collection

As part of this study and as required by the brief, a topographic river survey was carried out. Murphy Surveys Ltd. were contracted to complete this work and extent of survey specified was agreed between JBA Consulting and the client, Cork County Council, prior to work commencing.

The surveyors collated data for over 93 river cross sections and 24 structures. During the topographical river survey, observations of structures and other assets were made. Visual observations were also recorded on subsequent visits to the site. This information is used in the hydraulic model build process and to assess the hydraulic condition of existing culverts.

Survey data collected during the Lee CFRAMS for development of the original model was also available for review. In addition, JBA performed numerous walkover of the study area to identify and confirm important hydraulic features and assets within the modelled catchment.

Based on these sources, the defence assets identified in the catchment are listed in Table 6-1, trash screens are listed in Table 6-2 and a list of all flow structures including culverts and bridges and their approximate dimensions are presented below in Table 6-3.

This information is used in the build and development stage of the hydraulic model. The hydraulic modelling output, discussed in Section 9 identifies any structures that are hydraulically insufficient in terms of increasing flood risk in the catchment.

6.1 Defence Assets

The following, Table 6-1 lists the defence assets that have been identified in the study area. This lists includes features that form a defence role but were not necessarily designed for that purpose and / or are not included in any formal inspection or maintenance programme.

Table 6-1 List of Defence Assets

Ref. / Name	Location	Dimension (approx)	Comment
Slatty pump station	Slatty Area	4 x 1000m3 capacity pumps	Formal defences designed to maintain water levels in Slatty Pond below -0.9mAD. Recently installed and regularly maintained.
N25 and old Cobh road embankments	Extends between Kilacloyne Tidal Area and Slatty Bridge	Crest levels range from 2.7m to >4mOD	These are classed as an effective informal or de-facto defences; although not maintained as flood defences these roads are subject to regular maintenance. Roadside wall and banks are not considered as defences as they are not continuous and are not formally maintained as flood defences.
Embankments in Kilacloyne Tidal Area	Kilacloyne Tidal Area	Crest levels range from 2.5 to >3mOD	These are informal effective defences. They do not undergo regular inspection or maintenance by the local authority or OPW.

6.2 Trash Screens

A number of trash screens were identified along the watercourses included in the model. Trash screens, unless adequately and carefully designed, can increase flood risk. This is associated with a higher probability of blockage due to the movement of debris in high flow conditions. Trash screens require careful design and continued maintenance and management.

The following table, Table 6-2 lists the trash screens included in the 1D component of the fluvial hydraulic model.

Table 6-2 List of Trash Screens

Model Ref. / Location	Description / Photo
WOOD00333I Culvert along Church Road	A circular pipe acts as an inlet to an old stone arch culvert. A section of this old stone culvert collapsed in August 2012 following a period of heavy rain. The repair work included the addition of a trash screen at the inlet. 
Culvert_9 N25 Road Culvert near GAA grounds	
POUL0041I Culvert at Cúl Ard	

6.3 Culverts & Bridges

The following, Table 6-3, lists all culvert and bridges identified along the surveyed reaches of the study area. Detailed information, including pertinent survey information for these culverts is included in the Model Check File, in Appendix D.

Table 6-3 List of Culverts & Bridges

Ref. / Name	Location	Structure Size
KILA00084	179963, 73678	1.44m x 0.6m
KILA00077	179937, 73617	1.48 x 0.45m
KILA00070	179926, 73590	3 x 500mm dia pipes
KILA00068	179902, 73534	3 x 550mm dia pipes
KILA00065	179888, 73503	3 x 450mm dia pipes
KILA00050	179827, 73375	600mm & 450mm dia pipes
KILA00016	179504, 73247	2.1 x 1.0m
KILA00012	179502, 73229	900mm stone arch
TIBB00126	179793, 73244	4.3 x 1.2m
TIBB00107	179711, 73075	900mm dia pipe
TIBB00087	179543, 73118	900mm dia pipe
WOOD00382	182373, 74053	900mm dia pipe
WOOD00364	182240, 73909	600mm dia pipe
WOOD00350	182148, 73811	2.4 x 1m
WOOD00333	182038, 73701	1.1m dia pipe inlet into 900mm old stone arch
WOOD00277	181873, 73310	Twin 600mm dia pipes
Culvert 7 (Carrigtohill Bridge)	181493, 72972	Twin 1m dia pipes
POUL00097	183186, 73934	2.1 x 1.5m
POUL00061	182935, 73782	Twin 600mm pipes
POUL00041	182794, 73719	1500mm dia pipe
TIBB00190	180504, 73748	1m dia pipe
TIBB00188	180549, 73752	Twin 800mm dia pipe
TIBB00166	180618, 73557	8 x 1m
TIBB00150		
2CA1_1259	180792, 73248	Triple 450mm dia pipes
Culvert 2	180877, 73102	Triple 450mm dia pipes
Culvert 3	180935, 73005	Triple 600mm dia pipes
Culvert 4	180942, 72867	Twin 600mm dia pipe
Culvert 5	180951, 72828	750mm & 450mm dia pipes
Culvert 6	181133, 72310	1.23 x 1.23m
Culvert 9	181729, 72683	2.8 x 3m
Culvert 10	181294, 72276	5 x 2.5m
Culvert 11	181811, 72368	0.95m dia pipe
Culvert 12	181422, 72196	0.9m dia pipe
Slatty Bridge	180693, 72217	Bridge spans 40m channel with 5 openings of various sizes

7 Hydraulics Overview

The modelling carried out under this study expands and improves on the modelling that was scoped and completed under the Lee CFRAMS. The Lee CFRAMS model for Carrigtohill is a 1D ISIS model and recommendations outlined in the Lee CFRAMS reports acknowledged that the model required more detailed assessment to define flood risk in the study area.

Under the Carrigtohill Brief, JBA are tasked with preparing a 1D-2D hydraulic model, expanding on that prepared under the Lee CFRAMS for the purpose of flood mapping. The study is to investigate flood risk for a number of flood events. The flood events simulated include fluvial and tidal events with an annual exceedance probability (AEP) ranging from 50% to 0.1% (or a return period of 2 to 1000 years).

This chapter gives an overview of the hydraulic modelling stage of the study, for more technical detail on the hydraulic model see the Model Check File provided in Appendix D.

7.1 Fluvial Model Development

The linked fluvial model developed under this study represents a physical extension upstream to the ISIS 1D model produced for the Lee CFRAMS. The updated model also includes a link to 2D to represent floodplain flow. The 1D-2D ISIS-TUFLOW model development consists of:

- Creating a 1D-2D linked model for each river reach
- Extending each river reach upstream beyond the extent of the SLAP
- Including for groundwater attenuation based on detailed hydro geological study
- Including the pumping station at Slatty pond
- Representing the flow split at the IDA estate where water passes under the rail line via siphons
- Including an extra river reach that was not part of the Lee CFRAMS
- Update of the Lee CFRAMS model based on new survey data.

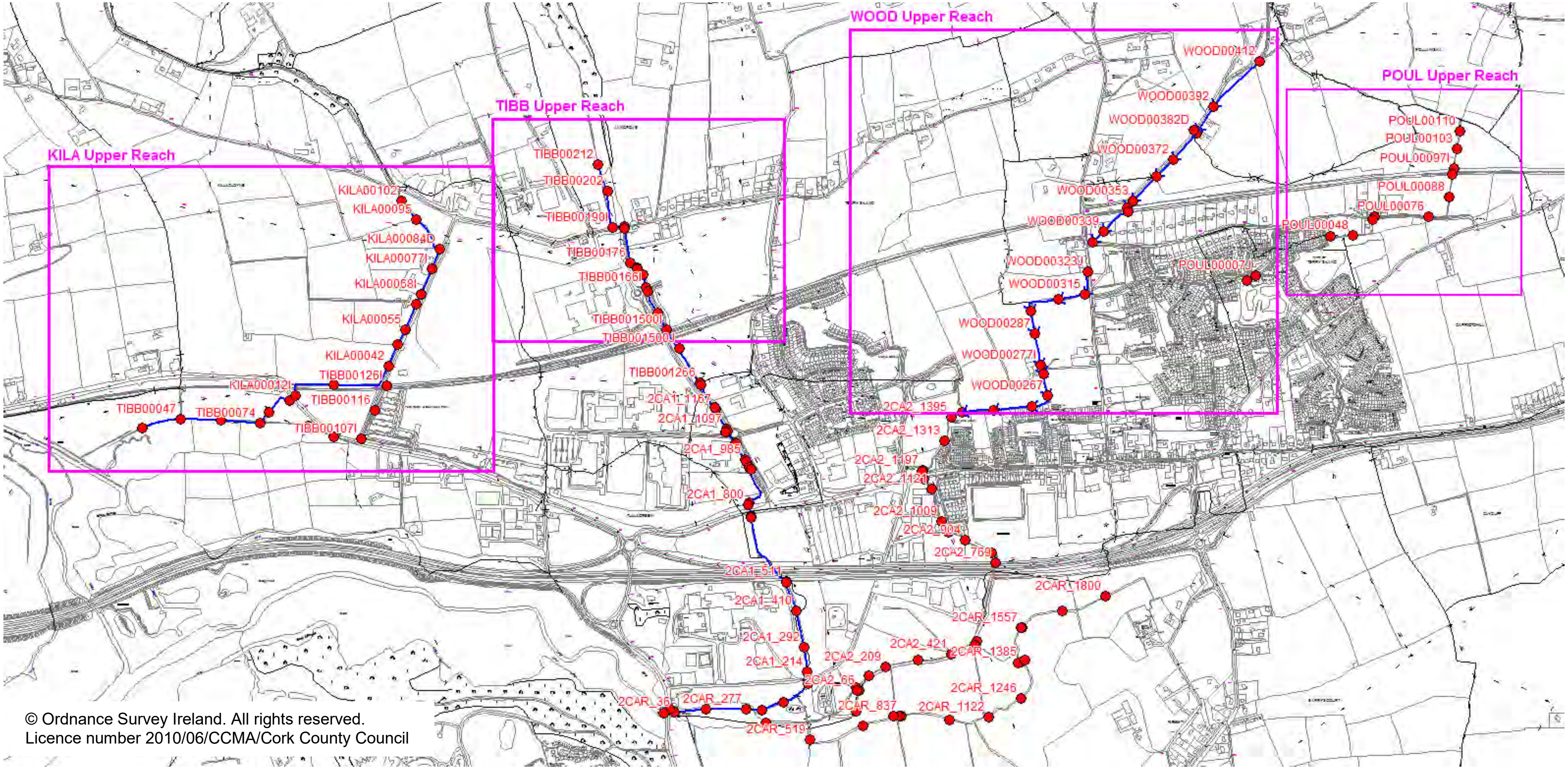
The model consists of 4 river reaches plus a reach to represent an artificial rail diversion channel. A graphical schematic of the fluvial model is presented in Figure 7-1 below.

7.1.1 Hydraulic Structures in the 1D-2D Linked Model

All structures identified along the modelled reaches are listed in Table 6-3, presented in the previous Section. These are detailed in the Model Check File and a justification is given for any structures that have not been included.

In addition to those structures identified along the survey reaches and included in the 1D model, a number of floodplain culverts have been included in the 2D component of the model to take into account floodplain flow routes, such as flow under the rail line embankment. These floodplain culverts and their inclusion in the model are also detailed in the Model Check File.

Figure 7-1 Fluvial Model Schematic



7.2 Tidal Model Development

In addition, to represent tidal flood events a 2D only TUFLOW model was developed. This tidal model is to assess the impact of extreme tides along the shore of the Carrigtohill catchment.

The 2D TUFLOW model development consists of:

- Creating a 2D model domain based on up-to-date LIDAR data
- Application of a tidal boundary along the shoreline of the Carrigtohill catchment.

A graphical schematic of the tidal model is presented in Figure 7-2 below.

7.2.1 Flooding Mechanism & Tidal Defences

Tidal flooding occurs when the tide level exceeds the elevation of the shoreline. A review of the defence assets in the study area highlights the N25 road embankment and a land embankment to the west in the area of the Kilacloyne estuary as having a flood defence function. These are not maintained formally as flood defences but are sizable features that are not expected to fail catastrophically in the current or near future term. These features have not been removed for an undefended scenario. The N25 road embankment is critical infrastructure and therefore is subject to regular maintenance. It forms a sizable topographic feature and catastrophic failure without warning is unlikely; failure is more likely to be overtopping. Overtopping is included in the modelling and the impact assessed.

7.2.2 Hydraulic Structures in the 2D Model

Although the tidal model is a 2D only model, important 1D elements are represented using the available ESTRY commands in TUFLOW.

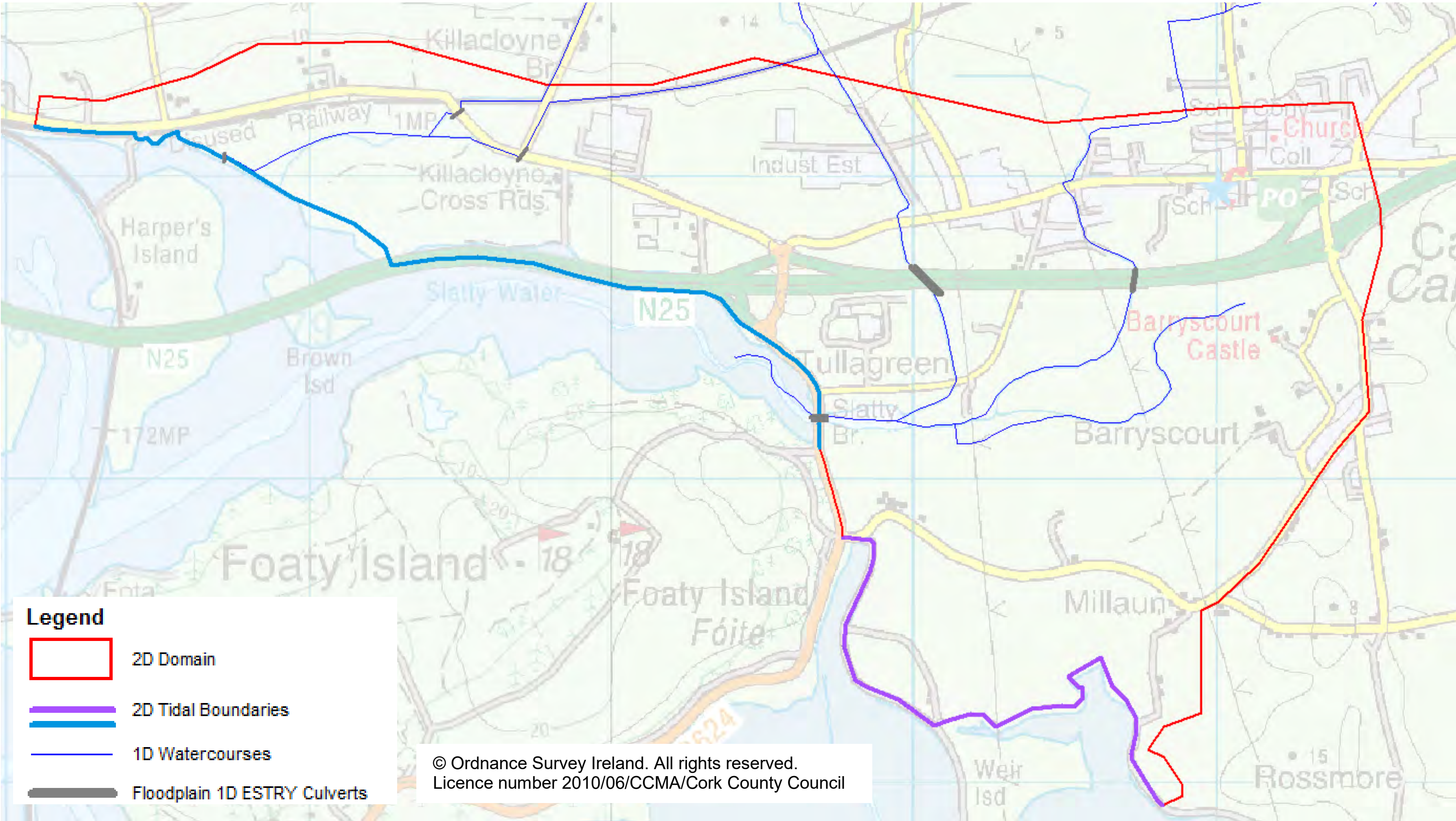
The location of the floodplain culverts included in the model are illustrated in Figure 7-2. Detail on these features can be found in the Model Check File in Appendix D.

Flapped outfalls at the model boundary allow flood water to drain into the estuary when the tide is low. The culverts under the N25 road embankment allow the propagation of tidal flood waters upstream along defined watercourse during extreme events.

7.2.3 Slatty Pump Station

The tidal model has been developed to model the flooding that will occur once the tide level exceeds the elevation of the shoreline and overtopping occurs. During such tidal inundation it is assumed that the pumps are not working and these are not represented in the tidal 2D only model.

Figure 7-2 Tidal Model Schematic



7.3 Key Model Parameters

7.3.1 Active model domain

The fluvial model active domain measures 6.3 km^2 and stretches from the shoreline to beyond the extent of the 1D modelled reaches.

The tidal model active domain is smaller representing the area that is tidally influenced and measures 4.6 km^2. The domain boundary stretches from the shoreline and follows high ground (generally ~ 10mOD).

7.3.2 Roughness

The model roughness is defined based on the following references Chow, 1965; USACE 1995; HR Wallingford & Barr D, 1994 as well as experienced JBA internal guidance. Roughness coefficients are set for the 1D and 2D models and are discussed in detail in the Model Check File. For key areas in the 1D model a more detailed approach was adopted for setting manning values based on assigning multiple roughness panels within the left and right bank markers. This for example takes into account the variation between a clean gravel bed and overgrown channel sides.

7.3.3 Model cell size (2D component)

The relatively small watercourse require a fine grid size to be accurately represented in the 2D domain. The model cell size for the fluvial 1D-2D linked model is set at 4m. This is a trade-off between model representation and computational times. With a cell size of 4m the model takes 3 to 4 hours to run. *(Note: Computational times are also dependent on other model parameters namely the time step)*.

The tidal model cell size is set 10m this is considered appropriate for such a tidal inundation model, considering the tidal floodplain is predominantly rural.

7.3.4 DTM modifications in 2D

The DTM for the model domain is defined using LIDAR flown in March 2011. The DTM was inspected for any anomalies such as areas of null data, or spikes in elevation. Areas of null data are patched utilising TUFLOW commands within the TUFLOW geometry control (.tgc) file.

The resolution of the LIDAR and also the model DTM can mean that certain features in the floodplain are not accurately represented in the model base DTM. To overcome this, embankment and other linear features in the floodplain are defined using zlines.

7.4 Model Boundary Conditions

For the fluvial model, the model boundaries consist of fluvial inflows at the upstream end and a tidal stage boundary at the downstream end. The upstream flow time boundaries are based on the flow estimates derived in the hydrological assessment. The downstream head time boundary is taken from the tidal data that was utilised in the Lee CFRAMS.

In addition lateral inflows were applied to the model to take into account runoff from areas within the modelled domain that are not incorporated in the fluvial flow estimates for the upstream boundaries.

The tidal model has only one model boundary and this utilises the same head time tidal boundary as above, applying it along the entire shore of the Carrigtohill catchment.

An overview of the Hydrology is given in Chapter 4; for more detail on the hydrology see the Hydrology Report in Appendix B.

7.5 Model Limitations & Uncertainty

All hydraulic models are prone to uncertainties due to factors such as inaccuracies in the key model inputs (i.e. flows, tide levels, topography), model parameters (i.e. roughness) the modelling software used and the nature of any assumptions made in the modelling process.

The key assumptions made are summarised below for information. All modelling assumptions are recorded in the Model Check File and /or as comments in the ISIS model DAT file and TUFLOW command files as appropriate.

The model build uses survey data which is a snapshot in time and changes, both natural hydro-geomorphologic or manmade, can have an impact on the hydraulics of a channel. The original Lee CFRAMS model developed in 2007 was based on survey collated at that time. Re-survey of the entire catchment was considered unnecessary as part of this study however where recent changes in river topography were noted, supplementary survey was specified to allow for updates to the model in these area. This included areas that were inaccessible during the original survey. The areas where re-survey was specified include Slatty Pond, a length of the Woodstock Stream in the vicinity of the Castlelake development and Carrigtohill Bridge and south of the N25.

Bank top survey data along the watercourse is sparse and this can mean potential over bank flow routes can be excluded where an isolated low point on the bank might exist.

Modelling uncertainty arises from a number of sources. The primary sources are uncertainties inherent in hydrology and flow estimation, particularly for ungauged catchments such as this; uncertainties linked with the hydraulics of a particular stretch of channel or structure e.g. split of flow in the 3 way at the rail siphon and uncertainties arising from the quality and resolution of the DTM or LIDAR grid.

Other parameters that can introduce uncertainty are parameters used in the hydraulic modelling i.e. roughness, calibration data etc. These can be assessed by carrying out a reasonability check and sensitivity analysis on the hydraulic model.

7.5.1 Key Model Assumptions

The hydraulic modelling process including model assumptions is outlined in detail in the Model Check File, which is presented in Appendix D of this report. The key assumptions made are summarised below:

- Accurate topographical survey of the invert levels at the 3-way split was not possible due to the arrangement of the culvert inlet. Invert levels, and hence determination of flow split were estimated based on observations on site, available drawings from IDA and nearest surveyed points.
- A number of culverts were observed to have a build up of sediment and the level of maintenance at these structures was assumed based on consultation with the local authority. The default approach was to model silted culverts as surveyed to represent the "Current Scenario" unless local data suggests that this is not appropriate i.e. well monitored and maintained.
- The risk of blockage is reviewed. A "clean culvert" situation is assessed by completing a sensitivity test and this is reported on to indicate the impact of siltation in key areas.
- Surface water runoff discharge points have been included in the model based on available data from previous studies, namely the TJ O'Connor Preliminary Report on the Surface Water Improvement Scheme.
- Attenuation to at least greenfield runoff rates will be provided for future development sites.
- Due to the nature of the modelled watercourses within the catchment minimum flows are applied to initialise flow in the model and prevent the streams running dry. The watercourses are narrow and steep with relatively small flows.
- The Kilacloyne Stream flows into Slatty Water. There are tidal embankments in this area and a tidal flapped outfall has been modelled at the downstream end of this reach. There is no survey data of this outlet and dimensions have been assumed as a 1m flapped diameter outlet.

- Informal ineffective defences along Cobh Road / Slatty Bridge were identified during visits to the site. However gaps in the wall and earthen embankment mean that these features are classed as ineffective and have not been included in the model. The road is constructed as an embankment and therefore is de-facto defence, which has been included in the model. The road levels as determined from the LIDAR have been used as the embankment crest level.
- Slatty Bridge was originally constructed in the 18th century. The bridge is porous and water can seep through the bridge structure. The model assumes there is no passage of water. Normal flow from Slatty passes through flapped openings in the bridge. The details of these bridge opening - passage of water through Slatty Bridge; headloss at flap valves / tideflex; water seeping through; sluices not modelled in 2D tidal

7.6 Model Sensitivity

7.6.1 Fluvial Model Sensitivity

A number of sensitivity tests were completed this includes testing the impact of the following:

- Variation in manning's roughness values
- Storm duration (6.5, 13 and 25 hours)
- Culvert blockage / cleaning - as part of this sensitivity check an initial screening assessment was carried out to identify the likelihood of a blockage occurring and its impact in terms of increasing flood risk. This screening assessment is outlined in Section 8 below.
- Timing of peak tide levels (in relation to fluvial peaks)
- Increase in tidal downstream boundary levels
- Fluvial and tidal combinations to test whether detailed analysis of joint probability is necessary.

7.6.2 Tidal Model Sensitivity

The sensitivity tests completed on the 2D tidal model are as follows:

- Reduction in the 2D model cell size from 10m to 4m
- Variation in 2D model roughness
- Variation of model boundary comparing results from different AEP event and climate change scenario.

The sensitivity results are presented in detail in the Model Check File, included in Appendix D of this report.

7.7 Model Design Runs

The design runs required to produce the flood maps required under the brief are summarised in the table below:

	Model	Tidal AEP	Fluvial AEP	Current	MRFS	HEFS	Current Undefended	MRFS Undefended
Fluvial Events	1D-2D	50%	50%	Y	Y			
	1D-2D	50%	20%	Y	Y			
	1D-2D	50%	10%	Y	Y	Y		
	1D-2D	50%	5%	Y	Y			
	1D-2D	50%	2%	Y	Y			
	1D-2D	50%	1%	Y	Y	Y	Y	Y
	1D-2D	50%	0.10%	Y	Y	Y	Y	Y
Tidal Events	2D	50%	-	-	Y	Y		
	2D	20%	-	-	Y			
	2D	10%	-	-	Y	Y		
	2D	5%	-	-	Y			
	2D	2%	-	Y	Y			
	2D	0.50%	-	Y	Y	Y	Y	Y
	2D	0.10%	-	Y	Y	Y	Y	Y

1D-2D model runs:	21
2D model runs:	17
Total Number Runs:	38

The model outputs are discussed in the latter sections of this report.

8 Hydro-geomorphology

8.1 Introduction

This chapter is a preliminary assessment of the hydro-geomorphology and sediment transport issues associated with the catchment, based on available or readily-derivable information. It also includes a blockage screening assessment to identify those culverts that are likely to block and have an impact on flood risk.

Hydro-geomorphology is the physical habitat created by water, either flowing or still, over the geomorphology or structural template of a watercourse. The hydro-geomorphology of a catchment is not static and consideration must be given to the reaction of a watercourse due to linked processes upstream and downstream. Erosion and sedimentation can have a big impact on overall flood risk, effect the onset or threshold of flooding.

The first section below highlights historic morphology, illustrating how features in the catchment have changed and this information helps identify the processes relevant to the current hydro-geomorphology of the study catchment.

Following on from that, this preliminary assessment aims to identify and discuss the following, with respect to sedimentation:

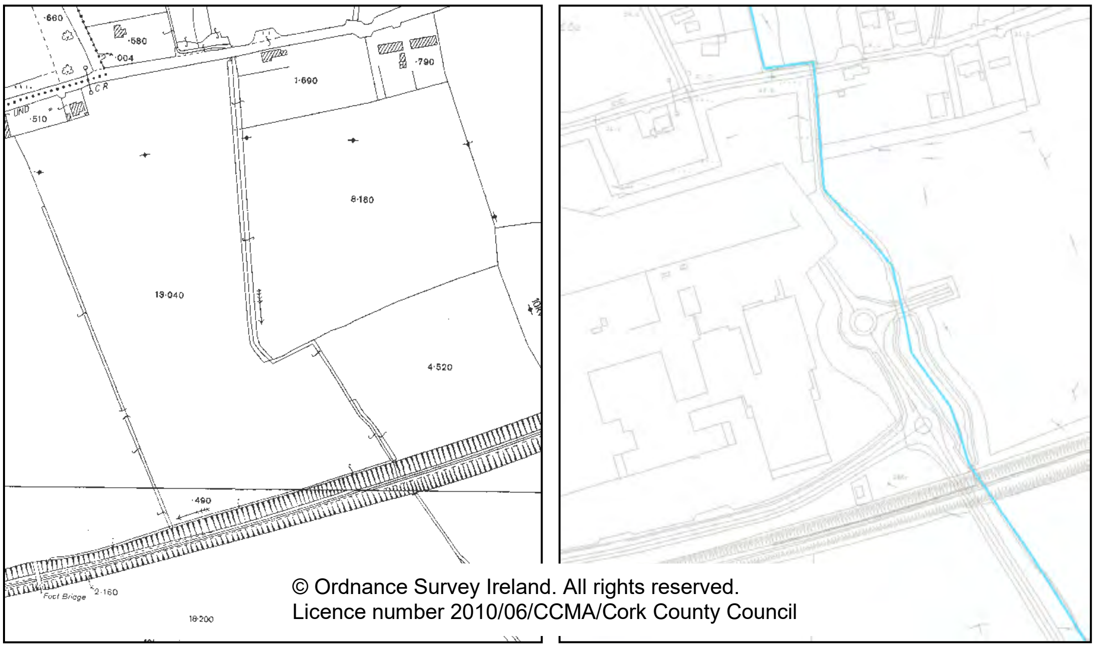
- Sources
- Conveyors and
- Sinks

8.2 Historic Morphology

8.2.1 Tibbotstown Stream

As part of the development of IDA lands in Carrigtohill, the Tibbotstown Stream has been realigned. This is illustrated in Figure 8-1 below.

Figure 8-1 Tibbotstown Stream at IDA lands

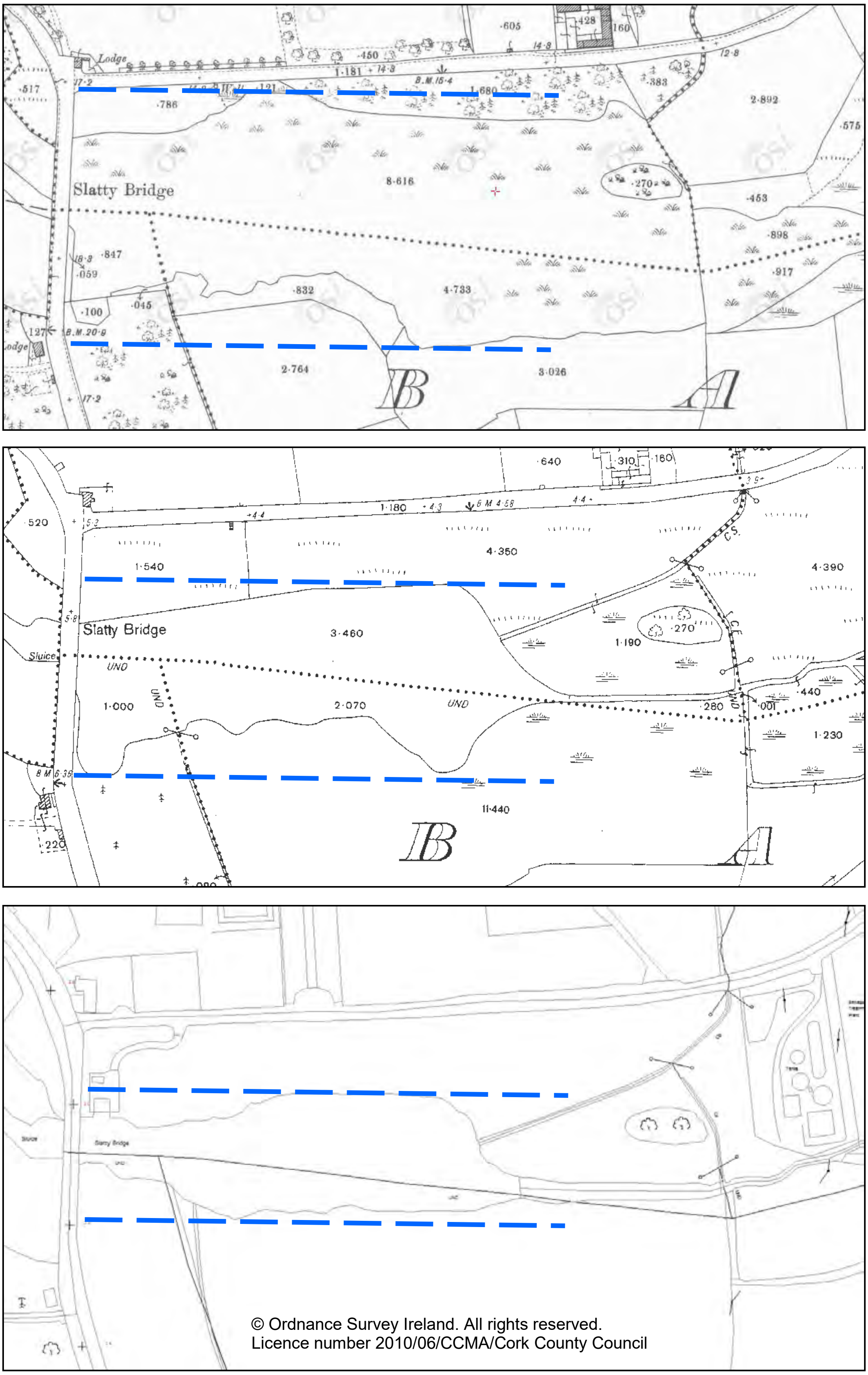


8.2.2 Slatty Pond

Historically, before the construction of Slatty Bridge in the 18th century, boats could navigate upstream from Slatty Water to Barryscourt Castle at high tide. Anecdotal evidence from locals suggests that water levels in Slatty Pond are higher by up to 750mm when compared with levels

20 years ago. Sedimentation and land reclamation practices have been a factor. Figure 8-2 illustrates the change / reduction in Slatty Pond since the earliest historic OSi mapping.

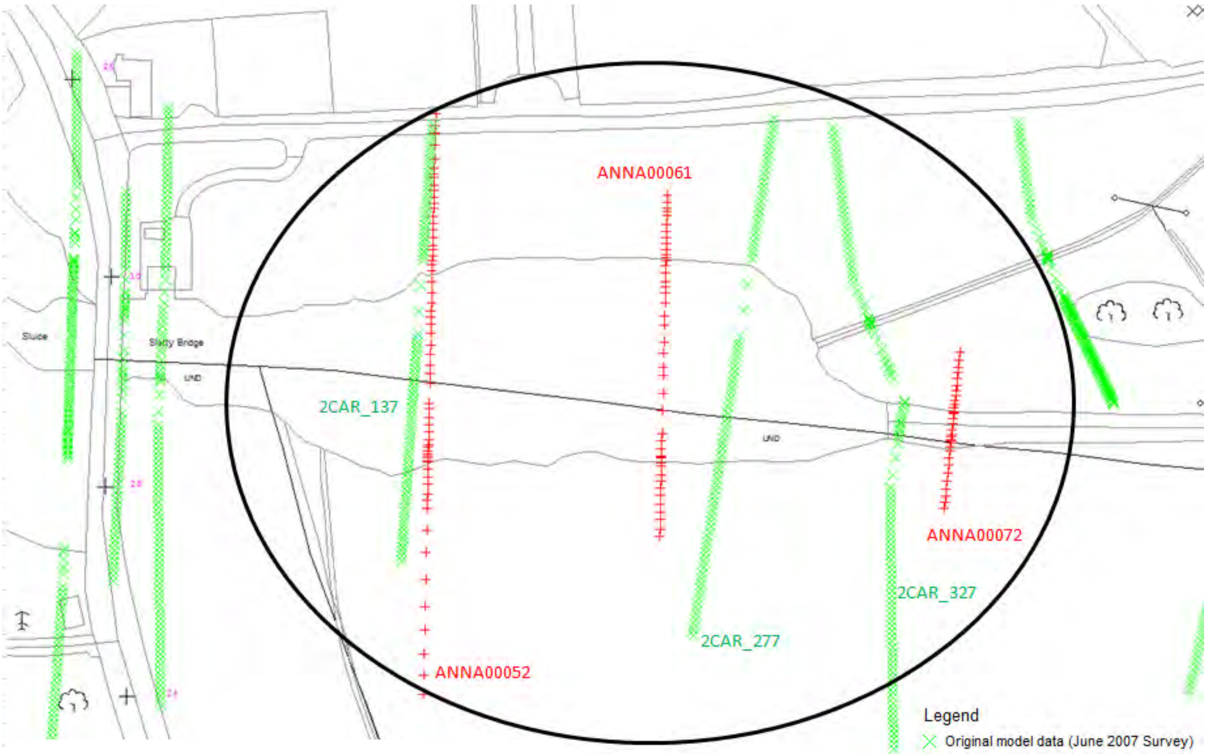
Figure 8-2 Extent of Slatty Pond



Survey of Slatty Pond was undertaken in 2007 as part of the development of the Lee CFRAMS model. This survey data has been compared with additional survey that was collated in 2012 as part of this study. Concerns were raised by locals about the potential of siltation to occur in the pond, reducing its storage capacity.

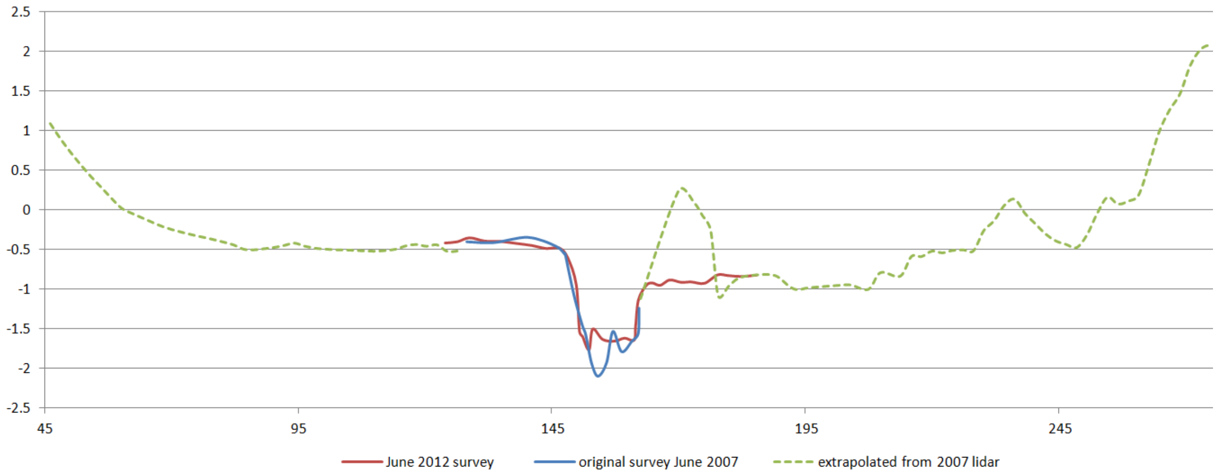
The surveyed cross sections were compared with sections from the original model. The following plan shows the location of these cross sections. Based on comments included in the original model and the 2007 survey deliverables, detailed survey spot levels were collated at one cross section (2CAR_327) while the others (2CAR_277 and 2CAR_137) were inferred from LIDAR data and therefore are not accurate representation of the pond bed.

Figure 8-3 Cross Section Location Plan



The following cross section plot (at 2CAR_327) illustrates the difference between the two sources of detailed survey data. The more recent surveyed levels indicate that the stream bed levels have risen by an average 300 to 400mm. This is based on the information at one cross-section only and therefore may not be representative of the overall pond.

Figure 8-4 Cross section plot for 2CAR_327 and ANNA000721



8.2.3 Cúl Ard Housing Estate

A disused quarry at Cúl Ard housing estate marks the location of an underground cave system. Surface water from the Cúl Ard development as well as water from the Polaniska Stream discharges to this point. Based on the available historic mapping there is little change in the topography of this area.

8.3 Sources &General Catchment Character

The upper Carrigtohill catchment is the primary source of sediment. It is a steep catchment sloping from a peak elevation of 150mAD in the highest part of the hills to an elevation of approx 20mAD to 30mAD at the foot. The lower catchment which is relatively flat, extends to the tidally influenced Slatty Water.

The upper catchment consists of sandstone bedrock geology and with limestone dominating the lower catchment.

The upper catchment is rural with predominantly agricultural landuse. Intensive development in and around Carrigtohill in recent years has led to agricultural land being developed for industrial and commercial landuse. In addition there are a number of quarries in close proximity to the town.

8.4 Conveyors - Channel Type & Velocities

Flow across the upper sandstone areas results in heavy sediment load that is transported further downstream, depositing in areas of low gradient and hence low energy / velocity.

Sedimentation patterns are controlled by river morphology and local artificial obstructions. In some cases excessive siltation has occurred due to the size and level of constructed culverts. The key structures are outlined in the following section.

There are number of reaches that have been identified as key conveyors of sediment and require active management to minimise erosion and ensure a balanced hydro-geomorphologic environment both within the reaches and further downstream. These key conveyors are the Kilacloyne Stream, the Rail Diversion Channel and Tibbotstown Stream and are highlighted in Figure 8-9.

Sections of these watercourses have been altered or modified in some way from that expected of a natural watercourse. These sections of watercourse are described below and photographs are provided in Figure 8-5 to Figure 8-8.

8.4.1 Kilacloyne Stream

A section of the Kilacloyne Stream that flows alongside the local third class road is straightened and maintained.

Figure 8-5 Kilacloyne Stream

KILA00065I_UP

KILA00068J_DOWN

8.4.2 Rail Diversion Channel

A diversion channel constructed along the rail line comprises concrete walls. A gravel bed and boulders are incorporated into the channel design.

Figure 8-6 Rail Diversion Channel

Rail channel at upstream end (cascade)

Rail channel at downstream end

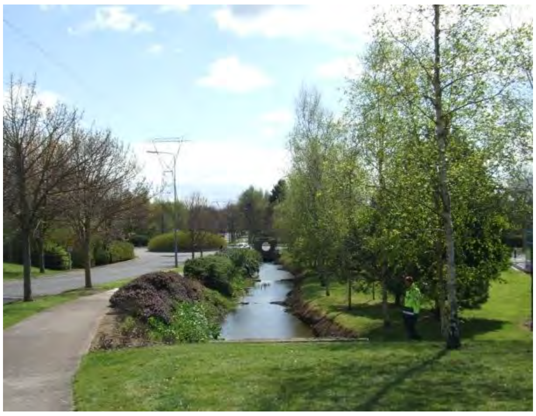
8.4.3 Tibbotstown Stream

A number of man-made weirs have been put in place on the Tibbotstown Stream downstream of the rail line.

Figure 8-7 Tibbotstown Stream

One of two similar weirs upstream of the rail line

pond / sedimentation area upstream of rail siphon



Series of weirs downstream of rail line (looking downstream)

Same series of weirs downstream of rail line (looking upstream)

8.4.4 Other Conveyors

In other areas, landscaping and paving associated with private residential property have altered the natural river banks of the Woodstock Stream.

Figure 8-8 Woodstock Stream

ANNA00382_UP

ANNA00382_DN.jpg

Watercourse velocities generally range from 0.4 to 1.5m/s with the higher end velocities in the steeper watercourses. Areas of low velocities coincide with areas of low gradient and are identified as areas prone to deposition of sediments. Based on this, supported by survey data and observations on site, the key locations in terms of siltation issues are illustrated on Figure 8-9.

8.5 Sinks - Hydraulic Controls

The rail line and the N25 road embankment are two significant linear features that stretch across the Carrigtohill catchment. There are a number of structures that convey flow through these embankments.

Detailed information on each hydraulic structure (included in the hydraulic model) is presented in the Model Check File and can be found in Appendix D. A list of the key structures in terms of hydro-geomorphology and sediment transport is summarised below in Table 8-1 Key Structures Table 8-1 and are illustrated in Figure 8-9.

Culvert upgrading works were carried out as part of the re-opening of the Glounthaune to Midleton railway line. Observations on site indicated that a number of the culverts under the rail line have been subject to sediment deposition. This was confirmed by a review of the Irish Rail construction drawings and the surveyed data.

Culverts with a low gradient were identified as a potential location for excessive sediment deposition. Also, due to their very nature, ponds and other attenuation features encourage sediment deposition and generally require careful design and maintenance to ensure they function as intended.

Adjacent to the Gilead site, heavy siltation has been observed on site. This siltation plays an important role in protecting the siphon under the rail line further downstream. Although two stone weirs have been put in place further upstream the majority of the siltation appears to occur at the IDA culvert. The IDA monitor the build up of silt here and carry out maintenance on a regular basis.

Figure 8-9 Key Structures & Hydro-Geomorphologic Features

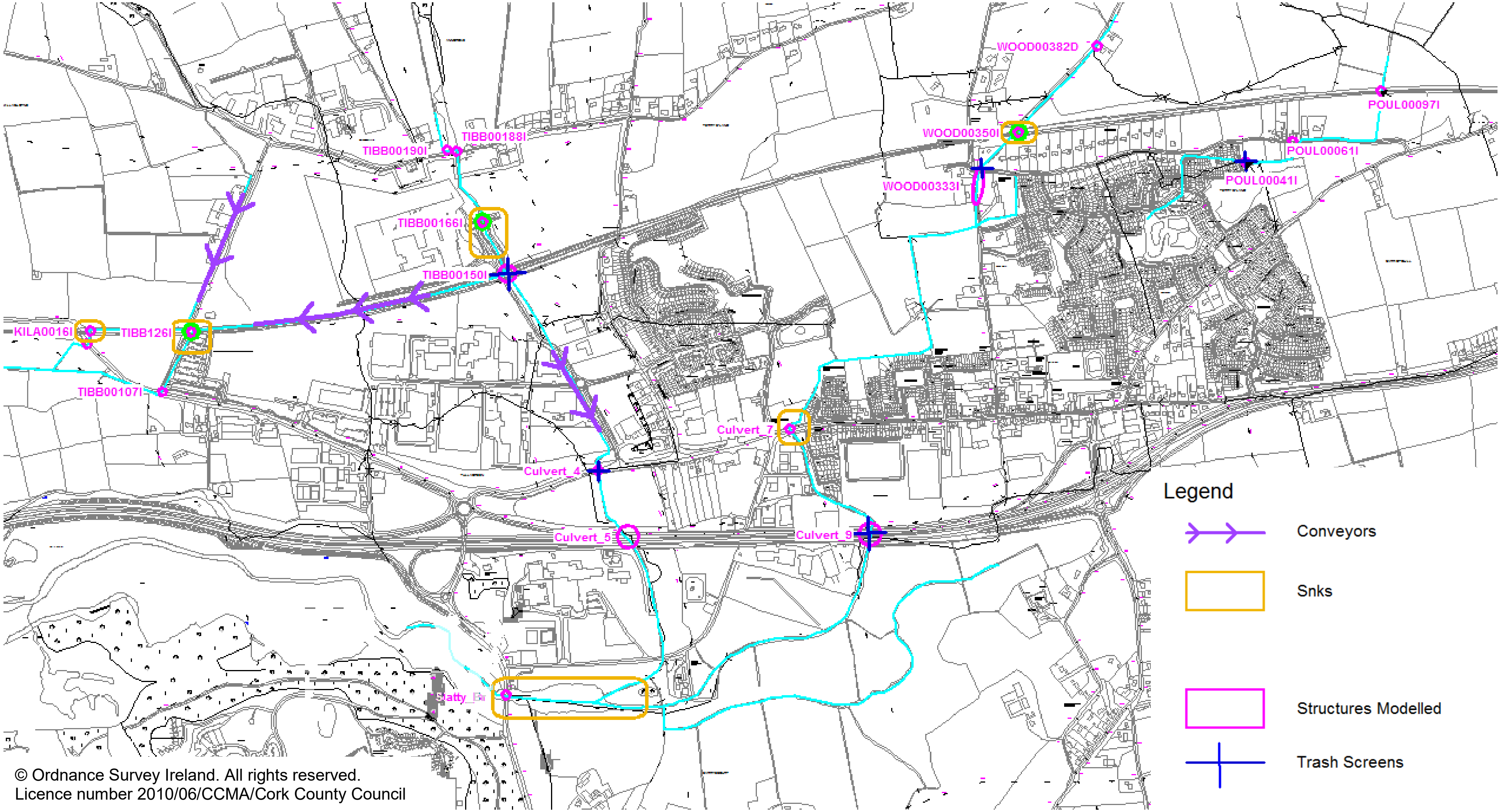
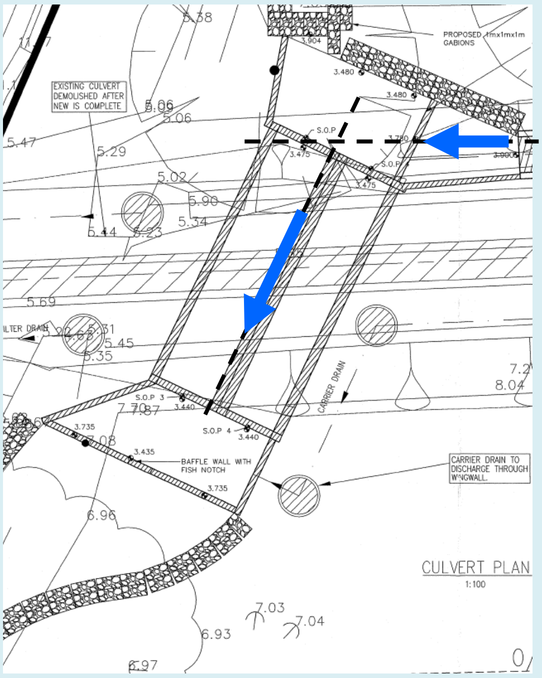


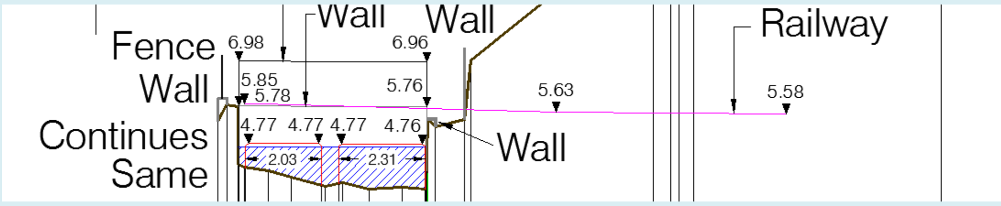
Table 8-1 Key Structures

Irish Rail culvert C3 (TIBB00126I)
Survey indicates that silt has built up at the culvert entrance. It is noted that this culvert is located at a 90° bend in the watercourse. The approach angle, observations on site and survey data indicate that this culvert is important in terms of hydro-geomorphology.



Plan showing culvert and stream alignment

Photo of inlet



Survey Cross Section

Culvert under local road (TIBB00107I)

This culvert is located downstream of the sink point at the Irish Rail culvert and while erosion is not an obvious issues at this location, it is noted that the culvert inlet is poorly constructed and flow is not directed into the culvert which could lead to erosion of the bank in high flow conditions. It was also observed on site that there is evidence of localised sedimentation at a potential Fota Retail Park drainage outfall.

Poor culvert inlet

Localised sediment at outfall

Culvert to east of Gilead (TIBB00166I)

Survey confirms silt has built up at this culvert restricting the culvert height at the inlet to 0.76m. IDA have confirmed that regular monitoring and maintenance works are carried out here. This is an important structure in terms of sediment transfer.

Upstream Face

Downstream Face

3 way split at rail line (TIBB00150I)

Site observations and survey data suggests that deposition occurs upstream of this structure. This minimises sediment entering the siphon arrangement that exists just downstream of this culvert inlet shown below. It is important that this is monitored on an ongoing basis.

Inlet to 3-way split

Irish Rail culvert C7 (WOOD00350)

Site visit confirms erosion on the left bank immediately upstream of this culvert. The survey data indicates that the culvert is severely silted with an effective height of 0.36m on the downstream face, whereas the Irish Rail construction drawings indicate that a 1m high culvert with 100mm gravel bed was included for in the design. This demonstrates that there are hydro-geomorphologic factors at play here and the situation should be monitored and managed.

Upstream Face

Evidence of erosion upstream

Carrigtohill Bridge (Culvert_7)

Based on the survey and site observations the channel is heavily vegetated and overgrown at this location. This overgrowth can result in reduced flow capacity and should be monitored on a regular basis.

Location of Downstream Face

Irish Rail culvert C9 (POUL0097I)

Based on the Irish Rail drawings this culvert was designed to include a 300mm gravel bed above the culvert invert. The surveyed invert levels indicate that this has not been retained however there are no indications of erosion or scour at this location.

Upstream Face

Downstream Face

Slatty Bridge

Slatty Bridge is situated in a tidal estuary, flapped outfalls are located at the downstream side of the bridge. Slatty pond is located immediately upstream of the bridge structure and sediment deposition occurs here with sediments from the contributing watercourses being deposited in the slower moving Slatty Water.

The introduction of the pumps at Slatty may have an impact on hydro-geomorphology of the channel downstream of Slatty Bridge. A reduction in flow through the bridge openings may result in an additional build up of silt on the downstream tidal side.

The photos below show the upstream face of the bridge and the second photo illustrates the geomorphology of the channel looking downstream from the pump outfall.

Upstream face of Slatty Bridge

Immediately downstream of Slatty Pump outfall

8.6 Blockage Screening Assessment

Hydraulic modelling of blockage is not included under the scope of the Carrigtohill FRA brief; however a screening assessment was completed, to identify those structures where blockage is considered likely and where a blockage will significantly increase flood risk in terms of the receptors affected and the probability of occurrence. This screening assessment ties in with a review of hydro-geomorphology in the catchment and is based on a guidance note prepared by JBA Consulting for the Western CFRAMs in conjunction with the OPW and other consultants involved in the National CFRAM Programme. The results of the screening assessment include a commentary on the likely impact of increased blockage at individual structures. These scenarios have not been included in the hydraulic modelling runs.

The following scoring system is applied; score = probability x consequences. Due to the lack of recorded data, the probability of a blockage is largely assessed based on anecdotal evidence or the size of the culvert and observed conditions on site.

	Score				
	5	4	3	2	1
Probability of a blockage	More frequently than 1 in 2 years	1 in 2 to 1 in 5 years	1 in 5 to 1 in 10 years	1 in 10 to 1 in 25 years	Less frequently than 1 in 25 years.
	Regularly recorded blockage (e.g. once or twice in the last two years)	Some record of blockage (e.g. once or twice in the last 5 years) or Culvert size under 1m2, catchment urban or woodland	Culvert size under 1m2 and at least 50% urban or woodland or Culvert size over 1m2 and under 3m2 with potential blockage points	Culvert size over 1m2 and under 3m2 or Culvert size over 3m2 with no upstream public access	Culvert size over 3m2
Consequence of a blockage	Properties flooded in the 2yr event	Properties flooded in the 5yr event	Properties flooded in the 10yr event	Properties flooded in the 25yr event	No properties flooded in the 25yr event

The following table presents the results of the scoring system and identifies a number of culverts that require more careful consideration. Those with a blockage score greater than 6 are considered key structures due to the likelihood and risk associated with potential blockage. These culverts should be inspected regularly and monitored. Blockage scenarios have not been modelled in the hydraulic assessment carried out, as this falls outside the scope of the study.

Table 8-2 Screening Assessment Results

Culvert ID	Blockage Score	Comment	Probability of Blockage	Consequences of Blockage
KILA0016I	2	Culvert 2.1x1m; No impact on properties	2	1
KILA0012I	4	900x900mm arch; not likely to flood any property.	4	1
TIBB126I	1	Culvert opening >3m2 but survey indicates siltation at entrance; located on sharp bend Blockage would cause water to back up rail diversion channel; unlikely to overtop into Fota Retail Park	1	1
TIBB00107I	1	900mm dia pipe; likely to flood road and low-lying fields to west	4	1
TIBB00190I	**20**	**1000mm dia pipe along road verge; high chance of blockage; increase in flood depths will affect the road but unlikely to affect houses in the immediate area; however potential increased flood depth at Gilead.**	**4**	**5**

Culvert ID	Blockage Score	Comment	Probability of Blockage	Consequences of Blockage
TIBB00188I	**20**	**Twin 800mm pipes with parapet wall; similar consequences to TIBB00190I just upstream**	**4**	**5**
TIBB00166I	5	Siltation and sedimentation has been recorded and is continuously monitored by IDA; increase flood depth here will cause more out of bank flow to east is not likely to have a significant impact on houses.	5	1
TIBB00150I	1 (5)	Complex flow structure; and in current scenario no flooding is predicted at this structure. Any out of bank flow here is likely to follow the rail line to the east; potential to flood the rail line in an extreme event.	1	1 (but risk to rail line not accounted for, increase to 5)
Culvert_4	4	Twin 600mm culvert with area <1m2 plus trash screen; flooding will affect road but unlikely to affect houses	4	1
Culvert_5	4	750mm and 450mm pipe; unlikely to flood houses	4	1
Culvert_9	1	Box culvert >3m2 with trash screen; unlikely to cause flooding in houses up to 25 year event.	1	1
Culvert_7	4	Heavily vegetated channel with twin 900mm pipes but with one blocked; unlikely to flood houses	4	1
WOOD00333I	**16**	**1.1m dia pipe with new trash screen; some history of blockage; likely to contribute to flooding of properties.**	**4**	**4**
WOOD00382D	**16**	**900mm dia pipe; likely to contribute to flooding at houses**	**4**	**4**
WOOD00350I	**2 (10)**	**2.4x2.1m box culvert with sedimentation at downstream end; erosion upstream, potential to flood rail line and cause a potential flow path to nearby properties.**	**1**	**2 (but risk to rail line not accounted for, increase to 5)**
POUL00041I	4	1500mm pipe with trash screen; chance of one property flooding in extreme (100yr) event less likely in 25yr event.	4	1
POUL00097I	1	Culvert ?3m2 unlikely to affect properties	1	1
POUL00061I	4	Culvert <1m2 likely to flood properties in extreme (100yr) event less likely in 25yr	4	1
Slatty_Br	0	Flapped outfalls in tidal reach; unlikely to affect any houses. Degree of sensitivity tested in undefended run.	4?	1

8.7 Conclusion

The main source of sediment is from the upper catchment which consists of an underlying sandstone layer. Additional silt has been provided in the system as a result of construction works in the catchment. It is evident from observations on the ground that deposition has occurred at a number of culverts in Carrigtohill, in particular the culvert to the east of Gilead and those located under the railway line.

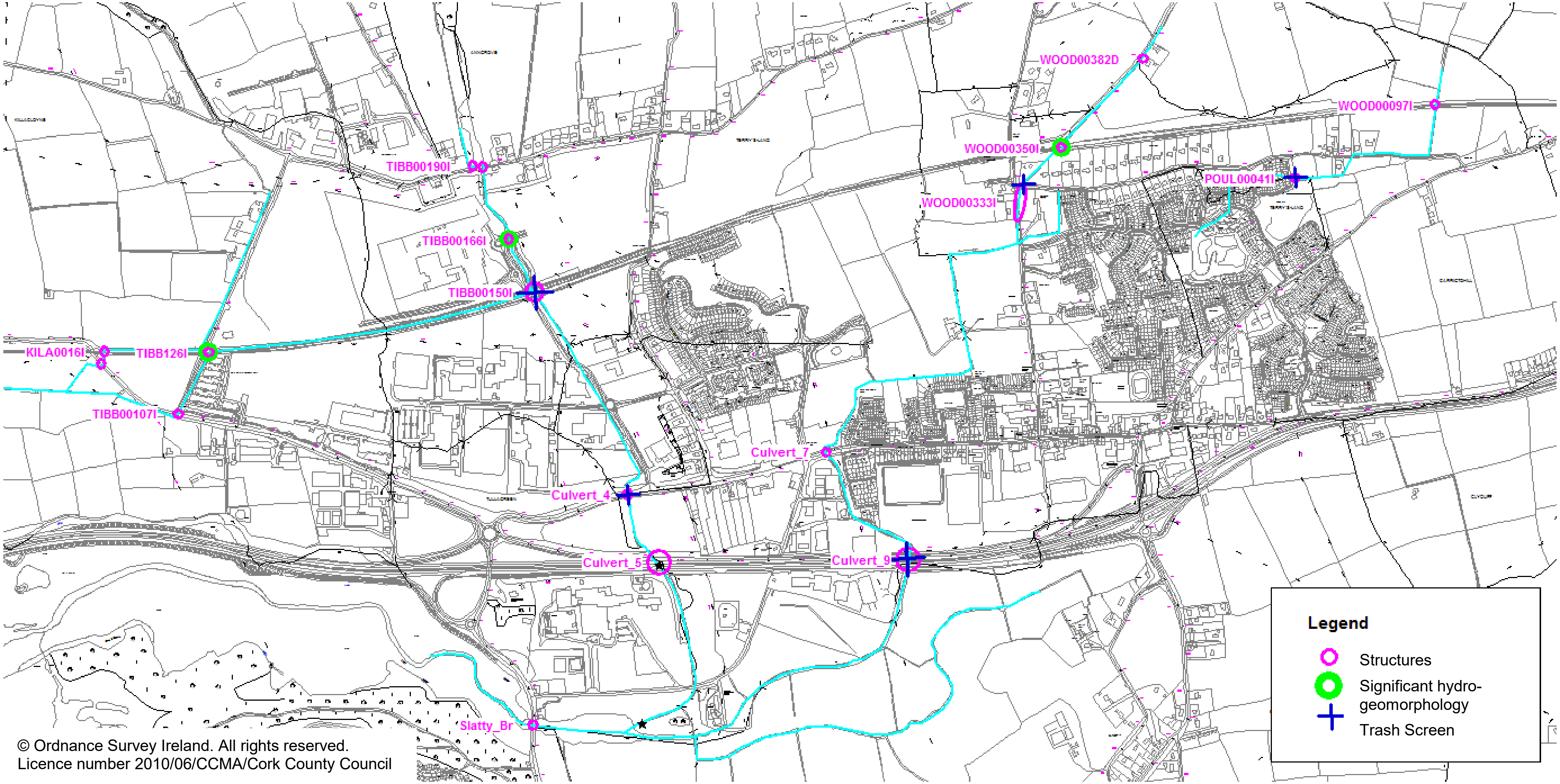
There are a number of stretches of watercourse that have been altered or modified from what would be expected of a natural river system. Siltation is occurring at control points in the upper reaches, upstream of the major crossing points i.e. along the rail line. This removal of silt can cause active erosion in the watercourses downstream (of the rail line). Some transfer of silt will occur through the control points along the rail line and in addition, velocities will be high enough to pick up fine silt in the middle reaches. This sediment load is transported and ultimately deposited in the lower reaches and Slatty Pond.

There is a need to carefully monitor and manage hydro-geomorphological processes to minimise erosion and siltation in the watercourses of the catchment. Monitoring will also be beneficial to help identify the merit of future control measures i.e. silt traps.

Monitoring at the following locations is recommended:

- Adjacent to Gilead - the following should be recorded amount of silt build up, silt removed and any other measures carried out
- Tibbotstown Stream and the rail diversion channel downstream of the rail siphon - this will help determine the impact of sedimentation and the maintenance carried out, and will be beneficial in assessing the merit of future measures.
- Slatty Pond - locals have expressed concern over sedimentation due to extensive development and construction work in Carrigtohill town. Sedimentation levels in Slatty should be monitored to assess this.
- Slatty Bridge downstream - sedimentation levels here should be monitored, taking into account the change in flow regime through the bridge openings due to the introduction of the pump station. In addition the geo-morphology of the channel in the vicinity of the pumps outfall should be monitored.
- Carrigtohill Bridge - historically this has been identified as a key structure in terms of flood risk. On site visits it was observed to be heavily vegetated indicating low velocities and sedimentation. This should be monitored to assess the need for regular maintenance works.
- Rail Culvert on Woodstock Stream - erosion just upstream of this culvert was noted on site and sedimentation was identified at the culvert inlet.
- All structures should be routinely inspected to check for defects and any build up of sediment or signs of erosion should be recorded. This is particularly important for the key structures listed in Table 8-1.

Figure 8-10 Structure in the Carrigtohill Model Extent



9 Validation of Model

Information on the health of the model, any stability or convergence issues are detailed in the model check file. This section evaluates the model and outlines the pattern of flooding expected based on the limited historical flood data and other records available.

Figure 9-2 summarises the anecdotal evidence collated during the study and it identifies a number of areas that are perceived at flood risk by the local community, local authority staff amongst others.

The areas mentioned that can be attributed to various types of flooding include:

- **Area 1:** To the north and east of Gilead and north of the rail line.
- **Area 2:** Bog Road and area to north of rail line
- **Area 3:** N25 culvert on Woodstock Stream
- **Area 4:** Slatty Pond
- **Area 5:** Hedgy Boreen

The flood risk assessment correlates with the anecdotal evidence for these areas.

With respect to fluvial flood risk, the following is noted. In a 2 year flood event out of bank flooding is predicted in Areas 1 and 2. In Area 3, based on the flood maps no flooding is predicted under normal conditions. However, it is noted that past flooding here is attributed to culvert blockage.

There is little evidence available to quantify past flooding events. A photo of a flooded area behind Ryan Aherne Place was taken during a flood event in 2009. During this flood cars were damaged, suggesting a depth greater than 300mm but there was no internal flooding of houses.

Reports on this flood event indicate that flooding was exacerbated by construction activities at the adjacent Castlelake development where a temporary small culvert was in place. Other activities in the vicinity of this area, such as realignment to the stream were suggested by residents in the area. Because of these reasons, the pattern of flooding witnessed during this event may not be (and are not) illustrated in the predictive flood maps produced by this study.

A photo recording flooding at Ryan Aherne Place, to the east of Castelake is shown in Photo 9-1.

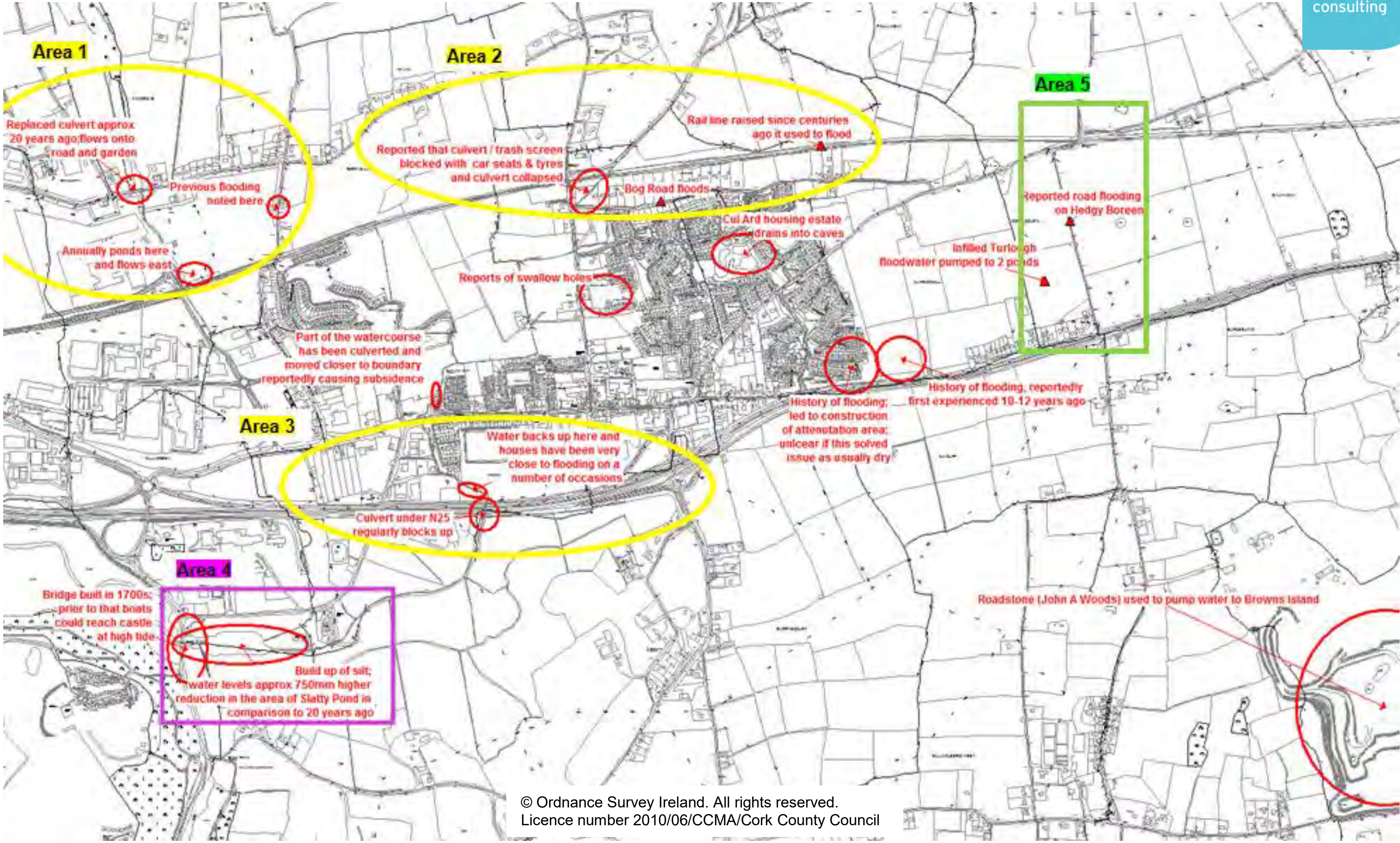
The tidal flood maps highlight Area 4 as a area of flood risk. Anecdotal evidence indicates that the Slatty Pond area was once part of the larger estuary and boats could sail up to Barryscourt Castle prior to the construction of Slatty Bridge in the 1700s. Locals indicated that water levels in Slatty Pond have risen by up to 750mm and also confirmed that land been reclaimed for agricultural purposes with a reduction in the area of Slatty Pond compared to 20 years ago.

Area 5 has been highlighted in the hydro-geological assessment as an area at risk of groundwater flooding. Cork County Council have confirmed ongoing flooding issues in this location which has required the installation of mobile pumps.

Photo 9-1 Flooding at Ryan Aherne Place in 2009

Source: Community Council

Figure 9-2 Summary of Anecdotal Evidence

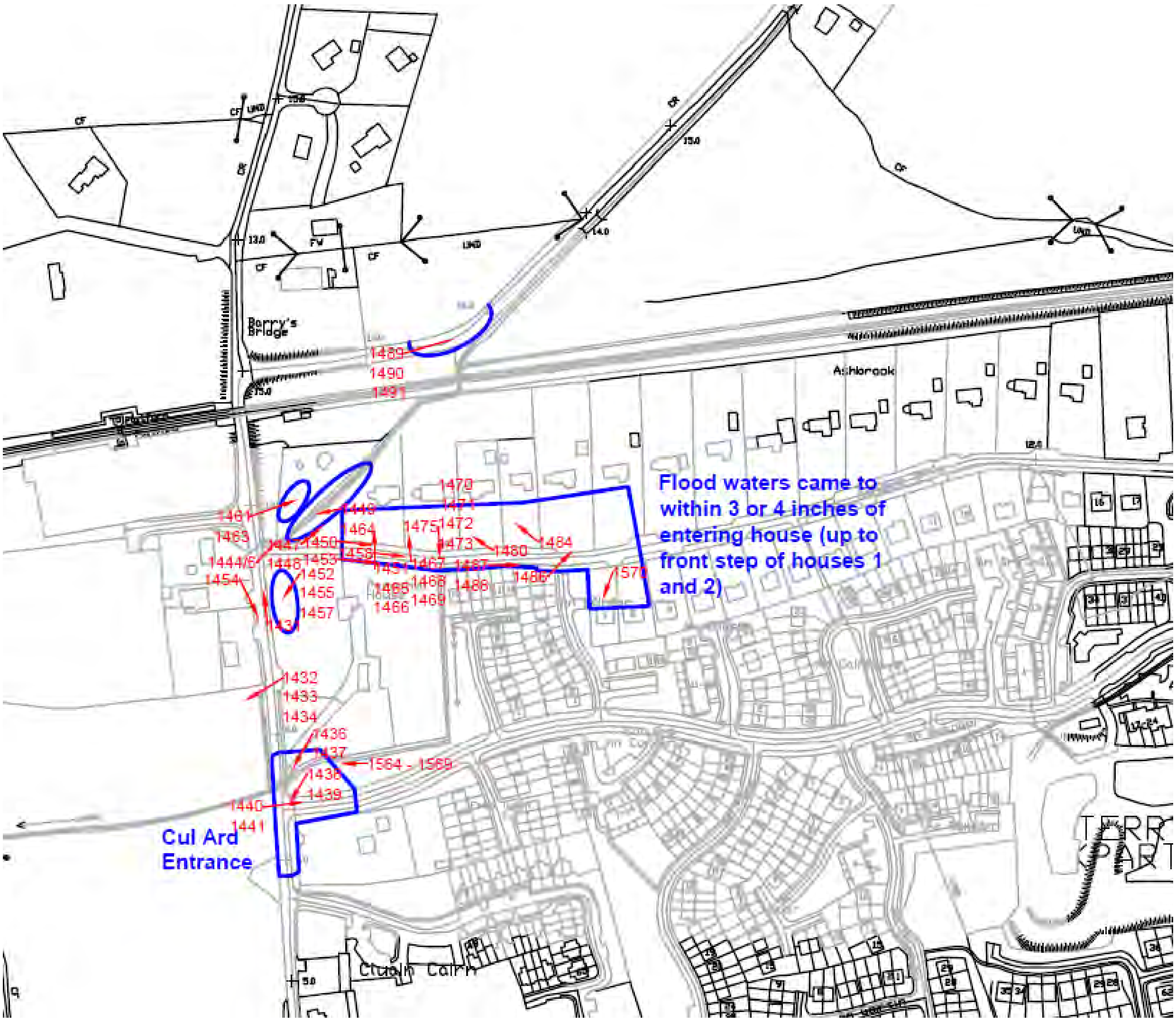


9.1.1 August 2012 Flooding

Heavy rain in August 2012 resulted in flooding in Carrigtohill. This did not result in any internal flooding however extensive road flooding was reported. A record of this flooding was prepared by Cork County Council and the following indicates the area that was flooded.

Flooding occurred in the Bog Road area, when a culvert failed structurally and collapsed. The flooding in this area is illustrated below.

Figure 9-3 Record of Flooding at Bog Road Aug 2012

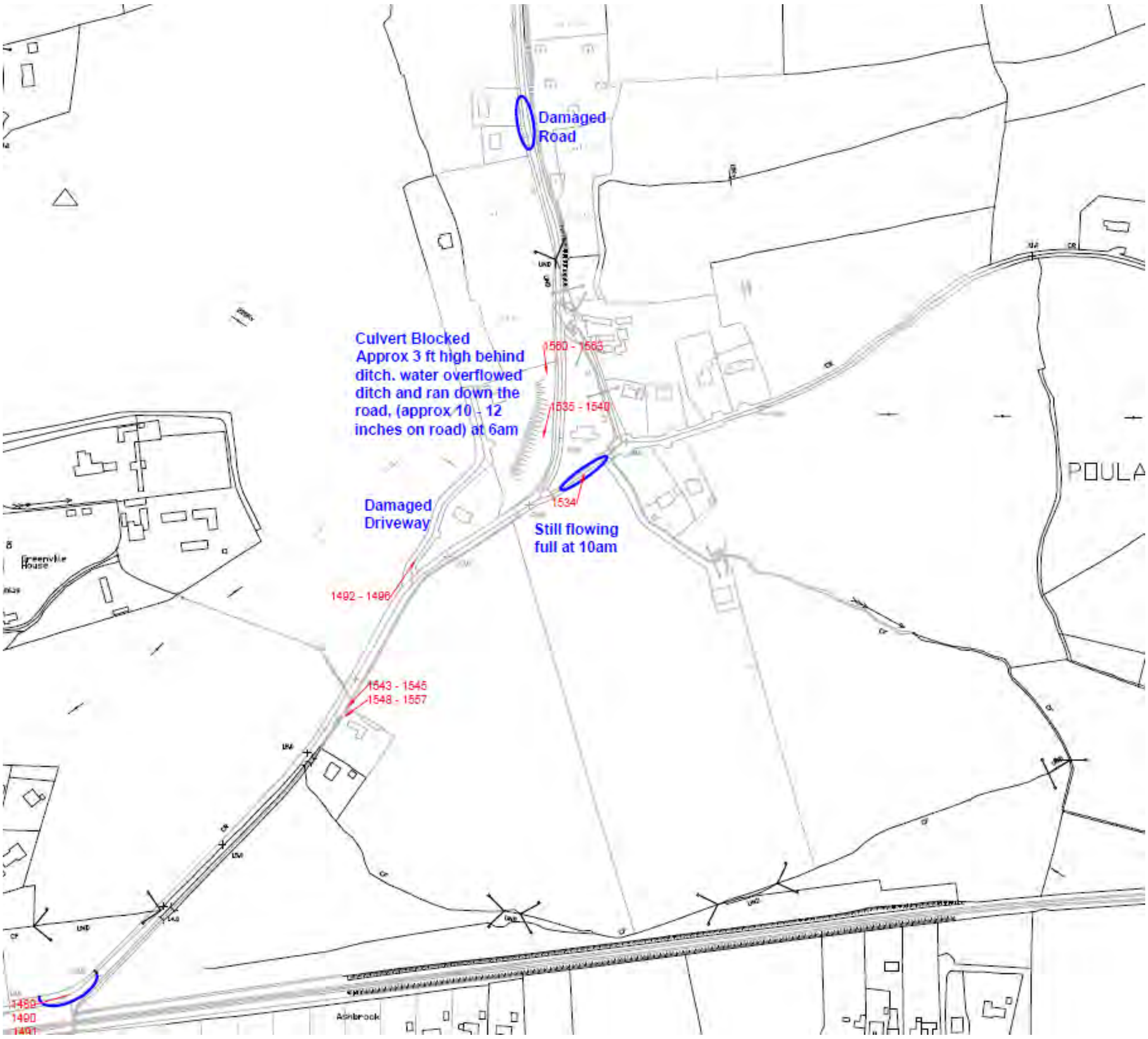


Source: Cork County Council

Another area, just upstream of the model extent, experienced road flooding, a culvert blocked and floodwater caused damage to the road pavement.

Surface water flooding was also reported at Hanover Tyres, on the right bank of the Woodstock Stream downstream of Carrigtohill Bridge.

Figure 9-4 Report of Flooding Upstream of Modelled Extent



Source: Cork County Council

10 Fluvial Model Results

The hydraulic model output in terms of maximum flood extent, depth, velocity and hazard are presented graphically in the flood maps that are included in Appendix F Also presented in Appendix E is a table of maximum stage and flow results at all nodes in the 1D model.

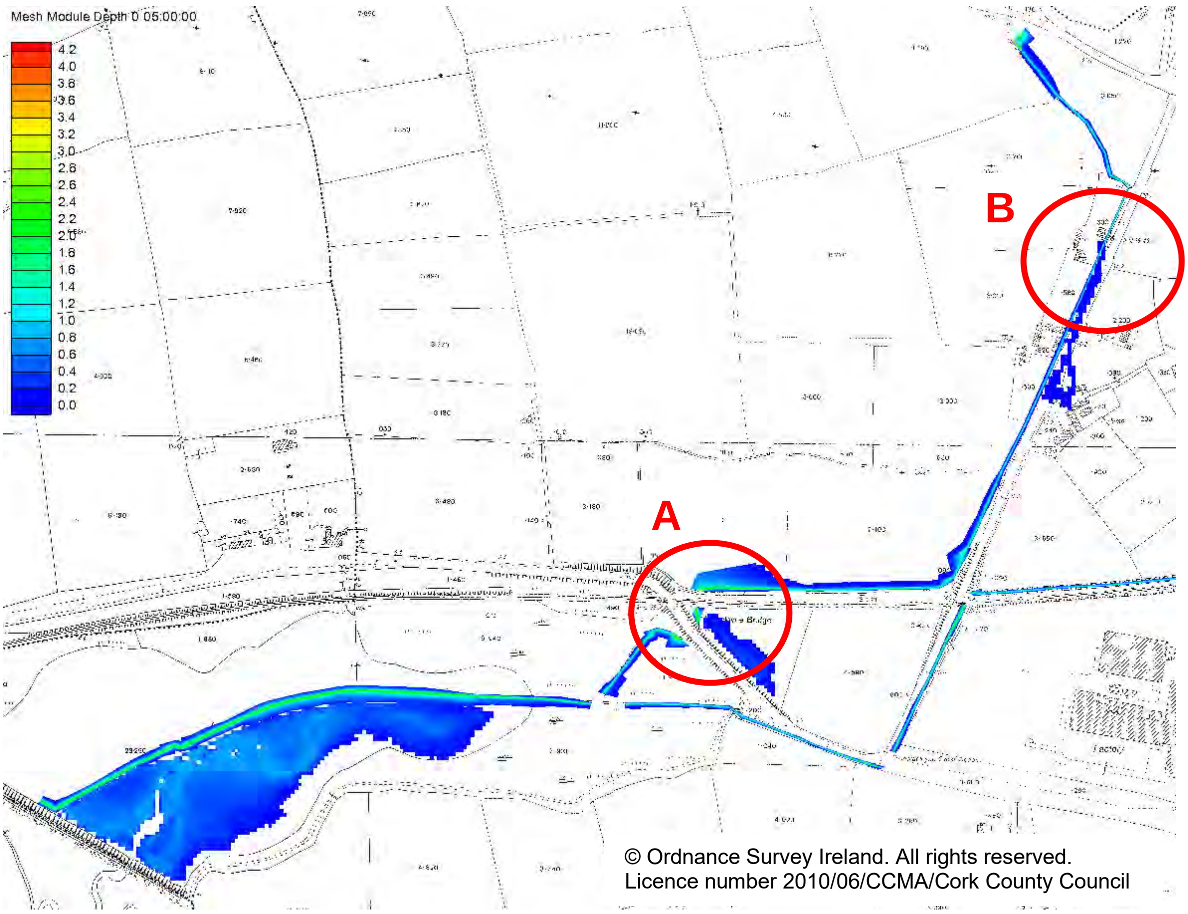
This section discusses the fluvial model results with an aim to provide more detail on the mechanism of flooding and it's progression during an extreme flood event.

The results for the 1% AEP fluvial event are detailed below. Screenshots from the flood result animation are used to detail the onset of flooding and indicate the threshold level at key flood risk locations. The flooding pattern is similar for the other AEP events; as mentioned above the maximum flood results for each particular event can be found in Appendix E.

(Note the raster mapping available for use in the SMS animations screenshots is older OS mapping)

10.1 Kilacloyne Stream

Figure 10-1 Kilacloyne Flood Depth at 5hours during 1% AEP fluvial event

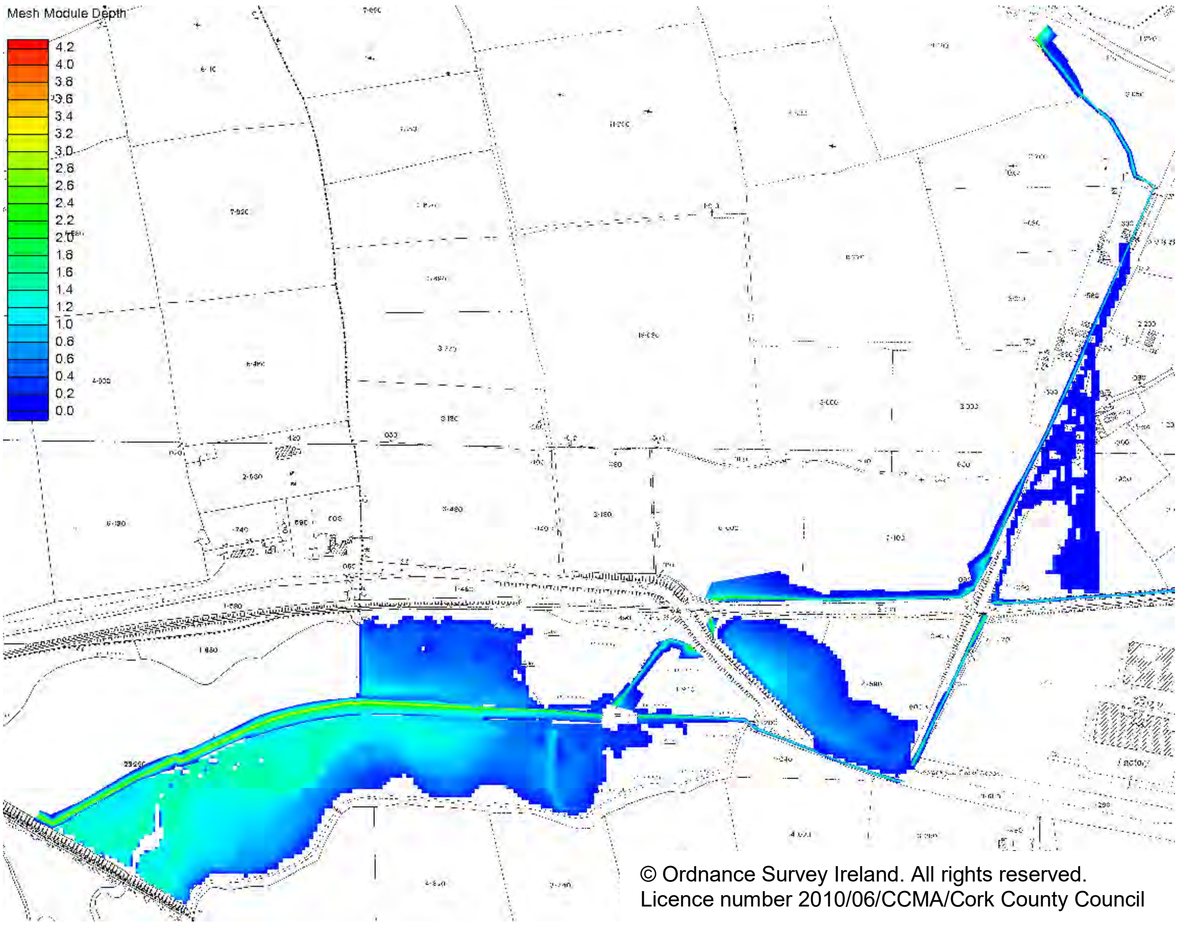


At 5 hours water begins to come out of channel adjacent to the culvert under the rail line Point A on the Map and at Point B further upstream. Flooding at Point A occurs in events greater that a 20% AEP (1 in 5 year), while out of channel flow from Point B occurs during events greater than a 10% AEP (1 in 10 year).

This out of bank flow continues until the maximum extent is reached at both locations at a time between 6 and 7 hours. During the 1% AEP event, the maximum flow depths resulting from out of bank flow at Point B is 0.02m, with a floodplain flow of 0.03m3/s.

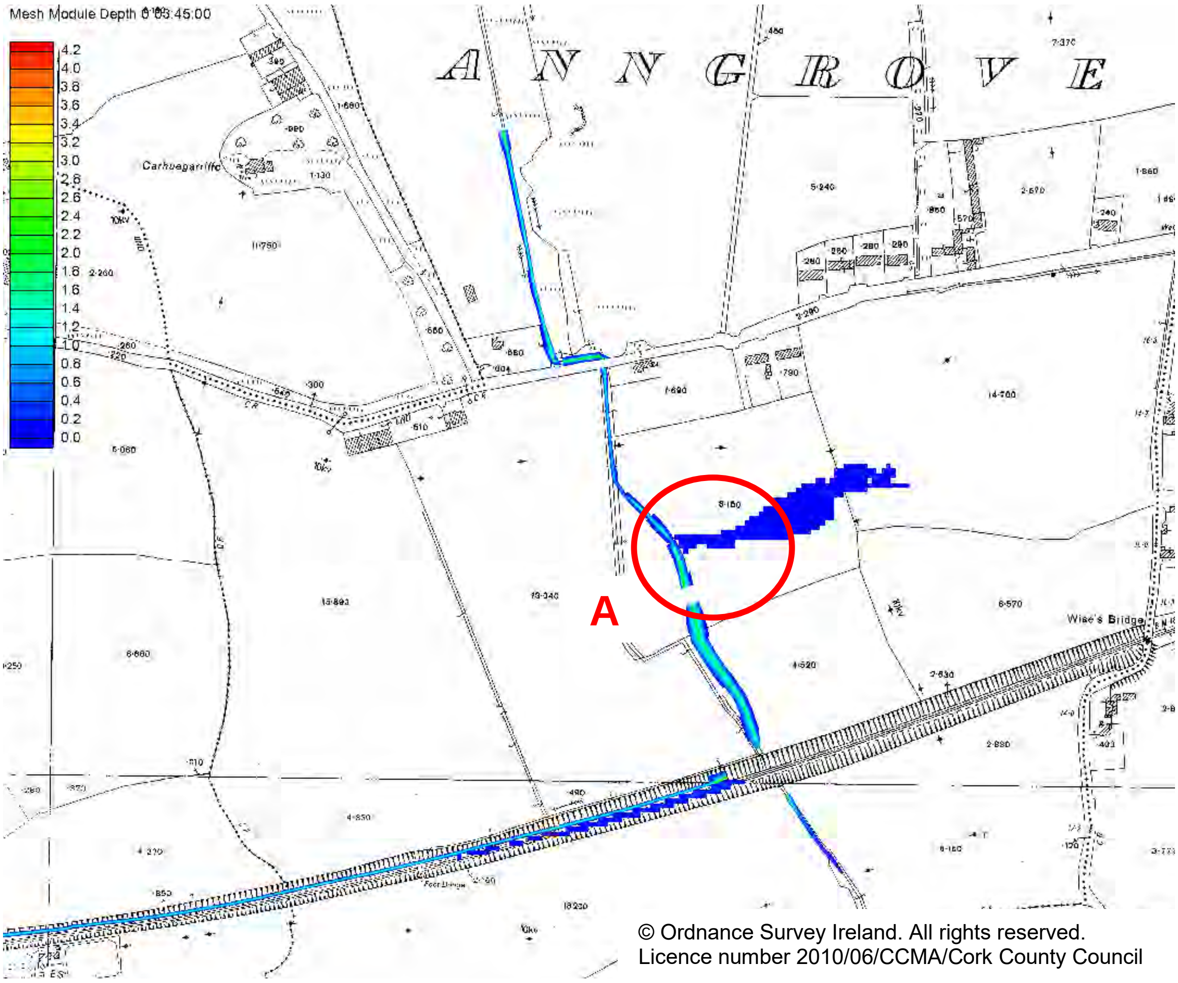
In the area of low land south of the rail line (and north of the road) at Point A, floodwater reaches up to 1m in depth.

Figure 10-2 Kilacloyne Maximum Flood Depth for a 1% AEP Fluvial Event



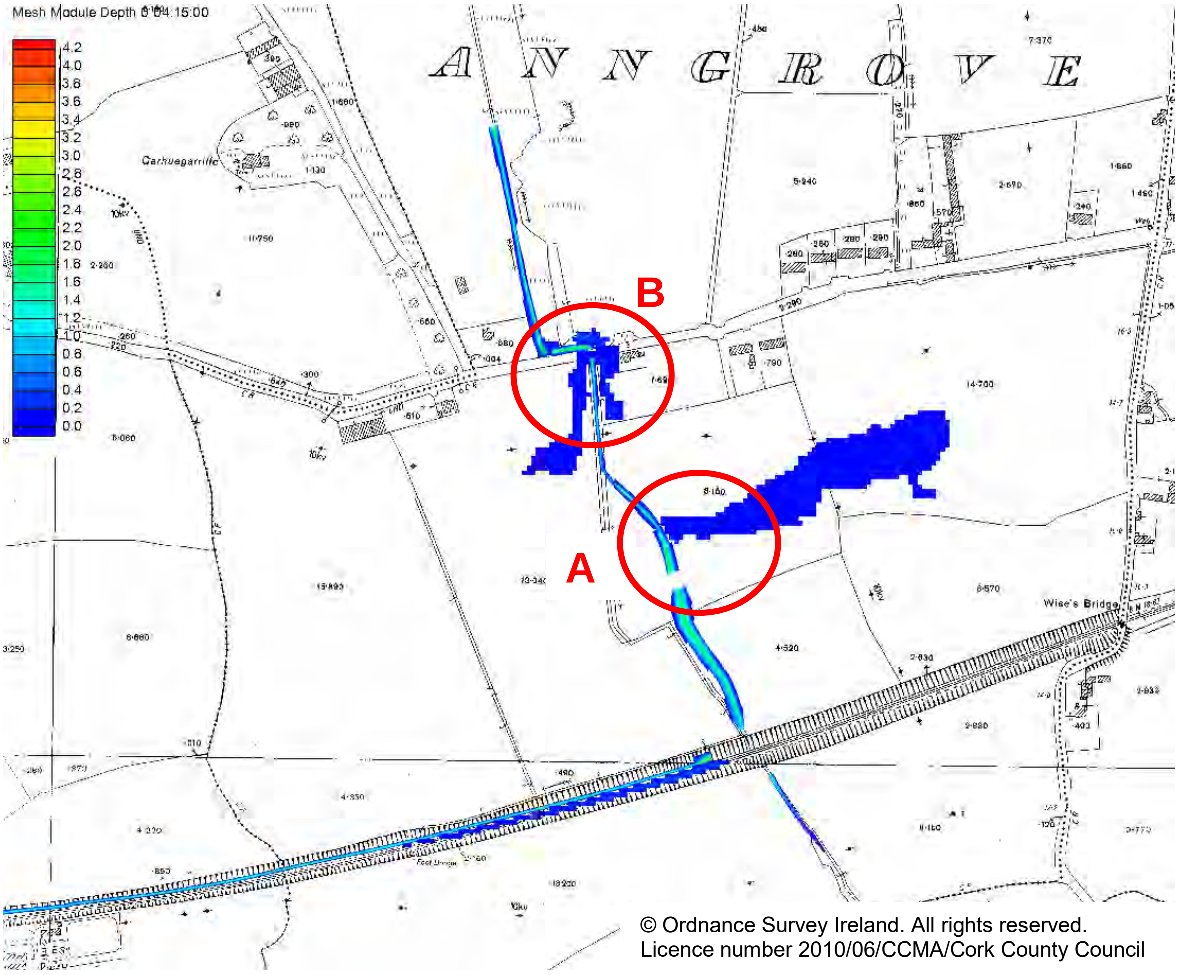
10.1.1 Tibbotstown Stream

Figure 10-3 Tibbotstown Flood Depth at 3h 45m during a 1% AEP Fluvial Event



Analysis of the results show that out of bank flow occurs after approximately 3 hours into the simulation of the Q100_T2 event, at Point A upstream of the IDA culvert, at the location of a weir in the channel, when flow in the stream reaches 1m3/s. Based on a threshold flow of 1m3/s, flooding occurs frequently, with a probability greater than a 50% AEP (1 in 2 year) event.

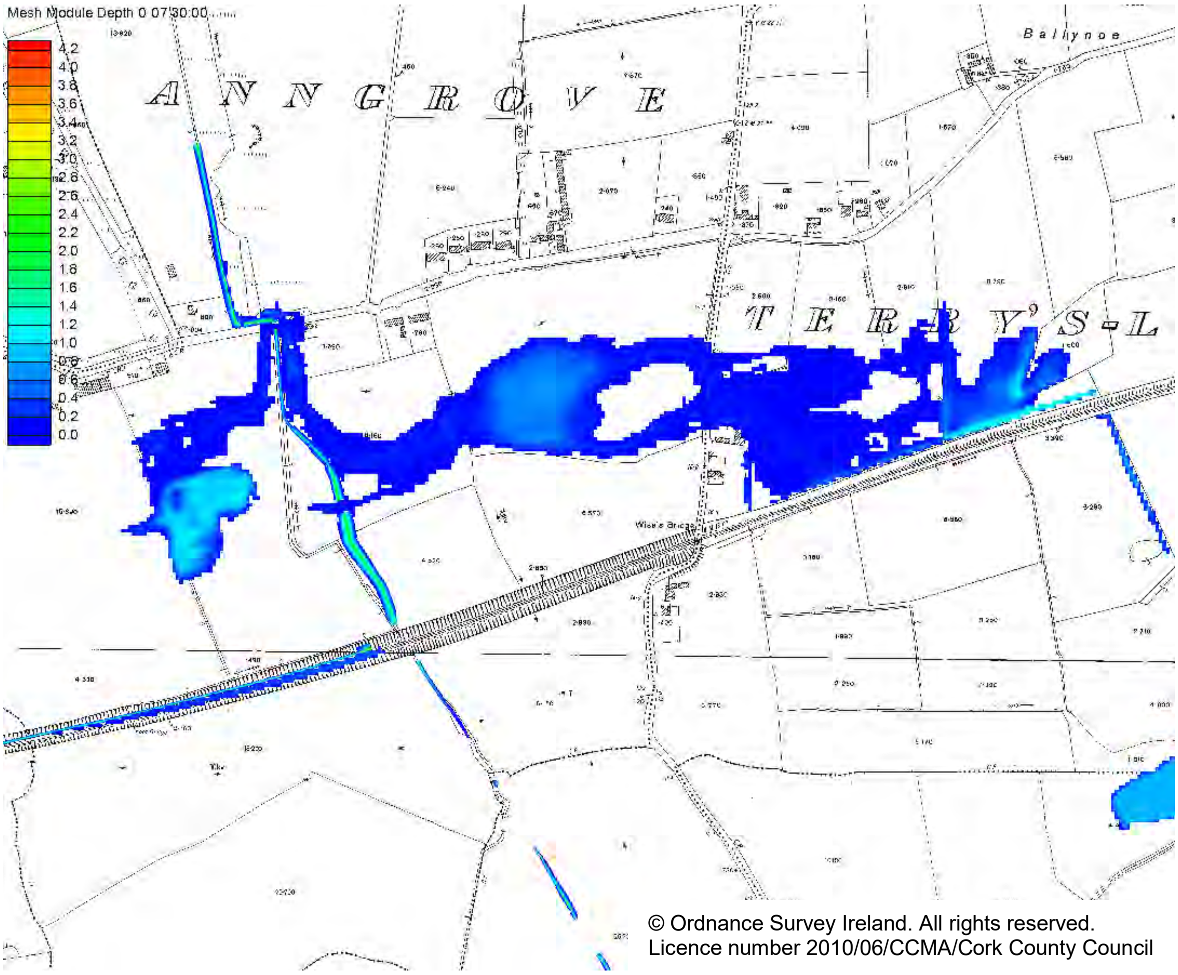
Figure 10-4 Tibbotstown Flood Depth at 4h 15m during a 1% AEP Fluvial Event



The existing channel and culvert that conveys water along the road side at Point B, is under sized to cope with nominal flows. Based on the stage-flow results from the hydraulic model the capacity here is in the order of 1.4m3/s. In the 50% AEP, shallow flooding in the order of 30mm initiates a flow route onto the road. Water floods onto the road, and makes its way into land on the south side of the road, bypassing the culvert under the road.

This occurs at approximately 4 hours into the simulation, when flow reaches 1.8m3/s, water bypasses the culvert crossing under the local road (Point B) and out of bank flow makes its way south-eastward towards the Gilead site.

Figure 10-5 Tibbotstown Flood Depth at 7h 30m during a 1% AEP Fluvial Event



Out of channel flow over the left bank, continues and floodwater propagates south westwards across undeveloped land to the rail line. This floodplain flow peaks at approximately 1.2m3/s at 7hrs. At 7h 30m into the simulation water finds its way through culvert crossings at the rail line and heads south adjacent to the Castlelake Development.

The floodplain culverts included in the model are based on Section 50 data from OPW and Irish Rail. Note if other crossing points were located along the rail line embankment then the route of floodwater would be altered. Recent works adjacent to the rail line included a re-alignment / re-grading of a drainage line.

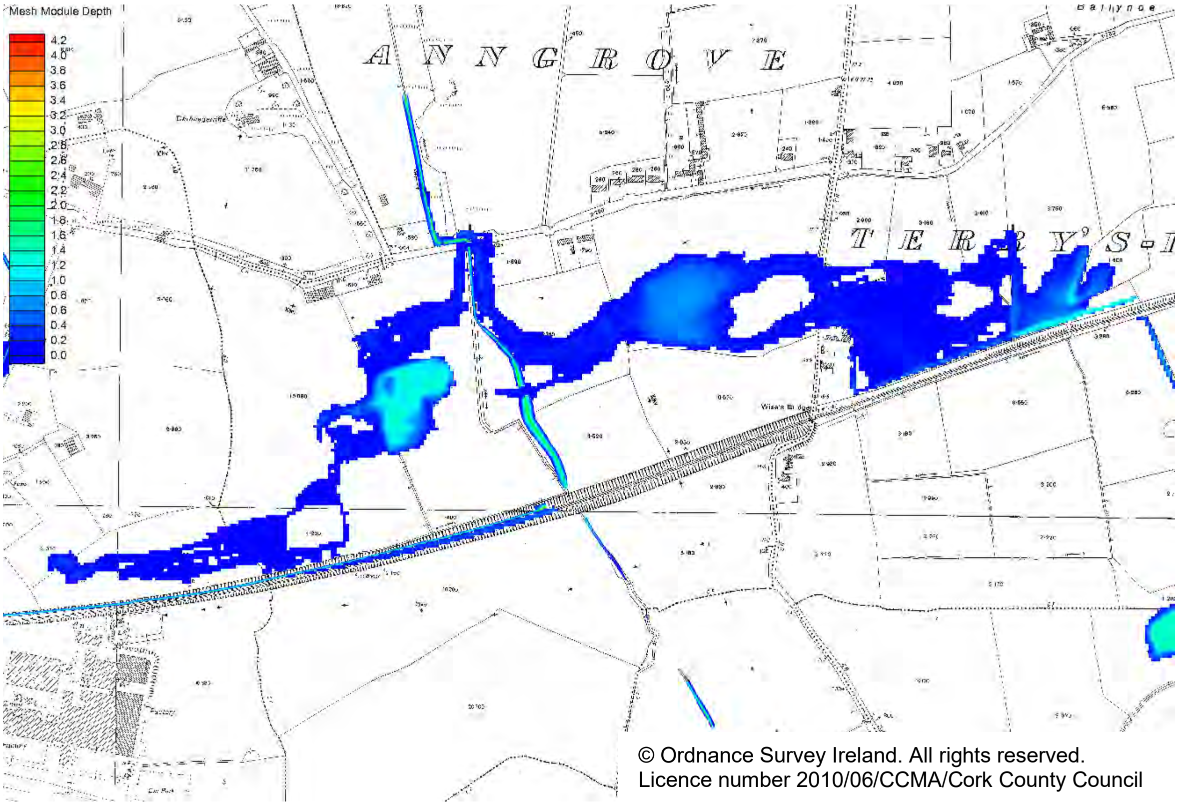
Out of channel flow over the right bank, makes its way westward across the Gilead site. During a 1% AEP event the depth of flow along this flow route from Point B into Gilead, is less than 0.1m and the out of channel flows peaks at 0.29m3/s at 6.5hrs.

The maximum flood output indicates max flood levels of 14.4mOD at Gilead with depths of up to 1m during a 1% AEP (1 in 100 year) fluvial event. During events less than 1% AEP floodwater remains within the environs of the Gilead site. In a larger flood events floodwater extends westwards towards the Kilacloyne area.

Out of bank flooding in the upper reaches in the model, results in a reduction in flow to the lower reaches and results in no out of bank flow in the Tibbotstown Stream downstream of the rail line.

The results presented here are based on the current as surveyed condition. Future improvements to mitigate flooding in these areas will require careful consideration of the impact further downstream.

Figure 10-6 Tibbotstown Maximum Flood Depth for a 1% AEP Fluvial Event



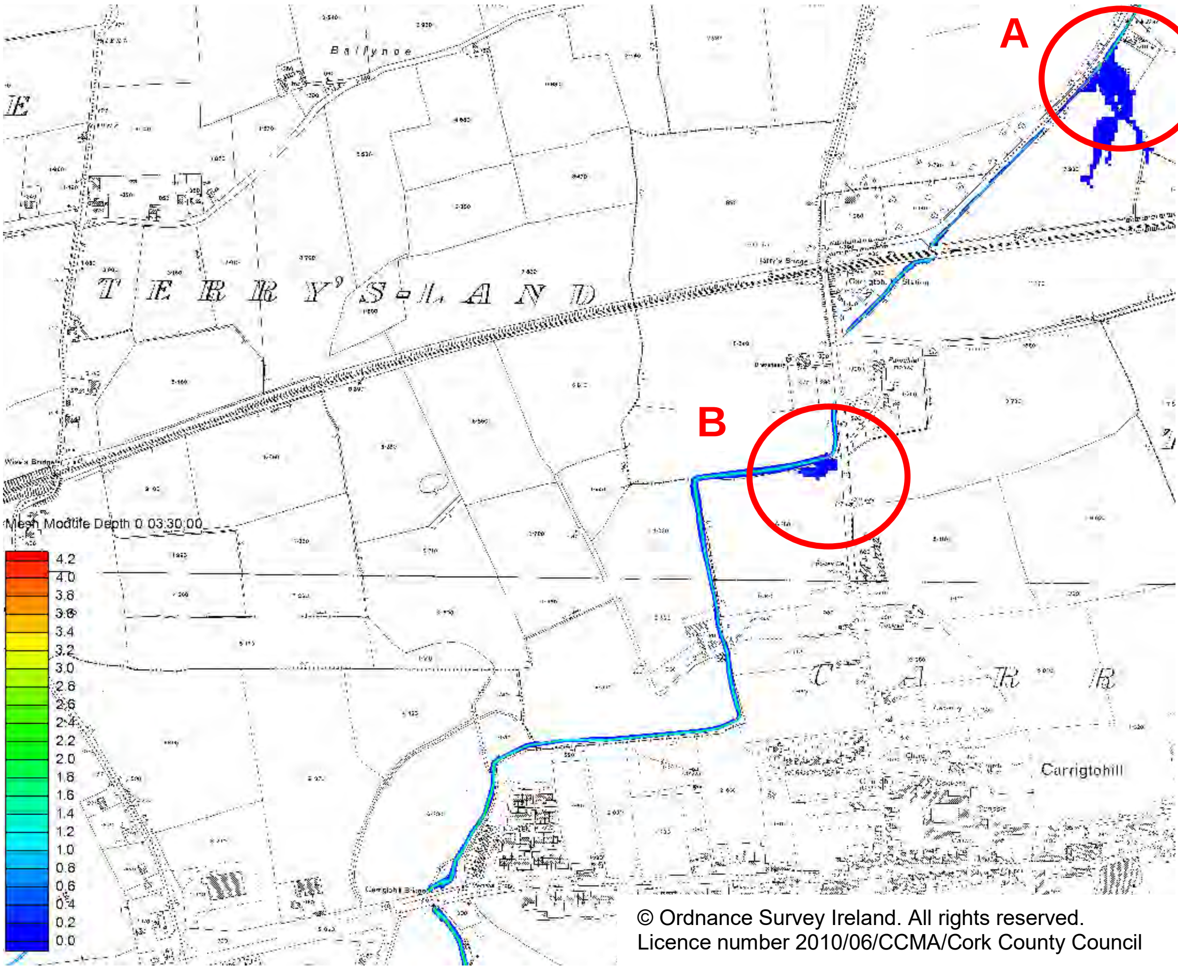
10.1.2 Rail Diversion Channel

Flows in the rail diversion channel reach a peak of 1.2m3/s; no out of bank flow occurs in the rail diversion channel during a 1% AEP event.

The capacity of the channel is not exceeded in any of the other events considered in this assessment, including the climate change scenarios.

10.1.3 Woodstock Stream

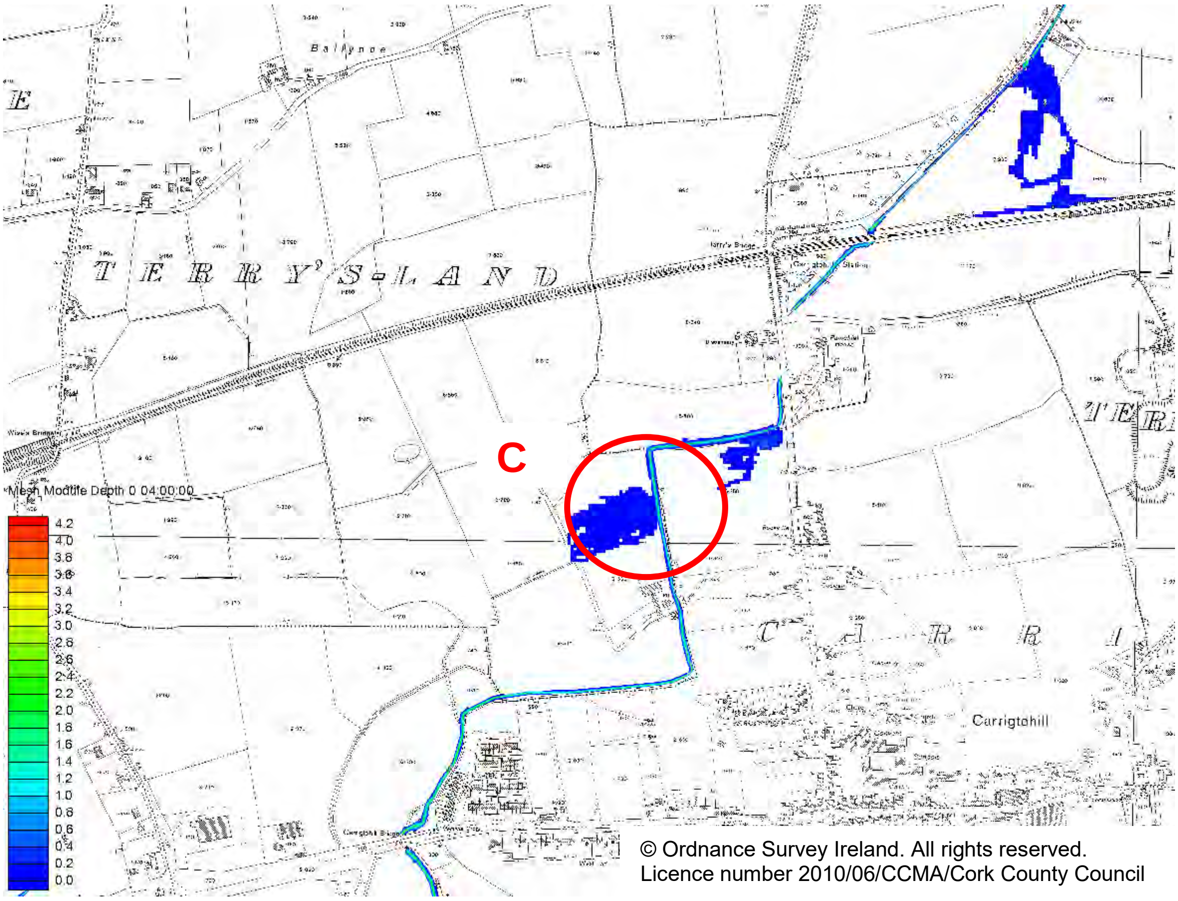
Figure 10-7 Woodstock Flood Depth at 3h 30m during a 1% AEP Fluvial Event



Out of channel flow first occurs at Point A on the map, adjacent to a private residential property. At this location a 900mm diameter culvert conveys water under the private driveway. Water also begins to come out of channel at Point B.

At Point A flooding occurs in a 50% AEP event with flood depth in the order of 30 to 50mm, limited out of channel flow (approx 30mm depth) also occurs at Point B in this lower return period event.

Figure 10-8 Woodstock Flood Depth at 4h during a 1% AEP Fluvial Event



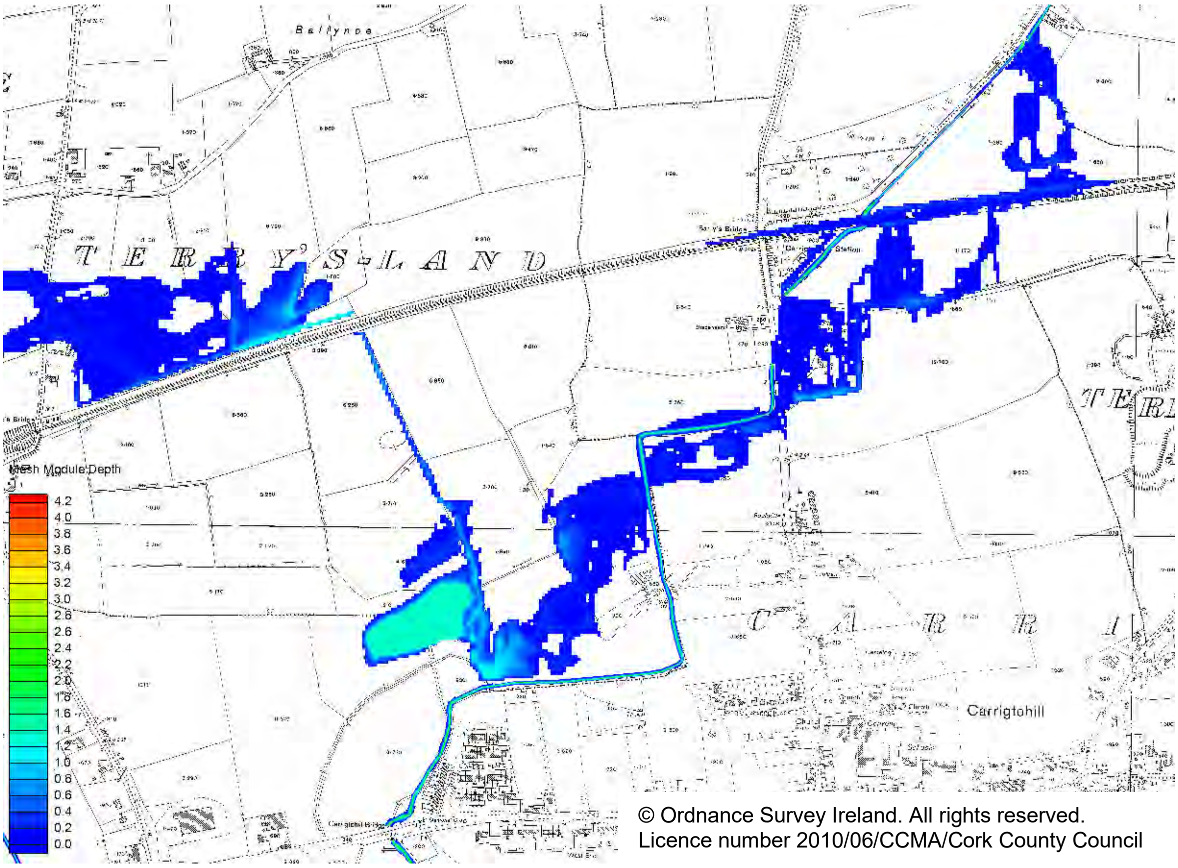
Water flows from Point A southwards towards the rail line and at approximately 4 hrs water begins to flow west along the rail line. At this stage in the simulation water has come out of bank at Point C also.

This out of channel flow continues heading in a south westerly direction until it reaches its peak around 5 to 6 hrs into the simulation. Floodplain flow from Point A, that reaches the rail line and flows in a westerly direction along the rail line peaks at 0.5m3/s at 5h 15m, in a 1% AEP event and out of channel flow, over the right bank at Point C, peaks at 0.3m3/s at 5h 15m. This flow route from Point C is active in a 20% AEP (1 in 5 year) event.

Floodwater from the Tibbotstown Stream (1.2m3/s) enters this system at about 8 hrs and adds to the flood levels in the Castlelake area, with flood levels up to 3.1mOD in the Castlelake area. This flow routes is active in a 10% and greater AEP event.

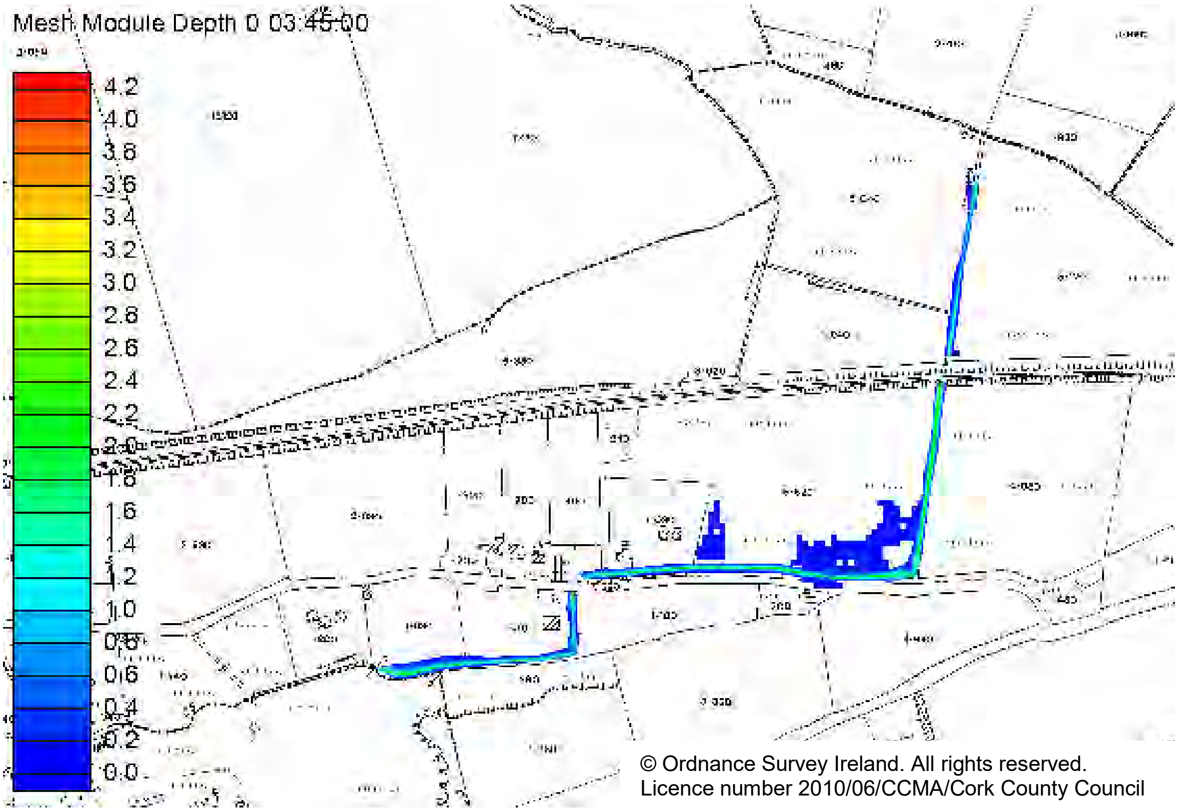
The maximum flood extent for a 1% AEP (1 in 100 year) event is illustrated below.

Figure 10-9 Woodstock Maximum Flood Depth for a 1% AEP Fluvial Event



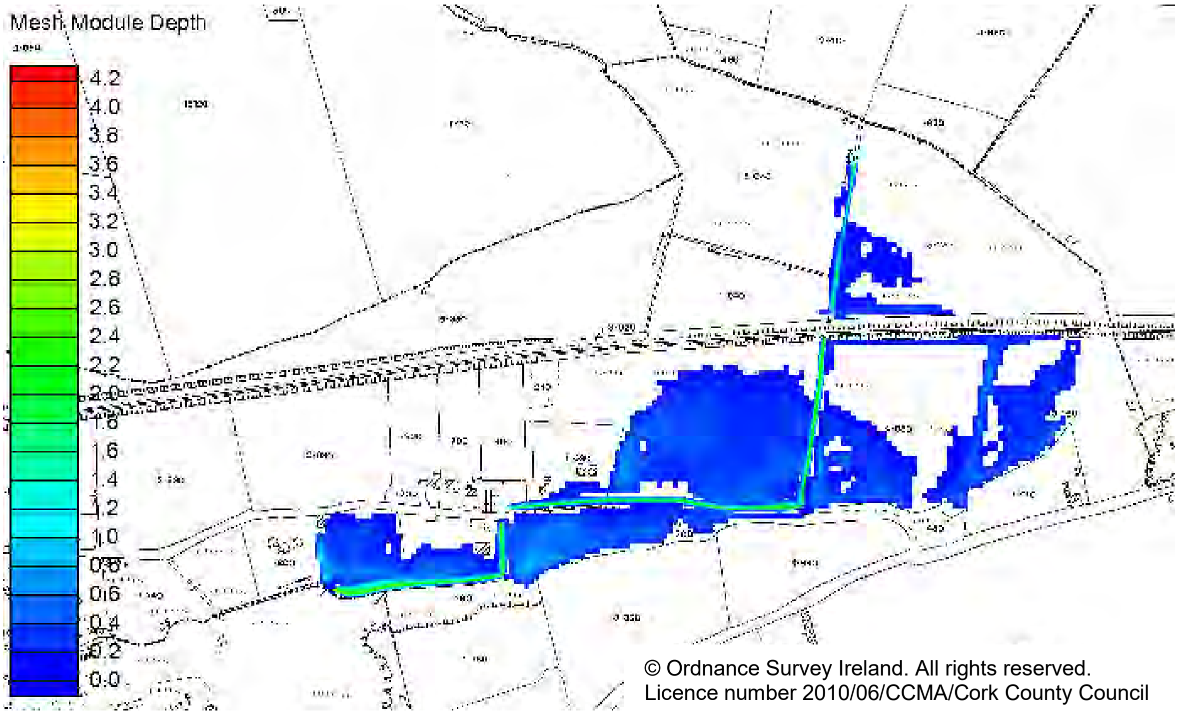
10.1.4 Poulaniska Stream

Figure 10-10 Poulaniska Flood Depth at 3h 45m during a 1% AEP Fluvial Event



Out of channel flow occurs after approximately 3h 30m into the simulation, when flow in the channel exceeds 0.5m3/s. Out of channel flow continues inundating low lying land. The maximum flood extent is illustrated below. Out of channel flooding occurs in as little as a 50% (1 in 2 year event). The floodplain topography is low lying with relatively steep sides, meaning that the flood extent varies very little for each AEP event.

Figure 10-11 Poulaniska Maximum Flood Depth for a 1% AEP Fluvial Event



10.2 Slatty Pump Station

10.2.1 Background

Consultation between Cork County Council and local landowners, resulted in the construction of the Slatty Pump station to maintain water levels in Slatty Pond to an agreed level. The pumps station has been operational since 2009 and was not included in the original Lee CFRAMS modelling of Carrigtohill.

The pumps have been added to the 1D hydraulic model and while the brief does not include for an investigation into the operation of the pump station, a number of model runs have been completed and the results analysed to review pump operations during extreme events.

10.2.2 Pump Setup

The pump station consists of 4 EMU Wilo submersible pump units, each with a capacity of 1000l/s. The purpose of the pumps is to maintain levels in Slatty Pond at or below -0.9mAD.

When the tide is low, gravity flow is possible through flapped tide valves in Slatty Bridge. The gravity outfall consists of 2 tidal flap gates and 3 tideflex non-return valves. The invert levels of these, range between -2.16mOD and 1.21mOD. The tidal range is between -1.4m and 2.5mOD. The following schematics illustrate the levels that play a role in the pump operation.

More detail on the pumps can be found in the Model Check File in Appendix D.

Figure 10-12 Outfall Cross Section

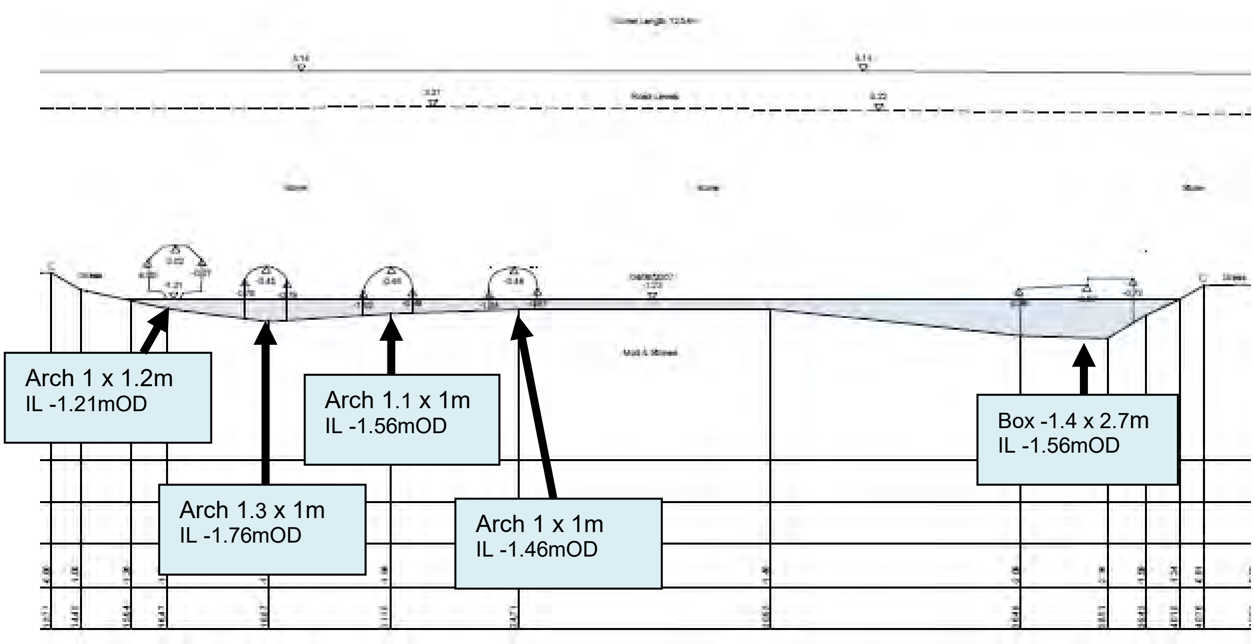
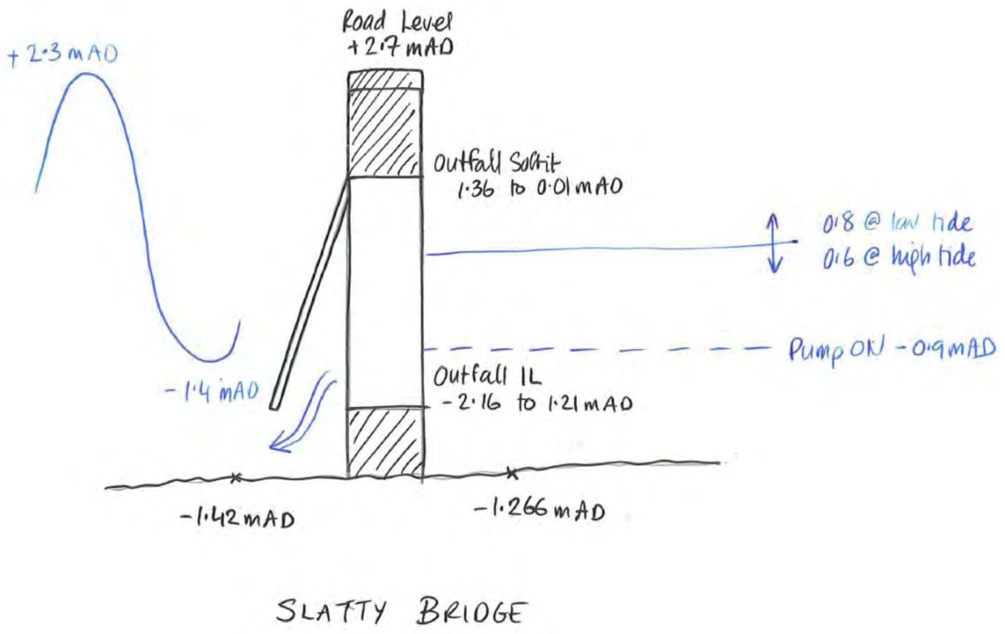


Figure 10-13 Schematic of Outfall Long Section



10.2.3 Model Results

1% AEP Fluvial Event with Pumps On and Off

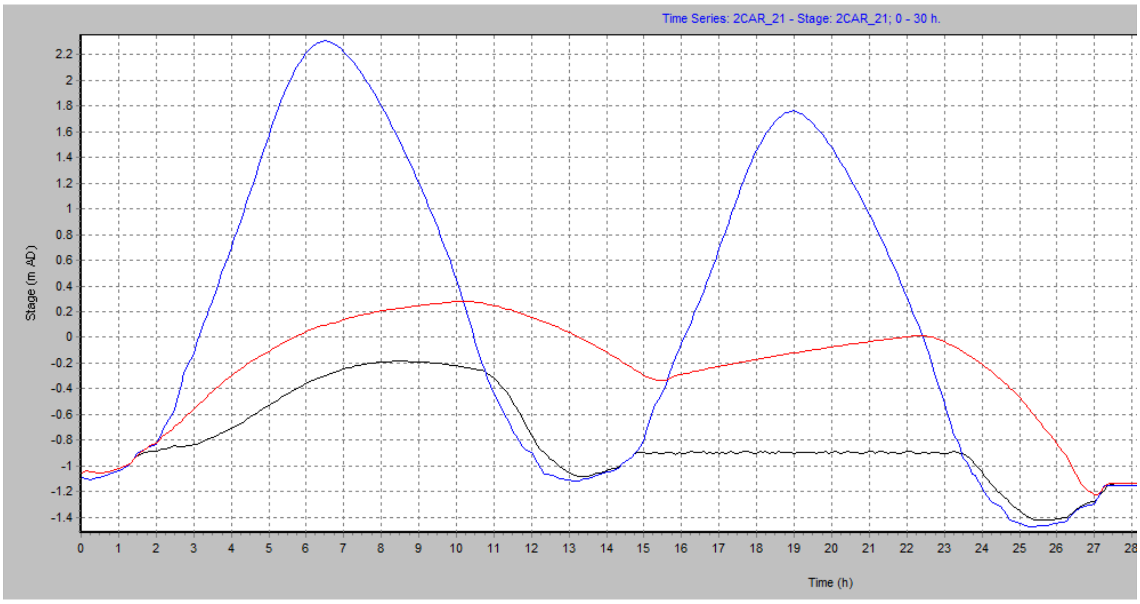
The model was simulated for a 1% AEP and 0.1% AEP fluvial event with the pumps on (defended) and pumps off (undefended) scenario. Both models were run with a 50% AEP (1 in 2 year) tidal downstream boundary.

The results for a 1% AEP fluvial event are discussed below in terms of how effectively the pumps are working during extreme events. Figure 10-14 illustrates the effectiveness of the pumps in lowering water levels at Slatty Pond. During the first tidal peak (with peak tide at 2.3mOD) the pumps fail to maintain levels at -0.9mOD with water levels in Slatty Pond rising to at -0.186mOD. This water level drops to -1.1mOD during the ebb tide.

During the second tidal cycle (with a tidal peak of 1.8mOD) the pumps are effective in maintaining the water level to -0.9mOD. At this time in the simulation the fluvial event has passed. The fluvial event peaks at the same time as the first tidal peak.

With the pumps off, the stage in Slatty Pond rises to 0.28mOD after the first tidal peak and to 0.01mOD after the second tidal peak. During low tide, without the benefit of the pumps the stage drops to a minimum of -0.34mOD.

Figure 10-14 Stage at Slatty Pond during a 1% AEP Event



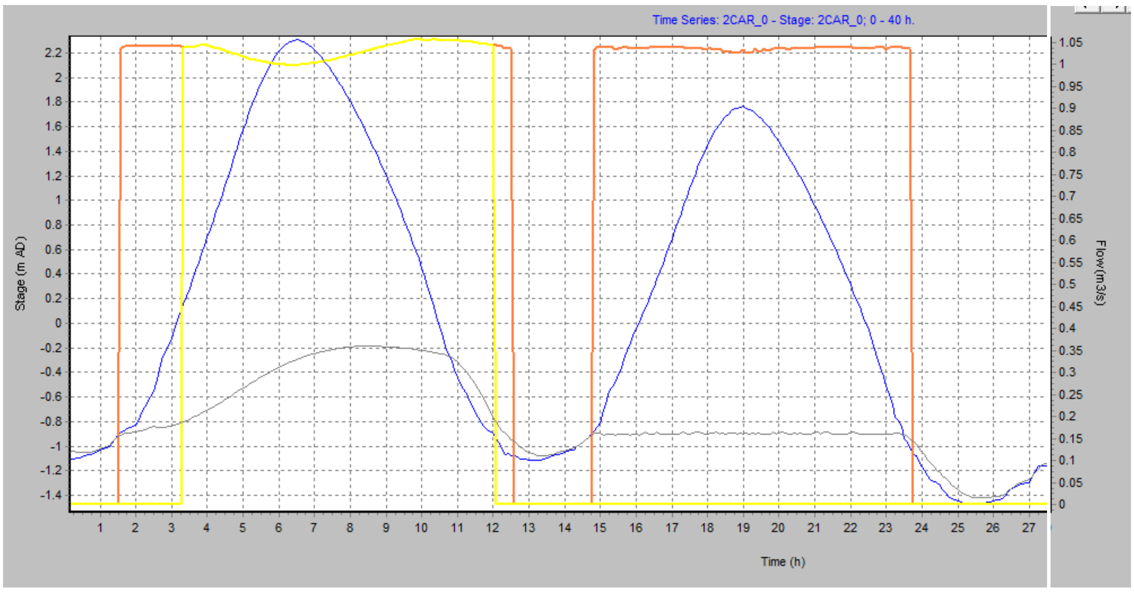
Legend

Black line	Slatty Pond Stage Defended
Blue line	Downstream Tidal Stage
Red line	Slatty Pond Stage Undefended

The following Figure 10-15 indicates the amount of time the pumps are switched on. All four pumps are on during the first tidal cycle. During the second rising tide, Pump 1 is on, Pump 2 switches on and off and Pumps 3 and 4 are not activated.

Pump 1 stays on for 20 hours out of 24 hours over two tidal cycles. Pump 4 stays on for 9 hours of the first 12 tidal cycle and remains off during the second tide cycle.

Figure 10-15 Pumped Flow during a 1% AEP Event

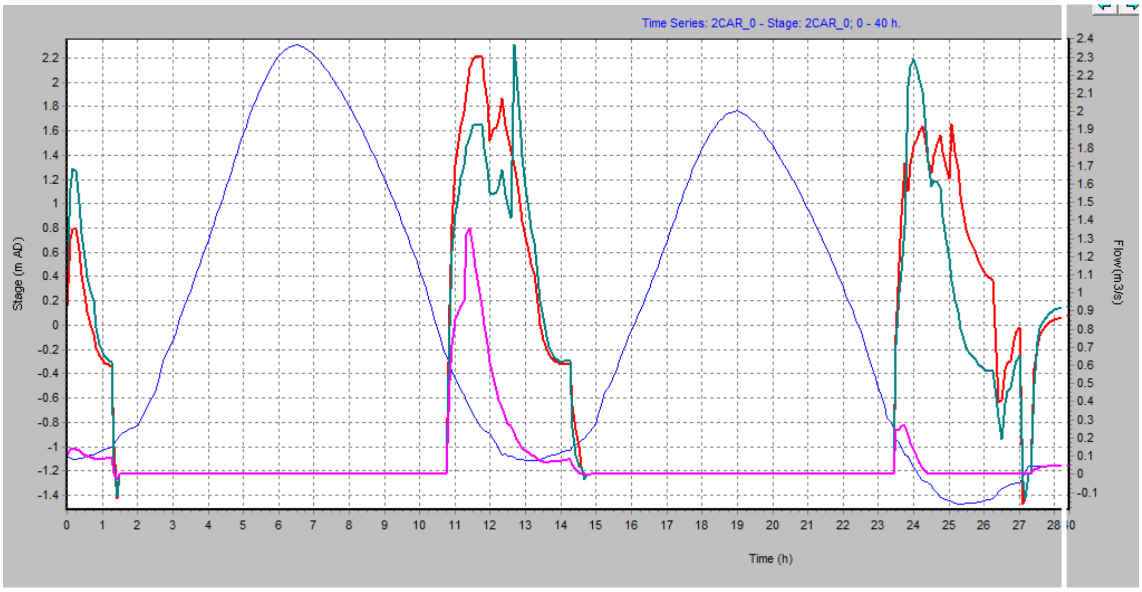


Legend

Blue line	Downstream Tidal Stage
Grey line	Slatty Pond Stage
Yellow line	Pump 4 Flow
Orange line	Pump 1 Flow

Gravity discharge through the non-return valves on the bridge is also possible. The following Figure 10-16 illustrates this. Gravity discharge occurs for approximately 4 hours during each period of low tide.

Figure 10-16 Gravity Flow during a 1% AEP Fluvial Event



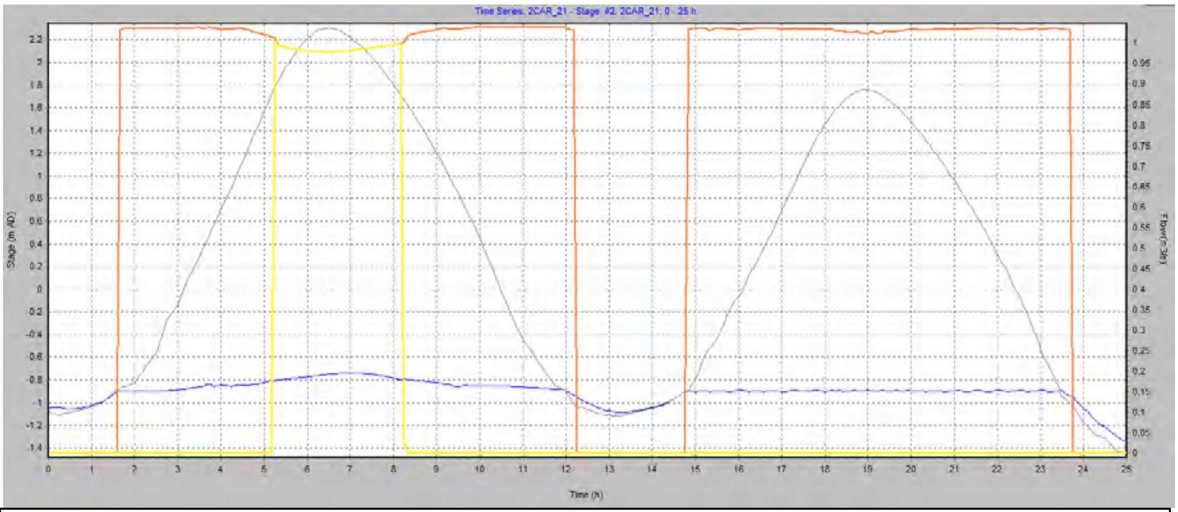
Legend

Downstream Tidal Stage
Opening 1 Flow
Opening 2 Flow
Opening 3 Flow

50% Fluvial Event with Pumps On

For comparison the results from a 50% AEP fluvial event are discussed. The following Figure 10-17 illustrates that during this event the water level in Slatty Pond rises to a peak of -0.74mOD at the peak of the event. This water level is drawn down to -0.9mOD by the pumps but remains at higher than -0.9mOD for approx 10 hours.

Figure 10-17 Pumped Flow during 50% AEP Fluvial Event

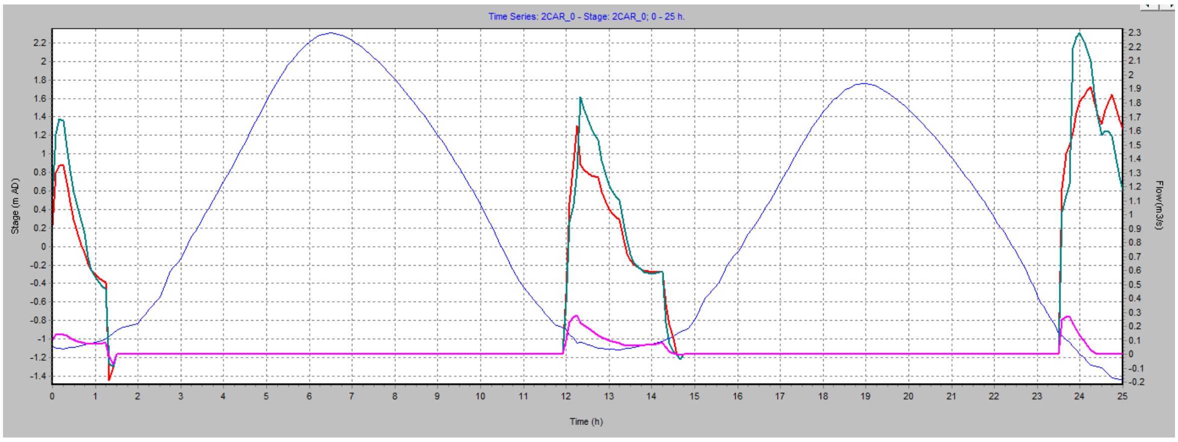


Legend

Blue line	Downstream Tidal Stage
Grey line	Slatty Pond Stage
Orange line	Pump 1 Flow
Yellow line	Pump 4 Flow

All four pumps are activated during the first tidal cycle. During the second rising tide, Pump 1 is on, Pump 2 kicks on and off and Pumps 3 and 4 are not activated. During this lower return period event, Pump 1 stays on for approx 20 hours out of 24 hours over two tidal cycles. Pump 4 stays on for approx 3 hours of the first 12 tidal cycle and remains off during the second tide cycle.

Figure 10-18 Gravity Flow during 50% AEP Fluvial Event



Legend

Blue line	Downstream Tidal Stage
Red line	Opening 1 Flow
Teal line	Opening 2 Flow
Magenta line	Opening 3 Flow

In conclusion, during the 1% AEP fluvial event (combined with a 50% AEP tide at the downstream boundary) the pump station fails to maintain the water level in Slatty Pond at -0.9mOD.

10.3 IDA and Irish Rail Siphon Arrangement

Where the Tibbotstown Stream intersects the rail line, flow is diverted three ways. The three routes are as follows:

- Irish Rail siphon under the rail line
- Irish Rail cascade leading to an Irish Rail diversion channel
- IDA siphon - draining to the IDA surface water network

These are represented in the 1D ISIS model, however due to lack of data, some assumptions were necessary. This is detailed in the Model Check File and outlined below.

Information was obtained from Irish Rail. This included design details and drawings of the cascade and diversion channel which was recently constructed as part of the re-opening of the rail line. This detail was used to represent the cascade in the model; due to the steepness of the cascade an ISIS siphon unit was used to effectively model this.

The Irish Rail siphon has been in place for a number of decades and design information on this was not available. Due to its inaccessible location, detailed survey of the inlet and invert levels was not possible. The siphon was represented in the ISIS model using a siphon unit of 450mm diameter. Levels were estimated based on nearest survey points and observations on site.

Information was also obtained from IDA. This included drainage drawings indicating the location of the main surface water network in the area. Interpretation of available information and observations on site led to the conclusion that the IDA siphon feeds into the surface water network. Investigation on site and consultation with IDA confirmed that flow from the stream can enter the surface water network via the IDA siphon and this flow is conveyed downstream into the surface water attenuation tank. It is assumed that this IDA siphon was intended as an overflow only, however based on the site investigation it appears that this flow route is regularly active and as a consequence the attenuation tank remains full. This tank has an overflow out-falling to the stream. Based on the available information the IDA siphon has been included in the model as a 600 diameter siphon unit that discharges directly to the stream further downstream (at the location of the tank outfall). It is assumed that the tank does not provide any attenuation as it is continuously taking flow from the stream and therefore is always full.

Photo 10-19 3 Way Split Structure

Irish Rail Siphon

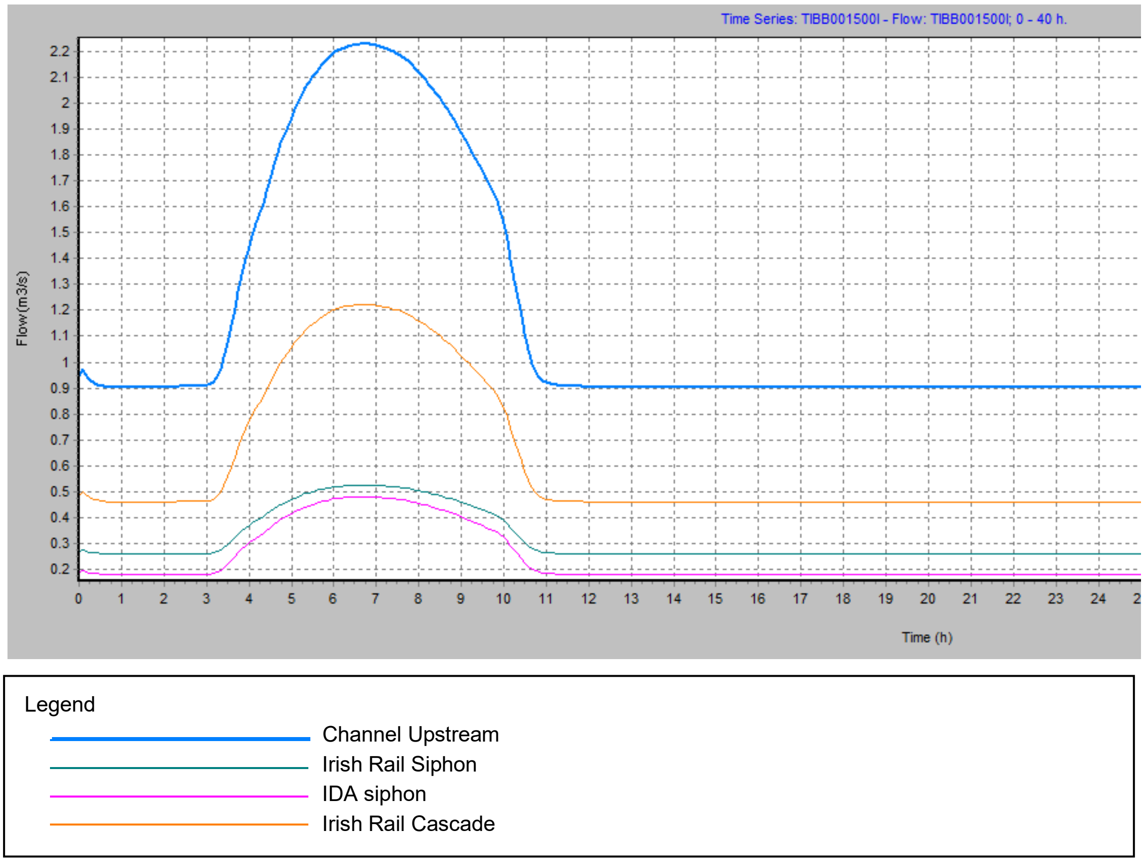
Inlet to Cascade and IDA Pipe

Photo 10-20 Irish Rail Cascade

10.3.1 Model Results

The model results indicate the following split in flows. The majority of flow, 55% enters the Irish Rail cascade; 23% enters the Irish Rail Siphon and the remainder (22%) enters the IDA siphon. This split is based on the size and invert levels assumed in the model representation and is consistent for fluvial events of varying magnitude / AEP.

Figure 10-21 Flows during a 1% AEP Event



10.4 Carrigtohill Bridge

The Woodstock Stream flows under the local road to Carrigtohill adjacent to the Castlelake development and just upstream of Hanover Tyres. This crossing point was modelled under the original Lee CFRAMS model. Survey collated in June 2007 confirmed this structure consisted of a twin 700mm diameter pipe and this was modelled as a single pipe of equivalent diameter.

Survey in June 2012 indicated only one pipe at this location. However based on observation made on site, it is considered likely that a second culvert exists but is blocked / overgrown with heavy vegetation and silt. This structure has been modelled as a single pipe of an equivalent diameter of 1.4m in ISIS. The invert levels downstream are based on the Lee CFRAMS survey.

Flooding occurred at this location in November 2009 and was reported on by RPS. This report indicates that the culverts at Carrigtohill Bridge are twin 900mm diameter pipes. Is reported that these culverts are under capacity and played a contributory factor in the flooding that occurred in 2009. The culvert crossing is in the ownership of Gable Developments.

Photo 10-22 Carrigtohill Bridge

June 2007

June 2012

10.4.1 Model Results

The model results from this study do not show out of bank flooding at Carrigtohill Bridge. The estimated flow in the channel upstream of Carrigtohill Bridge is 2.5m3/s with a flood level of 1.1mOD during a 1% AEP fluvial event. As discussed in Section 9 works in the area may have altered potential overland flow routes and altered the predicted flood extent in comparison to that observed in the past. Also, out of channel flooding further upstream leads to a reduction in peak flows in this area of interest.

11 Tidal Model Results

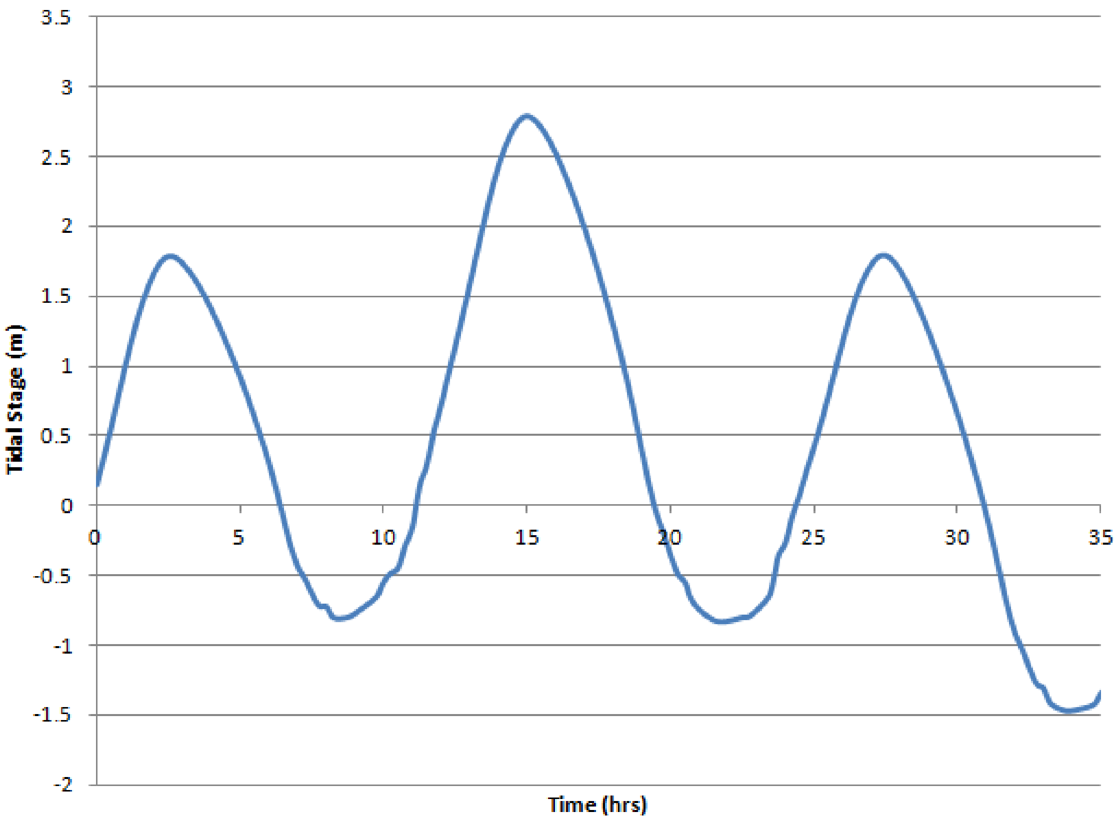
Tidal flooding occurs when the tide level exceed the elevation of the shoreline. A review of the defence assets in the study area highlights the N25 road embankment and a land embankment to the west in the area of the Kilacloyne estuary as having a flood defence function. These are not maintained formally as flood defences but are sizable features that are not expected to fail catastrophically in the current or near future scenario.

Based on the crest elevations along the shoreline, overtopping is predicted for tidal events greater that a 2% AEP (1 in 50 year). This includes all climate change scenarios; Mid Range and High End Future.

During such tidal inundation it is assumed that the pumps are not working and these are not represented in the tidal model.

The tide stage graph for a 0.5% AEP (1 in 200 year) tidal event is shown in Figure 10-1 below. Tidal inundation occurs when the tide level exceeds the crest level of the road embankment or shoreline.

Figure 11-1 Tidal Stage Graph for 0.5% AEP Event



11.1 Slatty Pond Area

At Slatty Pond, tidal inundation commences at Point A at a time 14h 45m into the simulation, when the tide level exceeds 2.7mOD. By inspecting the tidal stage graph, limited overtopping is expected at this location during the 0.5% AEP event.

Figure 11-2 Slatty Pond Flood Depth at 14h 45m

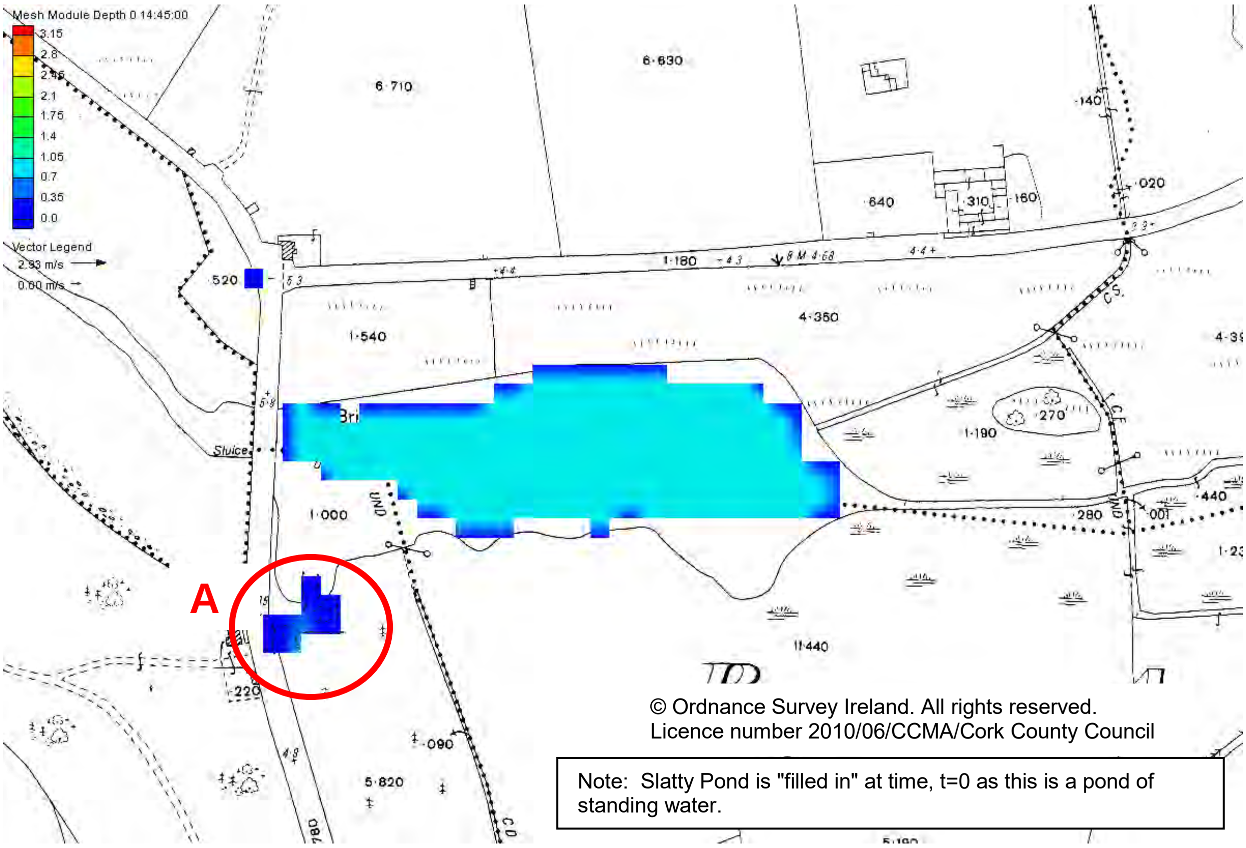
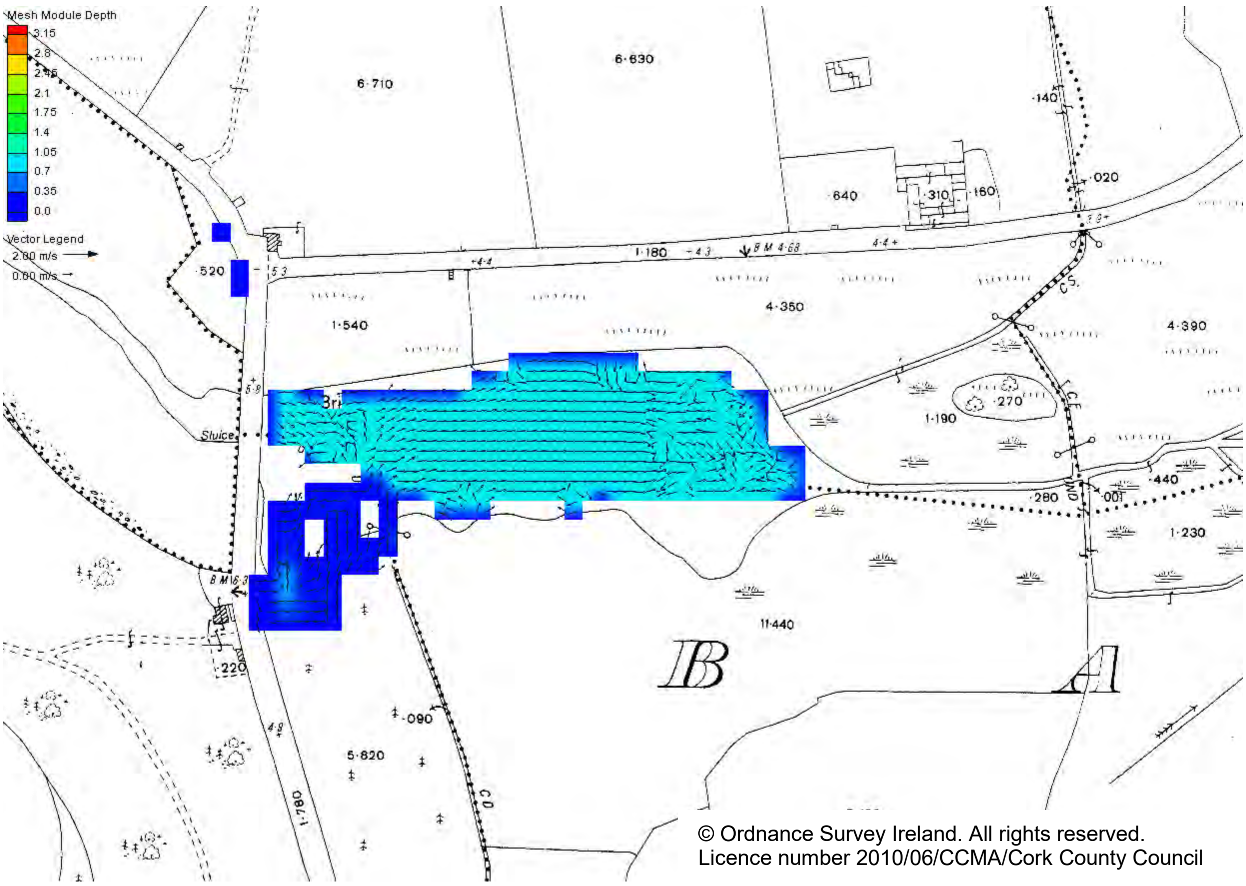


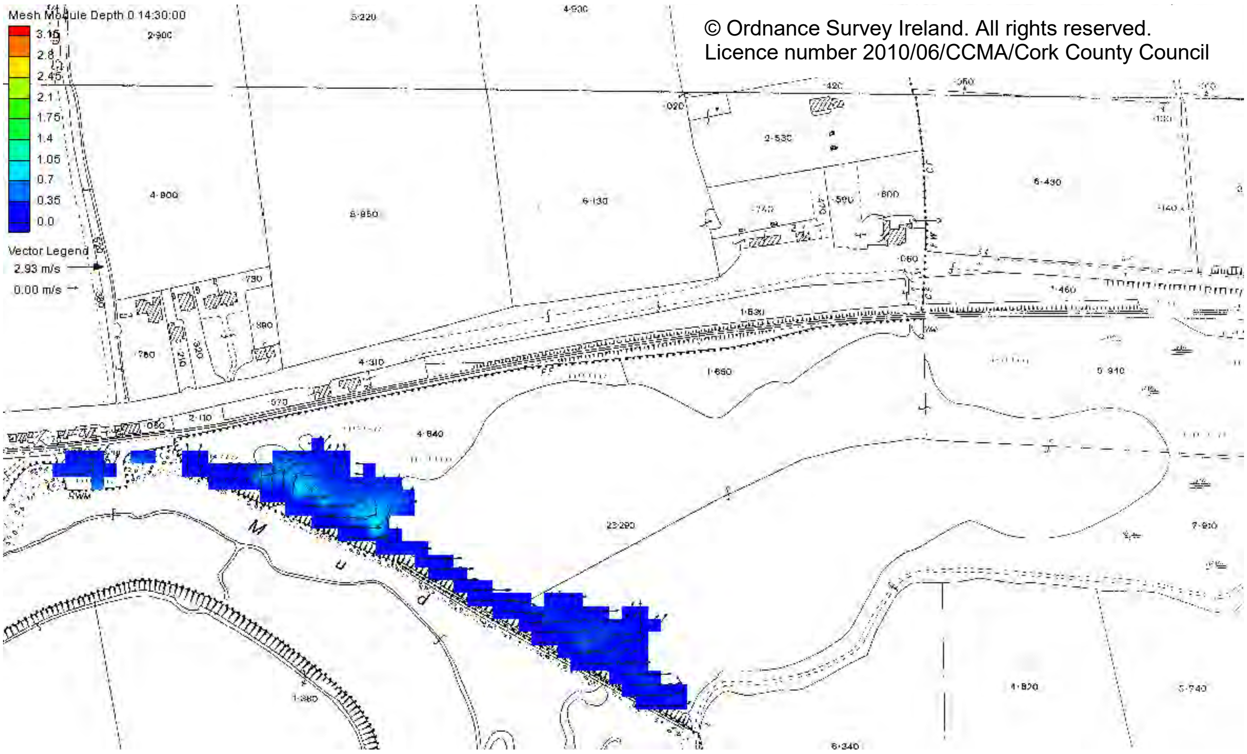
Figure 11-3 Slatty Pond Maximum Flood Depth



11.2 Kilacloyne Tidal Area

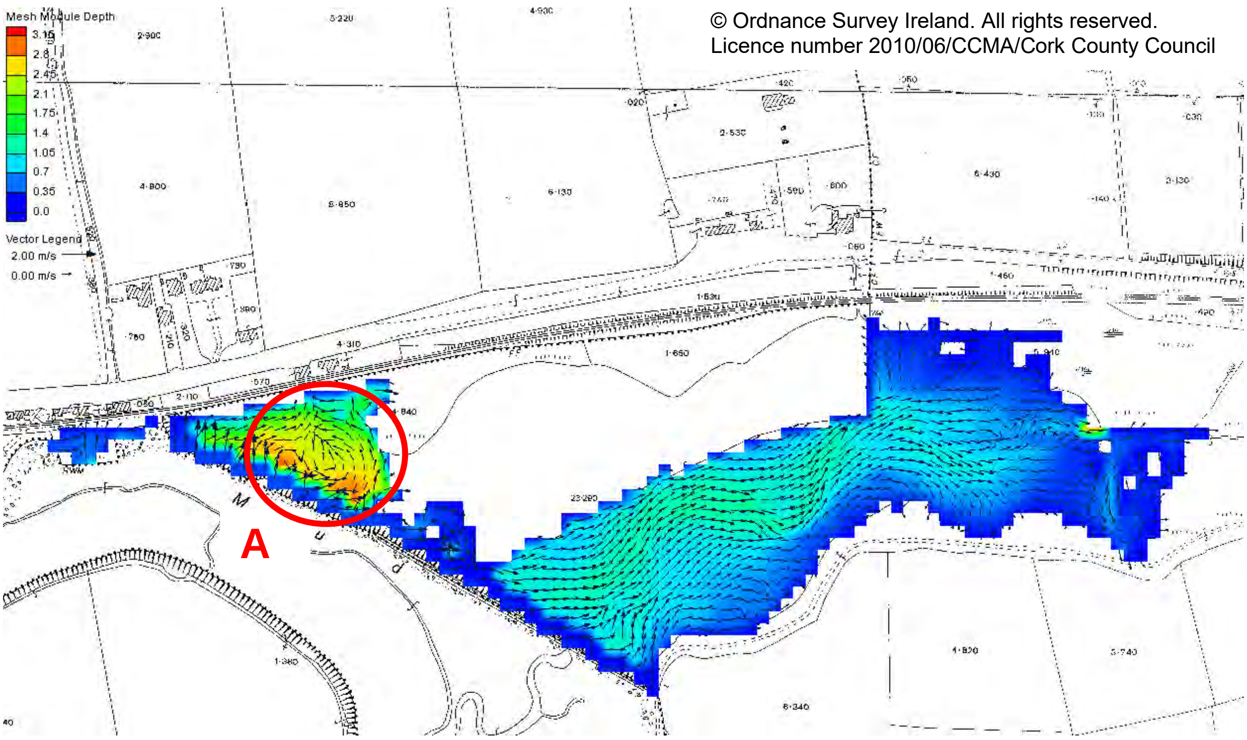
In the Kilacloyne area, tidal inundation commences at a time 14h 15m into the simulation, when the tide level exceeds 2.5mOD. Again by inspecting the tidal stage graph, some overtopping is expected at this location during the 0.5% AEP event.

Figure 11-4 Kilacloyne Tidal Area Flood Depth at 14h 30m



The flood water inundates the low lying mud flats of the estuary to a maximum flood level of approximately 2.8mOD at Point A on the map below. This area is disconnected from the main Kilacloyne Stream and therefore retains water to a higher level.

Figure 11-5 Kilacloyne Tidal Area Maximum Flood Extent

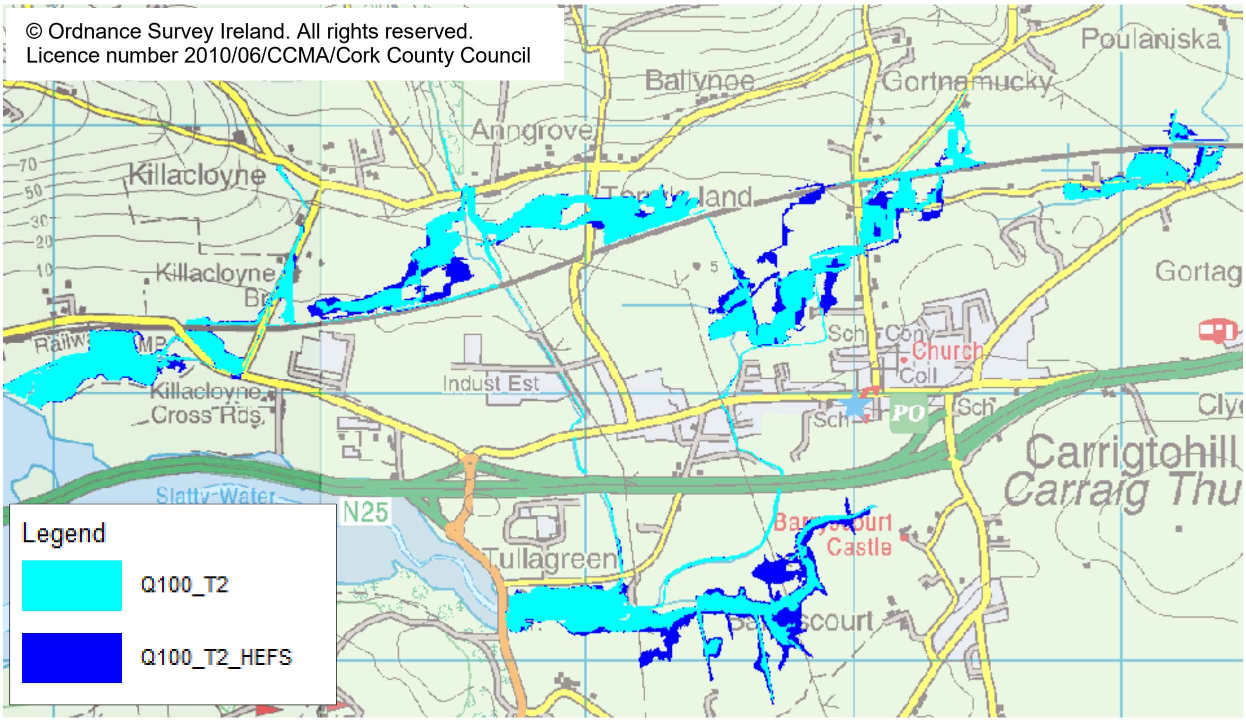


12 Climate Change Impacts

Climate change predictions for future scenarios impact on the magnitude of flooding and increase flood risk in populated areas. Based on OPW draft guidance, a mid range future scenario and high end future scenario are considered in the study. Fluvial flows are expected to increase by 20% and 30% respectively for the MRFS and HEFS and tide levels are expected to increase by up to 0.55m in a MRFS and 1.05m in a HEFS. (See Section 4.7).

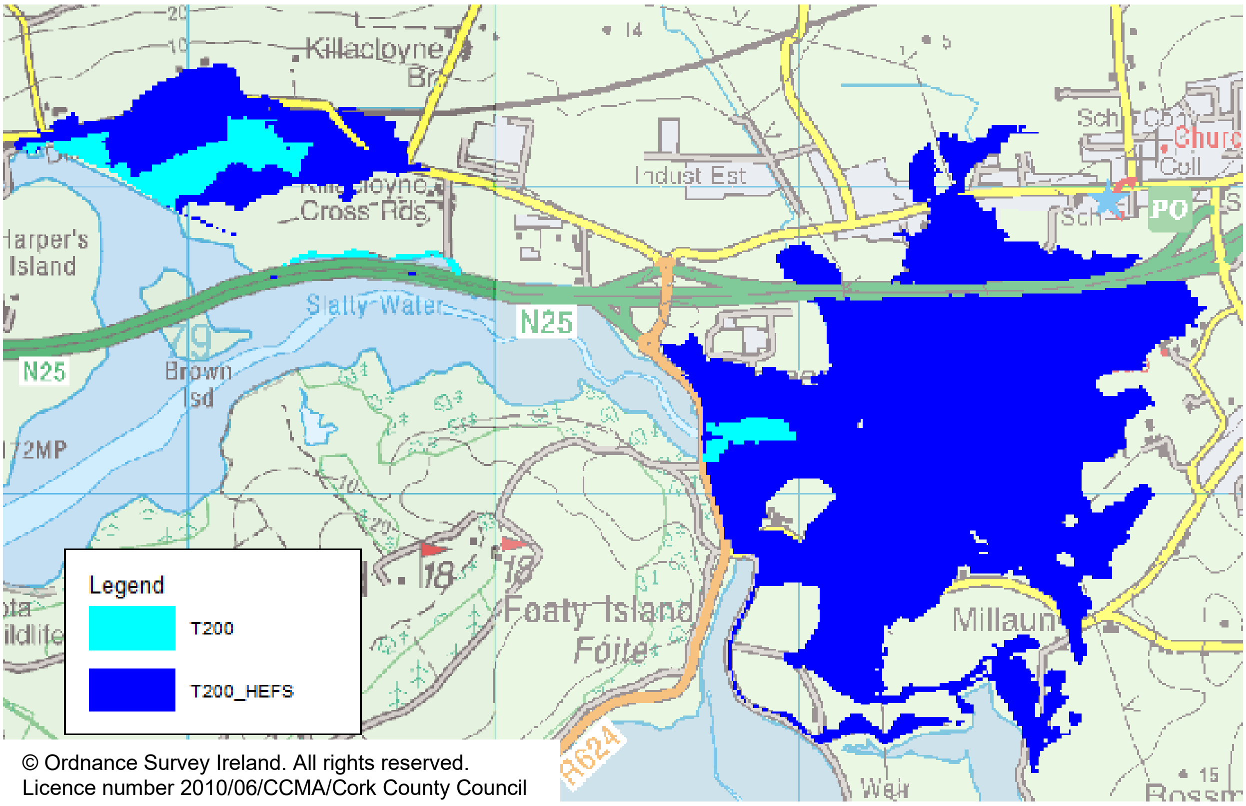
The following illustrates the impact of climate change on a 1% AEP fluvial event if the effect of climate change is included for.

Figure 12-1 Climate Change Impact on Fluvial Extent for High End Future Scenario



The impact of climate change when considering tidal AEP event is more dramatic, once the threshold for overtopping is exceeded tidal inundation will be more pronounced with an increasing tide level.

Figure 12-2 Climate Change Impact on Tidal Extent for High End Future Scenario



13 Flood Mapping

As required by the brief, flood maps have been prepared based on the model output for the hydraulic modelling. All model results are delivered to the client, Cork County Council in GIS format and a number of scenarios are compiled as print ready maps.

Following agreement from Cork County Council geo-pdfs are used to create interactive maps that allow the user to turn on and off layers as necessary depending on the type of mapped output (i.e. extent, depth, hazard etc) that is required and at what scale. The following is a list of the maps that have been prepared and provided in Appendix F.

Table 13-1 List of Flood Maps

Geo Pdf Map No	Scenario / Map Title	Applicable Models	Map Layers
1	Current Scenario (all AEPs)	Fluvial: DEF_Qxxx_T2_027 Tidal: Txxx	Fluvial Flood Extent for 10%, 1% and 0.1% AEPs Tidal Flood Extent for 1% & 0.1% AEPs UMAP outlines Table of flow & levels at key model nodes 5kOSi Basemap 50k OSi Raster Map
2	10% AEP Current Scenario Fluvial: 10% AEP Fluvial plus 50% AEP Tidal	Fluvial: DEF_Q10_T2_027 Tidal: N/A	Fluvial Depth Fluvial Velocity Fluvial Hazard 5kOSi Basemap 50k OSi Raster Map
3	1% (0.5%) AEP Current Scenario Fluvial: 1% AEP Fluvial plus 50% AEP Tidal Tidal: 0.5% AEP Tidal	Fluvial: DEF_Q100_T2_027 Tidal: T200	Fluvial Depth Fluvial Velocity Fluvial Hazard Tidal Depth Tidal Velocity Tidal Hazard 5kOSi Basemap 50k OSi Raster Map
4	0.1% AEP Current Scenario Fluvial: 0.1% AEP Fluvial plus 50% AEP Tidal Tidal: 0.1% AEP Tidal	Fluvial: DEF_Q1000_T2_027 Tidal: T1000	Fluvial Depth Fluvial Velocity Fluvial Hazard Tidal Depth Tidal Velocity Tidal Hazard 5kOSi Basemap 50k OSi Raster Map
5	Flood Zones	Fluvial: UNDEF_Q100_T2_030; UNDEF_Q1000_T2_030 Tidal: T200, T1000	Flood Zone A Flood Zone B 5kOSi Basemap 50k OSi Raster Map
6	Mid Range Future Scenario (all AEPs)	Fluvial Model: MRFA_DEF_Qxxx_T2_027 Tidal: Txxx_MRFS	Fluvial Flood Extent for 10%, 1% and 0.1% MRFS AEPs Tidal Flood Extent for 10%, 1% & 0.1% MRFS AEPs UMAP outlines Table of flow & levels at key model nodes 5kOSi Basemap 50k OSi Raster Map

13.1 Map Types

The maps produced include maximum extent, depth, velocity and hazard maps. Rather than a snapshot in time, the maps depict the maximum output during a model simulation e.g. the maximum at one location may occur earlier or later than a point upstream or downstream.

Flood hazard maps are a useful indicator of the potential for loss of life in more extreme events where residual risk is a prime consideration. Areas of high velocity and large depths combine to create a greater hazard to people and restrict access for emergency services. Flood Hazard is based on the Defra FD2321[2] formula. The TUFLOW command to calculate a flood hazard rating based on categories as set out in the DEFRA guidance has been used. Based on guidance developed for the national Catchment Flood Risk Assessment and Management (CFRAM) programme, a debris factor is not included. Flood Hazard has been used in this FRA to look at the impact of development in the surrounding area.

Flood Zone Maps have also been prepared for the study area. In the 'Planning System and Flood Risk Management', Flood Zones are used to indicate the likelihood of a flood occurring. The Flood Zones indicate a high, moderate or low risk of flooding from fluvial or tidal sources and are defined as follows in Table 13-2.

Table 13-2 Definition of Flood Zones

Zone	Description
Zone A High probability of flooding.	This zone defines areas with the highest risk of flooding from rivers (i.e. more than 1% probability or more than 1 in 100) and the coast (i.e. more than 0.5% probability or more than 1 in 200).
Zone B Moderate probability of flooding.	This zone defines areas with a moderate risk of flooding from rivers (i.e. 0.1% to 1% probability or between 1 in 100 and 1 in 1000) and the coast (i.e. 0.1% to 0.5% probability or between 1 in 200 and 1 in 1000).
Zone C Low probability of flooding.	This zone defines areas with a low risk of flooding from rivers and the coast (i.e. less than 0.1% probability or less than 1 in 1000).

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

The Flood Zones therefore are equivalent to the undefended mapped scenario are annotated as such on the relevant maps. For this study, in the undefended scenario the pumps are turned off. This results in more extensive flooding in the Slatty Pond area. The Flood Zone Maps are presented in Appendix F.

It is important to note, when viewing the Flood Zones produced under this study, consideration should be given to the wider County Flood Zones adopted in the County Development Plan.

13.2 Uncertainty & Confidence Intervals

In the Flood Extent Maps, the uncertainty (or level of confidence) is illustrated by the line style of the outline shown in the maps, and represents the following three categories for each of the 10%, 1% and 0.1% AEP events:

- High Confidence
- Medium Confidence
- Low Confidence

[2] Defra / Environment Agency Flood and Coastal Defence R&D Programme, R&D OUTPUTS: FLOOD RISKS TO PEOPLE Phase 2, FD2321/TR2, Guidance Document, March 2006

UMAP software code was adapted for used in this assessment. The indicator of degree of confidence is based on the following factors:

- Hydrological:

  Design flood parameter estimation method(s)

  Availability, proximity and quality of recorded flood flow or tidal level data

  Probability of the design flood event
- Hydraulics:

  The quality (including cross-section spacing) of the survey data

  Method for estimating roughness

  Complexity of the relevant hydraulics and / or hydraulic model

  Availability, proximity and quality of flood level or extent calibration data and / or the outcomes of the calibration and validation
- Topographical:

  The local topography / slope of the floodplains (taken from the LIDAR grid)

14 Summary & Conclusions

This report provides findings from the hydraulic modelling assessment that has been completed as part of the Carrigtohill Flood Risk Assessment Study.

The assessment considers risk primarily from fluvial and tidal sources but also considers groundwater influence. A hydrological analysis was completed to estimate fluvial flows in catchment. The estimation of flows is reliant on methods for ungauged catchment and due to the size and nature of the watercourses and strong groundwater influence, the estimation of flows is an area of uncertainty. To reduce this uncertainty and achieve more confidence in the predicted flows the installation of gauges and continuous monitoring would be beneficial.

The study area and model extents include four river reaches, Kilacloyne Stream, Tibbotstown Stream, Woodstock Stream and Poulaniska Stream and the tidal estuary, Slatty Water that they discharge to.

There are a number of stretches of watercourse that have been altered or modified from what would be expected of a natural river system and siltation is occurring at control points in the upper reaches. There is a need to carefully monitor and manage hydro-geomorphologic processes to minimise erosion and siltation in the watercourses of the catchment. Monitoring will also be beneficial to help identify the merit of future control measures i.e. silt traps.

As part of the study topographic river survey was collated and a number of site walkovers were conducted to identify and investigate the hydraulic features in the catchment. This data, along with a range of other data, was used to develop the hydraulic models. Two separate models were developed; a linked 1D-2D model to assess fluvial flood risk and a 2D model to assess tidal flood risk.

The analysis of hydraulic results identified a number of key structures where flooding occurs. In some instance due to under sized culverts and in other due to poor maintenance and siltation problems. These areas, listed below, would benefit from continued monitoring and an investigation into potential flood mitigation and management measures.

Kilacloyne Stream

- Railway culvert - surcharging / under capacity in 20% AEP event
- Culvert under the third class road from Glounthaune to Carrigtohill - under capacity in 10% AEP event

Tibbotstown Stream

- Culvert alongside the local road north of the IDA lands - under capacity in 50% AEP event
- Weirs upstream of the rail line - out of channel flow predicted in less than 50% AEP
- IDA culvert - severe siltation
- 3 way split - monitoring of flows to confirm hydraulics

Woodstock Stream

- Private driveway culvert - under capacity in a 50% AEP event
- Railway culvert - evidence of erosion
- Culvert inlet with new trash screen at Railway Station junction - high probability of blockage
- Carrigtohill Bridge - evidence of siltation / overgrowth
- Culvert under N25 with trash screen - higher probability of blockage therefore regular inspection and maintenance required

Poulaniska Stream

- Railway culvert - out of channel flow in 50% AEP event

- Twin culvert under Bog Road - under capacity in 50% AEP event
- Discharge to caves at Cúl Ard - monitoring to quantify flow contribution downstream

Slatty Pond

- Slatty Pump Station - monitor pump operations to investigate pump performance and optimisation
- Slatty Pond - monitoring of water levels and occasional survey to monitor bed levels and quantify sedimentation

Flow restrictions in the upper reaches reduces the flow in the lower reaches and therefore flood measures in the upper reaches must carefully consider any associated impact further downstream.

The flood maps illustrate, in an extreme event 1% AEP, the majority of overland flooding is of shallow depth and low hazard, indicating that the majority of flooding in the catchment can be easily and effectively managed.

Appendices

A Data Register

B Hydrology Report

C Hydrogeology Report

D Hydraulic Model Check File

E Model Output

E.1 Table of Model Results at 1D Nodes

F Flood Maps

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