Cork County Council

Douglas Flood Relief Scheme (Including Togher Culvert)

Douglas Hydraulics Report

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Executive Summary

Arup were commissioned by Cork County Council (CCC) to develop a Flood Relief Scheme for Douglas and Togher. CCC are acting as agents for the Office of Public Works (OPW) for the project.

The overall scheme will consist of:

- Flood alleviation measures along the Tramore River/Ballybrack stream in Douglas which offers the required standard of protection; and
- Flood alleviation measures along the Tramore River in Togher between Lehenaghmore Industrial Estate and Greenwood Estate which offer the required standard of protection.

This Hydraulics report is produced as part of Stage I of the project and details the hydraulic analysis undertaken as part of the study for Douglas. The hydraulic analysis for Togher is detailed in a separate report.

Douglas is one of the largest suburbs of Cork and is located approximately 4km to the South East of the City. Two rivers flow through Douglas and form the basis of this study: (1) The Tramore River, and (2) The Douglas River which is more commonly referred to as the Ballybrack Stream.

Design flows were estimated as part of the hydrological analysis of the study. It was ensured that the modelled flow in the various reaches of the model did not exceed the design flows. It was also assumed that the peak flows of all the sub-catchments and the peak tidal water level occur simultaneously.

The flood risk in Douglas is not sensitive to the fluvial-tidal combinations. The fluvial-tidal joint probability scenarios developed as part of the Lee CFRAMS were therefore adopted for this study as a more detailed analysis was not required.

A one-dimensional (1D) and two-dimensional (2D) model of the Ballybrack Stream and Tramore River (The “Douglas FRS” model) has been constructed as part of the study. The 1D model simulates the in-bank flows and has been constructed in ISIS Professional 1D (v3.7) software. The 2D model simulates the out of bank floodplain flows and it has been developed in Tuflow software (v2012). Both the 1D and 2D models are dynamically linked and run together as a coupled hydraulic model.

The Douglas FRS model was calibrated against the June 2012 flood event. Two significant blockages occurred on the Ballybrack during this event: (1) at the trash screen to the entrance of the DVSC Culvert at Church Street, and (2) as the Lower Ravensdale Bridge. These blockages were included in the model through use of the BLOCKAGE unit in ISIS. It was assumed that the trash screen at the entrance to DVSC Culvert was 88% blocked during the event. It was also assumed that Lower Ravensdale Bridge was 45% blocked during the event.

The Douglas FRS model is well calibrated against the June 2012 event:

- A very good match between the recorded and modelled peak water levels at Douglas East and in Ravensdale has been achieved.

- The modelled flood extent matches the recorded flood extents quite well. There are however a number of areas where sight differences exist between the two datasets.
- There is a very good match between the modelled flooding mechanisms and the observed mechanisms from the CCTV installed at DVSC.

The results of the Douglas FRS model have been examined to understand the mechanism of flooding for the current scenario events. The design runs assume that no blockages occur at any of the culverts or bridges in the model.

The Q2 event does not result in any flooding of Douglas as water stays in bank. It is noted however that all the garden walls and park walls in the vicinity of Ravensdale in the model are assumed to act as flood defence walls.

The Q5 event does not result in Douglas flooding as the water stays in bank. The capacity of the channel in the lower reach of Ravensdale in the vicinity of the ICA Hall is however exceeded during this event but it does not spill out of channel as the garden and boundary walls that line both sides of the channel keep the floodwater in bank.

The Q10 event results in both Douglas East and Douglas West being inundated with floodwater. The source of the flooding is overtopping of the Ballybrack stream in the vicinity of the ICA Hall in Ravensdale.

The Q25 event results in both Douglas East and Douglas West being inundated with floodwater. Douglas Village Shopping Centre is also flooded during this event but it is noted that the depth of flooding within the building is very shallow. The threshold of flooding for the Shopping Centre is therefore between the Q20 and Q25 year event.

The Q50 event results in Douglas East, Douglas West, Douglas Village Shopping Centre and the road being inundated with floodwater. The mechanism of flooding is the same as for the Q25 event. The greater volume of floodwater leads to greater flood depths and a larger flood extent.

The Q100 results in Douglas East, Douglas West, Douglas Village Shopping Centre and the road being inundated with floodwater. The mechanism of flooding is the same as for the Q25 and Q50 events.

The Q100 also results in flooding of the Donnybrook Commercial Centre. In this scenario water surcharges through the manholes of the existing 190m long culvert that runs underneath the site and floods the lower end of the centre.

1 Introduction

1.1 Context

The Office of Public Works (OPW) in partnership with Cork City Council and Cork County Council carried out a Catchment Flood Risk Assessment and Management (CFRAM) Study for the Lee Catchment. Douglas and Togher were included as part of the study as both are located in the Tramore catchment which is a sub catchment of the Lee Catchment. The Catchment Flood Risk Management Plan (CFRMP) which was published in January 2014, identified a preferred flood risk management option in Togher but it did not identify a preferred scheme for Douglas.

Douglas was however severely flooding in June 2012. As a consequence, Cork County Council, acting as agents for the OPW, has now commissioned a project to develop a Flood Relief Scheme for Douglas. The design of the flood relief measures in Togher is also included as part of the project.

The overall scheme will consist of:

- Flood alleviation measures along the Tramore River/Ballybrack stream in Douglas which offers the required standard of protection.
- Flood alleviation measures along the Tramore River in Togher between Lehenaghmore Industrial Estate and Greenwood Estate which offer the required standard of protection.

There are five stages to the project:

- Stage I - Development of a number of flood defence options and the identification of a preferred Scheme.
- Stage II - Public exhibition.
- Stage III - Detailed design, confirmation and tender.
- Stage IV – Construction.
- Stage V - Handover of works.

This Hydraulics report is produced as part of Stage I of the project and details the hydraulic analysis undertaken for Douglas. The hydraulic analysis for Togher is detailed in a separate report.

1.2 Scope

The purpose of this report is to detail the hydraulic analysis carried out as part of Stage I of the project for Douglas. The scope of the work is to:

- Review the hydraulic modelling undertaken as part of the Lee CFRAM Study.
- Develop a dynamic 1D/2D hydraulic model of the Tramore river and Ballybrack stream in the area of Douglas Village.
- Calibrate the hydraulic model against the June 2012 flood event.

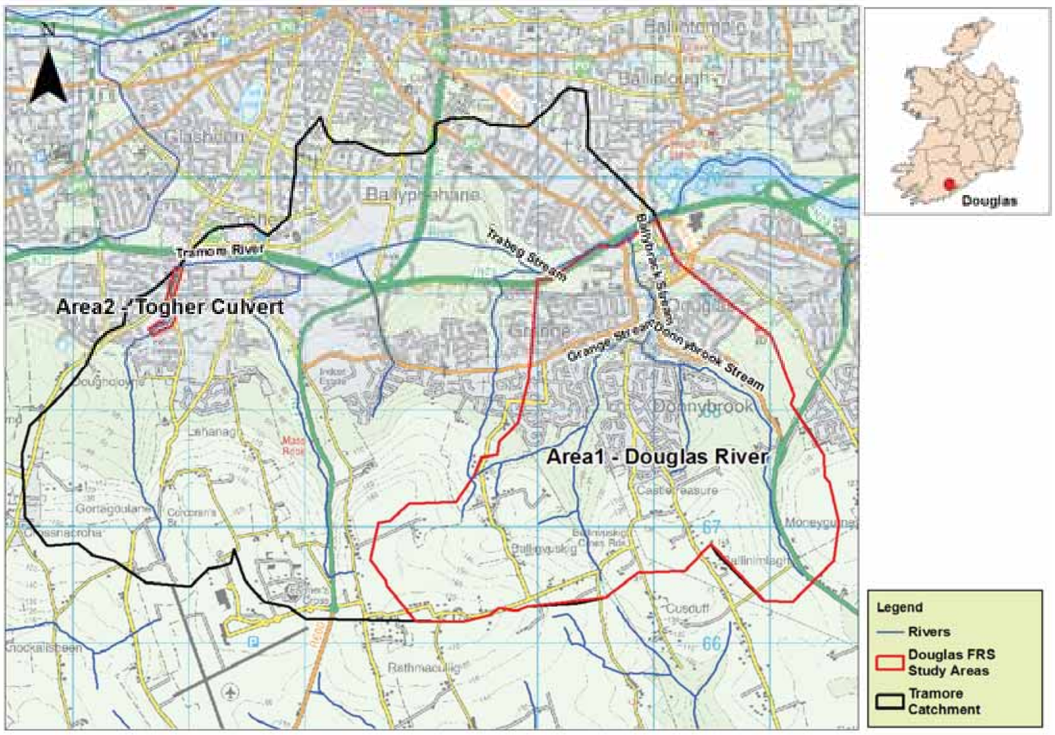
- Simulate a range of combined fluvial/tidal design flood events for the current scenarios using the Joint Probability Analysis undertaken as part of the Lee CFRAM Study. The combined return period events to be considered are the Q2, Q5, Q10, Q25, Q50 and Q100 events.
- Develop a flood extent map of the Q100 flood event for the Current scenario.
- Determine the most suitable options for a Flood Relief Scheme (FRS) for Douglas which offers the required standard of protection.
- Consider the impact that the proposed schemes will have on pluvial flood risk in Douglas and, if necessary, recommend any remedial measures.

1.3 Study Areas

For the purpose of this project there are two separate study areas which are both located within the Tramore River catchment (Figure 1):

1. Douglas
2. **Togher**

Figure 1: Douglas Flood Relief Scheme Study Areas



1.3.1 Area 1 – Douglas

Douglas is one of the largest suburbs of Cork and is located approximately 4km to the South East of the City. Two rivers flow through Douglas and form the basis of this study: (1) The Tramore River, and (2) The Douglas River which is more commonly referred to as the Ballybrack Stream and will be referred to as such in this report.

The Tramore River flows to the North of Douglas as indicated in Figure 2. The river enters a culvert to the West of Douglas Village Shopping Centre which conveys the River underneath the Shopping Centre for a distance of approximately 450m where it then discharges into the Douglas Estuary (Figure 3).

The Ballybrack Stream flows in a Northerly direction through Douglas. After passing through the Ballybrack Woods, Ravensdale and Church Road areas of Douglas, it enters the Community Park. At the downstream end of the park the stream enters a culvert which runs under the Douglas Village Shopping Centre. This culvert joins the larger culvert conveying the Tramore River.

This area (as presented in Figure 3) has been modelled as part of this phase of the work. A detailed description of the model is provided in Chapter 4.

Figure 2: Douglas Village. The shaded yellow area corresponds to the 2D Tuflow grid extent. The red arrows indicate the direction of flow.

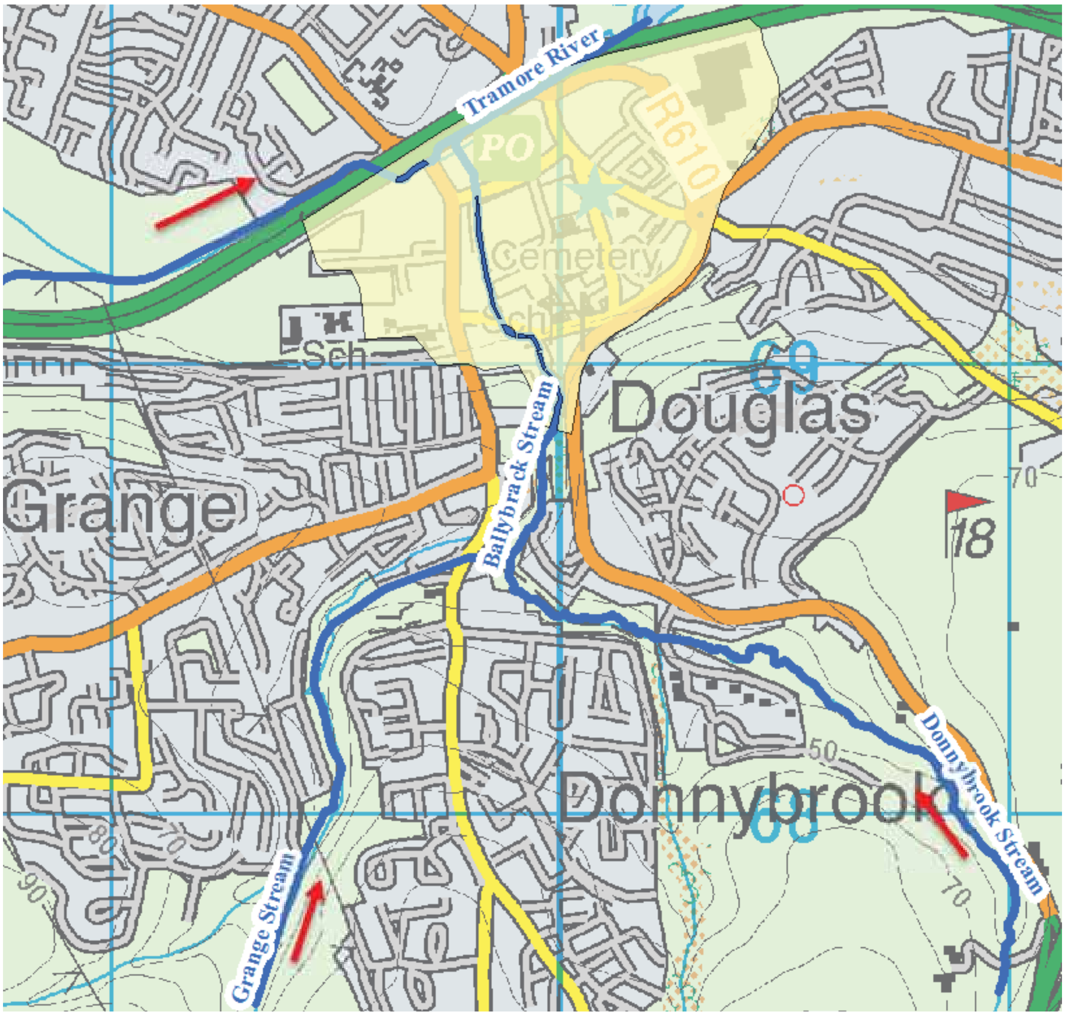


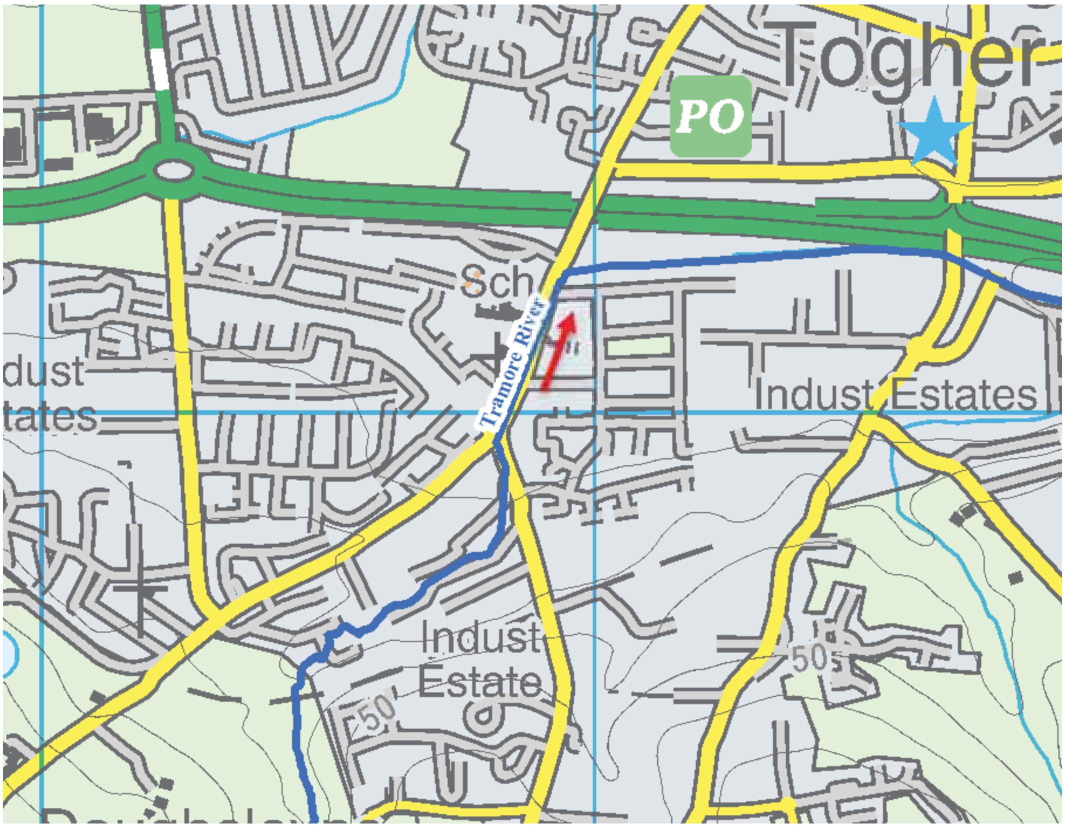
Figure 3: DVSC culvert entrances and exit locations

There is a hydrometric gauge located approximately 2km upstream of Douglas on the Tramore River. A hydrometric review of this gauge was undertaken as part of the project and is detailed in the accompanying hydrology report.

1.3.2 Area 2 – Togher

The hydraulic modelling of Togher undertaken as part of this project is detailed in a separate report.

Figure 4: Togher. The red arrow indicates the direction of flow



2 Data Collection

This chapter details the datasets used in the construction and running of the Douglas 1D/2D hydraulic model and the Togher 1D model.

2.1 Mapping

A suite of maps of varying resolutions (1:1000, 1:5000 and 1:50,000) have been used in the construction of the hydraulic models and in the presentation of model results. These maps have been provided under licence from Ordnance Survey Ireland (OSi).

The OSi NTF dataset has also been used in the hydraulic model construction for the purpose of defining the outline of existing buildings in the 2D Tuflow grid and for correctly identifying different surface types in the floodplain model.

2.2 River Survey Data

The 1D element of the hydraulic models have used channel and structure cross sectional survey data from two separate surveys:

- Lee CFRAM survey data.

A detailed channel and structure survey of the Lee Catchment was undertaken as part of the Lee CFRAM. It was carried out by Maltby Land Surveys Ltd between February and June 2007. Approximately 250 km of river channel were surveyed which included the Tramore River and the Ballybrack Stream. As both of these watercourses were classified as Urban Area Watercourses (UAW's) under the Lee CFRAM, cross sections were surveyed at approximately 100m intervals along the channel and at all structures that were deemed to be of hydraulic significance. The cross sections extended for approximately 20m into the floodplain on either side of the channel.

- CCC Channel Survey.

CCC undertook a channel survey of the Ballybrack Stream in 2012. Some of the cross sections from this survey were utilised in the Douglas FRS model;

- Douglas FRS Infill and validation survey.

As part of the review and quality assurance of the Lee CFRAM study undertaken as part of this project, Arup identified a number of areas where additional survey data would improve the performance and accuracy of the Douglas FRS model. Additionally, Arup also identified a number of areas where modifications to the river channels have occurred since the Lee CFRAM survey was undertaken. All of these areas were subsequently surveyed as part of the Infill and Validation Survey Management Contract being run by OPW. Murphy Surveys undertook the survey in April 2014.

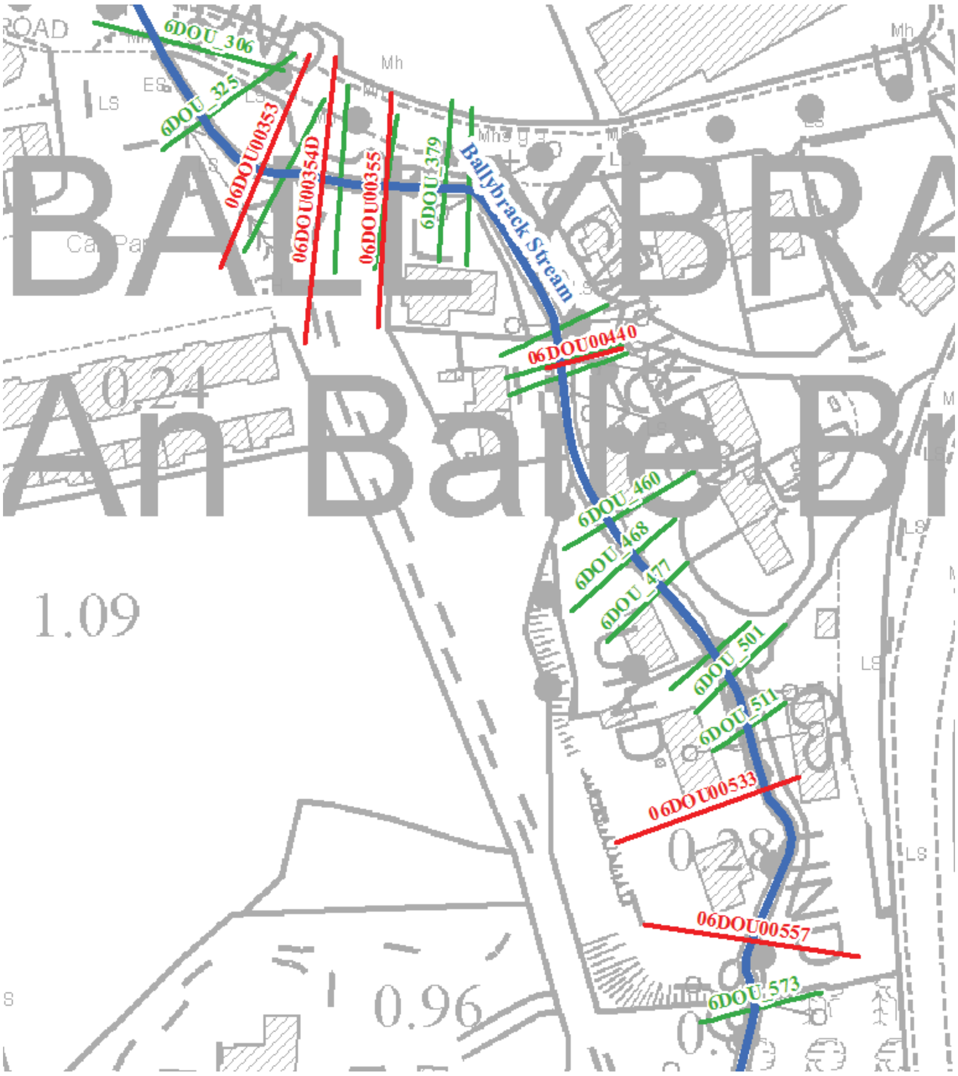
Figure 5 presents the 1D cross sectional data used for the model through Ravensdale.

It can be seen from the figure where the Lee CFRAM survey data has been used and where the more recent Infill and Validation survey data has been used. This figure is presented as an example of where the infill and validation survey data has been utilised.

The cross sections in red are from the Infill and Validation Survey undertaken in 2014. The cross sections in green are from the Lee CFRAM Study.

It can be seen that the infill sections are for areas for which the Lee CFRAM had no data (sections 06DOU00557 and 06DOU00533) and also for areas where changes have been made to the river channel since the Lee CFRAM survey was undertaken in 2007 (sections 06DOU00355, 06DOU00354D and 06DOU00353).

Figure 5: River Cross Sections for the model for the Ravensdale reach.



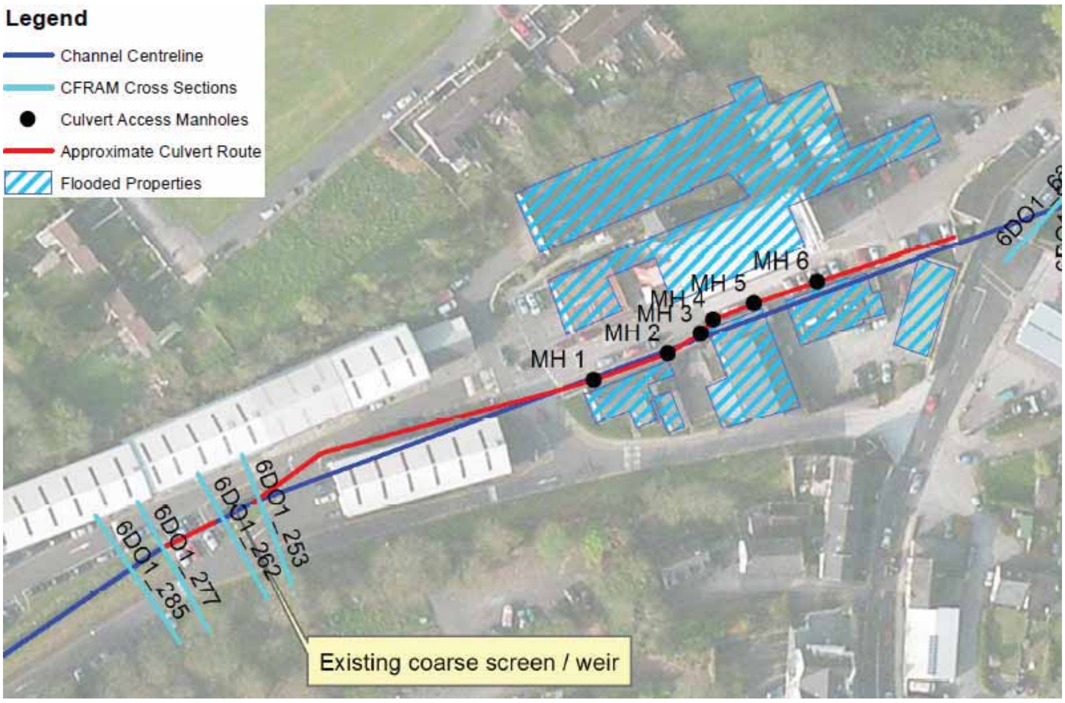
- Donnybrook Commercial Centre CCTV culvert survey

A CCTV and geometric survey of the 190m long culvert that runs under Donnybrook Commercial Centre was undertaken as part of the study. The internal dimensions and constrictions within the culvert were obtained from the survey.

2.3 CCTV Survey

There is a constriction in the 190m long culvert that runs underneath Donnybrook Commercial Centre in the vicinity of Manhole 2 and Manhole 3 (Figure 6) which has caused water to exit the culvert through Manhole 3 during previous flood events.

Figure 6: Approximate route of culvert in Donnybrook Commercial Centre



A CCTV survey and geometric survey of the culvert was therefore commissioned to determine the internal dimensions and condition of the culvert in order to facilitate the hydraulic modelling.

2.4 Digital Terrain Model

The Digital Terrain Model (DTM) is a bare earth representation of the floodplain topography in which all the buildings and vegetation have been removed. It is used in the model to define the ground elevations of the 2D model grid and represents a critical aspect of the model.

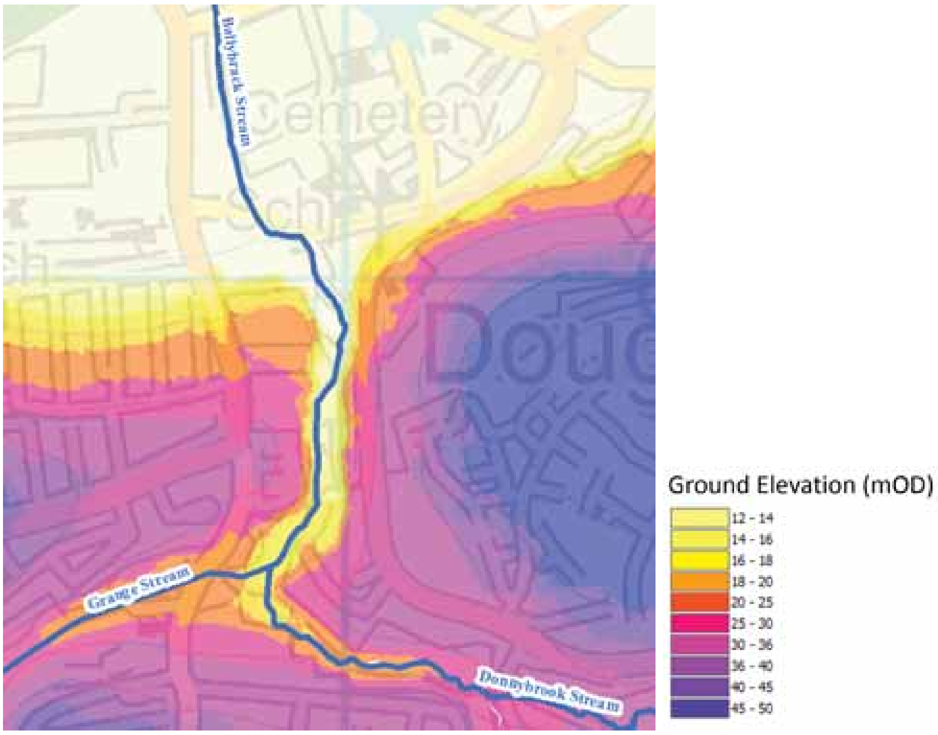
The DTM used in the study is taken from two separate Lidar (Light Detection and Ranging) datasets:

- Lidar data from the Lee CFRAM Study – this survey was undertaken in 2006 and 2007. The reader is referred to the Lee CFRAM Hydraulics Report for a detailed description of the dataset.
- Lidar data for Douglas from a more recent 2013 survey procured as part of this project. The data was collected as a point cloud with 2 points per m^2. The horizontal resolution of this dataset is 2m and the vertical accuracy is +/- 0.2m.

The 2013 Lidar data was validated by comparing the data against survey points taken as part of the cross sectional survey. It was found that the Root Mean Square (RMS) error was less than 0.2m. As this is within the specified Lidar accuracy of +/-0.2m no corrections were made to the dataset.

Figure 7 presents a snapshot of the Lidar Douglas dataset superimposed over the 1:50,000 OSi map for the area. The steep slopes of the reach through the Ballybrack Woods area is evident from the plot as are the relatively flat contours of Douglas Village.

Figure 7: Sample Lidar data from the 2013 Douglas dataset



2.5 Model Calibration Event Data

A significant amount of information on the June 2012 flood in Douglas was collected by Cork County Council and the South Western CFRAM consultants during and after the event. This dataset has been used to calibrate the Douglas FRS hydraulic model:

- Post flood event report produced by the South Western CFRAM consultants (Flooding at Douglas Village on 28 June 2012, OPW, July 2012 - available to download from the OPW National Flood Hazard Mapping website: www.floodmaps.ie.). This report presents a sketch of the maximum extent of the flood, photographs of high water marks which were taken the morning after the event and a description of the flooding mechanism which was collated from a number of sources. Figure 8 presents the recorded flood extent from the report.

The elevation of the high water marks identified from the photographs were surveyed as part of the Douglas Infill and Validation Survey.

This allowed the peak water level from the flood level to be determined relative OD Malin. A sample post flood event photograph is indicated in Figure 9.

- Post flood event report produced by Cork County Council. This report presents information on the flooding mechanism.
- Anecdotal information collected as part of the first Public Information Day for the project which was held in February 2014.
- Post flood event photographs submitted to Cork County Council by members of the public.
- CCTV footage from the Douglas Village Shopping Centre. A significant number of CCTV cameras are maintained at the Douglas Village Shopping Centre. A number of these camera recorded the inundation of the shopping centre from both inside and outside the building. As the footage is time stamped, this dataset allows an observation of the flood event be made as it occurred on the night. This data has also been used in the calibration of the model.

Figure 8: Maximum flood extent for the June 2012 flood event reproduced from the post flood event report prepared by the South Western CFRAM consultants.

Figure 9: Post flood event photographs from inside Douglas Village Shopping Centre. The high water mark is clearly evident from the image.

Photographs of the aftermath of the June 2012 flood event in Donnybrook Commercial centre were provided by the owner of the centre and are reproduced in Figure 10 and Figure 11. It is evident from the photographs that the commercial centre was severely flooded during the event.

Figure 10: Aftermath of June 2012 event in Donnybrook Commercial Centre

Figure 11: Aftermath of June 2012 event in Donnybrook Commercial Centre

2.6 Anecdotal Information on the Culvert in Donnybrook Commercial Centre

In addition to the June 2012 flood event photographs of Donnybrook Commercial centre presented in the previous section, the owner of the centre also provided Arup with anecdotal evidence on the culvert and the previous flood history of the site. These were:

- There has been at least three significant flood events in his lifetime of working in the commercial centre, with the June 2012 event being the worst event. During the 2012 event he removed the cover from manhole 4 and elevated it on bricks in order to allow flood water back into the culvert to alleviate flooding in the commercial centre.
- A significant build-up of sediment can occur along the bed of the culvert. He has on occasion removed this sediment from the culvert at the locations of manholes 2, 3 and 4 and has subsequently noted that sediment has deposited there again within 2 – 3 months.
- The two weir-like structures upstream of the 190m long culvert (one of which is indicated in Figure 12) are in fact metal screens across the channel.

Over time, sediment and material is observed to build up behind them such that they in effect act like weir structures.

Figure 12: Blocked screen upstream of culvert inlet

2.7 Additional Datasets

A gauge is maintained on the Tramore River approximately 2km upstream of Douglas. Data from the gauge has been used in the hydrometric analysis and is detailed in the accompanying hydrology report.

3 Hydrological Estimation and Integration of Design Flows into the Hydraulic Model

3.1 Hydrological Estimation Undertaken as Part of the Study

A detailed hydrological analysis of the Tramore Catchment has been undertaken as part of the study. The analysis has utilised a number of hydrological estimation methods to establish a range of design flows at various points in the study area which will be used as input to the hydraulic modelling stage of the project.

A summary of the hydrological estimation is provided in this chapter as well as a description of how the data was integrated with the hydraulic models. The reader is referred to the accompanying Hydrology Report for a detailed description of this work.

3.2 Overview of the Hydrological Estimation Undertaken as Part of the Study

A set of index flow (Qmed) estimates were produced for key points in the study area (Figure 14). Given that the catchments in the study area are small and predominantly ungauged, it was considered important to compare the estimated index flows using a range of methods.

A rating review of the existing Environment Protection Agency hydrometric gauge at Cork Landfill was also carried out and a revised rating curve was generated. The revised rating curve was then used to update the high flow series at the gauge. The updated flows were then analysed to provide an alternative estimate of Qmed at the gauge site at Cork Landfill (HEP_08) of approximately 5m^3/s. However, since the length of the gauge record is only four years long, the confidence in the estimate produced by this method is low.

Based on the index flows estimated, it is apparent that there is a wide range of flows which could be adopted for the study. It is acknowledged that each of the index flood estimation methods used contain a significant amount of uncertainty. This is in part due to the limited resolution of mapped and digital data, and also due to the fact that many methods are calibrated to large catchments. No single method is entirely suitable for the full range of catchment sizes in the study areas.

Notwithstanding the above, and due to the uncertainty associated with the flow estimation, it was felt appropriate to adopt the FSU index flows, as they appear to be conservative, while still remaining reasonably consistent with other methods. The design index flows are shown in Table 1.

A flood frequency analysis was carried out, which established a study growth curve and in turn a set of design peak flows. The adopted growth curve was produced using the FSU pooling group methodology. The design flows are tabulated in the table below.

A design flood hydrograph shape was also established. The adopted shape was produced using the FSR unit hydrograph method. It was ensured that the peak of the design hydrographs correctly matched the derived design flows as presented in Table 1.

Table 1: Design Flows

Return Period (years)	Design Peak Flow (m^3/s)								
	HEP_01	HEP_02	HEP_03	HEP_04	HEP_05	HEP_06	HEP_07	HEP_08	HEP_09
2 (Qmed)	15.22	9.95	5.48	5.16	2.59	2.84	0.90	8.47	2.97
5	20.39	13.33	7.34	6.91	3.47	3.81	1.20	11.35	3.98
10	24.20	15.81	8.71	8.20	4.12	4.52	1.43	13.47	4.72
25	30.44	19.89	10.96	10.31	5.18	5.68	1.80	16.95	5.94
50	34.09	22.28	12.27	11.55	5.80	6.37	2.01	18.98	6.65
100	38.96	25.46	14.03	13.20	6.63	7.28	2.30	21.69	7.60

3.3 Integrating the Design Flows into the Hydraulic Model

3.3.1 Insertion of the Hydrological Estimation Points

Figure 13 presents the location of HEPs used in the study. The design flows estimated at each HEP were not inserted into the model at the geographical location of the HEP, but instead the design flow from the downstream HEP was applied at the upstream end of the reach. This is indicated in Figure 14.

It can be seen for example that HEP_06 was not inserted at its geographical location as presented in Figure 13, but instead applied at the location of HEP_07 as shown in Figure 14. This is a conservative approach that has been adopted to ensure that the design flow is never underestimated in the model and also to simplify the hydraulic model build.

It can be seen from Figure 14 that there are three point inflows to the model:

- **HEP_02 flow:** inserted into the model just upstream of the geographical location of HEP_08.
- **HEP_05 flow:** inserted into the model at the upstream end of the Donnybrook reach.
- **HEP_06 flow:** inserted into the model at the upstream end of the Grange reach at the geographical location of HEP_07.

There is one lateral inflow into the model:

- **HEP_03:** inserted into the model as a point inflow at the confluence of the Donnybrook and Grange stream. To avoid double counting of design flows, the design flows for this inflow were estimated by subtracting the design flows for HEP_04 from the design flows for HEP_03.

Figure 13: HEP points used in the study

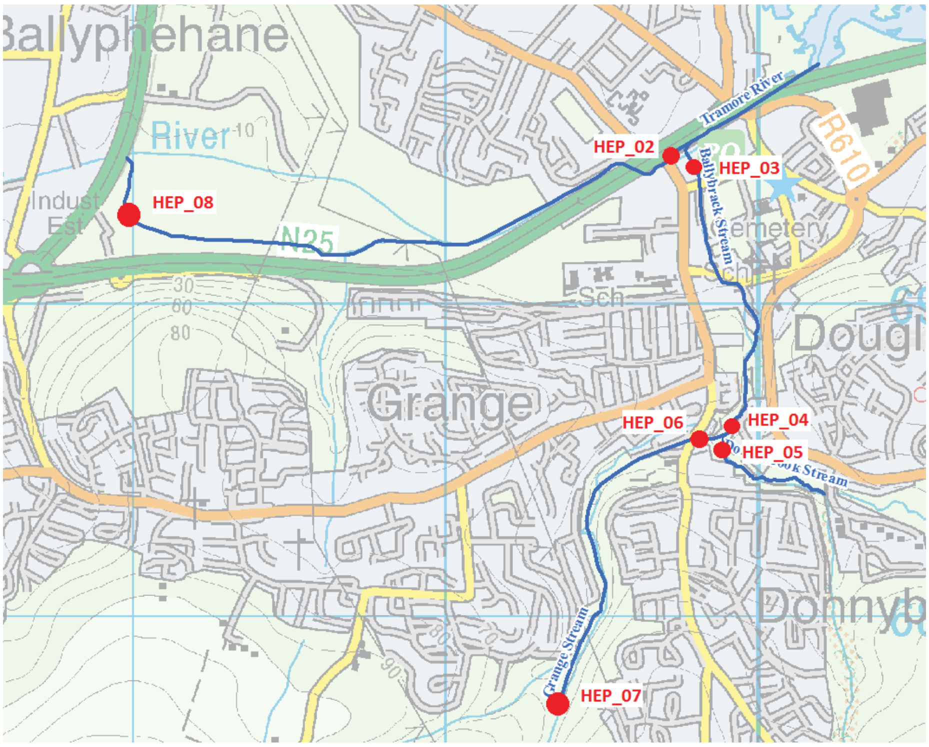


Figure 14: Design flows from the HEP points as applied to the hydraulic model

3.3.2 Fluvial-Fluvial Joint Probability of Flows

In hydrological estimation, the sum of the design flows from two or more sub catchments can exceed the estimated design flow for the whole catchment.

It can be seen from Table 2 for example that for HEP_04, the sum of the design flows for HEP_05 and HEP_06 is greater than the design flow for HEP_04:

- The Q100 flow for HEP_05 is **6.63m^3/s**;
- The Q100 flow for HEP_06 is **7.28m^3/s**;
    - The sum of these flows is **13.91m^3/s**.
- The Q100 flow for HEP_04 is **13.2m^3/s**;
    - For the Q100 design flow there is a difference of 0.71m^3/s between HEP_03 and the sum of HEP_05 with HEP_06.

To address this issue in the Douglas FRS model, the model design flows for HEP_05 were reduced to ensure that the modelled flow in the Ballybrack reach did not exceed the estimated design flow for the reach. The amount by which the various flows were reduced is indicated in the fifth column of Table 2.

It is noted that the design flows could equally have been reduced for HEP_06 and not for HEP_05 as it is the sum of the flows which must not exceed the estimated design flow in the Ballybrack reach. HEP_05 was selected on the basis that there are no properties at risk along the Donnybrook Stream and a small reduction of the design flows in the model will have no adverse consequences to the estimation of flood risk.

Table 2: Difference in design flows

HEP_05	HEP_06	HEP_05 + 06	HEP_04	(HEP_05 + 06) - HEP_04
2.59	2.84	5.43	5.16	0.27
3.47	3.81	7.28	6.91	0.37
4.12	4.52	8.64	8.2	0.44
5.18	5.68	10.86	10.31	0.55
5.8	6.37	12.17	11.55	0.62
6.63	7.28	13.91	13.2	0.71

3.3.3 Low Flows in the Hydrograph

A minimum flow of 1m^3/s was applied to all of the hydrographs to ensure hydraulic model stability at the start of the run. A minimum flow value of 0.2m/^{3} was used for HEP_03 in the hydraulic model.

3.3.4 Coincidence of the Design Hydrograph Peaks

Given the relatively small size of the catchment and the lack of data, it was assumed that the design flow peaks occurs simultaneously on all the sub-catchments.

The time axis of all the inflows hydrographs were therefore edited to ensure that the peak flow on all the hydrographs occurred at a design time of 5hr into the simulation.

3.3.5 Downstream Tidal Boundary Conditions

The design boundary condition of the model is the tidal signal in the Douglas Estuary. We have utilised the design tidal heights and design tidal curves that were estimated as part of the Lee CFRAM study in this study.

The time axis of the tidal signals were however edited to ensure the peak tidal water level occurred at the same time as the peak design flow of the inflow hydrographs (i.e. at the 5hr mark).

3.3.6 Urban Drainage Network

The urban drainage network in Douglas is likely to influence the response of the urbanised catchment to flooding, particularly for the lower return period events as it may act as a sink to, or a source of, flood waters. We have not however accounted for the drainage in the model as it is outside the scope of the work to construct a model of this network.

3.3.7 Fluvial Tidal Joint Probability

A tidal-fluvial joint probability analysis was carried out as part of the Lee CFRAM Study. This established combinations of tide levels and fluvial flows for each design event. The Lee CFRAMS analysis was based on an application of UK guidance using certain assumptions about the dependence of tidal/fluvial floods in the Lee catchment. The Lee CFRAMS acknowledged that the design combinations were conservative, and this is the case.

It is proposed to adopt the Lee CFRAMS joint probability scenarios for this study as it is outside the scope of this study to carry out a detailed joint probability analysis and the flood risk in Douglas in not sensitive to the combinations. The scenarios are tabulated in Table 3 below.

Table 3: Design tidal-fluvial joint probability scenarios

Scenario	Design Event (AEP)	Boundary		
		Fluvial (AEP)	Tidal (AEP)	Lee CFRAMS Tidal Flood Level (node 6TRA_0)
1	50%	50%	50%	2.44
2	20%	20%	50%	2.44
3	20%	50%	20%	2.54
4	10%	10%	50%	2.44
5	10%	50%	10%	2.62
6	4%	4%	50%	2.44
7	4%	50%	4%	2.71
8	2%	2%	50%	2.44

Scenario	Design Event (AEP)	Boundary		
		Fluvial (AEP)	Tidal (AEP)	Lee CFRAMS Tidal Flood Level (node 6TRA_0)
9	2%	50%	2%	2.78
10	1%	1%	20%	2.54
11	0.5%	10%	0.5%	2.92

4 Model Development

4.1 Introduction

A one-dimensional (1D) and two-dimensional (2D) model of the Ballybrack Stream and Tramore River has been constructed to simulate flood events in Douglas. The 1D model simulates the in-bank flows and has been constructed in ISIS Professional 1D (v3.7) software. The 2D model simulates the out of bank floodplain flows and it has been developed in Tuflow software (v2012). Both the 1D and 2D models are dynamically linked and run together as a coupled model.

The upper reaches of the Ballybrack have been modelled in 1D only. Given that the floodplain consists of steeply sloping sides in these areas, the out of bank flow will be predominately one-dimensional in nature. A 1D modelling approach is therefore sufficient to capture the floodplain hydraulics.

It is noted that ISIS Professional 1D is at the time of publication of this report known as Flood Modeller Pro.

4.2 Model Development

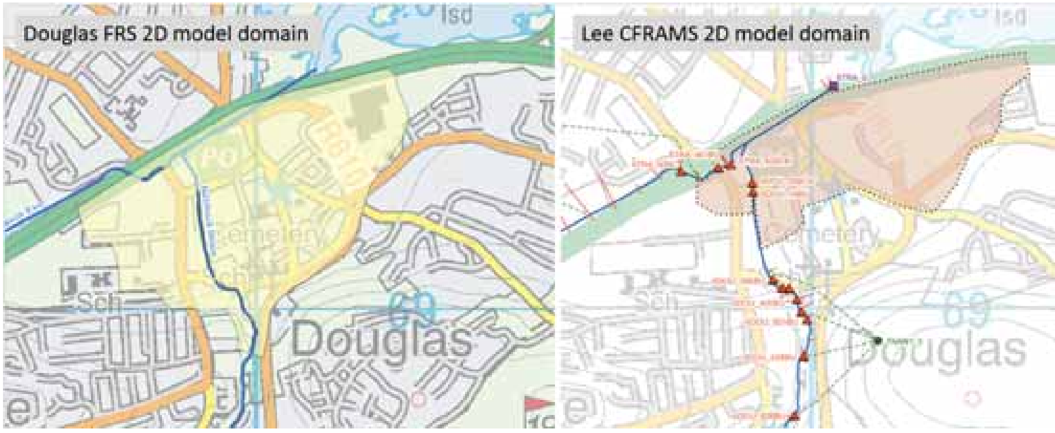
A hydraulic model of the Tramore River and Ballybrack Stream was developed as part of the Lee CFRAM Study. The model was a coupled 1D/2D model – the 1D element was developed in ISIS and the 2D element was developed in ISIS 2D. The reader is referred to the Lee CFRAMS Hydraulics Report for a detailed description of this model.

The Douglas FRS hydraulic model was developed from the Lee CFRAM hydraulic model. It is a refined and improved version of the Lee CFRAM model and is more detailed and robust than it.

The development of the Douglas FRS model from the Lee CFRAM model involved a number of steps which can be summarised as:

- <u>Replacement of the 2D domain in Douglas</u> – Although the Lee CFRAMS modelled some areas of Douglas in 2D, our analysis of the June 2012 flood event suggested that the Lee CFRAMS 2D model domain did not cover a large enough area to capture the significant floodplain flow mechanisms. The 2D domain of the Douglas FRS model therefore covers a larger area which ensures that these mechanisms are captured in the 2D model. The extent of both grids is presented in Figure 15. It can be seen that the Douglas FRS model domain includes the area around Ravensdale, Church Road and Churchyard Lane. It can also be seen that the full extent of Douglas West has been included in the Douglas FRS model domain. The flood mechanism of the 2012 event is described in Chapter 5.

Figure 15: Comparison of the 2D extents – Lee CFRAM and Douglas FRS 2D model domains.



- 2D modelling software – the Lee CFRAM model used ISIS 2D to model the out-of-bank flows. The Douglas FRS model has used Tuflow. Tuflow is recognised internationally as being one of the leading 2D modelling softwares.
- The representation of the Douglas Village Shopping Centre (DVSC) culverts in the model – The culverts underneath DVSC were represented in a simplified manner in the Lee CFRAM hydraulic model by only considering the upstream and downstream faces of the culvert. Arup designed the culverts as part of the DVSC development and submitted Section 50 applications for them. The hydraulic models of the culverts that were developed as part of the Section 50 applications were therefore incorporated into the Douglas FRS hydraulic model. As these culvert models are a detailed representation of the actual culverts, the complex hydraulics associated with the flow through the culverts is correctly represented in the model.
- Infill and Validation Survey – As detailed in Section 2.2, Arup identified a number of areas where additional river survey data would improve the performance and accuracy of the Douglas FRS model over the Lee CFRAM model. Additionally, Arup also identified a number of areas where modifications to the river channels have occurred since the Lee CFRAM survey was undertaken. All of these areas were subsequently surveyed as part of the Infill and Validation Survey Management and incorporated into the model.
- Changes to the Ballybrack Stream – The Ballybrack channel immediately upstream of its entrance to the DVSC culvert underneath Church Street was significantly modified since the Lee CFRAM survey was undertaken. These channel works were undertaken as part of the installation of the trash screen upstream of Church Street. The dimensions of revised channel dimensions were obtained from the "as built" drawings of the works and incorporated into the Douglas FRS model.
- CCC Channel Survey – CCC undertook a channel survey of the Ballybrack in 2012. Some of the cross sections from this survey were utilised in the Douglas FRS model.
- Interpolate Units – A significant number of the interpolate units are included in the Lee CFRAM Hydraulic model. The majority of these were removed from the Douglas FRS model as they are not required.

- Model Parameters – A number of the model parameters used in the Lee CFRAM model were altered in the Douglas FRS model. These include channel roughness and structure coefficients which are described in Section 4.4 of this report.

4.3 Model Extents

4.3.1 Douglas FRS Model

The Irish National Grid (ING) coordinates of the extent of the Douglas FRS model is presented in Figure 16. The extent is presented graphically in Figure 17.

Figure 16: Extents of the Douglas FRS model. All coordinates are in Irish National Grid.

Watercourse	Model Upstream Extent		Model Downstream Extent	
	Easting	Northing	Easting	Northing
Tramore River	167977	69470	170072	69714
Ballybrack (Grange)	169364	67707	169812	69372
Ballybrack (Donnybrook)	170209	68392	169812	69372
	Entrance to DVSC Culvert			
Tramore River	169698	69449		
Ballybrack	169812	69372		
	Junction			
Tramore River & Ballybrack	169766	69506		

Figure 17: Extent of the Douglas FRS model with 2D model domain (yellow shaded area) and 1D model cross sections (purple nodes and labels) indicated. The blue line is the extent of the 1D model.

The 2D model domain is represented with the yellow shading in Figure 16. It can be seen that it covers the main urban area of Douglas. The key out-of-bank flooding mechanisms within Douglas are therefore modelled in two dimensions which offers a significant improvement over the Lee CFRAMS model. The purple nodes in the figure plot the location of the 1D model cross sections.

4.4 Model Parameters

4.4.1 Labelling System

The model nodes (including the cross sections surveyed as part of the infill and validation survey) have followed the same labelling format as used for the Lee CFRAM models. The reader is referred to the Lee CFRAM Hydraulics report for a detailed description.

4.4.2 Model Resolution

The 1D model resolution is determined by the distance between adjacent cross sections which changes throughout the model domain. For the key urban area however this distance never exceeds 50m and is frequently much less than this. This is of sufficient resolution to appropriately model the one-dimensional flow in the channel.

The 2D model resolution is defined by the spacing of the 2D grid. Defining this parameter involves a trade-off between accurately resolving the two-dimensional flow in an urban environment using a high-resolution grid and the computational run time of the model which is reduced with the lower resolution grids.

A 2m grid resolution has been selected for the Douglas FRS 2D model domain. This resolution is more than sufficient to accurately resolve the flow as it splits and divides in the urban environment of Douglas. The relatively short duration of the design runs combined with the relatively small domain ensure than the computational burden of the model runs is manageable.

4.4.3 Manning’s n for the 1D and 2D Models

The roughness values of the 1D model have been defined for three separate sections of each cross section: (1) The left bank, (2) The main channel, and (3) The right bank. These sections of each cross section in the model are defined through the use of panel markers.

Some cross sections located in the 2D domain of the model have no left or right bank as they link to the 2D model domain at the point where the left/right bank begins.

The Manning’s n roughness values of the 1D model were selected based on a detailed analysis of a number of datasets:

- The values previously used in the Lee CFRAM study.
- Survey photographs.

- Site visits undertaken by Arup and
- Model calibration (June 2012 event).

Typical values used in the study are presented in Figure 18. A detailed description of the manning values used is provided in Appendix C of the report.

Figure 18: 1D Manning's n values used in the study

Channel Characteristics	Manning's n values
Main Channel	
Clean, straight	0.030
Clean, meandering	0.035
Stones & weeds, meandering	0.045
Banks	
Weeds & vegetation	0.040
Heavy weeds & vegetation	0.050
Mature trees and thick vegetation	0.060

The Manning's n floodplain values were selected based on an analysis of datasets:

- Land use derived from OSi NTF mapping;
- Site visits undertaken by Arup; and
- The calibration of the model against the 2012 flood event.

Typical values used in the study are presented in Figure 19.

Figure 19: 2D Manning's values used in the study

Floodplain	Manning's n values
Land use	
Roads	0.020
Buildings	0.100
Parkland	0.030
Open Space	0.035
Forestry	0.06

4.4.4 Representation of the River Structures

All of the bridges in the model have been modelled using the Bridge ARCH unit as this is the most suitable bridge model within ISIS for modelling the bridges along the Tramore River due to their size relative to the river channel. Overtopping of the bridges has been accounted for through the use of a spill unit in the 1D domain of the model. Overtopping in the 1D-2D areas of the model has been modelled within the 2D domain.

In-line weirs have been modelled using the spill unit in ISIS.

Culvert have been modelled through use of the conduit units in ISIS.

The dimensions of all the hydraulic structures have been taken from the surveyed data.

The reader is referred to Appendix C which presents a datasheet for all the key structures included in the Douglas FRS model.

4.4.5 Modelling the Donnybrook Commercial Centre Culvert

Through inspection of the detailed CCTV survey of the 190m long culvert that runs under Donnybrook Commercial Centre, it was seen that the culvert is not uniform in terms of its dimensions and internal surface, confirming the anecdotal evidence offered by the owner of the centre.

Additionally, numerous service pipes and beams cross the culvert at circa 90 degrees to the direction of flow and run parallel to the direction of flow throughout the length of culvert. There are also a number of channel constrictions both within the culvert and immediately downstream of it.

A number of steps were taken in order to accurately model the culvert as part of the study:

- The dimensions of the culvert conduit units in the model were edited to allow the geometry of various constrictions in the culvert be represented in the model. The beams crossing the underside of the soffit of the culvert were also accounted for;
- The invert levels throughout the culvert were raised by 100mm to account for the observed sediment layer at the bottom of the culvert. The geometry data obtained from the surveyor measured the internal height of the culvert from the invert level to the soffit level. On our site visits however, we observed through inspection of the open manholes a circa 100mm thick layer of sediment on the bottom of the culvert. The surveyor confirmed that this sediment layer is present throughout the length of the culvert. This layer will reduce conveyance through the culvert and has therefore been accounted for in the model. It is noted however that the depth of sediment on the bed of the culvert is very likely to vary spatially throughout the culvert and will also change over time;
- The Manning’s number was increased to a high roughness value of 0.028 throughout the length of the culvert. This is a relatively high value for the internal roughness of a culvert. It is justified however by consideration of: (1) the presence of a number of pipes within the culvert, (2) the uneven and broken surfaces of the interior walls of the culvert, and (3) the presence of a number of openings throughout the length of the culvert.
- Culvert bend units were inserted into the model to account for the head losses associated with the two bends along the reach of the culvert in the vicinity of manhole 3 and manhole 4.

There are two screens within the main channel in the Commercial centre that has caused debris to collect behind the screens in the past. These have been included in the model. The combined sewer crossing at the upstream end of the centre has also been included in the model.

4.4.6 Representation of Buildings and other Structures in the 2D grid

The buildings in the 2D domain were represented in the model by raising the level of the footprint of the building by 150mm above the existing ground level as defined by the Lidar DTM. Additionally, the Manning's n of the grid cells which form part of the building footprint were increased to a high value (0.1).

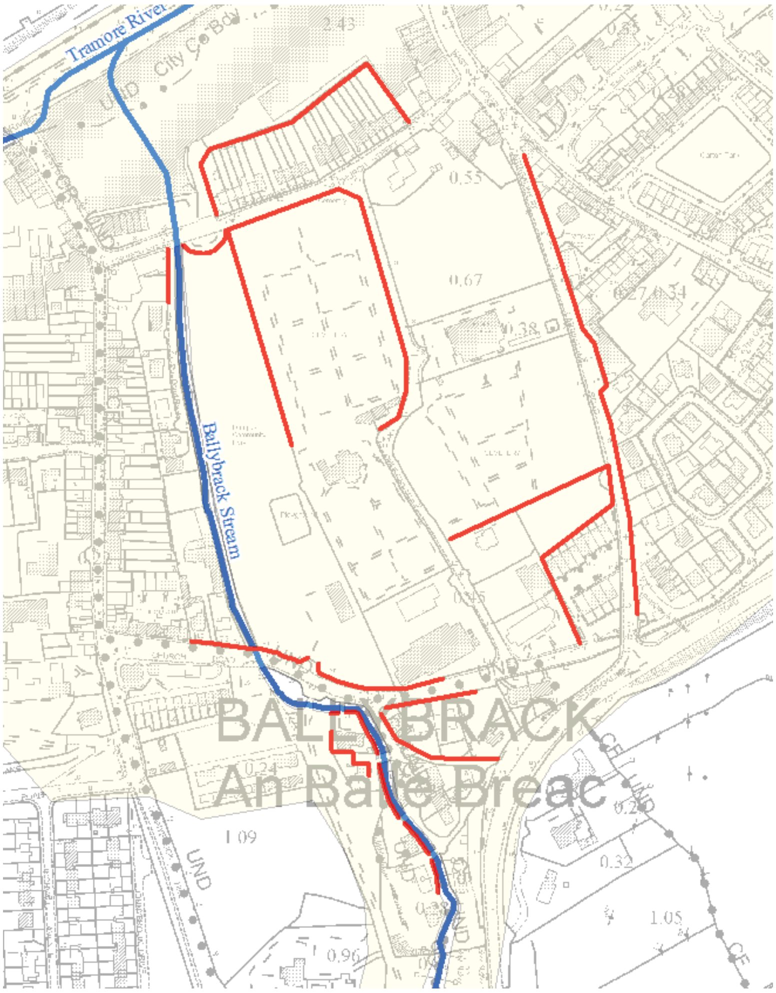
The footprint of the buildings were identified from the OSi NTF dataset.

Raising the level of the buildings by 150mm allows a realistic flood depth to be estimated at each property as 150mm equates to a typical building threshold. Raising the buildings, as opposed to blocking out the buildings, also ensures that the storage offered by the space within each building is accounted for in the model. Increasing the Manning's number to a high value of 0.1 ensures however that the significant reduction in flow and velocity caused by the fabric of the building is accounted for in the model.

The floor levels of the DVSC were not raised by 150mm. Instead, we have used the actual floor levels of the building which we have obtained from the "as built" drawings.

Other structures such as walls and embankments can influence the movement of water in the floodplain and must be correctly represented in the model (Figure 20) through the use of Z lines shapefiles in the model. It has been assumed that these walls will not fail during a flood event. This assumption is based on our appreciation of the structural integrity of the wall. The heights of each wall have been estimated from site visits.

Figure 20: Walls in the 2D domain (red lines). The blue lines present the river channel centrelines



4.4.7 Network of Culverts Underneath the Douglas Village Shopping Centre

The complex network of culverts underneath the DVSC have been included in the Douglas FRS model. These culverts were initially modelled by Arup as part of their Section 50 applications and were imported into the Douglas model.

As part of our quality assurance, the original culvert models were reviewed in detail and compared against the available “as built” drawings before inclusion in the Douglas model. This was to ensure they correctly represent the culverts in their present form.

4.5 1D and 2D Model Linkage

There are two parameters which control the volume of water that spills onto the floodplain (the 2D model domain) from the river channel (the 1D model domain):

- The water level in the river channel.

- The elevation of the bank of the channel i.e. the elevation at which water spills from the river to the floodplain.

The water level in the river channel is calculated by the 1D model. The elevation of the bank however is defined in the model by the user using the topographic survey data. It is a very important dataset in the model as it controls the volume of water that spills into the 2D domain of the model. Its correct specification is essential in ensuring an accurate and credible hydraulic model.

The elevation of the left and right banks throughout the 2D model domain of the model were defined from actual surveyed elevations from the river channel survey and were accounted for in the model through the use of Z lines in Tuflow. These Z lines were defined for the entire 1D-2D reach of the model and ensured an accurate representation of the volume of water spilling from the 1D to the 2D domain.

4.6 Hydraulic Modelling of the Options

The Douglas FRS model was modified to model the various flood relief options considered as part of the development of the scheme. The reader is referred to the accompanying Options Report for a description of this element of the work.

A sensitivity analysis on some of the modelling parameters is also described in the options report.

5 Model Calibration

5.1 Introduction

The Douglas hydraulic model was calibrated against the June 2012 flood event given the large amount of post-flood event data collected (detailed in Section 2.5) and the magnitude of the event. The event lead to severe flooding of Douglas with approximately 12 private properties, 100 commercial properties and 2 community premises flooded.

5.2 Post Flood Event Survey Reports

A detailed description of the flood event is provided in the two post flood event reports which are available to download from the OPW's National Flood Hazard Mapping website (www.floodmaps.ie). One of the reports was produced by CCC and the other by OPW.

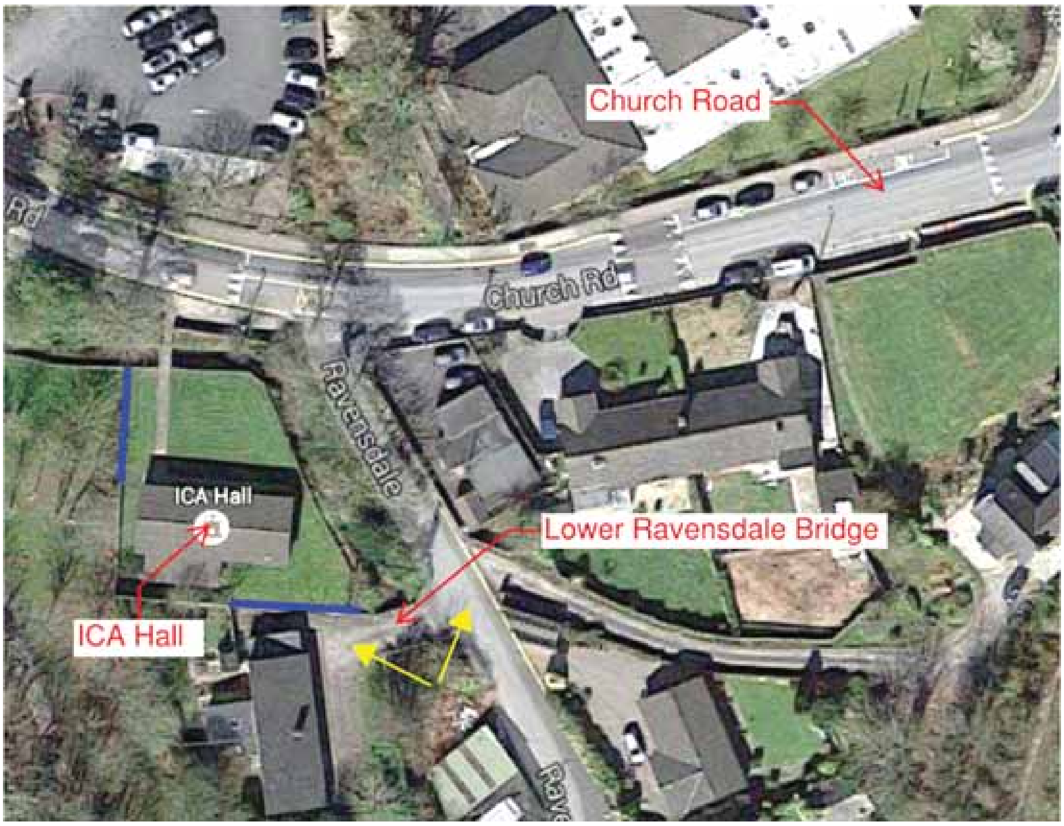
An extract from the OPW report is reproduced below in Figure 21 which details a summary of the event.

Figure 21: Extract from the OPW's flood event report which provides a summary of the event (Flooding at Douglas Village on 28 June 2012, OPW, July 2012 - available to download from www.floodmaps.ie)

Extremely heavy rainfall and steep catchment area gave rise to flooding of the Donnybrook River to the south of Douglas Village. The river burst its banks upstream of the village at a blocked bridge, entered 2No. residential properties, knocked a block wall, entered a meeting hall and knocked a second block wall. Flood waters flowed onto the road and through the park. The Donnybrook River is culverted from the edge of the village where there is a trash screen. The trash screen became blocked due to the volume of debris. Flooding reported from entrance to park and at trash screen.
The Donnybrook River is culverted under a shopping centre where it joins the Tramore River, which is tidal and also culverted. High Tide was at approx12.30am, just prior to the peak of the flood.
Reports of very high volume storm water runoff from Donnybrook Hill may also have contributed to the flooding.

The bridge referred to in the text was the Lower Ravensdale Bridge which is indicated in Figure 22. The yellow arrows in the figure highlight the route of the water as the water level overtopped the river bank due to the blockage that occurred at the bridge. The blue lines indicate the two walls that were subsequently knocked over by the floodwater. The meeting hall referred to in the report was the Irish Countrywoman's Association (ICA) hall which is also indicated in the figure.

Figure 22: Lower Ravensdale Bridge



The trash screen at the entrance to the DVSC Culvert at Church Street got blocked during the event. The location of the trash screen is indicted in Figure 23 and is shown in Figure 24 in low conditions. It can be seen that the trash screen is a two stage screen with inclined bars (spaced at 150mm).

The trash screen is shown from the morning after the event in Figure 25. It can be seen from the figure that the screen is almost completely blocked with debris. The image on the left shows the top grate of the trash screen with a thick coating of mud in the immediate aftermath of the flood event. The image on the right shows the first tier of the screen from the morning after the flood event. It can be seen that the screen has just been cleared of some of the debris by the JCB which is visible in the top right of the picture.

It is noted that subsequent to the event the entire trash screen was removed by Cork County Council.

Figure 23: Location of Trash Screen

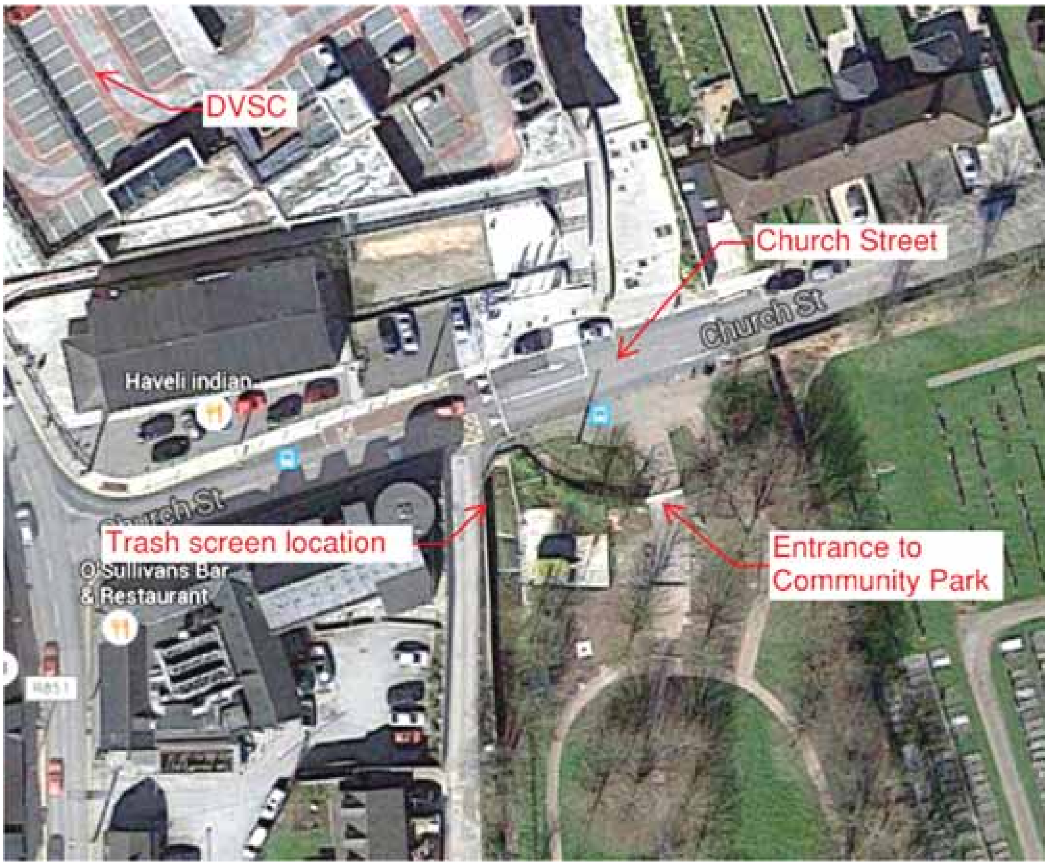


Figure 24: Church Road culvert trash screen - normal conditions

Figure 25: Church Road culvert trash screen.

One of the post flood event photographs from the OPW's post flood event report is reproduced in Figure 26. It presents the high water mark from outside KC's Chipper in Douglas East. This mark was subsequently surveyed as part of the Infill and Validation Survey and used in the calibration of the model. The debris mark is evident from the photo.

Figure 26: Post flood event high water mark (indicated in red) from outside KC's Chipper in Douglas West.

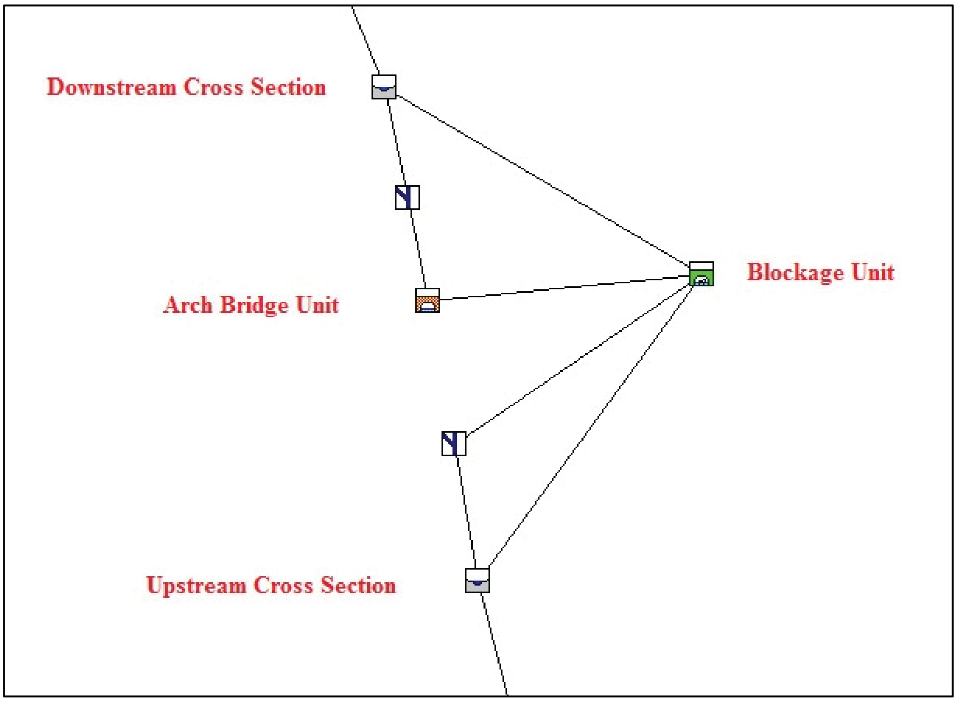
5.3 Modelling the Blockages

The blockages of the June 2012 flood event were included in the Douglas FRS model through use of the BLOCKAGE unit in ISIS. This unit is based around a simple time-varying parameter *p* (the blockage ratio), which represents the proportion of the flow area obstructed. It is assumed that the blockage occupies the same proportion of the width of the section at all water levels. The set-up of the unit for Ravensdale Bridge in the model is presented in Figure 27. It is noted that there is no spill unit included at the bridge to model overtopping as this bridge is located in the 2D model domain.

The Ravensdale Bridge blockage ratio was estimated from the model calibration and anecdotal evidence provided in the post flood event reports. It was assumed that there was no blockage at the start of the simulation (blockage ratio = 0) and that when the blockage was at its maximum, 45% of the cross sectional area of the bridge opening was blocked (blockage ratio = 0.45). The progression of the blockage ratio from 0 to 0.45 was described using a time series in the model.

A similar methodology was used for the Church Road culvert trash screen blockage ratio time series. In this instance a value of 0.88 was selected as the maximum blockage ratio.

Figure 27: Blockage Unit for Ravensdale Bridge



5.4 Calibration Hydrology – Deriving the Hydrograph for the June 2012 Event

Hydrographs for the June 2012 flood event were established using the ISIS FSSR16 Boundary Module. Catchment Seasonal Average Annual Rainfall (SAAR) data was used to calculate standard percentage runoff (SPR). The SPR along with hourly rainfall data recorded at Cork Airport rain station and other catchment descriptors such as catchment area, stream slope and main stream length were then used to derive hydrographs for each HEP for the event.

The reader is referred to the accompanying Hydrology report for a detailed description of the hydrological estimation of the calibration hydrographs.

5.5 Calibration Results in Douglas

The calibration achieved by the Douglas FRS hydraulic model against the June 2012 event is presented in the following sections of the report. A comparison is made between the peak water level, maximum flood extents and the mechanisms of flooding as observed from CCTV footage of the event.

5.5.1 Peak Water Level Calibration

A number of high water marks were identified from the post flood event survey photographs. The elevation of these marks were surveyed as part of the Infill and Validation Survey contract and compared against the peak water level from the model. The calibration is presented in Figure 28. It can be seen that a very good match between the recorded and modelled peak water levels has been achieved.

The difference is 0.1m for Douglas East and 0.08m for the ICA Hall in Ravensdale. This suggests the model is able to reproduce the peak water levels with a good degree of accuracy.

Figure 28: Peak water level calibration

Peak Water Level Calibration		
Douglas East (KC's Chipper)		
Recorded Flood Depth	0.73	m
Modelled Flood Depth	0.83	m
Difference	*0.10*	*m*
Ravensdale (ICA Hall)		
Recorded Flood Depth	0.25	m
Modelled Flood Depth	0.33	m
Difference	*0.08*	*m*

5.5.2 Maximum Flood Extents Calibration Plot

An estimate of the maximum flood extent of the June 2012 event was presented in the post flood event report produced by CCC. It is compared against the maximum modelled flood event in Figure 29. It can be seen from the figure that the modelled flood extent matches the recorded flood extents quite well. The key areas of Douglas East, Douglas West and the Douglas Village Shopping Centre are inundated in the model as per the estimated flood extent. Equally, the area around Ravensdale, Churchyard Land and the Northern end of the Community Park are also indicated as being flooded as per the estimated extent.

There are however a number of differences between the extents:

- Douglas Mills – this area is shown as inundated in the estimated flood extent but the model is not predicting any flooding in this area. There are two mechanisms of flooding at this location: (1) floodwaters enter Douglas Mills from Douglas East through the vehicular entrance to Douglas Mills, and (2) water levels in the Tramore River exceed the capacity of the channel and flow out of bank into Douglas Mills. For the June 2012 event the first mechanism applies. The difference between the estimated and modelled datasets can be attributed to slight discrepancies in the Lidar dataset which has overestimated the ground elevation at the entrance to Douglas Mills.
- Top of Churchyard Land – the model is predicting that the area was inundated but the estimated flood extent suggests that there was no flooding in the area. As with Douglas Mills, this difference can be attributed to slight discrepancies in the Lidar dataset.
- Area to the right of Douglas East – the model is slightly over predicting the flood extent in this area.
- Community Park – The estimated flood extent is suggesting that a large area of the park was flooded. The model however is predicting inundation at the Northern End of the park and a pathway of shallow flooding from the Church Road entrance.

Figure 29: June 2012 Flood extent calibration plot

5.5.3 Mechanisms of Flooding from the DVSC CCTV Footage

A large number of CCTV cameras are maintained at Douglas Village Shopping Centre. Some of these cameras were operational on the night of the June 2012 flood event and recorded footage of the inundation of the shopping centre.

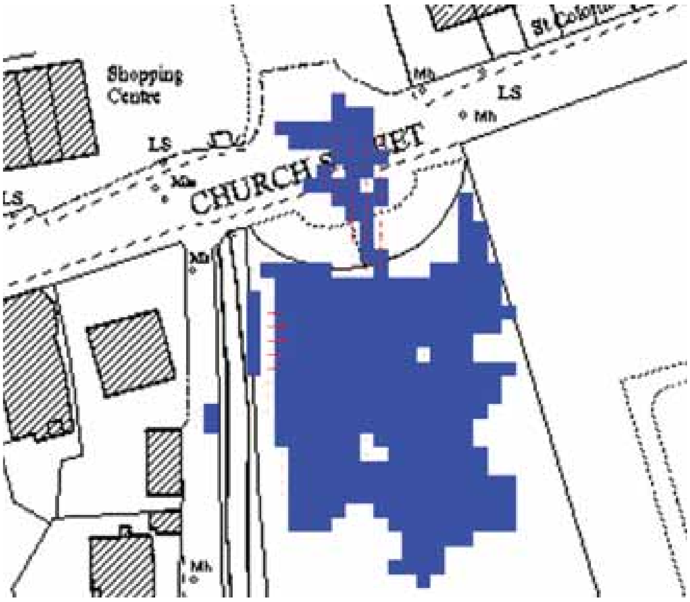
We have compared our model output against the CCTV footage. Overall there is a very good match between the modelled flooding mechanisms and the observed mechanisms from the CCTV. There are a few instances however when our model lags behind the real events by approximately 10 – 15 minutes. Given the uncertainly on the formation of the blockages during the event and the representation of the blockages in the model, this difference in timing is well within the bounds of accuracy of flood modelling.

The key flooding mechanisms are presented over the next series of figures. Snapshots of the CCTV footage are presented first followed by snapshots of the model results.

- **1.57am –** Flood water starts to spill from the Community Park across Church Street into DVSC. By **1.59am** a significant volume is flowing across the across Church Street into DVSC;

Figure 30: Flood waters crossing Church Street @ 2:05 am. While most of the image is obscured by vegetation, the movement of water across Church Street can be seen

Figure 31: Flood waters crossing Church Street @ 2:10 am in the model. It is noted that the model is lagging behind the observed events by approximately 13 minutes.



- **2.00am –** Minor flooding of Douglas East. Rain on the lens of the camera has rendered the image somewhat blurry. On close inspection however, shallow flooding of the street is evident. This flooding is easier to see when viewing the actual video footage from the camera. The source of this flooding has not been determined by Arup. It may be due to the capacity of the local drainage system being exceeded during the event or it may be out of bank flow from the Ballybrack Stream originating in the Ravensdale area of Douglas. It is noted that by **2.16am** this minor flooding receded.
- **2.25am –** Significant flooding of Douglas East by flood waters travelling from Church Street.
- Figure 34 captures the moment at which the flood wave arrived. The area of street immediately adjacent to the bus stop has just been inundated at this time while the area of the street to the left of the image has not been inundated yet. It is noted that the source of this flood water was from Church Street and hence was caused by the blocked trash screen.

Figure 32: Minor flooding of Douglas East @ 2.00am.

Figure 33: By 2:19am the minor flooding has receded from Douglas East.

Figure 34: The significant flooding of Douglas East commenced @ 2:25 am.

Figure 35: Flood waters entering Douglas East @ 2:30 am in the model. The model is lagging behind the observed events by approximately 5 minutes.

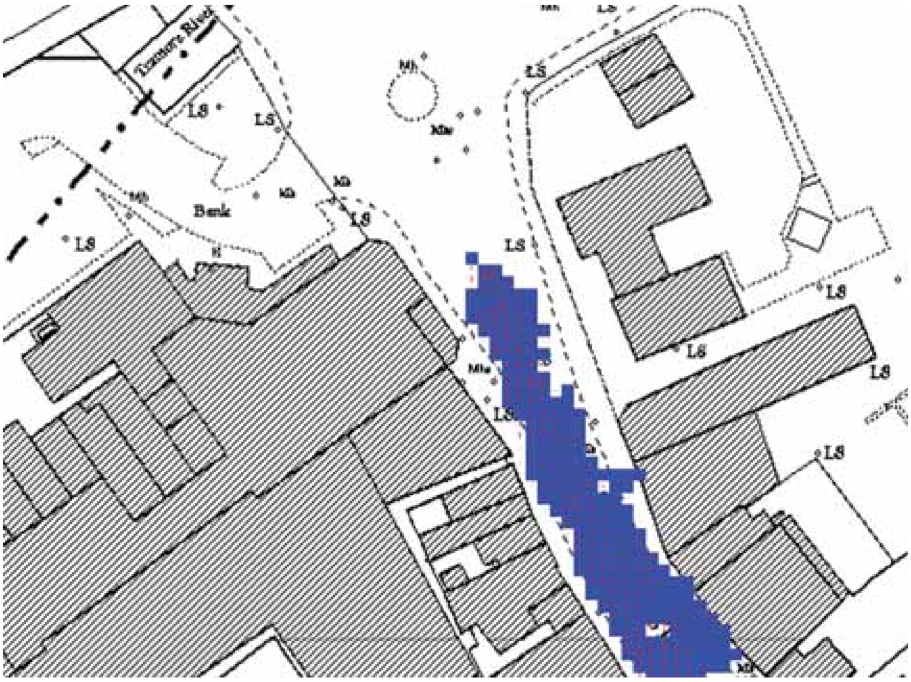


Figure 36: By 2:45am Douglas East is completely flooded

- **2.10am –** Flood water enters Douglas Village Shopping Centre through the front entrance facing onto Church Street by squeezing through the doors. It is noted that the glass doors of the entrance are intact at this time. At **2.36am** however the doors break apart due to the pressure exerted by the head of flood water against them. From this moment forward flood water flows unimpeded into the Shopping Centre through the front entrance. It is noted that the doors of the shopping centre were not accounted for in the model so the localised flow through the doors and the behaviour of the doors during the event is not accounted for in the model.

Figure 37: Flood waters entering Douglas Village Shopping Centre through the front entrance @ 2:15 am in the model.

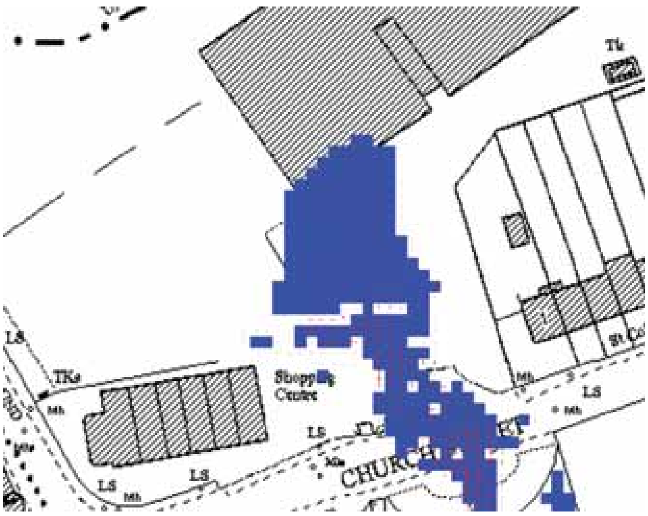


Figure 38: Front doors of the Douglas Village Shopping Centre @ 2:14am. It can be seen from the left of the figure that flood water is entering the shopping centre in through the left door. Water is also entering under the front door but is difficult to see this from the image.

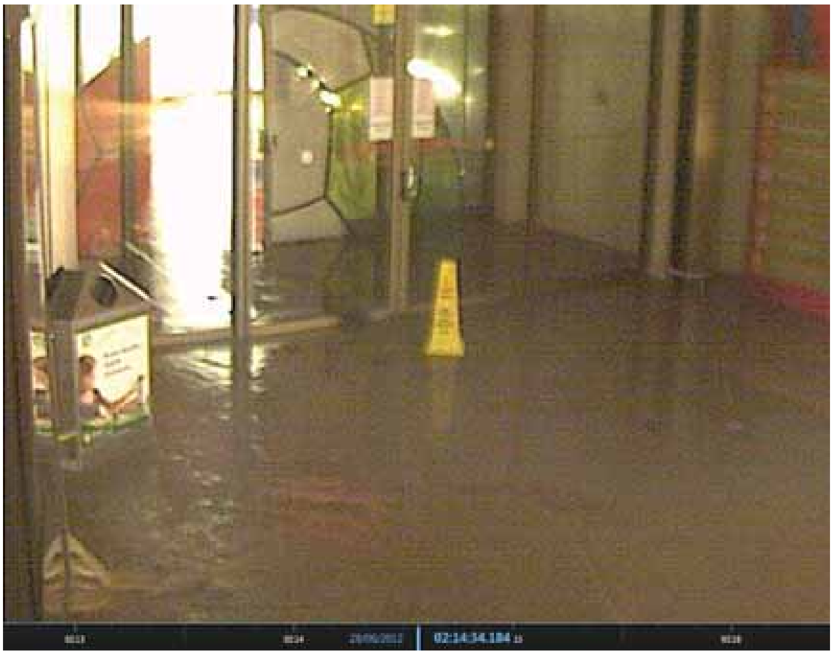


Figure 39: The front doors of the shopping centre broke at 2:36am allowing flood water to flow unimpeded into the shopping centre. This image is taken at 4:06am.

- **2.10am –** Flood water flows past the Cashman's security gate on Church Street. By **2.20am** there is significant flooding along Church Street;
- **2.17am –** Flood water flows underneath the Cashman's security gate onto Church Street. This floodwater has travelled past the entrance to DVSC and through the service yard from where it is able to flow underneath the security gate;

Figure 40: Floodwater can be seen flowing past Cashman's security gate down Church Road at 2:17am. Flood water can also be seen flowing underneath the gate from behind the gate.

Figure 41: Floodwater in the model moving down Church Street @ 2:25am. The model is lagging behind the observed events by approximately 8 minutes.

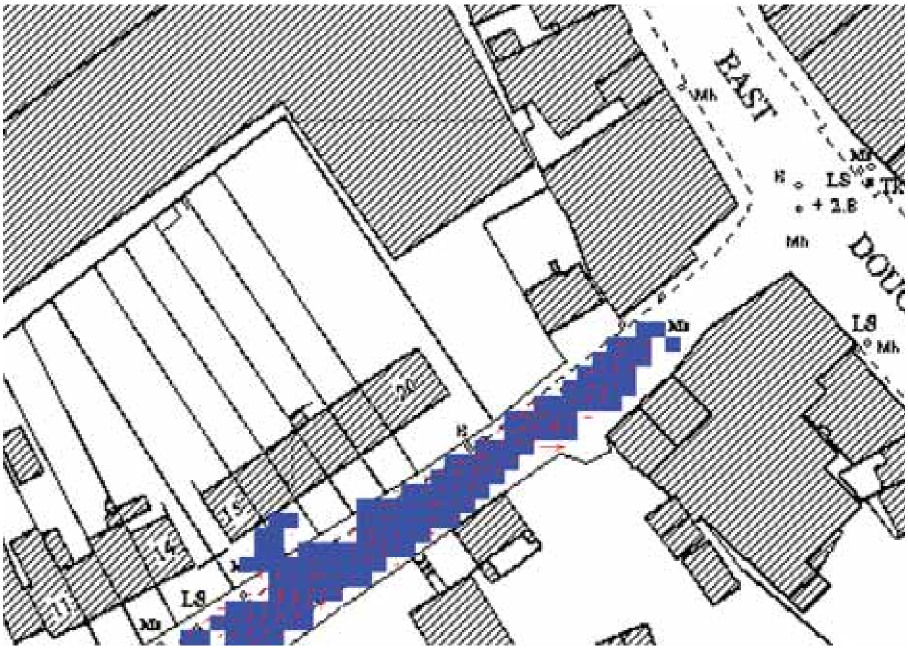


Figure 42: Floodwater flowing down Church Street and from behind Cashman's security gate @ 3:37am. This is very close to the time at which peak water level of the flood. It can be seen from the image that the flooding is relatively shallow as it is ankle deep for the person walking through the flood.

- **2.33am –** Within DVSC, flood waters that have entered through the front entrance approach the Eastern entrance. It therefore took approximately 23 minutes for the flood water to travel to the Eastern Entrance;
- **2.44am –** Significant flooding of the Eastern entrance of the shopping centre.

Figure 43: Floodwaters nearing the Eastern Entrance of DVSC @ 2:41am. This flood water has entered the shopping centre from the front door

.

Figure 44: Eastern Entrance at 3:30am. There is extensive flooding and objects are seen floating around in the water.

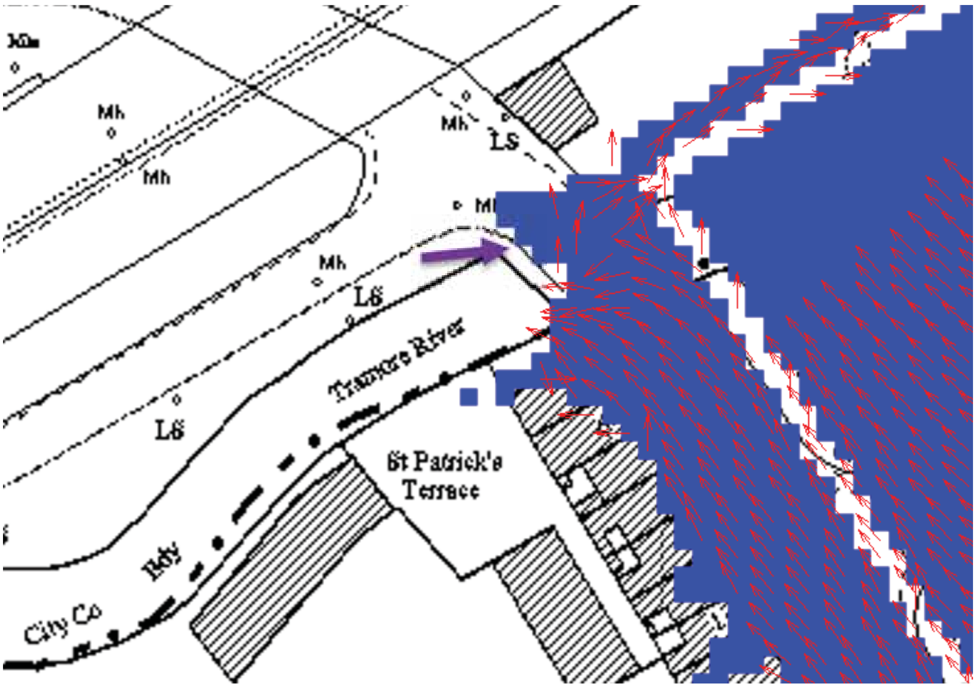
5.5.4 Mechanisms of Flooding from the Videos Captured by Members of the Public

A number of videos of the flood event were captured by members of the public and posted to Youtube. We have compared our model output against this recorded footage recorded to investigate how well the model captures the flooding mechanism. Overall there is a very good match between the modelled flooding mechanisms and the observed mechanisms.

- **Flood waters entering the Tramore River on Douglas West –** It can be seen from the image that flood waters entered the Tramore River at the Douglas West road bridge

Figure 45: Flood waters can be seen entering the Tramore River from Douglas West. This mechanism succeeded in reducing the water levels in Douglas West

Figure 46: Flood waters entering the Tramore River from Douglas West in the model. The purple arrow indicates the direction from which the photograph in Figure 45 was taken.

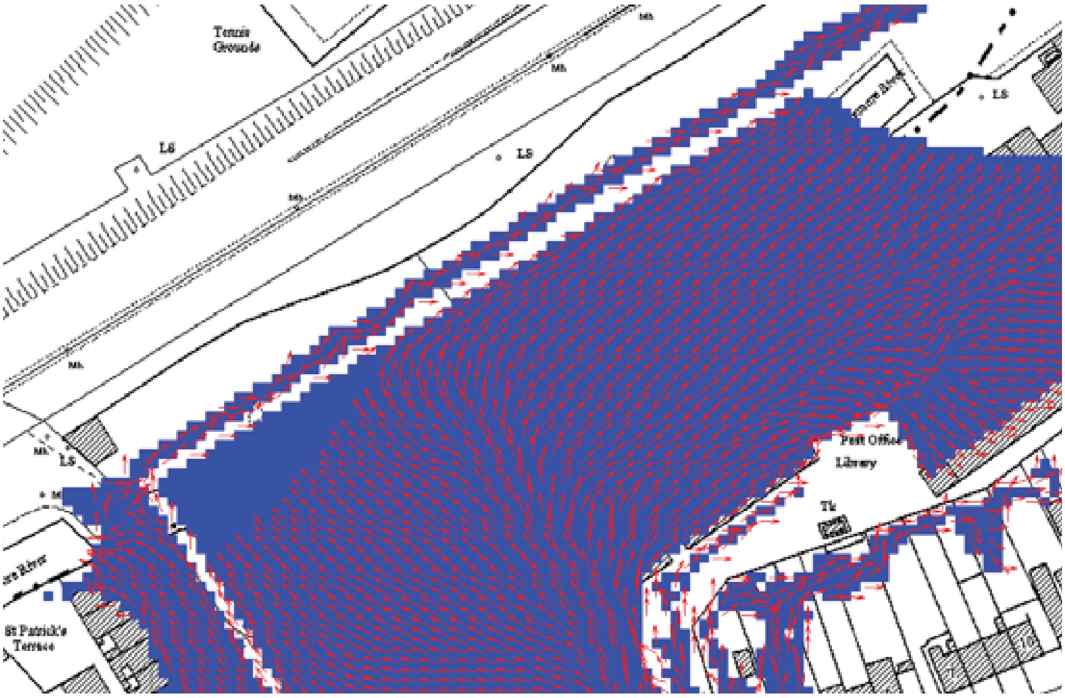


- **Flooding on the road behind DVSC –** It can be seen that in contrast to the estimated maximum flood extent as presented in the post flood event report by CCC (as presented in Figure 8 of this report), the full width of the road is not flooded. It is noted however that the time at which this footage was recorded is not known and the maximum flood extent may therefore not be indicated on the figure.

Figure 47: Flood water behind the DVSC

Figure 48: Second image of the road behind DVSC

Figure 49: Floodwaters inundating the road behind DVSC in the model. The gap between the floodwaters in the shopping centre and on the road is a result of the wall of the shopping centre being represented in Tuflow by a THICK Z line.



5.6 Calibration runs in Donnybrook Commercial Centre

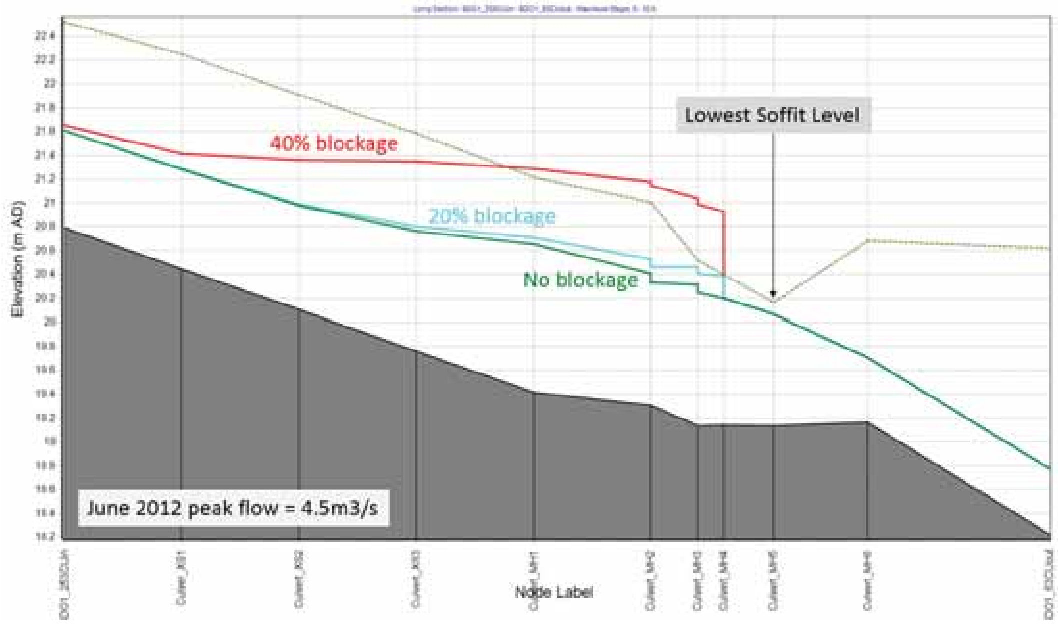
The June 2012 flood event was simulated using a number of blockage scenarios that are assumed to occur at the location of manhole 4 within the 190m long culvert that runs underneath Donnybrook Commercial Centre. Results from the model are presented in Figure 50. The solid lines in the figure presents the maximum water level for the various model runs. The dashed green line represents the existing soffit level of the culvert.

It can be seen from the figure that the maximum water level for the no blockage scenario is circa 100mm below the soffit level of the culvert at manhole 5. This suggests that there would have been sufficient capacity in the culvert to pass the June 2012 flood event should no blockage have occurred during the event.

It can also be seen that the maximum water level for the 20% blockage at MH4 scenario (i.e. the cross sectional area is reduced by 20%) is at the same level as the soffit of the culvert – i.e. the culvert is not surcharging for the 20% blockage scenario. Given the observed mechanism of flooding during the event, the results suggest that the blockage that occurred during the event was greater than 20%.

It can be seen that the 40% blockage scenario results in significant surcharging of the culvert.

Figure 50: Maximum water levels within Donnybrook Commercial Centre Culvert for the June 2012 flow rate with various blockage scenario assumptions



It is noted that our model does not simulate out of bank flow within Donnybrook commercial centre. The water levels presented in Figure 50 for the 40% blockage scenarios is therefore not representative of flood levels within the commercial centre but instead presents the piezometer head in the culvert under the conditions considered.

It is noted however that in order to produce flood maps for the commercial centre, the model was refined by inserting a manhole unit to calculate the volume of water surcharging through manhole 3. This is discussed further in Section 6.5.

5.6.1 Culvert at the Upstream end of Donnybrook Commercial Centre

The results of the model indicate that water levels upstream of the culvert at the upstream end of the commercial centre (Figure 50) were kept in bank for the June 2012 event – the lowest point of the bank is set at 26.0mOD while the maximum modelled water level is 25.3mOD. It is noted that there is no record of flooding at this location.

We have assumed in our model that the screen upstream of this culvert was fully blocked during this event.

Figure 51: Culvert at the upstream end of Donnybrook commercial centre

6 Design Runs

6.1 Design Model Runs

The calibrated model was used to simulate the design model runs. Eleven model runs were simulated for the current scenario and are listed in Table 4.

Table 4: Design Tidal-Fluvial Joint Probability Scenarios

Scenario	**Design Event (AEP)**	**Boundary**		
		Fluvial (AEP)	**Tidal (AEP)**	**Lee CFRAMS Tidal Flood Level (node 6TRA_0) (mOD Malin)**
1	50%	50%	50%	2.44
2	20%	20%	50%	2.44
3	20%	50%	20%	2.54
4	10%	10%	50%	2.44
5	10%	50%	10%	2.62
6	4%	4%	50%	2.44
7	4%	50%	4%	2.71
8	2%	2%	50%	2.44
9	2%	50%	2%	2.78
10	1%	1%	20%	2.54
11	0.5%	10%	0.5%	2.92

The Q100 design model run (1% Annual Exceedance Probability event) was used to produce the maximum flood extent map associated with the Q100 event. This is presented in Section 6.2.

The results of all the design model runs were used in the estimation of the average annual damage and net present value of damages for the Multi Criteria Analysis. The user is referred to the accompanying Options Report for a detailed description of this work.

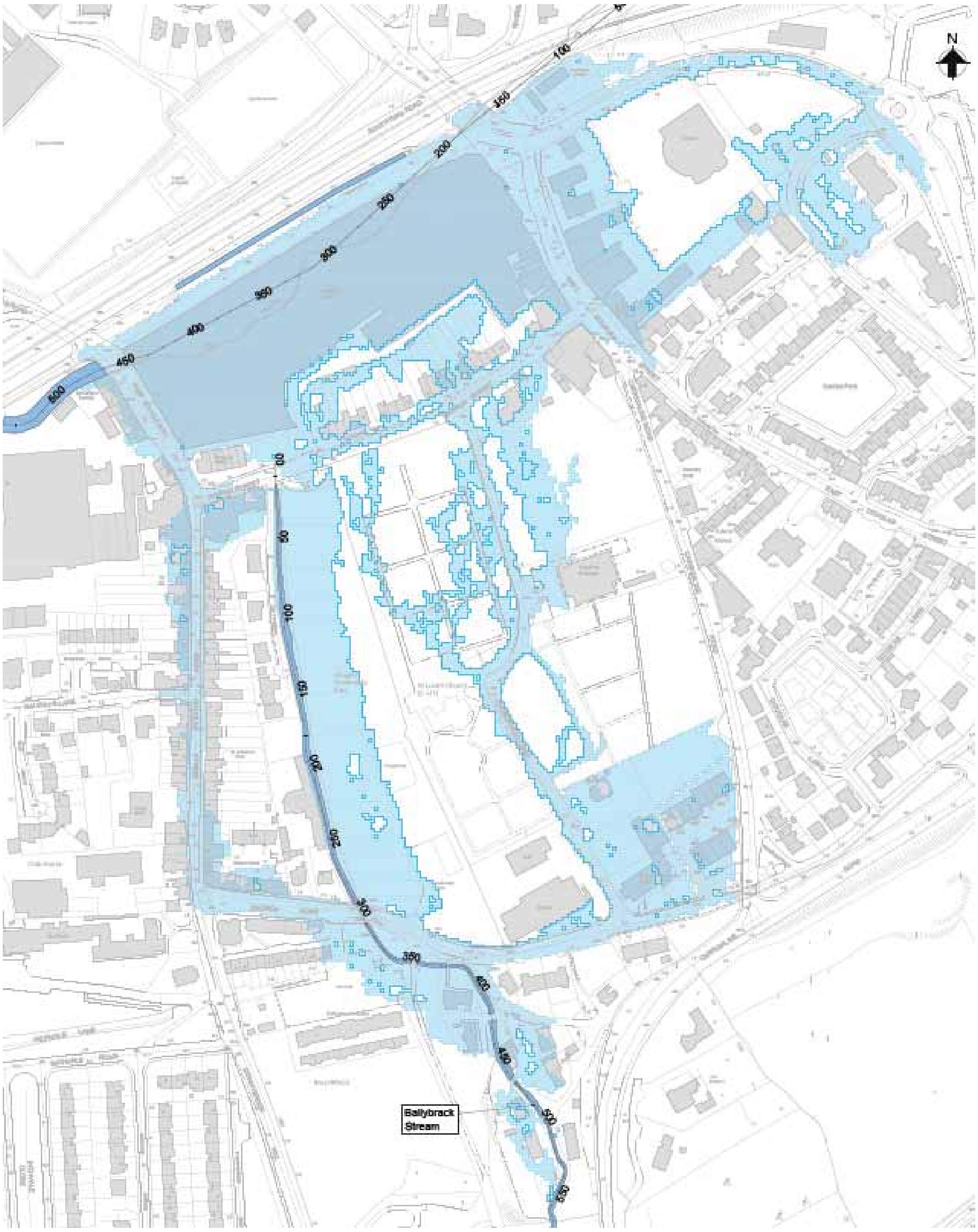
6.2 Maximum Flood Extent for the Q100 Design run

The maximum flood extent for the design Q100 event in Douglas is presented in Figure 52 and for Donnybrook Commercial Centre in Figure 55.

It is noted that the flood extent map for Donnybrook Commercial was developed using a stage-volume curve which is a more simplified approach that the approach used to produce the map for Douglas (output from the 2D model). A detailed description of the methodology used to produce the flood map in the commercial centre is presented in

The reader is referred to Appendix A for the flood extent map produced as part of the study which details the 1 in 10, 1 in 100 and 1 in 1000 year flood extent.

Figure 52: Maximum flood extent for the design Q100 event. The blue shading represents the flood extent.



6.3 Maximum Flood Extent for the Q100 Design run in Donnybrook Commercial Centre

In order to produce a flood extent map for Donnybrook Commercial Centre it is necessary to first estimate the volume of water surcharging through the manholes from the long culvert than runs underneath the centre. In order to calculate this volume, a manhole unit was fitted to the hydraulic model which in turn connected to a reservoir unit.

This manhole unit calculates the discharge through the manhole by applying a standard weir equation to the piezometric head in the culvert. The unit assumes that the manhole is open and does not take account of its lid or its weight. The volume of water in the manhole shaft is also ignored.

It was assumed in the model that water can only surcharge through manhole 3 in the culvert. For the Q100 event the total volume discharged through manhole 3 was calculated as 2,500m^3. For the Q1000 event the total volume was estimated as 14,700m^3.

A stage-volume curve for Donnybrook Commercial Centre was derived using the Lidar data as is presented in Figure 54. From this we can see that the Q100 volume of 2,500m^3 equates to a level of 21.6mOD. The Q1000 volume equates to a level of 23.8mOD.

It is noted however that a level of 23.8mOD cannot be achieved within the centre as water will overtop the entrance to the centre (set at circa 23.3mOD) before it can reach this level. We have therefore assumed a water level of 23.4mOD for the Q1000 flood event in Donnybrook Commercial Centre.

Figure 53: Area (enclosed by pink line) for which the stage volume curve in Figure 54 is calculated for

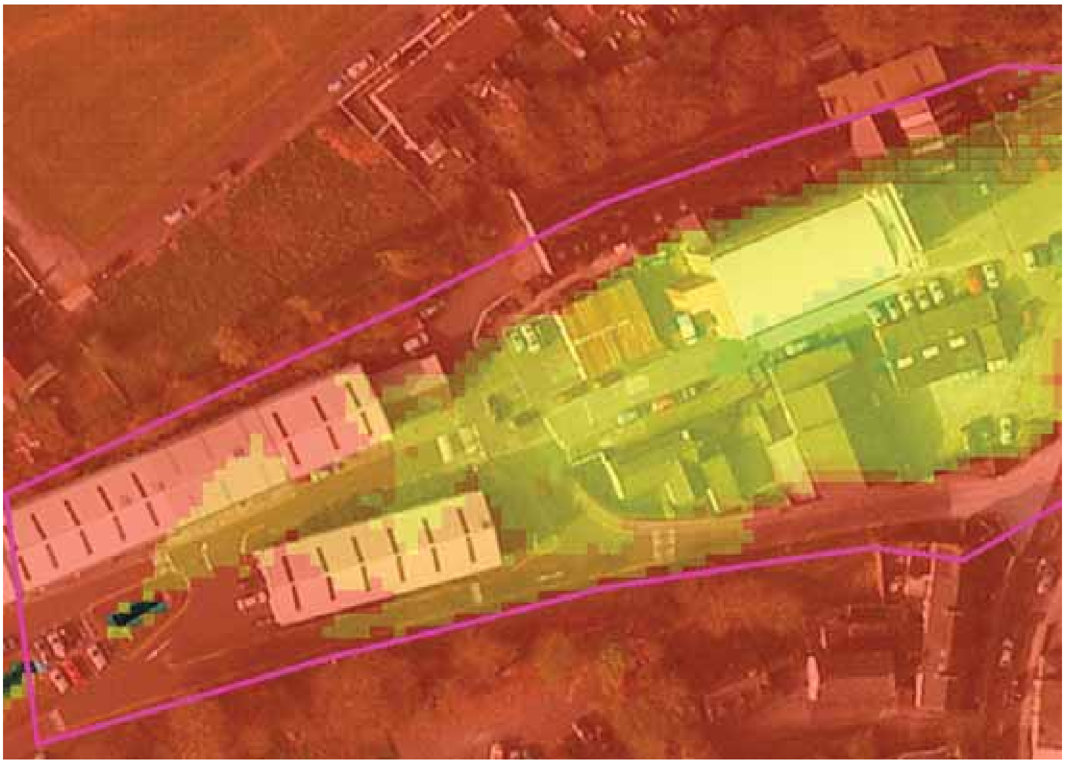
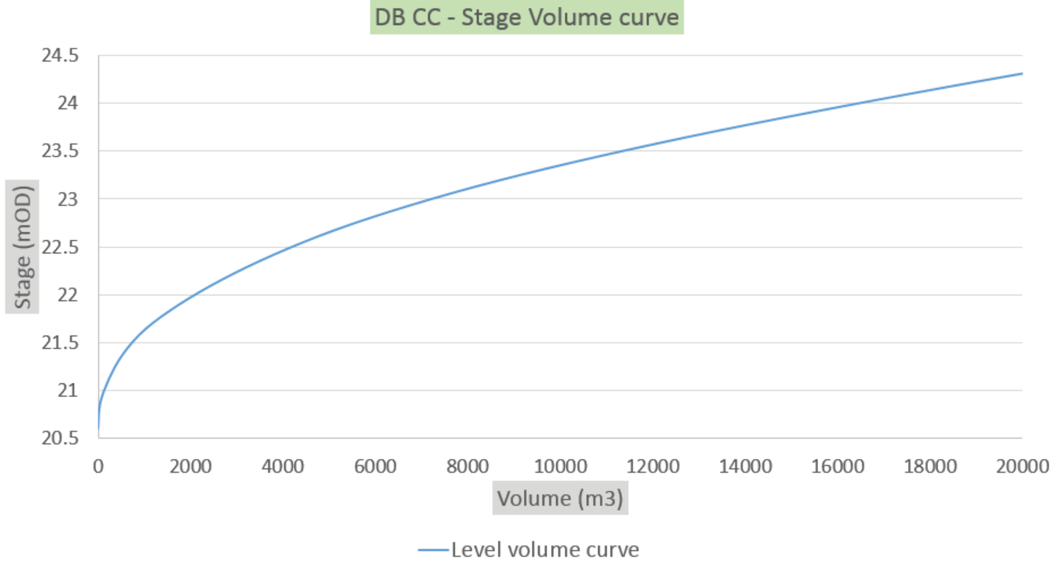


Figure 54: Stage-volume curve for Donnybrook Commercial Centre

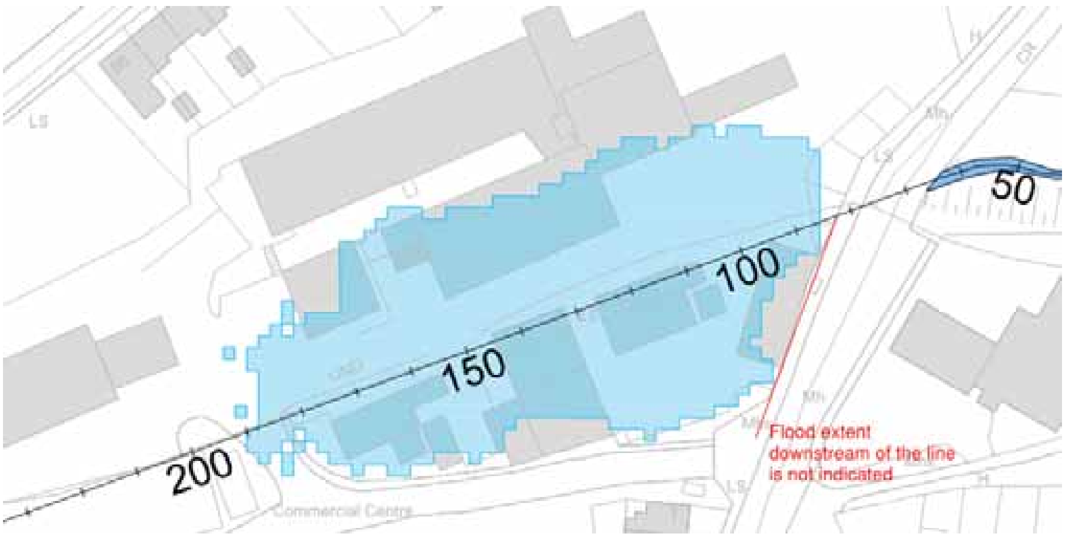


Flood maps for both the Q100 and Q1000 scenarios have been produced by making a horizontal projection of 21.6mOD and 23.4mOD, respectively, through the Lidar dataset. The area with ground elevations less than the flood levels are defined as being within the flood extent on the map.

It is noted that utilising a stage-volume curve to produce a flood extent maps represents a more simplified approach that the approach used for Douglas (i.e. utilising a 2D hydraulic model). Given that the floodplain in Donnybrook Commercial Centre is contained due to its topography, this approach is deemed appropriate. It is noted that this approach has been agreed with the Project Steering Committee.

The Q100 flood extent for the commercial centre is presented in Figure 55.

Figure 55: Maximum flood extent for the design Q100 event. The blue shading represents the flood extent.

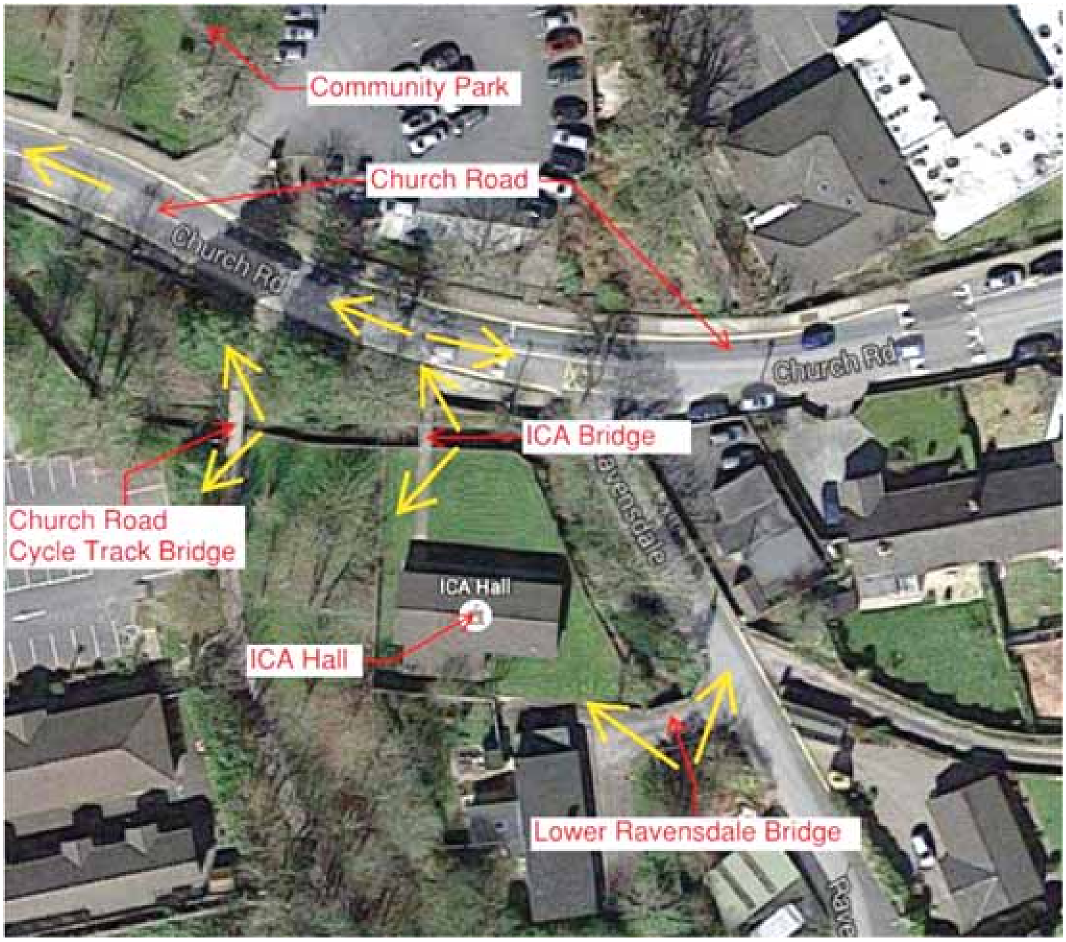


6.4 Flooding in Douglas – Discussion of the Current Scenarios Model Results

The results of the Douglas FRS model have been examined to understand the mechanism of flooding for the current scenario events. The design runs assume that no blockages occurred at any of the culverts or bridges in the model. The mechanism of flooding for the design events is therefore considerably different to that of the June 2012 calibration event.

As the main source of flooding in Douglas is in the area of Ravensdale, a diagram of the route of the floodwaters is presented in Figure 56 to aid the reader in understating the flooding mechanisms.

Figure 56: Flood routes of the Ballybrack Stream in the vicinity of Ravensdale in Douglas. The yellow arrows indicate flood routes.



- **Q2 year flood event (Design flow at HEP_03 = 5.48m^3/s) –**

The Q2 event does not result in any flooding of Douglas as the water stays in bank. It is noted however that all the garden walls and park walls in the model are assumed to act as flood defence walls.

- **Q5 year flood event (Design flow at HEP_03 = 7.34m^3/s) –**

The Q5 event does not result in Douglas flooding as the water stays in bank.

The capacity of the channel in the lower reach of Ravensdale in the vicinity of the ICA Hall is however exceeded during this event but it does not spill out of channel as the garden and boundary walls (Figure 57) that line both sides of the channel keep the floodwater in bank. It is noted that the Q5 year flood does not exceed the deck level of the two pedestrian bridges in the vicinity of the ICA Hall. The Q5 event can therefore be approximated to the threshold of flooding for the Ballybrack stream in the Douglas area.

Figure 57: Photograph of the boundary wall that surrounds the site of the ICA Hall in Ravensdale

Q10 year flood event (Design flow at HEP_03 = 8.71m^3/s) –

The Q10 event results in both Douglas East and Douglas West being inundated with floodwater. The source of the flooding is overtopping of the Ballybrack stream in the vicinity of the ICA Hall in Ravensdale. The floodwaters overtop in two ways:

- The water level in the Ballybrack Stream exceeds the capacity of the channel in the section of the river parallel to Church Road and spills onto the floodplain out over the pedestrian bridge. Both the left and right floodplain are flooded. There is a relatively steep gradient on Church road and once water from the Ballybrack spills onto the road, it travels both East and West along the road. It is noted that no water enters the community park for the Q10 event as the water depth on the road is below the ground level of the entrance to the park.
- The water level in the Ballybrack channel immediately upstream of the Lower Ravensdale Bridge exceeds the capacity of the channel due to the backwater effect of the bridge and spills onto the floodplain. For the Q10 event only the right hand bank is overtopped and this flood water travels down Ravendale onto Church Road and meets the floodwater that exited the channel out over the pedestrian bridge.

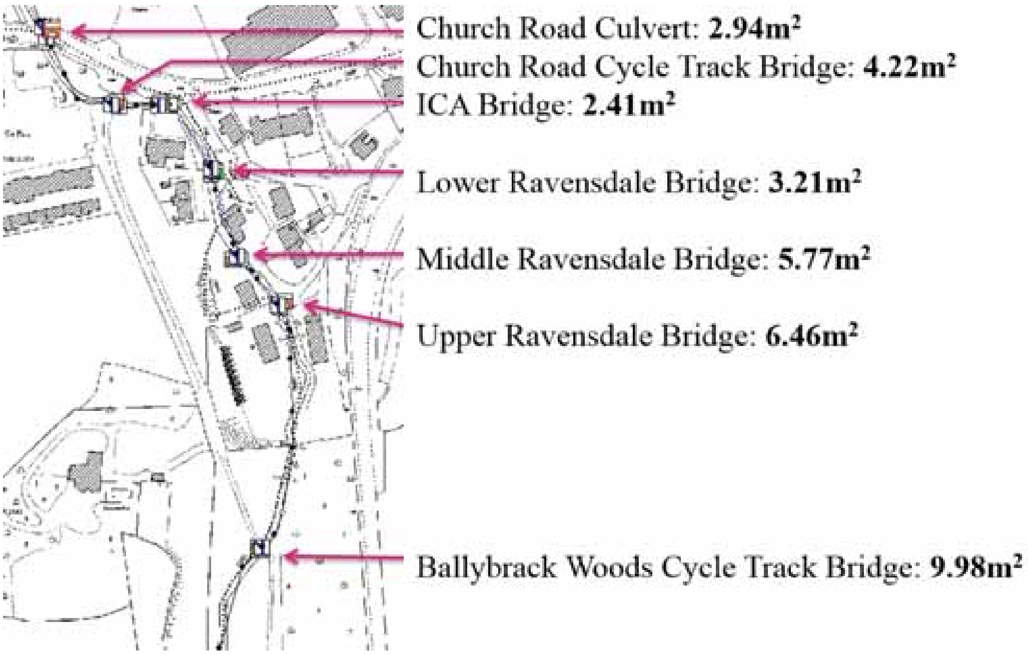
There is a sufficient volume of floodwater entering the floodplain at Ravensdale for the Q10 event to flood Douglas East and Douglas West. Douglas East is flooded by floodwater travelling from Church Road onto Churchyard Lane; Douglas West is flooded directly from Church Road.

It is noted that Douglas Village Shopping Centre is not flooded during this event.

It is noted that the Lower Ravensdale Bridge has a cross sectional area of $3.21m^2$. When compared to the bridges further upstream (Figure 58) it can be seen that this is relatively small and therefore acts as a significant obstacle for the flow.

The flood extent for this event is presented in Appendix A.

Figure 58: Cross Sectional Areas of the culvert and bridge entrances through Ravensdale. It is noted that the cross sectional area of the DVSC culvert at its entrance at Church Street is **$5.95m^2$**.



- **Q25 year flood event (Design flow at HEP_03 = 10.96m3/s) –**

The Q25 event results in both Douglas East and Douglas West being inundated with floodwater. Douglas Village Shopping Centre is also flooded during this event but it is noted that the depth of flooding within the building is very shallow. The threshold of flooding for the Shopping Centre is therefore estimated between the Q20 and Q25 year event. The road behind the shopping centre is also flooded during this event.

The source of the flooding for the Q25 year event is again overtopping of the Ballybrack stream in the vicinity of the ICA Hall in Ravensdale with the same mechanisms as for the Q10 event. The higher water levels of the Q25 event however lead to overtopping on both sides of the channel immediately upstream of the Ravensdale Lower Bridge. The higher water levels on Church Road also lead to floodwaters entering the Community Park at the upstream end of the park. From here, these flood waters flow through the park and exit the park onto Church Street and enter the shopping centre through the front entrance.

It is noted however that by the time flood waters enter the front entrance of the Shopping Centre, the building is already being flooded through the Eastern Entrance on Douglas East. There are therefore two routes by which flood waters can enter the shopping centre.

- Q50 year flood event (Design flow at HEP_03 = 12.27m^3/s) –

The Q50 event results in Douglas East, Douglas West, Douglas Village Shopping Centre and the road being the centre being inundated with floodwater. The mechanism of flooding is the same as for the Q25 event. The greater volume of floodwater leads to greater flood depths and a larger flood extent.

It is noted that the Ballybrack Stream does not overtop the channel within the Community Park during the event. Further it is noted that the Tramore River also does not get out of bank within the area of Douglas Village.

- Q100 year flood event (Design flow at HEP_03 = 14.03m^3/s) –

The Q100 results in Douglas East, Douglas West, Douglas Village Shopping Centre and the road being the centre being inundated with floodwater. The mechanism of flooding is the same as for the Q25 and Q50 events.

The greater volume of floodwater leads to greater flood depths and a larger flood extent. The flood extent for this event is presented in Figure 52 and Appendix A. It is noted that the Ballybrack Stream is close to bank full within the community park for this event. Further it is noted that the Tramore River does not get out of bank within the area of Douglas Village during the event.

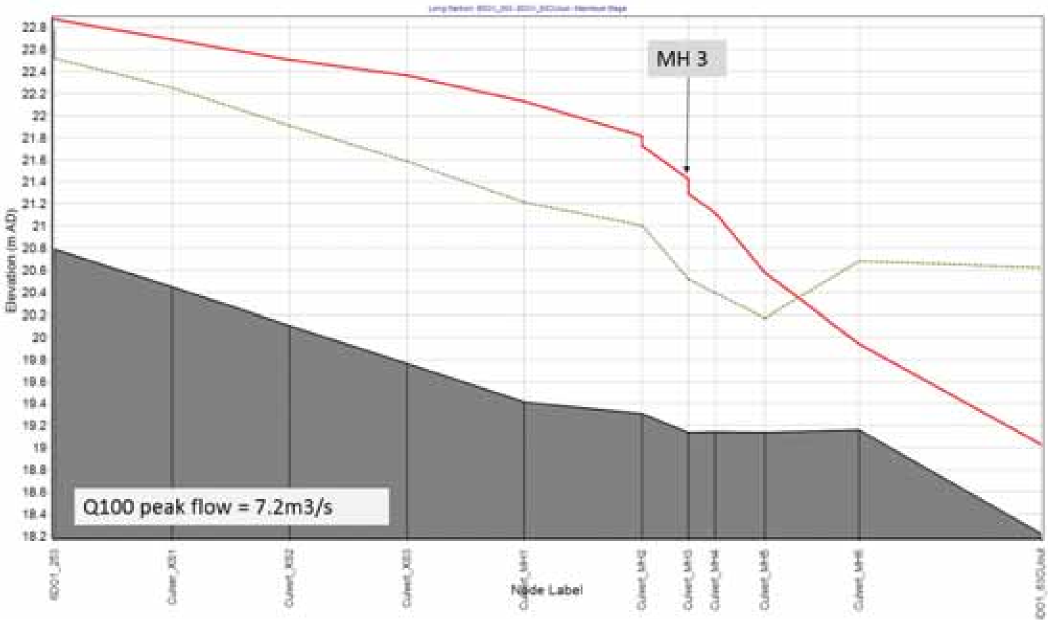
6.5 Design runs in Donnybrook Commercial Centre

6.5.1 The 190m Long Culvert that Runs Under Donnybrook Commercial Centre

The maximum water level throughout the length of the culvert for the design Q100 flow is presented with the red line in Figure 59. The dashed green line presents the soffit level of the culvert. It is noted this model run assumes no blockages in the culvert. This model run assumes no blockage in the culvert.

The location of Manhole 3 is highlighted on the figure. It can be seen that the culvert is surcharged for the event which will lead to flooding of the commercial centre.

Figure 59: Design Q100 maximum water levels within Donnybrook Commercial Centre Culvert – no blockage



6.5.2 Culvert at the Upstream end of Donnybrook Commercial Centre

The results of the model indicate that the water levels upstream of the culvert are in-bank for the Q100 design event – the lowest point of the bank is set at 26.0mOD while the maximum modelled water level is 25.65mOD.

Similar to the June 2012 calibration model described in the previous section, the design Q100 model run assumed that the screen is fully blocked but omitted the pipes that cross the face of the culvert due to concerns with model instability issues.

The underside of the lower of the two pipes is set at 25.54mOD which is below the modelled Q100 design water level of 25.65mOD. The pipes will therefore act as obstacle to the flow in the Q100 design conditions and elevate water levels higher than 25.65mOD.

7 Conclusions

7.1 Conclusion

A one-dimensional (1D) and two-dimensional (2D) model of the Ballybrack Stream and Tramore River (The "Douglas FRS" model) has been constructed as part of the study.

The Douglas FRS model is well calibrated against the June 2012 event in terms of peak water levels, modelled flood extents and the observed mechanisms of flooding from the CCTV cameras at DVSC.

The results of the Douglas FRS model have been examined to understand the mechanism of flooding for the current scenario events.

The Q2 event does not result in any flooding of Douglas as the water stays in bank.

The Q5 event does not result in Douglas flooding as the water stays in bank.

The Q10 event results in both Douglas East and Douglas West being inundated with floodwater.

The Q25 event results in both Douglas East and Douglas West being inundated with floodwater. Douglas Village Shopping Centre is also flooded during this event but only to a shallow depth.

The Q50 event results in Douglas East, Douglas West, Douglas Village Shopping Centre and the road being the centre being inundated with floodwater.

The Q100 results in Douglas East, Douglas West, Douglas Village Shopping Centre and the road being the centre being inundated with floodwater. The mechanism of flooding is the same as for the Q25 and Q50 events.

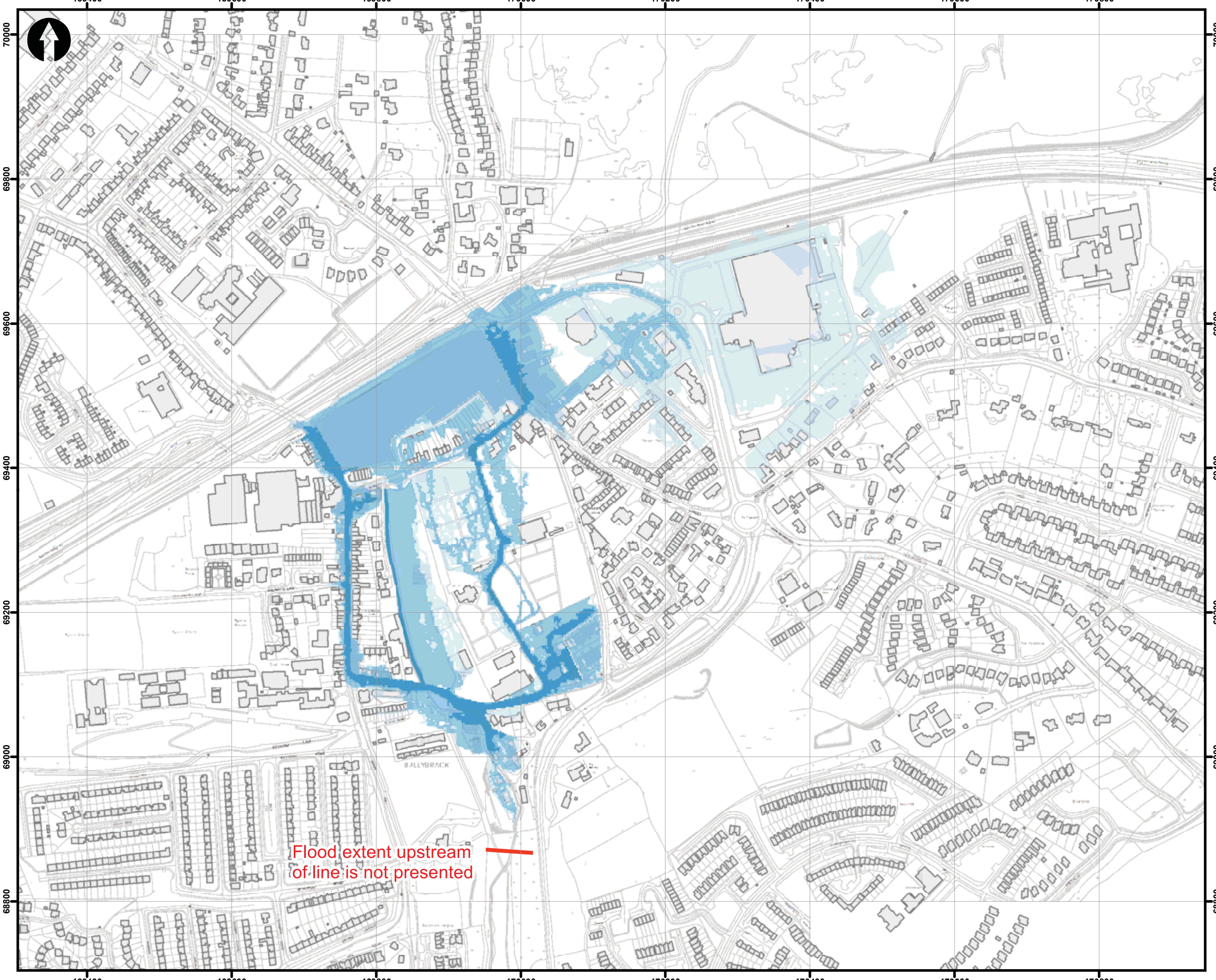
The Q100 event also results in Donnybrook Commercial Centre being flooded.

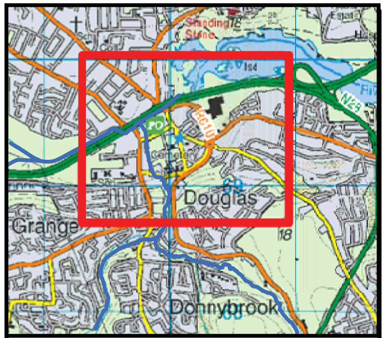
Appendix A

Flood Extent Maps

A1

A3





Legend:

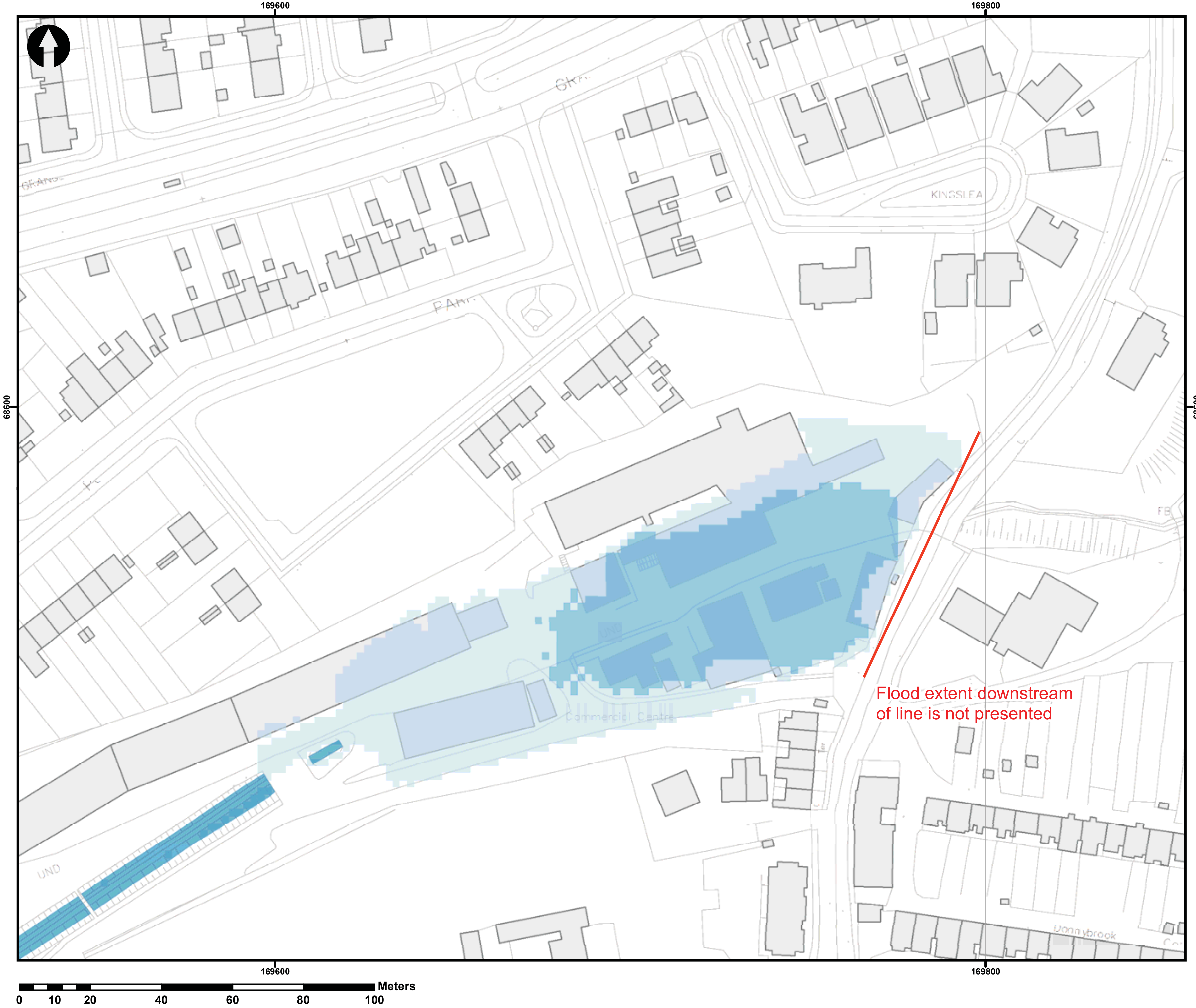
- 10% Fluvial AEP
- 1% Fluvial AEP
- 0.1% Fluvial AEP

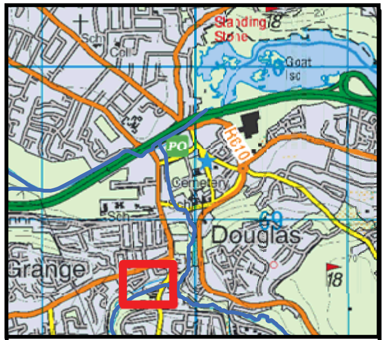
Rev:	Note:	Date:

ARUP

Map: Douglas Fluvial Flood Extents		
Map type:	Fluvial Flood Extent	
Source:	Douglas Flood Relief Scheme	
Scenario:	Current	
Drawn By:	P.S.	Date: 26/04/2017
Checked By:	K.B.	Date: 26/04/2017
Approved By:	K.L.	Date: 26/04/2017
Drawing No:	1	
Map Series:	Page 1 of 2	
Drawing Scale:	1:5,000 @ A3	

A3





Legend:

- 10% Fluvial AEP
- 1% Fluvial AEP
- 0.1% Fluvial AEP

Rev:	Note:	Date:

ARUP

Map: Douglas Fluvial Flood Extents		
Map type:	Fluvial Flood Extent Donnybrook	
Source:	Douglas Flood Relief Scheme	
Scenario:	Current	
Drawn By:	C.B	Date: 26/04/2017
Checked By:	K.B.	Date: 26/04/2017
Approved By:	K.L.	Date: 26/04/2017
Drawing No:	1	
Map Series:	Page2 of 2	
Drawing Scale:	1:1,000 @ A3	

Appendix B

Hydraulic Model Results

B1 Model Results

B1.1 Q2 Model Results

Table 5: Q2 model run - Existing scenario

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6TRA_2506	3.99	9.95	0.5
6TRA_2446	3.958	9.933	0.613
6TRA_2406	3.948	9.924	0.47
6TRA_2329	3.926	9.914	0.477
6TRA_2263	3.645	9.908	1.571
6TRA_2170	3.567	9.888	0.315
6TRA_2088	3.554	9.864	0.308
6TRA_2014	3.298	9.857	1.302
6TRA_1900	3.011	9.84	0.843
6TRA_1785	2.812	9.814	1.603
6TRA_1735	2.814	9.821	0.468
6TRA_1655	2.778	9.877	0.654
6TRA_1541	2.708	9.937	0.891
6TRA_1431	2.671	10	0.671
6TRA_1340	2.647	10.066	0.69
6TRA_1263	2.63	10.127	0.612
6TRA_1175	2.609	10.204	0.683
6TRA_1096	2.593	10.277	0.636
6TRA_1021	2.582	10.375	0.585
6TRA_938	2.573	10.508	0.516
6TRA_852	2.563	10.678	0.573
6TRA_759	2.548	10.822	0.78
6TRA_682	2.534	10.926	0.648
6TRA_619	2.524	10.995	0.682
6TRA_609Cin	2.512	11.006	0.64
6TRA_538Cout	2.509	11.088	0.636
6TRA_538	2.502	11.088	0.685
6TRA_532	2.503	11.095	0.637
USbridge1	2.492	11.176	0.558
USbridge2	2.491	11.192	0.561
USu	2.491	11.192	0.557
2d	2.491	11.221	0.537

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
3u	2.491	11.221	0.508
4u2	2.49	11.259	0.504
4u3	2.49	10.471	0.468
4u4	2.489	10.481	0.468
4u5	2.489	9.792	0.437
4u6	2.489	9.802	0.437
4u7	2.489	9.127	0.407
N25culv3	2.481	0.811	0.278
4u8	2.489	9.136	0.406
4u9	2.489	8.464	0.376
4d	2.489	8.474	0.376
5CUL	2.489	8.184	0.505
6CUL	2.488	8.213	0.507
6CULd	2.488	8.213	0.507
6CULdi	2.488	11.31	0.688
bal3d	2.488	5.503	1.38
7CULu	2.487	11.313	0.687
7CULd	2.487	11.313	0.687
8CULU	2.47	11.455	0.67
8CUL	2.47	12.328	0.72
8CULa	2.468	12.339	0.718
8CULb	2.468	12.592	0.733
8CULbb	2.467	12.6	0.731
8CULD	2.467	13.011	0.755
8CULDd	2.466	13.022	0.753
8CULDa	2.466	13.901	0.79
8culDD	2.464	13.909	0.789
N25culv9d	2.468	3.876	0.674
COMB1	2.468	5.345	0.398
9CULup2	2.464	16.67	0.82
COMB3	2.464	3.012	0.459
9CULdd	2.464	16.67	0.82
9CULOLD	2.464	16.67	0.821
9CULOLDd	2.45	16.723	0.824
9CULOLDdd	2.45	16.723	0.816
9CULstrucup	2.439	16.793	0.821
9CULoutU	2.439	16.793	0.821
9CULoutUd	2.434	16.828	0.823

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
9CULoutDu	2.434	16.828	0.823
9CULoutD	2.431	16.862	0.824
6TRA_20	2.429	16.862	1.066
6TRA_0s	2.428	16.894	2.409
Sedtrap_Cul1	2.695	5.471	3.213
Sedtrap_Cul2	2.581	5.471	3.211
bal1u	2.581	5.471	5.016
bal1u2	2.527	5.472	1.677
bal_new	2.527	5.472	1.677
bal1d	2.518	5.472	1.643
bal2u	2.518	5.472	1.643
bal2d	2.499	5.501	1.469
bal3u	2.499	5.501	1.469
5ochd	2.487	1.066	0.167
6och	2.486	1.069	0.166
7och	2.486	2.852	0.445
8och	2.47	2.887	0.436
N25culv4	2.481	0.813	0.184
N25culv5	2.481	1.527	0.323
N25culv6	2.481	1.529	0.323
N25culv7	2.481	2.235	0.458
N25culv7a	2.481	2.237	0.457
N25culv7b	2.481	2.942	0.595
N25culv8	2.481	2.944	0.593
N25culv9U	2.47	2.986	0.56
N25culv9	2.47	3.875	0.677
COMB1a	2.468	5.349	0.398
COMB1b	2.468	4.402	0.328
COMB2	2.467	4.408	0.328
COMB2a	2.467	3.003	0.242
6DOU_1370	25.088	2.321	1.874
6DOU_1276	23.268	2.32	1.636
6DOU_1130	20.356	2.321	2.003
6DOU_1130d	20.356	2.321	2.003
6DOU_1100	19.846	2.321	1.711
6DOU_1059	19.135	2.321	1.703
6DOU_1009	18.213	2.321	1.727
6DOU_960	17.302	2.321	1.9

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DOU_952	17.133	2.321	1.675
6DOU_960d	17.302	2.321	1.9
6DOU_952d1	16.712	2.321	1.79
6DOU_952d2	16.712	2.321	1.79
6DOU_914	16.319	2.32	0.94
6DOU_914J	16.319	5.472	2.199
6DO1_0	17.312	2.839	1.501
6DO1_0S	16.319	2.839	1.906
6DOU_845	15.548	5.472	1.208
6DOU_828	15.168	5.472	3.081
6DOU_828d	15.168	5.472	3.081
6DOU_803	14.464	5.472	2.19
6DOU_758	13.861	5.472	1.55
6DOU_721	13.602	5.471	1.689
6DOU_678	13.29	5.471	1.447
6DOU_641	12.567	5.471	2.574
6DOU_628	12.282	5.471	1.95
6DOU_611	12.059	5.471	1.63
6DOU_614i1	11.801	5.471	1.772
6DOU_573	11.557	5.471	2.021
6DOU_559	11.334	5.471	2.365
6DOU_539	11.031	5.471	2.114
6DOU_524	10.962	5.471	1.632
6DOU_518	10.916	5.471	1.782
6DOU_511	10.835	5.471	2.212
6DOU_506	10.751	5.471	2.12
6DOU_501	10.686	5.471	2.076
6DOU_501d	10.686	5.471	2.076
6DOU_495	10.604	5.471	2.133
6DOU_490	10.507	5.471	2.413
6DOU_484	10.428	5.471	2.267
6DOU_477	10.345	5.471	2.131
6DOU_472	10.284	5.471	2.095
6DOU_468	10.233	5.471	2.09
6DOU_468d	10.233	5.471	2.09
6DOU_464	10.179	5.471	2.102
6DOU_460	10.122	5.471	2.137
6DOU_455	10.052	5.471	2.126

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DOU_448	9.961	5.471	2.087
6DOU_443	9.904	5.471	2.036
6DOU_438	9.859	5.471	1.952
6DOU_433	9.838	5.471	1.812
6DOU_428	9.825	5.471	1.673
6DOU_425	9.742	5.471	2.069
6DOU_420	9.678	5.471	2.088
6DOU_415	9.632	5.471	2.061
6DOU_405	9.557	5.471	2.011
6DOU_395	9.498	5.471	1.967
6DOU_384	9.454	5.471	1.877
6DOU_384r	9.422	5.471	1.97
6DOU_379	9.291	5.471	2.422
6DOU_379d	9.28	5.471	2.461
6DOU_367	9.114	5.471	2.578
6DOU_358	8.985	5.471	2.28
6DOU_358d	8.985	5.471	2.28
6DOU_341	8.558	5.471	3.671
6DOU_325	8.098	5.471	2.635
6DOU_306	7.859	5.471	1.982
6DOU_306d	7.859	5.471	1.982
6DOU_282	7.61	5.471	2.012
6DOU_234	7.1	5.471	2.039
6DOU_204	6.713	5.471	2.271
6DOU_154	6.089	5.471	1.926
6DOU_89	4.826	5.471	2.882
6DOU_65	4.206	5.471	2.667
6DOU_54	4.012	5.471	2.277
DOUFRS_18_3	3.924	5.471	1.561
DOUFRS_14_0	3.96	5.471	1.187
DOUFRS_10r	3.655	5.471	1.322
DOUFRS_14_0r	3.625	5.471	1.673
DOUFRS_10	3.655	5.471	1.322
DOUFRS_5_86	3.666	5.471	1.155
DOUFRS_3_36	3.652	5.471	1.21
DOUFRS_2_86	3.439	5.471	1.477
DOUFRS_00	3.41	5.471	1.587
BB_culv	2.92	5.471	3.098

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
BB_culv2	2.695	5.471	4.868
6DO1_1177	44.948	5.674	2.053
6DO1_1129	42.846	5.674	2.567
6DO1_1076	41.458	5.674	1.634
6DO1_1045	40.499	5.673	2.295
6DO1_1014	39.456	5.673	1.842
6DO1_929	37.173	5.673	2.612
6DO1_805	34.041	5.673	1.898
6DO1_726	32.297	5.674	1.508
6DO1_581	28.723	5.671	2.328
6DO1_498	26.947	5.67	1.818
6DO1_466	26.342	5.67	2.024
6DO1_434	25.793	5.67	1.953
6DO1_402	25.507	5.67	1.23
402_rpt	25.453	5.67	0.314
397_us	25.433	5.67	0.672
397_ds	24.382	5.67	1.883
6DO1_395us	24.351	5.67	3.438
6DO1_395cul	24.234	5.67	4.825
6DO1_387culd	24.201	5.67	2.518
6DO1_387_ds	24.201	5.67	2.768
6DO1_382	24.146	5.67	1.375
6DO1_374	23.911	5.67	2.179
6DO1_374BU	23.911	5.67	0.638
6DO1_374BD	23.911	5.67	0.638
6DO1_374d	23.911	5.67	2.179
6DO1_324	23.192	5.67	2.41
6DO1_285	22.529	5.67	2.281
6DO1_277	22.465	5.673	1.686
6DO1_277Bu	22.465	5.673	2.583
6DO1_277Spu	22.465	0	2.583
6DO1_277Bd	22.216	5.673	2.583
6DO1_277d	22.216	5.673	2.341
6DO1_277Spd	22.216	0	2.583
6DO1_262	21.979	5.682	2.611
6DO1_253	21.816	5.684	2.673
6DO1_253CUin	21.816	5.684	2.85
6DO1_253Spu	21.816	0	0.999

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DO1_253Spd	19.074	0	0.999
Culver_XS1	21.535	5.68	2.865
Culvert_XS2	21.348	5.695	2.737
Culvert_XS3	21.325	5.695	2.298
Culvert_MH1	21.226	5.736	2.171
Culvert_MH2	21.055	5.684	2.463
Cul_MH2DS	21	5.684	2.662
Culvert_MH3	20.828	5.676	2.324
Cul_MH3_DS	20.746	5.676	2.478
Culvert_MH4	20.64	5.676	2.481
Culvert_MH4B	20.64	5.676	2.481
Culvert_MH5	20.309	5.676	2.931
Culvert_MH6	19.807	5.674	3.666
6DO1_63CUout	19.074	5.674	2.669
Culvert_DS	19.074	5.674	1.393
6DO1_const_	19.006	5.67	1.715
6DO1_63b	18.753	5.664	1.973
6DO1_63a	19.07	5.664	1.086
Bridge_US	19.07	5.664	0.568
6DO1_56	18.482	5.663	2.525
Bridge_DS	18.753	5.664	0.568
6DO1_4	17.749	5.665	1.959
6DO1_4Bu	17.749	5.665	2.399
6DO1_4Spu	17.749	0	2.399
6DO1_4Bd	17.746	5.665	2.399
6DO1_4d	17.746	5.665	1.96
6DO1_4Spd	17.746	0	2.399
6DO1_0	17.716	5.662	1.757
6DO1_0S	16.779	5.662	1.906

B1.2 Q5 Model Results

Table 6: Q5 Model Run - Existing Scenario

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6TRA_2506	4.19	13.333	0.55
6TRA_2446	4.17	13.309	0.62
6TRA_2406	4.15	13.298	0.51
6TRA_2329	4.13	13.289	0.52

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6TRA_2263	3.77	13.285	1.82
6TRA_2170	3.69	13.28	0.36
6TRA_2088	3.68	13.275	0.36
6TRA_2014	3.41	13.266	1.31
6TRA_1900	3.15	13.221	0.84
6TRA_1785	2.98	13.148	1.74
6TRA_1735	2.99	13.114	0.48
6TRA_1655	2.94	13.119	0.74
6TRA_1541	2.85	13.165	1.02
6TRA_1431	2.80	13.204	0.78
6TRA_1340	2.77	13.247	0.76
6TRA_1263	2.75	13.287	0.71
6TRA_1175	2.72	13.345	0.74
6TRA_1096	2.70	13.418	0.70
6TRA_1021	2.69	13.514	0.66
6TRA_938	2.68	13.771	0.60
6TRA_852	2.66	14.044	0.63
6TRA_759	2.64	14.187	0.86
6TRA_682	2.62	14.282	0.79
6TRA_619	2.60	14.341	0.82
6TRA_609Cin	2.58	14.351	0.79
6TRA_538Cout	2.57	14.422	0.81
6TRA_538	2.56	14.422	0.86
6TRA_532	2.56	14.427	0.81
USbridge1	2.54	14.5	0.70
USbridge2	2.54	14.519	0.71
USu	2.54	14.519	0.70
2d	2.54	14.548	0.68
3u	2.54	14.548	0.64
4u2	2.54	14.583	0.64
4u3	2.54	13.45	0.59
4u4	2.54	13.459	0.59
4u5	2.54	12.511	0.55
4u6	2.53	12.523	0.55
4u7	2.53	11.593	0.51
N25culv3	2.52	1.178	0.32
4u8	2.53	0.997	0.51
4u9	2.53	0.986	0.47

Model Cross Section	**Max Stage (mOD)**	**Max Flow (m^3/s)**	**Max Vel (m/s)**
4d	2.53	11.602	0.47
5CUL	2.53	10.694	0.62
6CUL	2.53	10.703	0.62
6CULd	2.53	10.26	0.62
6CULdi	2.53	10.289	0.86
bal3d	2.53	10.29	1.43
7CULu	2.53	14.337	0.86
7CULd	2.53	7.334	0.86
8CULU	2.50	14.341	0.84
8CUL	2.50	14.341	0.91
8CULa	2.50	14.496	0.91
8CULb	2.50	0.592	0.93
8CULbb	2.50	15.68	0.93
8CULD	2.50	0.592	0.96
8CULDd	2.49	15.692	0.96
8CULDa	2.49	16.062	1.02
8culDD	2.49	16.072	1.02
N25culv9d	2.50	16.692	0.84
COMB1	2.50	16.705	0.52
9CULup2	2.49	18.109	1.05
COMB3	2.49	18.118	0.53
9CULdd	2.49	5.308	1.05
9CULOLD	2.49	7.022	1.07
9CULOLDd	2.47	21.73	1.07
9CULOLDdd	2.47	3.783	1.05
9CULstrucup	2.45	21.73	1.06
9CULoutU	2.45	21.73	1.06
9CULoutUd	2.44	21.787	1.06
9CULoutDu	2.44	21.787	1.06
9CULoutD	2.43	21.856	1.07
6TRA_20	2.43	21.856	1.16
6TRA_0s	2.43	21.886	2.48
Sedtrap_Cul1	2.79	21.886	3.48
Sedtrap_Cul2	2.68	21.917	3.21
bal1u	2.68	21.917	5.01
bal1u2	2.61	21.948	1.67
bal_new	2.61	7.331	1.67
bal1d	2.59	7.331	1.63

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
bal2u	2.59	7.331	1.63
bal2d	2.55	7.331	1.39
bal3u	2.55	7.331	1.43
5ochd	2.53	7.331	0.23
6och	2.53	7.331	0.23
7och	2.53	7.333	0.60
8och	2.50	7.333	0.58
N25culv4	2.52	1.483	0.21
N25culv5	2.52	1.49	0.37
N25culv6	2.52	3.84	0.37
N25culv7	2.52	3.867	0.52
N25culv7a	2.52	1.18	0.52
N25culv7b	2.52	2.177	0.67
N25culv8	2.52	2.18	0.67
N25culv9U	2.50	3.165	0.67
N25culv9	2.50	3.168	0.84
COMB1a	2.50	4.161	0.52
COMB1b	2.50	4.163	0.43
COMB2	2.50	4.196	0.43
COMB2a	2.50	5.308	0.28
6DOU_1370	25.17	7.028	2.08
6DOU_1276	23.32	5.767	1.76
6DOU_1130	20.46	-0.018	2.23
6DOU_1130d	20.46	-0.018	2.23
6DOU_1100	19.92	5.775	1.92
6DOU_1059	19.20	3.769	1.87
6DOU_1009	18.29	3.11	1.90
6DOU_960	17.39	3.109	2.10
6DOU_952	17.22	3.11	1.86
6DOU_960d	17.39	3.11	2.10
6DOU_952d1	16.80	3.109	1.93
6DOU_952d2	16.80	3.109	1.93
6DOU_914	16.43	3.109	1.01
6DOU_914J	16.43	3.109	2.36
6DO1_0	17.47	3.109	1.60
6DO1_0S	16.43	3.109	1.91
6DOU_845	15.67	3.109	1.34
6DOU_828	15.28	3.109	3.44

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DOU_828d	15.28	3.109	3.44
6DOU_803	14.57	7.333	2.19
6DOU_758	13.98	3.804	1.60
6DOU_721	13.70	3.804	1.70
6DOU_678	13.36	7.332	1.58
6DOU_641	12.67	7.332	2.74
6DOU_628	12.39	7.332	2.23
6DOU_611	12.16	7.332	1.72
6DOU_614i1	11.93	7.332	1.84
6DOU_573	11.70	7.332	2.15
6DOU_559	11.49	7.332	2.54
6DOU_539	11.20	7.331	2.29
6DOU_524	11.13	7.332	1.85
6DOU_518	11.08	7.332	1.99
6DOU_511	10.99	7.332	2.39
6DOU_506	10.91	7.332	2.24
6DOU_501	10.86	7.332	2.13
6DOU_501d	10.86	7.332	2.13
6DOU_495	10.76	7.332	2.33
6DOU_490	10.67	7.332	2.70
6DOU_484	10.58	7.332	2.53
6DOU_477	10.49	7.332	2.36
6DOU_472	10.43	7.332	2.30
6DOU_468	10.38	7.332	2.26
6DOU_468d	10.38	7.332	2.26
6DOU_464	10.33	7.332	2.27
6DOU_460	10.28	7.332	2.29
6DOU_455	10.21	7.332	2.27
6DOU_448	10.12	7.332	2.22
6DOU_443	10.08	7.332	2.16
6DOU_438	10.04	7.332	2.05
6DOU_433	10.03	7.332	1.92
6DOU_428	10.02	7.332	1.79
6DOU_425	9.91	7.332	2.23
6DOU_420	9.85	7.332	2.26
6DOU_415	9.81	7.332	2.24
6DOU_405	9.73	7.332	2.18
6DOU_395	9.68	7.332	2.10

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DOU_384	9.63	7.332	1.99
6DOU_384r	9.59	7.332	2.08
6DOU_379	9.50	7.332	2.51
6DOU_379d	9.44	7.331	2.60
6DOU_367	9.26	7.331	2.70
6DOU_358	9.11	7.331	2.49
6DOU_358d	9.10	7.331	2.50
6DOU_341	8.70	7.331	3.90
6DOU_325	8.26	7.331	2.91
6DOU_306	8.01	7.331	2.25
6DOU_306d	8.00	7.331	2.26
6DOU_282	7.76	7.331	2.17
6DOU_234	7.25	7.331	2.25
6DOU_204	6.86	7.331	2.47
6DOU_154	6.20	7.331	2.24
6DOU_89	4.96	7.331	3.07
6DOU_65	4.38	7.331	2.89
6DOU_54	4.19	7.331	2.48
DOUFRS_18_3	4.11	7.331	1.73
DOUFRS_14_0	4.15	7.331	1.37
DOUFRS_10r	3.85	7.331	1.49
DOUFRS_14_0r	3.82	7.331	1.81
DOUFRS_10	3.85	7.331	1.49
DOUFRS_5_86	3.86	7.331	1.33
DOUFRS_3_36	3.84	7.331	1.39
DOUFRS_2_86	3.67	7.331	1.60
DOUFRS_00	3.63	7.331	1.75
BB_culv	3.00	7.331	3.56
BB_culv2	2.79	7.331	5.27
6DO1_1014	39.32	7.331	1.70
6DO1_929	37.00	7.331	2.43
6DO1_805	33.96	7.331	1.46
6DO1_726	32.22	7.331	1.57
6DO1_581	28.66	7.331	1.73
6DO1_498	26.82	7.331	1.70
6DO1_403	25.40	3.805	0.96
6DO1_395U	24.84	3.805	1.35
6DO1_395D	24.73	3.806	1.49

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DO1_395db	24.73	3.805	5.22
6DO1_395DU	24.73	3.805	1.49
6DO1_382	24.01	3.805	0.79
6DO1_363	23.69	3.804	1.93
6DO1_285	22.87	3.804	1.14
6DO1_277	22.86	3.804	0.91
6DO1_277Bd	22.78	3.804	2.58
6DO1_277d	22.78	3.804	1.00
6DO1_262	22.72	3.804	1.23
6DO1_253u	21.58	3.804	2.45
6DO1_253	21.39	3.804	2.62
6DO1_253CUin	21.39	3.804	5.41
6DO1_63CUout	18.45	3.804	5.00
6DO1_63	18.45	3.804	1.15
6DO1_56	18.31	3.804	2.29
6DO1_4	17.48	3.804	1.72
6DO1_4Bu	17.48	3.804	2.40
6DO1_4Spu	17.48	3.804	2.40
6DO1_4Bd	17.48	3.804	2.40
6DO1_4d	17.48	3.804	1.72
6TRA_470	2.55	3.803	0.79
6TRA_461	2.55	3.803	0.73
6DO1_1177	44.87	3.806	1.905
6DO1_1129	42.636	3.806	2.508
6DO1_1076	41.356	3.806	1.32
6DO1_1045	40.399	3.806	2.293
6DO1_1014	39.305	3.805	1.785
6DO1_929	37.009	3.805	2.454
6DO1_805	33.937	3.805	1.567
6DO1_726	32.23	3.805	1.506
6DO1_581	28.584	3.804	2.089
6DO1_498	26.827	3.803	1.684
6DO1_466	26.229	3.803	1.81
6DO1_434	25.638	3.803	1.902
6DO1_402	25.273	3.803	1.228
402_rpt	25.216	3.803	0.244
397_us	25.204	3.803	0.52
397_ds	24.122	3.803	1.88

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DO1_395us	24.059	3.803	3.433
6DO1_395cul	24.006	3.803	4.816
6DO1_387culd	23.945	3.803	2.36
6DO1_387_ds	23.945	3.803	2.645
6DO1_382	23.876	3.803	1.375
6DO1_374	23.721	3.803	1.789
6DO1_374BU	23.721	3.803	0.638
6DO1_374BD	23.721	3.803	0.638
6DO1_374d	23.721	3.803	1.789
6DO1_324	23.019	3.803	2.239
6DO1_285	22.279	3.802	2.195
6DO1_277	22.174	3.802	1.64
6DO1_277Bu	22.174	3.802	2.583
6DO1_277Spu	22.174	0	2.583
6DO1_277Bd	22.02	3.802	2.583
6DO1_277d	22.02	3.802	2.105
6DO1_277Spd	22.02	0	2.583
6DO1_262	21.727	3.802	2.472
6DO1_253	21.528	3.802	2.356
6DO1_253CUin	21.528	3.802	2.577
6DO1_253Spu	21.528	0	0.999
6DO1_253Spd	18.844	0	0.999
Culver_XS1	21.2	3.802	2.59
Culvert_XS2	20.888	3.802	2.489
Culvert_XS3	20.65	3.802	2.086
Culvert_MH1	20.548	3.802	1.815
Culvert_MH2	20.321	3.802	2.141
Cul_MH2DS	20.25	3.802	2.346
Culvert_MH3	20.249	3.802	1.934
Cul_MH3_DS	20.192	3.802	2.038
Culvert_MH4	20.154	3.802	2.036
Culvert_MH4B	20.154	3.802	2.036
Culvert_MH5	20.022	3.802	2.285
Culvert_MH6	19.64	3.802	3.317
6DO1_63CUout	18.844	3.802	2.45
Culvert_DS	18.844	3.802	1.392
6DO1_const_	18.781	3.802	1.67
6DO1_63b	18.612	3.802	1.818

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DO1_63a	18.842	3.802	1.086
Bridge_US	18.842	3.802	0.568
6DO1_56	18.315	3.802	2.358
Bridge_DS	18.612	3.802	0.568
6DO1_4	17.481	3.802	1.758
6DO1_4Bu	17.481	3.802	2.399
6DO1_4Spu	17.481	0	2.399
6DO1_4Bd	17.481	3.802	2.399
6DO1_4d	17.481	3.802	1.758
6DO1_4Spd	17.481	0	2.399
6DO1_0	17.472	3.802	1.632
6DO1_0S	16.716	3.802	1.906

B1.3 Q10 Model Results

Table 7: Q10 model run - Existing scenario

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6TRA_2506	4.32	15.77	0.57
6TRA_2446	4.30	15.77	0.63
6TRA_2406	4.29	15.77	0.53
6TRA_2329	4.26	15.76	0.54
6TRA_2263	3.84	15.76	2.00
6TRA_2170	3.77	15.75	0.40
6TRA_2088	3.75	15.75	0.39
6TRA_2014	3.49	15.74	1.32
6TRA_1900	3.25	15.68	0.84
6TRA_1785	3.10	15.57	1.77
6TRA_1735	3.10	15.53	0.50
6TRA_1655	3.05	15.49	0.77
6TRA_1541	2.95	15.50	1.08
6TRA_1431	2.90	15.52	0.83
6TRA_1340	2.86	15.55	0.82
6TRA_1263	2.84	15.58	0.76
6TRA_1175	2.80	15.62	0.80
6TRA_1096	2.78	15.66	0.76
6TRA_1021	2.76	15.71	0.72
6TRA_938	2.76	15.98	0.65
6TRA_852	2.73	16.36	0.68

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6TRA_759	2.71	16.49	0.91
6TRA_682	2.68	16.59	0.90
6TRA_619	2.66	16.66	0.93
6TRA_609Cin	2.63	16.68	0.90
6TRA_538Cout	2.62	16.77	0.91
6TRA_538	2.60	16.77	0.96
6TRA_532	2.60	16.80	0.92
USbridge1	2.58	17.07	0.82
USbridge2	2.57	17.09	0.82
USu	2.57	17.09	0.82
2d	2.57	17.11	0.79
3u	2.57	17.11	0.75
4u2	2.57	17.14	0.74
4u3	2.57	15.75	0.68
4u4	2.57	15.77	0.68
4u5	2.57	14.66	0.63
4u6	2.57	14.67	0.63
4u7	2.57	13.58	0.59
N25culv3	2.55	1.45	0.36
4u8	2.57	13.59	0.59
4u9	2.57	12.51	0.54
4d	2.57	12.52	0.54
5CUL	2.57	11.92	0.71
6CUL	2.56	11.96	0.72
6CULd	2.56	11.96	0.72
6CULdi	2.56	16.59	0.99
bal3d	2.56	8.00	1.56
7CULu	2.56	16.59	0.99
7CULd	2.56	16.59	0.99
8CULU	2.52	16.84	0.97
8CUL	2.52	18.21	1.05
8CULa	2.52	18.23	1.04
8CULb	2.52	18.68	1.07
8CULbb	2.52	18.70	1.07
8CULD	2.52	19.48	1.11
8CULDd	2.51	19.51	1.11
8CULDa	2.51	21.12	1.18
8culDD	2.51	21.13	1.18

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
N25culv9d	2.52	6.28	1.00
COMB1	2.52	8.19	0.61
9CULup2	2.51	25.33	1.22
COMB3	2.51	4.49	0.63
9CULdd	2.51	25.33	1.22
9CULOLD	2.51	25.33	1.25
9CULOLDd	2.48	25.40	1.25
9CULOLDdd	2.48	25.40	1.23
9CULstrucup	2.45	25.51	1.24
9CULoutU	2.45	25.51	1.24
9CULoutUd	2.44	25.55	1.25
9CULoutDu	2.44	25.55	1.25
9CULoutD	2.44	25.58	1.26
6TRA_20	2.43	25.58	1.25
6TRA_0s	2.43	25.61	2.48
Sedtrap_Cul1	2.83	7.97	3.63
Sedtrap_Cul2	2.73	7.97	3.21
bal1u	2.73	7.97	5.01
bal1u2	2.66	7.97	1.66
bal_new	2.66	7.97	1.66
bal1d	2.64	7.97	1.61
bal2u	2.64	7.97	1.61
bal2d	2.59	7.99	1.32
bal3u	2.59	7.99	1.56
5ochd	2.56	1.74	0.27
6och	2.56	1.75	0.27
7och	2.56	4.45	0.69
8och	2.53	4.48	0.68
N25culv4	2.55	1.45	0.24
N25culv5	2.55	2.64	0.43
N25culv6	2.55	2.64	0.43
N25culv7	2.55	3.81	0.62
N25culv7a	2.55	3.81	0.62
N25culv7b	2.55	4.99	0.82
N25culv8	2.55	4.99	0.82
N25culv9U	2.52	5.04	0.80
N25culv9	2.52	6.27	1.00
COMB1a	2.52	8.19	0.61

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
COMB1b	2.52	6.71	0.50
COMB2	2.52	6.72	0.50
COMB2a	2.52	4.48	0.33
6DOU_1370	25.22	3.69	2.21
6DOU_1276	23.36	3.69	1.81
6DOU_1130	20.53	3.69	2.38
6DOU_1130d	20.53	3.69	2.38
6DOU_1100	19.97	3.69	2.05
6DOU_1059	19.24	3.69	1.98
6DOU_1009	18.34	3.69	2.00
6DOU_960	17.44	3.69	2.23
6DOU_952	17.27	3.69	1.97
6DOU_960d	17.44	3.69	2.23
6DOU_952d1	16.87	3.69	2.02
6DOU_952d2	16.87	3.69	2.02
6DOU_914	16.51	3.69	1.05
6DOU_914J	16.51	8.69	2.45
6DO1_0	17.57	4.51	1.66
6DO1_0S	16.51	4.51	1.91
6DOU_845	15.75	8.69	1.42
6DOU_828	15.35	8.69	3.68
6DOU_828d	15.35	8.69	3.68
6DOU_803	14.63	8.69	2.21
6DOU_758	14.04	8.69	1.61
6DOU_721	13.76	8.69	1.69
6DOU_678	13.40	8.69	1.64
6DOU_641	12.73	8.69	2.84
6DOU_628	12.46	8.69	2.41
6DOU_611	12.23	8.69	1.76
6DOU_614i1	12.02	8.69	1.87
6DOU_573	11.79	8.69	2.22
6DOU_559	11.60	8.69	2.63
6DOU_539	11.31	8.69	2.40
6DOU_524	11.23	8.69	1.98
6DOU_518	11.18	8.69	2.13
6DOU_511	11.08	8.69	2.51
6DOU_506	11.01	8.69	2.33
6DOU_501	10.98	8.69	2.17

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DOU_501d	10.98	8.69	2.17
6DOU_495	10.87	8.69	2.44
6DOU_490	10.79	8.69	2.83
6DOU_484	10.69	8.69	2.66
6DOU_477	10.60	8.69	2.46
6DOU_472	10.55	8.69	2.35
6DOU_468	10.52	8.69	2.28
6DOU_468d	10.52	8.69	2.28
6DOU_464	10.48	8.69	2.29
6DOU_460	10.45	8.69	2.31
6DOU_455	10.44	8.67	2.29
6DOU_448	10.42	8.67	2.24
6DOU_443	10.41	8.67	2.19
6DOU_438	10.41	8.67	2.08
6DOU_433	10.41	8.67	1.94
6DOU_428	10.41	8.67	1.81
6DOU_425	10.41	8.11	2.25
6DOU_420	9.93	8.11	2.28
6DOU_415	9.89	8.11	2.25
6DOU_405	9.83	8.11	2.19
6DOU_395	9.79	8.11	2.11
6DOU_384	9.75	8.11	1.99
6DOU_384r	9.71	8.11	2.08
6DOU_379	9.66	7.79	2.51
6DOU_379d	9.50	7.79	2.62
6DOU_367	9.32	7.86	2.70
6DOU_358	9.18	7.97	2.49
6DOU_358d	9.14	7.97	2.52
6DOU_341	8.74	7.97	3.95
6DOU_325	8.32	7.97	2.97
6DOU_306	8.07	7.97	2.28
6DOU_306d	8.05	7.97	2.34
6DOU_282	7.81	7.97	2.22
6DOU_234	7.30	7.97	2.31
6DOU_204	6.91	7.97	2.53
6DOU_154	6.23	7.97	2.34
6DOU_89	5.01	7.97	3.12
6DOU_65	4.44	7.97	2.94

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DOU_54	4.24	7.97	2.54
DOUFRS_18_3	4.17	7.97	1.78
DOUFRS_14_0	4.21	7.97	1.42
DOUFRS_10r	3.91	7.97	1.54
DOUFRS_14_0r	3.88	7.97	1.86
DOUFRS_10	3.91	7.97	1.54
DOUFRS_5_86	3.92	7.97	1.38
DOUFRS_3_36	3.91	7.97	1.45
DOUFRS_2_86	3.75	7.97	1.63
DOUFRS_00	3.70	7.97	1.80
BB_culv	3.03	7.97	3.70
BB_culv2	2.83	7.97	5.51
6DO1_1014	39.39	4.52	1.76
6DO1_929	37.07	4.52	2.54
6DO1_805	34.00	4.52	1.60
6DO1_726	32.25	4.52	1.57
6DO1_581	28.72	4.51	1.82
6DO1_498	26.87	4.52	1.74
6DO1_403	25.48	4.51	1.01
6DO1_395U	24.97	4.51	1.44
6DO1_395D	24.84	4.51	1.59
6DO1_395db	24.84	4.51	5.22
6DO1_395DU	24.84	4.51	1.59
6DO1_382	24.10	4.51	0.85
6DO1_363	23.77	4.51	2.00
6DO1_285	23.02	4.52	1.14
6DO1_277	23.01	4.52	0.93
6DO1_277Bd	22.92	4.52	2.58
6DO1_277d	22.92	4.52	1.02
6DO1_262	22.85	4.51	1.30
6DO1_253u	21.71	4.51	2.52
6DO1_253	21.54	4.51	2.62
6DO1_253CUin	21.54	4.51	5.42
6DO1_63CUout	18.52	4.51	5.51
6DO1_63	18.52	4.51	1.20
6DO1_56	18.38	4.51	2.37
6DO1_4	17.58	4.51	1.82
6DO1_4Bu	17.58	4.51	2.40

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DO1_4Spu	17.58	0.00	2.40
6DO1_4Bd	17.58	4.51	2.40
6DO1_4d	17.58	4.51	1.82
6TRA_470	2.59	16.86	0.91
6TRA_461	2.59	17.07	0.85
6DO1_1177	44.9	4.516	1.974
6DO1_1129	42.725	4.516	2.565
6DO1_1076	41.396	4.516	1.454
6DO1_1045	40.44	4.516	2.294
6DO1_1014	39.37	4.516	1.842
6DO1_929	37.08	4.516	2.555
6DO1_805	33.98	4.515	1.7
6DO1_726	32.255	4.517	1.507
6DO1_581	28.638	4.513	2.192
6DO1_498	26.878	4.514	1.733
6DO1_466	26.276	4.513	1.902
6DO1_434	25.698	4.513	1.935
6DO1_402	25.365	4.513	1.229
402_rpt	25.31	4.513	0.272
397_us	25.295	4.513	0.582
397_ds	24.212	4.513	1.881
6DO1_395us	24.165	4.513	3.436
6DO1_395cul	24.092	4.513	4.82
6DO1_387culd	24.045	4.513	2.423
6DO1_387_ds	24.045	4.513	2.69
6DO1_382	23.983	4.513	1.375
6DO1_374	23.798	4.513	1.945
6DO1_374BU	23.798	4.513	0.638
6DO1_374BD	23.798	4.513	0.638
6DO1_374d	23.798	4.513	1.945
6DO1_324	23.086	4.513	2.324
6DO1_285	22.37	4.512	2.262
6DO1_277	22.284	4.512	1.667
6DO1_277Bu	22.284	4.512	2.583
6DO1_277Spu	22.284	0	2.583
6DO1_277Bd	22.09	4.512	2.583
6DO1_277d	22.09	4.512	2.214
6DO1_277Spd	22.09	0	2.583

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DO1_262	21.816	4.512	2.519
6DO1_253	21.629	4.512	2.492
6DO1_253CUin	21.629	4.512	2.688
6DO1_253Spu	21.629	0	0.999
6DO1_253Spd	18.936	0	0.999
Culver_XS1	21.307	4.512	2.692
Culvert_XS2	21.002	4.512	2.578
Culvert_XS3	20.795	4.512	2.128
Culvert_MH1	20.684	4.512	1.923
Culvert_MH2	20.435	4.512	2.283
Cul_MH2DS	20.356	4.512	2.456
Culvert_MH3	20.341	4.512	2.119
Cul_MH3_DS	20.272	4.512	2.247
Culvert_MH4	20.225	4.512	2.257
Culvert_MH4B	20.225	4.512	2.257
Culvert_MH5	20.092	4.512	2.513
Culvert_MH6	19.704	4.512	3.47
6DO1_63CUout	18.936	4.512	2.532
Culvert_DS	18.936	4.512	1.393
6DO1_const_	18.86	4.512	1.714
6DO1_63b	18.666	4.512	1.911
6DO1_63a	18.932	4.512	1.086
Bridge_US	18.932	4.512	0.568
6DO1_56	18.382	4.512	2.427
Bridge_DS	18.666	4.512	0.568
6DO1_4	17.575	4.512	1.861
6DO1_4Bu	17.575	4.512	2.399
6DO1_4Spu	17.575	0	2.399
6DO1_4Bd	17.575	4.512	2.399
6DO1_4d	17.575	4.512	1.861
6DO1_4Spd	17.575	0	2.399
6DO1_0	17.574	4.512	1.69
6DO1_0S	16.741	4.512	1.906

B1.4 Q25 Model Results

Table 8: Q25 model run - Existing scenario

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6TRA_2506	4.52	19.88	0.60
6TRA_2446	4.51	19.84	0.64
6TRA_2406	4.49	19.82	0.55
6TRA_2329	4.47	19.81	0.57
6TRA_2263	3.95	19.80	2.26
6TRA_2170	3.88	19.80	0.45
6TRA_2088	3.86	19.78	0.43
6TRA_2014	3.61	19.76	1.33
6TRA_1900	3.39	19.64	0.85
6TRA_1785	3.27	19.48	1.79
6TRA_1735	3.27	19.40	0.51
6TRA_1655	3.22	19.33	0.84
6TRA_1541	3.11	19.32	1.19
6TRA_1431	3.05	19.32	0.91
6TRA_1340	3.02	19.35	0.88
6TRA_1263	2.99	19.37	0.82
6TRA_1175	2.95	19.40	0.85
6TRA_1096	2.92	19.43	0.81
6TRA_1021	2.90	19.49	0.77
6TRA_938	2.91	19.72	0.70
6TRA_852	2.88	20.05	0.75
6TRA_759	2.84	20.23	0.95
6TRA_682	2.80	20.31	1.05
6TRA_619	2.77	20.39	1.08
6TRA_609Cin	2.73	20.40	1.05
6TRA_538Cout	2.73	20.50	1.06
6TRA_538	2.70	20.50	1.13
6TRA_532	2.70	20.50	1.07
USbridge1	2.65	21.45	0.99
USbridge2	2.65	21.48	1.00
USu	2.65	21.48	0.99
2d	2.65	21.52	0.96
3u	2.65	21.52	0.90
4u2	2.64	21.56	0.90
4u3	2.64	19.74	0.82

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
4u4	2.64	19.74	0.82
4u5	2.64	18.40	0.77
4u6	2.64	18.40	0.76
4u7	2.64	17.11	0.71
N25culv3	2.62	1.87	0.46
4u8	2.64	17.11	0.71
4u9	2.64	15.82	0.65
4d	2.64	15.82	0.65
5CUL	2.64	14.68	0.86
6CUL	2.63	14.71	0.86
6CULd	2.63	14.72	0.86
6CULdi	2.63	19.64	1.16
bal3d	2.63	8.56	1.67
7CULu	2.63	19.64	1.15
7CULd	2.63	19.64	1.15
8CULU	2.57	19.84	1.16
8CUL	2.57	0.85	0.00
8CULa	2.57	22.11	1.28
8CULb	2.56	22.12	1.27
8CULbb	2.56	23.15	1.33
8CULD	2.56	23.17	1.32
8CULDd	2.56	25.03	1.43
8CULDa	2.57	7.55	1.20
8culDD	2.57	9.71	0.72
N25culv9d	2.55	30.02	1.46
COMB1	2.55	5.04	0.71
9CULup2	2.55	30.02	1.46
COMB3	2.55	30.02	1.48
9CULdd	2.50	30.13	1.49
9CULOLD	2.50	30.13	1.48
9CULOLDd	2.47	30.26	1.51
9CULOLDdd	2.47	30.26	1.51
9CULstrucup	2.45	30.31	1.53
9CULoutU	2.45	30.31	1.53
9CULoutUd	2.44	30.35	1.54
9CULoutDu	2.43	30.35	1.54
9CULoutD	2.43	30.39	2.52
6TRA_20	2.90	8.56	3.83

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6TRA_0s	2.82	8.56	3.33
Sedtrap_Cul1	2.82	8.56	5.20
Sedtrap_Cul2	2.75	8.56	1.67
bal1u	2.75	8.56	1.67
bal1u2	2.73	8.56	1.67
bal_new	2.73	8.56	1.60
bal1d	2.66	8.56	1.34
bal2u	2.66	8.56	1.67
bal2d	2.63	2.18	0.33
bal3u	2.63	2.19	0.33
5ochd	2.63	5.43	0.81
6och	2.58	5.47	0.81
7och	2.63	1.87	0.31
8och	2.63	3.28	0.53
N25culv4	2.62	3.28	0.53
N25culv5	2.62	4.66	0.76
N25culv6	2.62	4.66	0.76
N25culv7	2.62	6.06	0.98
N25culv7a	2.62	6.07	0.98
N25culv7b	2.57	6.13	0.97
N25culv8	2.57	7.55	1.20
N25culv9U	2.57	9.72	0.72
N25culv9	2.57	7.96	0.59
COMB1a	2.57	-0.04	0.00
COMB1b	2.57	-0.04	0.00
COMB2	25.30	4.64	2.37
COMB2a	23.42	4.64	1.92
6DOU_1370	20.63	4.64	2.58
6DOU_1276	20.63	4.64	2.58
6DOU_1130	20.04	4.64	2.21
6DOU_1130d	19.30	4.64	2.13
6DOU_1100	18.42	4.64	2.14
6DOU_1059	17.53	4.64	2.41
6DOU_1009	17.36	4.64	2.12
6DOU_960	17.53	4.64	2.41
6DOU_952	16.96	4.64	2.13
6DOU_960d	16.96	4.64	2.13
6DOU_952d1	16.62	4.64	1.10

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DOU_952d2	16.62	10.93	2.55
6DOU_914	17.72	5.67	1.71
6DOU_914J	16.62	5.67	1.91
6DO1_0	15.88	10.92	1.52
6DO1_0S	15.45	10.92	4.05
6DOU_845	15.45	10.92	4.05
6DOU_828	14.71	10.92	2.38
6DOU_828d	14.11	10.92	1.63
6DOU_803	13.83	10.92	1.69
6DOU_758	13.47	10.92	1.70
6DOU_721	12.83	10.92	2.90
6DOU_678	12.58	10.92	2.66
6DOU_641	12.34	10.92	1.79
6DOU_628	12.16	10.92	1.90
6DOU_611	11.94	10.92	2.32
6DOU_614i1	11.75	10.92	2.77
6DOU_573	11.47	10.92	2.56
6DOU_559	11.40	10.92	2.11
6DOU_539	11.33	10.92	2.31
6DOU_524	11.23	10.92	2.67
6DOU_518	11.17	10.92	2.45
6DOU_511	11.15	10.92	2.24
6DOU_506	11.15	10.92	2.24
6DOU_501	11.04	10.92	2.58
6DOU_501d	10.96	10.92	3.02
6DOU_495	10.85	10.92	2.85
6DOU_490	10.75	10.92	2.64
6DOU_484	10.70	10.92	2.52
6DOU_477	10.67	10.92	2.41
6DOU_472	10.67	10.92	2.41
6DOU_468	10.64	10.92	2.37
6DOU_468d	10.61	10.92	2.33
6DOU_464	10.52	11.23	2.42
6DOU_460	10.50	11.23	2.27
6DOU_455	10.49	11.23	2.17
6DOU_448	10.50	11.23	2.06
6DOU_443	10.50	11.23	1.93
6DOU_438	10.51	11.23	1.80

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DOU_433	10.62	8.42	2.25
6DOU_428	9.94	8.45	2.35
6DOU_425	9.90	8.45	2.33
6DOU_420	9.83	8.45	2.28
6DOU_415	9.79	8.45	2.21
6DOU_405	9.75	8.45	2.14
6DOU_395	9.71	8.45	2.25
6DOU_384	9.73	7.80	2.51
6DOU_384r	9.56	7.80	2.62
6DOU_379	9.48	7.94	2.70
6DOU_379d	9.33	8.52	2.49
6DOU_367	9.18	8.52	2.53
6DOU_358	8.79	8.56	3.97
6DOU_358d	8.39	8.56	2.99
6DOU_341	8.15	8.56	2.28
6DOU_325	8.09	8.56	2.41
6DOU_306	7.85	8.56	2.26
6DOU_306d	7.34	8.56	2.36
6DOU_282	6.95	8.56	2.58
6DOU_234	6.26	8.56	2.42
6DOU_204	5.05	8.56	3.15
6DOU_154	4.49	8.56	2.98
6DOU_89	4.29	8.56	2.59
6DOU_65	4.22	8.56	1.83
6DOU_54	4.26	8.56	1.47
DOUFRS_18_3	3.97	8.56	1.59
DOUFRS_14_0	3.94	8.56	1.89
DOUFRS_10r	3.97	8.56	1.59
DOUFRS_14_0r	3.98	8.56	1.43
DOUFRS_10	3.96	8.56	1.50
DOUFRS_5_86	3.81	8.56	1.66
DOUFRS_3_36	3.77	8.56	1.85
DOUFRS_2_86	3.07	8.56	3.75
DOUFRS_00	2.90	8.56	5.80
BB_culv	39.46	5.67	1.77
BB_culv2	37.16	5.67	2.61
6DO1_1014	34.06	5.67	1.81
6DO1_929	32.29	5.67	1.57

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DO1_805	28.80	5.67	1.97
6DO1_726	26.94	5.67	1.81
6DO1_581	25.59	5.67	1.06
6DO1_498	25.16	5.67	1.58
6DO1_403	25.03	5.67	1.73
6DO1_395U	25.03	5.67	5.22
6DO1_395D	25.03	5.67	1.73
6DO1_395db	25.03	0.00	0.00
6DO1_395DU	24.24	5.67	0.94
6DO1_382	23.25	5.67	1.14
6DO1_363	23.24	5.67	0.94
6DO1_285	23.13	5.67	2.58
6DO1_277	23.13	5.67	1.04
6DO1_277Bd	23.13	0.00	2.58
6DO1_277d	23.05	5.67	1.40
6DO1_262	21.80	5.67	2.62
6DO1_253u	21.80	5.67	5.42
6DO1_253	18.60	5.67	6.28
6DO1_253CUin	18.60	5.67	1.28
6DO1_63CUout	18.48	5.67	2.47
6DO1_63	17.74	5.67	1.92
6DO1_56	17.74	5.67	2.40
6DO1_4	17.74	0.00	2.40
6DO1_4Bu	17.74	5.67	2.40
6DO1_4Spu	17.74	5.67	1.92
6DO1_4Bd	17.74	0.00	2.40
6DO1_4d	2.68	20.61	1.07
6TRA_470	40.50	5.67	2.24
6TRA_461	41.46	5.67	1.61
6DO1_1177	44.948	5.674	2.053
6DO1_1129	42.846	5.674	2.567
6DO1_1076	41.458	5.674	1.634
6DO1_1045	40.499	5.673	2.295
6DO1_1014	39.456	5.673	1.842
6DO1_929	37.173	5.673	2.612
6DO1_805	34.041	5.673	1.898
6DO1_726	32.297	5.674	1.508
6DO1_581	28.723	5.671	2.328

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DO1_498	26.947	5.67	1.818
6DO1_466	26.342	5.67	2.024
6DO1_434	25.793	5.67	1.953
6DO1_402	25.507	5.67	1.23
402_rpt	25.453	5.67	0.314
397_us	25.433	5.67	0.672
397_ds	24.382	5.67	1.883
6DO1_395us	24.351	5.67	3.438
6DO1_395cul	24.234	5.67	4.825
6DO1_387culd	24.201	5.67	2.518
6DO1_387_ds	24.201	5.67	2.768
6DO1_382	24.146	5.67	1.375
6DO1_374	23.911	5.67	2.179
6DO1_374BU	23.911	5.67	0.638
6DO1_374BD	23.911	5.67	0.638
6DO1_374d	23.911	5.67	2.179
6DO1_324	23.192	5.67	2.41
6DO1_285	22.529	5.67	2.281
6DO1_277	22.465	5.673	1.686
6DO1_277Bu	22.465	5.673	2.583
6DO1_277Spu	22.465	0	2.583
6DO1_277Bd	22.216	5.673	2.583
6DO1_277d	22.216	5.673	2.341
6DO1_277Spd	22.216	0	2.583
6DO1_262	21.979	5.682	2.611
6DO1_253	21.816	5.684	2.673
6DO1_253CUin	21.816	5.684	2.85
6DO1_253Spu	21.816	0	0.999
6DO1_253Spd	19.074	0	0.999
Culver_XS1	21.535	5.68	2.865
Culvert_XS2	21.348	5.695	2.737
Culvert_XS3	21.325	5.695	2.298
Culvert_MH1	21.226	5.736	2.171
Culvert_MH2	21.055	5.684	2.463
Cul_MH2DS	21	5.684	2.662
Culvert_MH3	20.828	5.676	2.324
Cul_MH3_DS	20.746	5.676	2.478
Culvert_MH4	20.64	5.676	2.481

Model Cross Section	Max Stage (mOD)	Max Flow (m³/s)	Max Vel (m/s)
Culvert_MH4B	20.64	5.676	2.481
Culvert_MH5	20.309	5.676	2.931
Culvert_MH6	19.807	5.674	3.666
6DO1_63CUout	19.074	5.674	2.669
Culvert_DS	19.074	5.674	1.393
6DO1_const_	19.006	5.67	1.715
6DO1_63b	18.753	5.664	1.973
6DO1_63a	19.07	5.664	1.086
Bridge_US	19.07	5.664	0.568
6DO1_56	18.482	5.663	2.525
Bridge_DS	18.753	5.664	0.568
6DO1_4	17.749	5.665	1.959
6DO1_4Bu	17.749	5.665	2.399
6DO1_4Spu	17.749	0	2.399
6DO1_4Bd	17.746	5.665	2.399
6DO1_4d	17.746	5.665	1.96
6DO1_4Spd	17.746	0	2.399
6DO1_0	17.716	5.662	1.757
6DO1_0S	16.779	5.662	1.906

B1.5 Q50 Model Results

Table 9: Q50 model run - Existing scenario

Model Cross Section	Max Stage (mOD)	Max Flow (m³/s)	Max Vel (m/s)
6TRA_2506	4.63	22.29	0.61
6TRA_2446	4.62	22.25	0.64
6TRA_2406	4.60	22.23	0.55
6TRA_2329	4.58	22.21	0.58
6TRA_2263	4.00	22.21	2.41
6TRA_2170	3.94	22.20	0.47
6TRA_2088	3.92	22.20	0.46
6TRA_2014	3.68	22.16	1.33
6TRA_1900	3.48	21.99	0.85
6TRA_1785	3.37	21.79	1.80
6TRA_1735	3.37	21.70	0.52
6TRA_1655	3.32	21.61	0.87
6TRA_1541	3.20	21.58	1.25
6TRA_1431	3.15	21.56	0.96

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6TRA_1340	3.11	21.56	0.92
6TRA_1263	3.08	21.55	0.84
6TRA_1175	3.04	21.58	0.88
6TRA_1096	3.01	21.61	0.83
6TRA_1021	2.99	21.64	0.79
6TRA_938	3.00	21.84	0.72
6TRA_852	2.97	22.25	0.78
6TRA_759	2.93	22.56	0.97
6TRA_682	2.88	22.65	1.11
6TRA_619	2.85	22.71	1.16
6TRA_609Cin	2.80	22.72	1.13
6TRA_538Cout	2.80	22.79	1.14
6TRA_538	2.77	22.79	1.22
6TRA_532	2.77	22.80	1.16
USbridge1	2.71	24.18	1.09
USbridge2	2.70	24.19	1.10
USu	2.70	24.19	1.09
2d	2.70	24.21	1.06
3u	2.70	24.21	1.00
4u2	2.69	24.22	1.01
4u3	2.69	22.16	0.92
4u4	2.69	22.17	0.92
4u5	2.69	20.68	0.86
4u6	2.69	20.69	0.86
4u7	2.69	19.27	0.80
N25culv3	2.67	2.12	0.55
4u8	2.69	19.28	0.80
4u9	2.69	17.85	0.75
4d	2.69	17.86	0.75
5CUL	2.69	16.33	0.97
6CUL	2.68	16.37	0.98
6CULd	2.68	16.37	0.98
6CULdi	2.68	21.29	1.28
bal3d	2.68	8.78	1.71
7CULu	2.68	21.28	1.27
7CULd	2.68	21.28	1.27
8CULU	2.61	21.34	1.22
8CUL	2.61	23.15	1.32

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
8CULa	2.60	23.16	1.32
8CULb	2.60	23.76	1.35
8CULbb	2.60	23.77	1.35
8CULD	2.60	24.92	1.42
8CULDd	2.59	24.92	1.42
8CULDa	2.59	27.71	1.55
8culDD	2.58	27.72	1.55
N25culv9d	2.60	8.44	1.34
COMB1	2.60	10.73	0.80
9CULup2	2.58	33.21	1.60
COMB3	2.58	5.59	0.79
9CULdd	2.58	33.21	1.60
9CULOLD	2.58	33.21	1.64
9CULOLDd	2.52	33.25	1.64
9CULOLDdd	2.52	33.25	1.60
9CULstrucup	2.47	33.31	1.65
9CULoutU	2.47	33.31	1.65
9CULoutUd	2.45	33.34	1.67
9CULoutDu	2.45	33.34	1.67
9CULoutD	2.44	33.37	1.70
6TRA_20	2.43	33.37	1.69
6TRA_0s	2.43	33.40	2.61
Sedtrap_Cul1	2.93	8.75	3.93
Sedtrap_Cul2	2.86	8.75	3.47
bal1u	2.86	8.75	5.42
bal1u2	2.80	8.75	1.71
bal_new	2.80	8.75	1.71
bal1d	2.78	8.75	1.71
bal2u	2.78	8.75	1.59
bal2d	2.71	8.77	1.37
bal3u	2.71	8.77	1.71
5ochd	2.68	2.45	0.37
6och	2.67	2.46	0.36
7och	2.67	6.05	0.89
8och	2.61	6.10	0.89
N25culv4	2.67	2.14	0.37
N25culv5	2.67	3.61	0.62
N25culv6	2.67	3.62	0.62

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
N25culv7	2.67	5.12	0.86
N25culv7a	2.67	5.12	0.86
N25culv7b	2.67	6.64	1.09
N25culv8	2.67	6.64	1.10
N25culv9U	2.61	6.71	1.07
N25culv9	2.61	8.31	1.32
COMB1a	2.60	10.73	0.80
COMB1b	2.60	8.80	0.66
COMB2	2.60	8.80	0.66
COMB2a	2.60	5.59	0.42
6DOU_1370	25.34	5.20	2.44
6DOU_1276	23.45	5.20	1.97
6DOU_1130	20.68	5.20	2.69
6DOU_1130d	20.68	5.20	2.69
6DOU_1100	20.08	5.20	2.27
6DOU_1059	19.34	5.20	2.21
6DOU_1009	18.46	5.20	2.19
6DOU_960	17.58	5.20	2.51
6DOU_952	17.40	5.20	2.20
6DOU_960d	17.58	5.20	2.51
6DOU_952d1	17.01	5.20	2.20
6DOU_952d2	17.01	5.20	2.20
6DOU_914	16.68	5.20	1.13
6DOU_914J	16.68	12.25	2.61
6DO1_0	17.77	6.36	1.71
6DO1_0S	16.68	6.36	1.91
6DOU_845	15.95	12.25	1.56
6DOU_828	15.51	12.25	4.25
6DOU_828d	15.51	12.25	4.25
6DOU_803	14.75	12.25	2.46
6DOU_758	14.16	12.25	1.64
6DOU_721	13.87	12.25	1.69
6DOU_678	13.50	12.25	1.74
6DOU_641	12.89	12.25	2.90
6DOU_628	12.64	12.25	2.78
6DOU_611	12.41	12.25	1.80
6DOU_614i1	12.24	12.25	1.91
6DOU_573	12.02	12.25	2.36

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DOU_559	11.84	12.25	2.83
6DOU_539	11.57	12.25	2.60
6DOU_524	11.49	12.25	2.17
6DOU_518	11.42	12.25	2.39
6DOU_511	11.32	12.25	2.77
6DOU_506	11.25	12.25	2.53
6DOU_501	11.24	12.25	2.30
6DOU_501d	11.24	12.25	2.30
6DOU_495	11.13	12.25	2.67
6DOU_490	11.05	12.25	3.12
6DOU_484	10.94	12.25	2.95
6DOU_477	10.84	12.25	2.74
6DOU_472	10.79	12.23	2.61
6DOU_468	10.76	12.23	2.49
6DOU_468d	10.76	12.23	2.49
6DOU_464	10.74	12.23	2.45
6DOU_460	10.71	12.23	2.40
6DOU_455	10.58	12.90	2.63
6DOU_448	10.51	12.90	2.54
6DOU_443	10.50	12.90	2.45
6DOU_438	10.50	12.90	2.31
6DOU_433	10.50	12.90	2.16
6DOU_428	10.51	12.90	1.93
6DOU_425	10.72	8.42	2.25
6DOU_420	9.94	8.48	2.35
6DOU_415	9.90	8.48	2.34
6DOU_405	9.83	8.48	2.30
6DOU_395	9.79	8.48	2.23
6DOU_384	9.75	8.48	2.17
6DOU_384r	9.71	8.48	2.28
6DOU_379	9.75	7.80	2.51
6DOU_379d	9.58	7.80	2.62
6DOU_367	9.58	7.95	2.70
6DOU_358	9.59	8.67	2.49
6DOU_358d	9.24	8.67	2.53
6DOU_341	8.81	8.77	3.98
6DOU_325	8.41	8.77	3.00
6DOU_306	8.19	8.77	2.28

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DOU_306d	8.10	8.77	2.44
6DOU_282	7.86	8.77	2.28
6DOU_234	7.35	8.77	2.38
6DOU_204	6.97	8.76	2.60
6DOU_154	6.27	8.76	2.44
6DOU_89	5.07	8.76	3.17
6DOU_65	4.50	8.75	2.99
6DOU_54	4.31	8.75	2.61
DOUFRS_18_3	4.24	8.75	1.84
DOUFRS_14_0	4.28	8.75	1.49
DOUFRS_10r	3.99	8.75	1.60
DOUFRS_14_0r	3.96	8.75	1.91
DOUFRS_10	3.99	8.75	1.60
DOUFRS_5_86	4.00	8.75	1.44
DOUFRS_3_36	3.98	8.75	1.51
DOUFRS_2_86	3.84	8.75	1.68
DOUFRS_00	3.79	8.76	1.86
BB_culv	3.09	8.76	3.85
BB_culv2	2.93	8.75	5.95
6DO1_1014	39.51	6.36	1.81
6DO1_929	37.21	6.36	2.61
6DO1_805	34.09	6.36	1.91
6DO1_726	32.31	6.36	1.57
6DO1_581	28.84	6.36	2.04
6DO1_498	26.98	6.36	1.85
6DO1_403	25.65	6.36	1.09
6DO1_395U	25.27	6.36	1.66
6DO1_395D	25.13	6.36	1.81
6DO1_395db	25.13	6.36	5.22
6DO1_395DU	25.13	6.36	1.81
6DO1_382	24.33	6.36	0.98
6DO1_363	23.97	6.36	2.13
6DO1_285	23.38	6.36	1.14
6DO1_277	23.37	6.36	0.94
6DO1_277Bd	23.24	6.36	2.58
6DO1_277d	23.24	6.36	1.05
6DO1_262	23.16	6.36	1.46
6DO1_253u	22.05	6.36	2.59

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DO1_253	21.96	6.36	2.62
6DO1_253CUin	21.96	6.36	5.42
6DO1_63CUout	18.66	6.36	6.65
6DO1_63	18.66	6.36	1.31
6DO1_56	18.54	6.36	2.52
6DO1_4	17.82	6.36	1.92
6DO1_4Bu	17.82	6.34	2.40
6DO1_4Spu	17.82	0.02	2.40
6DO1_4Bd	17.80	6.34	2.40
6DO1_4d	17.80	6.36	1.97
6TRA_470	2.75	22.86	1.16
6TRA_461	2.73	24.18	1.11
6DO1_1177	44.974	6.362	2.105
6DO1_1129	42.902	6.362	2.568
6DO1_1076	41.503	6.362	1.676
6DO1_1045	40.533	6.361	2.295
6DO1_1014	39.499	6.361	1.865
6DO1_929	37.221	6.361	2.615
6DO1_805	34.075	6.361	2.002
6DO1_726	32.317	6.361	1.508
6DO1_581	28.767	6.359	2.399
6DO1_498	26.983	6.359	1.869
6DO1_466	26.376	6.359	2.087
6DO1_434	25.846	6.359	1.955
6DO1_402	25.586	6.358	1.229
402_rpt	25.533	6.358	0.336
397_us	25.511	6.358	0.721
397_ds	24.492	6.358	1.883
6DO1_395us	24.466	6.358	3.44
6DO1_395cul	24.319	6.358	4.827
6DO1_387culd	24.29	6.358	2.568
6DO1_387_ds	24.29	6.358	2.81
6DO1_382	24.238	6.358	1.375
6DO1_374	23.974	6.358	2.301
6DO1_374BU	23.974	6.358	0.638
6DO1_374BD	23.974	6.358	0.638
6DO1_374d	23.974	6.358	2.301
6DO1_324	23.25	6.358	2.451

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DO1_285	22.634	6.357	2.282
6DO1_277	22.609	6.357	1.687
6DO1_277Bu	22.609	6.357	2.583
6DO1_277Spu	22.609	0	2.583
6DO1_277Bd	22.385	6.357	2.583
6DO1_277d	22.385	6.357	2.346
6DO1_277Spd	22.385	0	2.583
6DO1_262	22.197	6.357	2.614
6DO1_253	22.027	6.356	2.678
6DO1_253CUin	22.027	6.356	2.855
6DO1_253Spu	22.027	0	0.999
6DO1_253Spd	19.143	0	0.999
Culver_XS1	21.924	6.355	2.869
Culvert_XS2	21.872	6.355	2.74
Culvert_XS3	21.788	6.355	2.304
Culvert_MH1	21.609	6.355	2.175
Culvert_MH2	21.371	6.355	2.465
Cul_MH2DS	21.301	6.355	2.664
Culvert_MH3	21.07	6.355	2.602
Cul_MH3_DS	20.966	6.355	2.602
Culvert_MH4	20.835	6.355	2.748
Culvert_MH4B	20.835	6.355	2.748
Culvert_MH5	20.421	6.355	3.282
Culvert_MH6	19.867	6.355	3.761
6DO1_63CUout	19.143	6.356	2.766
Culvert_DS	19.143	6.356	1.393
6DO1_const_	19.074	6.357	1.716
6DO1_63b	18.804	6.359	1.973
6DO1_63a	19.139	6.359	1.09
Bridge_US	19.139	6.359	0.568
6DO1_56	18.544	6.368	2.569
Bridge_DS	18.804	6.359	0.568
6DO1_4	17.832	6.37	1.961
6DO1_4Bu	17.832	6.339	2.399
6DO1_4Spu	17.832	0.031	2.399
6DO1_4Bd	17.806	6.339	2.399
6DO1_4d	17.806	6.37	1.987
6DO1_4Spd	17.806	0.031	2.399

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DO1_0	17.776	6.359	1.756
6DO1_0S	16.802	6.359	1.906

B1.6 Q100 Model Results

Table 10: Q100 model run - Existing scenario

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6TRA_2506	4.72	25.47	0.73
6TRA_2446	4.70	26.15	0.66
6TRA_2406	4.69	26.58	0.68
6TRA_2329	4.66	28.73	0.76
6TRA_2263	4.33	31.18	2.53
6TRA_2170	4.05	32.23	0.63
6TRA_2088	4.02	29.32	0.55
6TRA_2014	3.80	27.54	1.34
6TRA_1900	3.63	27.50	0.85
6TRA_1785	3.53	25.96	1.80
6TRA_1735	3.53	25.54	0.51
6TRA_1655	3.48	25.18	0.89
6TRA_1541	3.37	25.03	1.32
6TRA_1431	3.33	25.20	1.02
6TRA_1340	3.29	25.32	0.96
6TRA_1263	3.27	25.03	0.88
6TRA_1175	3.22	24.58	0.90
6TRA_1096	3.20	24.48	0.84
6TRA_1021	3.18	24.70	0.81
6TRA_938	3.20	24.80	0.73
6TRA_852	3.18	25.02	0.79
6TRA_759	3.13	25.40	0.97
6TRA_682	3.08	25.50	1.19
6TRA_619	3.05	25.55	1.22
6TRA_609Cin	3.00	25.56	1.20
6TRA_538Cout	2.99	25.63	1.21
6TRA_538	2.96	25.63	1.30
6TRA_532	2.96	25.63	1.23
USbridge1	2.88	27.64	1.17
USbridge2	2.88	27.66	1.18
USu	2.88	27.66	1.21

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
2d	2.88	27.67	1.17
3u	2.88	27.67	1.11
4u2	2.87	27.68	1.11
4u3	2.87	25.26	1.01
4u4	2.86	25.26	1.01
4u5	2.86	23.65	0.95
4u6	2.86	23.65	0.95
4u7	2.86	22.12	0.89
N25culv3	2.84	2.42	0.58
4u8	2.86	22.12	0.89
4u9	2.86	20.59	0.82
4d	2.86	20.59	0.82
5CUL	2.86	17.79	1.01
6CUL	2.85	17.80	1.02
6CULd	2.85	17.80	1.02
6CULdi	2.85	22.46	1.27
bal3d	2.85	8.78	1.72
7CULu	2.85	22.46	1.27
7CULd	2.85	22.46	1.27
8CULU	2.76	22.93	1.32
8CUL	2.76	24.68	1.43
8CULa	2.75	24.71	1.43
8CULb	2.75	25.16	1.45
8CULbb	2.74	25.13	1.45
8CULD	2.74	26.81	1.52
8CULDd	2.73	26.81	1.51
8CULDa	2.73	30.46	1.71
8culDD	2.72	30.46	1.71
N25culv9d	2.75	9.17	1.46
COMB1	2.75	11.87	0.88
9CULup2	2.72	36.50	1.76
COMB3	2.72	6.07	0.85
9CULdd	2.72	36.50	1.76
9CULOLD	2.72	36.50	1.80
9CULOLDd	2.65	36.53	1.80
9CULOLDdd	2.65	36.53	1.71
9CULstrucup	2.59	36.70	1.76
9CULoutU	2.59	36.70	1.76

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
9CULoutUd	2.57	36.75	1.79
9CULoutDu	2.57	36.75	1.79
9CULoutD	2.55	36.78	1.82
6TRA_20	2.54	36.78	1.82
6TRA_0s	2.54	36.81	2.54
Sedtrap_Cul1	3.00	8.76	3.92
Sedtrap_Cul2	2.95	8.75	3.42
bal1u	2.95	8.75	5.35
bal1u2	2.97	8.75	1.71
bal_new	2.97	8.75	1.71
bal1d	2.95	8.75	1.71
bal2u	2.95	8.75	1.59
bal2d	2.88	8.77	1.37
bal3u	2.88	8.77	1.71
5ochd	2.84	2.85	0.40
6och	2.84	2.86	0.40
7och	2.84	7.03	0.97
8och	2.76	7.10	0.97
N25culv4	2.84	2.42	0.38
N25culv5	2.84	4.04	0.64
N25culv6	2.84	4.04	0.64
N25culv7	2.84	5.57	0.89
N25culv7a	2.84	5.57	0.89
N25culv7b	2.84	7.10	1.14
N25culv8	2.84	7.10	1.14
N25culv9U	2.76	7.14	1.13
N25culv9	2.76	9.16	1.46
COMB1a	2.75	11.87	0.88
COMB1b	2.75	9.72	0.72
COMB2	2.75	9.72	0.72
COMB2a	2.75	6.07	0.45
6DOU_1370	25.38	5.94	2.50
6DOU_1276	23.49	5.94	2.03
6DOU_1130	20.89	5.94	2.72
6DOU_1130d	20.75	5.94	2.82
6DOU_1100	20.13	5.94	2.33
6DOU_1059	19.38	5.94	2.31
6DOU_1009	18.51	5.94	2.23

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DOU_960	17.64	5.94	2.63
6DOU_952	17.46	5.94	2.29
6DOU_960d	17.64	5.94	2.63
6DOU_952d1	17.07	5.94	2.28
6DOU_952d2	17.07	5.94	2.28
6DOU_914	16.74	5.94	1.16
6DOU_914J	16.74	14.00	2.69
6DO1_0	17.84	7.27	1.71
6DO1_0S	16.74	7.27	1.91
6DOU_845	16.04	14.00	1.57
6DOU_828	15.58	14.00	4.49
6DOU_828d	15.58	14.00	4.49
6DOU_803	14.80	14.00	2.58
6DOU_758	14.21	14.00	1.65
6DOU_721	13.92	14.00	1.69
6DOU_678	13.54	14.00	1.82
6DOU_641	12.99	14.00	2.90
6DOU_628	12.77	14.00	2.83
6DOU_611	12.57	14.00	1.80
6DOU_614i1	12.37	14.00	1.91
6DOU_573	12.11	14.00	2.43
6DOU_559	11.94	14.00	2.92
6DOU_539	11.68	14.00	2.66
6DOU_524	11.56	14.00	2.29
6DOU_518	11.51	14.00	2.50
6DOU_511	11.41	14.00	2.90
6DOU_506	11.34	14.00	2.67
6DOU_501	11.32	14.00	2.44
6DOU_501d	11.32	14.00	2.44
6DOU_495	11.21	14.00	2.82
6DOU_490	11.13	14.00	3.32
6DOU_484	11.01	14.00	3.15
6DOU_477	10.90	14.00	2.95
6DOU_472	10.87	13.75	2.71
6DOU_468	10.84	13.75	2.59
6DOU_468d	10.84	13.75	2.59
6DOU_464	10.81	13.74	2.59
6DOU_460	10.78	13.74	2.55

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DOU_455	10.64	14.49	2.78
6DOU_448	10.57	14.49	2.70
6DOU_443	10.52	14.50	2.63
6DOU_438	10.50	14.49	2.59
6DOU_433	10.51	14.50	2.47
6DOU_428	10.51	14.49	2.31
6DOU_425	10.79	8.42	2.25
6DOU_420	9.96	8.72	2.38
6DOU_415	9.91	8.72	2.37
6DOU_405	9.83	8.74	2.34
6DOU_395	9.79	8.73	2.27
6DOU_384	9.75	8.73	2.24
6DOU_384r	9.71	8.73	2.36
6DOU_379	9.78	7.80	2.51
6DOU_379d	9.61	7.80	2.63
6DOU_367	9.62	7.95	2.70
6DOU_358	9.69	8.69	2.49
6DOU_358d	9.31	8.69	2.53
6DOU_341	8.84	8.77	3.98
6DOU_325	8.41	8.77	3.00
6DOU_306	8.19	8.76	2.29
6DOU_306d	8.10	8.76	2.44
6DOU_282	7.86	8.75	2.28
6DOU_234	7.35	8.74	2.38
6DOU_204	6.97	8.75	2.60
6DOU_154	6.27	8.75	2.44
6DOU_89	5.07	8.76	3.17
6DOU_65	4.50	8.76	2.99
6DOU_54	4.31	8.76	2.61
DOUFRS_18_3	4.24	8.76	1.84
DOUFRS_14_0	4.28	8.76	1.49
DOUFRS_10r	3.99	8.76	1.60
DOUFRS_14_0r	3.96	8.76	1.91
DOUFRS_10	3.99	8.76	1.60
DOUFRS_5_86	4.00	8.76	1.44
DOUFRS_3_36	3.98	8.76	1.52
DOUFRS_2_86	3.84	8.76	1.68
DOUFRS_00	3.79	8.76	1.86

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
BB_culv	3.13	8.76	3.84
BB_culv2	3.00	8.76	5.94
6DO1_1014	39.55	7.27	1.87
6DO1_929	37.27	7.27	2.61
6DO1_805	34.13	7.27	2.05
6DO1_726	32.34	7.27	1.57
6DO1_581	28.88	7.27	2.14
6DO1_498	27.02	7.27	1.92
6DO1_403	25.72	7.27	1.12
6DO1_395U	25.40	7.27	1.75
6DO1_395D	25.26	7.27	1.90
6DO1_395db	25.26	7.27	5.22
6DO1_395DU	25.26	7.27	1.90
6DO1_382	24.43	7.27	1.02
6DO1_363	24.07	7.27	2.17
6DO1_285	23.55	7.27	1.14
6DO1_277	23.54	7.27	0.94
6DO1_277Bd	23.37	7.11	2.58
6DO1_277d	23.37	7.27	1.08
6DO1_262	23.29	7.27	1.47
6DO1_253u	22.25	7.27	2.60
6DO1_253	22.18	7.27	2.63
6DO1_253CUin	22.18	7.27	5.43
6DO1_63CUout	18.72	7.27	7.14
6DO1_63	18.72	7.27	1.36
6DO1_56	18.61	7.27	2.59
6DO1_4	17.96	7.27	1.99
6DO1_4Bu	17.96	6.98	2.40
6DO1_4Spu	17.96	0.29	2.40
6DO1_4Bd	17.87	6.98	2.40
6DO1_4d	17.87	7.27	2.07
6TRA_470	2.94	25.68	1.25
6TRA_461	2.92	27.64	1.19
6DO1_1177	45.009	7.27	2.159
6DO1_1129	42.957	7.271	2.569
6DO1_1076	41.545	7.27	1.762
6DO1_1045	40.574	7.27	2.311
6DO1_1014	39.542	7.27	1.923

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
6DO1_929	37.277	7.269	2.617
6DO1_805	34.117	7.27	2.134
6DO1_726	32.343	7.27	1.508
6DO1_581	28.809	7.268	2.511
6DO1_498	27.019	7.268	1.935
6DO1_466	26.424	7.268	2.148
6DO1_434	25.91	7.267	1.958
6DO1_402	25.687	7.267	1.229
402_rpt	25.635	7.267	0.364
397_us	25.609	7.267	0.781
397_ds	24.636	7.267	1.884
6DO1_395us	24.615	7.267	3.441
6DO1_395cul	24.424	7.267	4.829
6DO1_387culd	24.398	7.267	2.648
6DO1_387_ds	24.398	7.267	2.885
6DO1_382	24.347	7.267	1.374
6DO1_374	24.035	7.267	2.498
6DO1_374BU	24.035	7.267	0.638
6DO1_374BD	24.035	7.267	0.638
6DO1_374d	24.035	7.267	2.498
6DO1_324	23.395	7.266	2.492
6DO1_285	23.127	7.255	2.282
6DO1_277	23.129	7.252	1.687
6DO1_277Bu	23.129	7.252	2.583
6DO1_277Spu	23.129	0	2.583
6DO1_277Bd	23.012	7.252	2.583
6DO1_277d	23.012	7.252	2.348
6DO1_277Spd	23.012	0	2.583
6DO1_262	22.941	7.251	2.616
6DO1_253	22.867	7.251	2.682
6DO1_253CUin	22.867	7.251	2.859
6DO1_253Spu	22.867	0	0.999
6DO1_253Spd	19.225	0	0.999
Culver_XS1	22.687	7.251	2.874
Culvert_XS2	22.503	7.251	2.741
Culvert_XS3	22.359	7.251	2.308
Culvert_MH1	22.125	7.251	2.177
Culvert_MH2	21.815	7.251	2.467

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Vel (m/s)
Cul_MH2DS	21.725	7.251	2.667
Culvert_MH3	21.423	7.251	2.968
Cul_MH3_DS	21.289	7.251	2.968
Culvert_MH4	21.117	7.251	3.135
Culvert_MH4B	21.117	7.251	3.135
Culvert_MH5	20.579	7.251	3.744
Culvert_MH6	19.942	7.251	3.872
6DO1_63CUout	19.225	7.25	2.895
Culvert_DS	19.225	7.25	1.394
6DO1_const_	19.156	7.25	1.716
6DO1_63b	18.861	7.25	1.99
6DO1_63a	19.222	7.25	1.112
Bridge_US	19.222	7.25	0.568
6DO1_56	18.611	7.25	2.639
Bridge_DS	18.861	7.25	0.568
6DO1_4	17.958	7.25	1.964
6DO1_4Bu	17.958	6.957	2.399
6DO1_4Spu	17.958	0.293	2.399
6DO1_4Bd	17.87	6.957	2.399
6DO1_4d	17.87	7.25	2.042
6DO1_4Spd	17.87	0.293	2.399
6DO1_0	17.836	7.25	1.756
6DO1_0S	16.832	7.25	1.906

Appendix C

Hydraulic Model Build

C1 Introduction

This section presents photographs of the relevant reaches of the Ballybrack and Tramore River and the associated mannings values used in the model building.

A datasheet for all the structures in the model is also presented.

C2 Manning Values at Selected Locations

Table 11: Donnybrook stream

Reach	Upstream Label	Downstream Label	Bed Roughness / Bank Roughness
Donnybrook Stream	6DO1_1177	6DO1_0	0.045 & 0.50

Table 12: Ballybrack stream

Reach	Upstream Label	Downstream Label	Bed Roughness / Bank Roughness
Ballybrack Stream	6DOU_1370	6DOU_914	0.035 & 0.06

Table 13: Ballybrack stream

Reach	Upstream Label	Downstream Label	Bed Roughness / Bank Roughness
Ballybrack Stream	6DOU_845	DOUFRS_00	Varies: 0.03/0.035 & 0.05/0.06

Table 14: Tramore river

Reach	Upstream Label	Downstream Label	Bed Roughness / Bank Roughness
Tramore River	6TRA_2506	6TRA_461	Varies: 0.03/0.035 & 0.04/0.05

C3 Structures Datasheet- Bridges and Culverts

Name/model node label	**6DO1_395ub**	
River Reach	Grange Stream	
Type of structure	Flat Deck Road Bridge	
Description	Flat concrete road bridge supported on both sides of the channel	
Survey Reference	6DO1_395.4	
Irish Grid Reference(s)	169499.3 68426.6	
Included in model	Yes	
Photograph		
Dimensions & levels	***Invert Level***	23.662mOD
	Soffit level	25.583mOD
	Springing level	25.582mOD
	Length	7.57m
Manning's n	0.045	
How modelled	Culvert conduit units with entrance and exit losses	

Name/model node label	**6DO1_277Bu**	
River Reach	Grange Stream	
Type of structure	Flat Deck Road Bridge	
Description	Flat concrete road bridge supported on both sides of the channel	
Survey Reference	6DO1_276.8	
Irish Grid Reference(s)	169596.4 68494.6	
Included in model	Yes	
Photograph		
Dimensions & levels	***Invert Level***	21.633mOD
	Soffit level	23.26mOD
	Springing level	23.259mOD
	Length	15.0m
Manning's n	0.040	
How modelled	Culvert conduit units with entrance and exit losses	

Name/model node label	LONG CULVERT	
River Reach	Grange Stream	
Type of structure	190m long culvert	
Description	190m long culvert with multiple constrictions and obstructions throughout its reach	
Survey Reference	6DO1_253CUin - 6DO1_63CUout	
Irish Grid Reference(s)	169629, 68510	
Included in model	Yes. Multiple conduit units used to account for the varying geometry and constrictions in the culvert.	
Photograph (looking into the culvert through manhole)		
Dimensions & levels	***Invert Level***	20.79
	Soffit level	22.52
	Springing level	22.52
	Length	190
Manning's n	0.028	
How modelled	Multiple conduit units with entrance and exit head loss units.	

Name/model node label	**6DO1_4Bu**	
River Reach	Grange Stream	
Type of structure	Flat Deck Road Bridge	
Description	Flat concrete road bridge supported on both sides of the channel	
Survey Reference	6DO1_4	
Irish Grid Reference(s)	169854.7 68566.5	
Included in model	Yes	
Photograph		
Dimensions & levels	***Invert Level***	16.476mOD
	Soffit level	18.02mOD
	Springing level	18.0mOD
	Length	1.7m
Manning's n	0.060	
How modelled	Bridge Arch	

Name/model node label	**6DOU_1130Bu**	
River Reach	Donnybrook Stream	
Type of structure	Flat Deck Foot Bridge	
Description	Stone footbridge supported at the sides of the channel	
Survey Reference	6DOU_1129.9	
Irish Grid Reference(s)	169996.7 68441.3	
Included in model	Yes	
Photograph		
Dimensions & levels	***Invert Level***	19.794mOD
	Soffit level	20.70mOD
	Springing level	20.70mOD
	Length	1.14m
Manning's n	0.060	
How modelled	Bridge Arch	

Name/model node label	**6DOU_960Bu**	
River Reach	Donnybrook Stream	
Type of structure	Flat Deck Foot Bridge	
Description	Flat concrete footbridge supported at the sides of the bridge	
Survey Reference	6DOU_960.2	
Irish Grid Reference(s)	169887.6 68542.5	
Included in model	Yes	
Photograph		
Dimensions & levels	***Invert Level***	16.805mOD
	Soffit level	18.32mOD
	Springing level	18.32mOD
	Length	2.27m
Manning's n	0.060	
How modelled	Bridge Arch	

Name/model node label	**6DOU_828Bu**	
River Reach	Ballybrack Stream	
Type of structure	Flat Deck Foot Bridge	
Description	Flat concrete footbridge supported at the sides of the bridge	
Survey Reference	6DOU_828.5	
Irish Grid Reference(s)	169945 68652	
Included in model	Yes	
Photograph		
Dimensions & levels	***Invert Level***	14.284mOD
	Soffit level	15.77mOD
	Springing level	15.77mOD
	Length	1.79m
Manning's n	0.035	
How modelled	Bridge Arch	

Name/model node label	**6DOU_628Bu**	
River Reach	Ballybrack Stream	
Type of structure	Flat Deck Foot Bridge	
Description	Flat concrete footbridge supported at the sides of the bridge	
Survey Reference	6DOU_627.9	
Irish Grid Reference(s)	169975 68842	
Included in model	Yes	
Photograph		
Dimensions & levels	***Invert Level***	11.45mOD
	Soffit level	14.00mOD
	Springing level	13.398mOD
	Length	3.6m
Manning's n	0.035	
How modelled	Bridge Arch	

Name/model node label	**6DOU_501Bu**	
River Reach	Ballybrack Stream	
Type of structure	Flat Deck Road Bridge	
Description	Flat stone road bridge supported at either side of the channel	
Survey Reference	6DOU_500.6	
Irish Grid Reference(s)	169987 68962	
Included in model	Yes	
Photograph		
Dimensions & levels	***Invert Level***	9.917mOD
	Soffit level	11.46mOD
	Springing level	11.46mOD
	Length	3.73m
Manning's n	0.035	
How modelled	Bridge Arch	

Name/model node label	6DOU_468Bu	
River Reach	Ballybrack Stream	
Type of structure	Flat Deck Foot Bridge	
Description	Flat concrete footbridge supported at either side of the channel	
Survey Reference	6DOU_468.5	
Irish Grid Reference(s)	169967 68986	
Included in model	Yes	
Photograph		
Dimensions & levels	***Invert Level***	9.47mOD
	Soffit level	10.95mOD
	Springing level	10.95mOD
	Length	3.55m
Manning's n	0.035	
How modelled	Bridge Arch	

Name/model node label	**6DOU_425BLD**	
River Reach	Ballybrack Stream	
Type of structure	Flat Deck Road Bridge	
Description	Flat concrete road bridge supported at either side of the channel	
Survey Reference	6DOU_425.3	
Irish Grid Reference(s)	169954 69027	
Included in model	Yes	
Photograph		
Dimensions & levels	***Invert Level***	8.997mOD
	Soffit level	9.99mOD
	Springing level	9.930mOD
	Length	5.02m
Manning's n	0.035	
How modelled	Bridge Arch	

<table>
<tr><th>Name/model node label</th><th colspan="2">6DOU_379Bu</th></tr>
<tr><td>River Reach</td><td colspan="2">Ballybrack Stream</td></tr>
<tr><td>Type of structure</td><td colspan="2">Flat Deck Footbridge</td></tr>
<tr><td>Description</td><td colspan="2">Flat concrete footbridge supported at either side of the channel</td></tr>
<tr><td>Survey Reference</td><td colspan="2">6DOU_379.2</td></tr>
<tr><td>Irish Grid Reference(s)</td><td colspan="2">169929 69062</td></tr>
<tr><td>Included in model</td><td colspan="2">Yes</td></tr>
<tr><td>Photograph</td><td colspan="2"></td></tr>
<tr><td rowspan="4">Dimensions & levels</td><td>Invert Level</td><td>8.272mOD</td></tr>
<tr><td>Soffit level</td><td>9.420mOD</td></tr>
<tr><td>Springing level</td><td>9.400mOD</td></tr>
<tr><td>Length</td><td>1.57m</td></tr>
<tr><td>Manning's n</td><td colspan="2">0.030</td></tr>
<tr><td>How modelled</td><td colspan="2">Bridge Arch</td></tr>
</table>

Name/model node label	**6DOU_358Bu**	
River Reach	Ballybrack Stream	
Type of structure	Flat Deck Footbridge	
Description	Flat concrete footbridge supported at either side of the channel	
Survey Reference	6DOU_357.8	
Irish Grid Reference(s)	169907 69064	
Included in model	Yes	
Photograph		
Dimensions & levels	***Invert Level***	8.106mOD
	Soffit level	9.39mOD
	Springing level	9.39mOD
	Length	3.6m
Manning's n	0.030	
How modelled	Bridge Arch	

<table>
<tr><th>Name/model node label</th><th colspan="2">6DOU_306Bu</th></tr>
<tr><td>River Reach</td><td colspan="2">Ballybrack Stream</td></tr>
<tr><td>Type of structure</td><td colspan="2">Flat Deck Road Bridge</td></tr>
<tr><td>Description</td><td colspan="2">Flat concrete road bridge supported at either side of the channel</td></tr>
<tr><td>Survey Reference</td><td colspan="2">6DOU_305.6</td></tr>
<tr><td>Irish Grid Reference(s)</td><td colspan="2">169876 69091</td></tr>
<tr><td>Included in model</td><td colspan="2">Yes</td></tr>
<tr><td>Photograph</td><td colspan="2"></td></tr>
<tr><td rowspan="4">Dimensions & levels</td><td>Invert Level</td><td>6.89mOD</td></tr>
<tr><td>Soffit level</td><td>8.09mOD</td></tr>
<tr><td>Springing level</td><td>7.98mOD</td></tr>
<tr><td>Length</td><td>10.96m</td></tr>
<tr><td>Manning's n</td><td colspan="2">0.035</td></tr>
<tr><td>How modelled</td><td colspan="2">Bridge Arch</td></tr>
</table>

Name/model node label	**6DO1_253CUin**		
River Reach	Grange Stream		
Type of structure	Culvert		
Description	Rectangular culvert under road, with weir near downstream end.		
Survey Reference	6DO1_252.6		
Irish Grid Reference(s)	169617.9 68506.0		
Included in model	Yes		
Photograph			
Dimensions & levels		***Upstream***	***Downstream***
	Invert Level	20.658mOD	17.662mOD
	Soffit level	22.528mOD	19.532mOD
	Culvert Length	190m	
Friction	0.00015m (Colebrook – White Friction)		
How modelled	Bridge Arch		

Name/model node label	**DOUFRS_00/ 6TRA_461**
River Reach	Ballybrack Stream/Tramore River
Type of structure	Detailed Culvert System
Description	Complex network of culverts with two separate entrances: (1) The Ballybrack stream enters at Church Road, and (2) The Tramore River enters at Douglas West. There is one exit from the culvert which discharges into Douglas Estuary.
Survey Reference	6TRA_461
Irish Grid Reference(s)	169617.9 68506.0
Included in model	Yes. As described in the main body of the report the DVSC culvert model was originally developed for the Section 50 application and incorporated into the Douglas FRS model.
Photograph	 **Culvert entrance at Church Road**  **Culvert entrance at Douglas West**

	 **Exit of culvert into Douglas Estuary**		
Dimensions & levels		***Upstream @ Church Road***	***Downstream @ exit to Douglas Estuary***
	Invert Level	2.380mOD	0.186mOD
	Soffit level	4.18mOD	2.786mOD
		Upstream @ Douglas West	
	Invert Level	0.41mOD	
	Soffit level	2.97mOD	
	Culvert Length	Circa 530m	
Friction	0.015 (Manning's n)		
How modelled	Multiple rectangular conduit and orifice units utilised to model the complex culvert in ISIS.		

C4 Structures Datasheet – Weirs

Name/model node label	**DOUFRS_14_0r**	
River Reach	Ballybrack Stream	
Type of structure	Weir	
Description	Rectangular	
Survey Reference	6DOU_3_36	
Irish Grid Reference(s)	169814.2 69355.5	
Included in model	Yes	
Photograph		
Dimensions & levels	***Crest elevation***	2.79mOD
	Notch elevation	2.69mOD
	Notch Width	1.0m
Weir Coefficient	1.7	
How modelled	Spill	

Appendix D

Donnybrook Commercial Centre - Flood Map Production Methodology

D1

In order to produce a flood extent map for Donnybrook Commercial Centre it is necessary to first estimate the volume of water surcharging through the manholes from the long culvert than runs underneath the centre. In order to calculate this volume, a manhole unit was fitted to the hydraulic model which in turn connects to a reservoir unit.

This manhole unit calculates the discharge through the manhole by applying a standard weir equation to the piezometric head in the culvert. The unit assumes that the manhole is open and does not take account of its lid or its weight. The volume of water in the manhole shaft is also ignored. It was assumed in the model that water can only surcharge through manhole 3 in the culvert.

For the Q100 event the total volume discharged through manhole 3 was calculated as 2,500m^3. For the Q1000 event the total volume was estimated as 14,700m^3.

A stage-volume curve for Donnybrook Commercial Centre was derived using the Lidar data as is presented in Figure 60. From this we can see that the Q100 volume of 2,500m^3 equates to a level of 21.6mOD. The Q1000 volume equates to a level of 23.8mOD.

It is noted however that a level of 23.8mOD cannot be achieved within the centre as water will overtop the entrance to the centre (set at circa 23.3mOD) before it can reach this level. We have therefore assumed a water level of 23.4mOD for the Q1000 flood event in Donnybrook Commercial Centre.

Figure 60: Area (enclosed by pink line) for which the stage volume curve in Figure 61 is calculated for

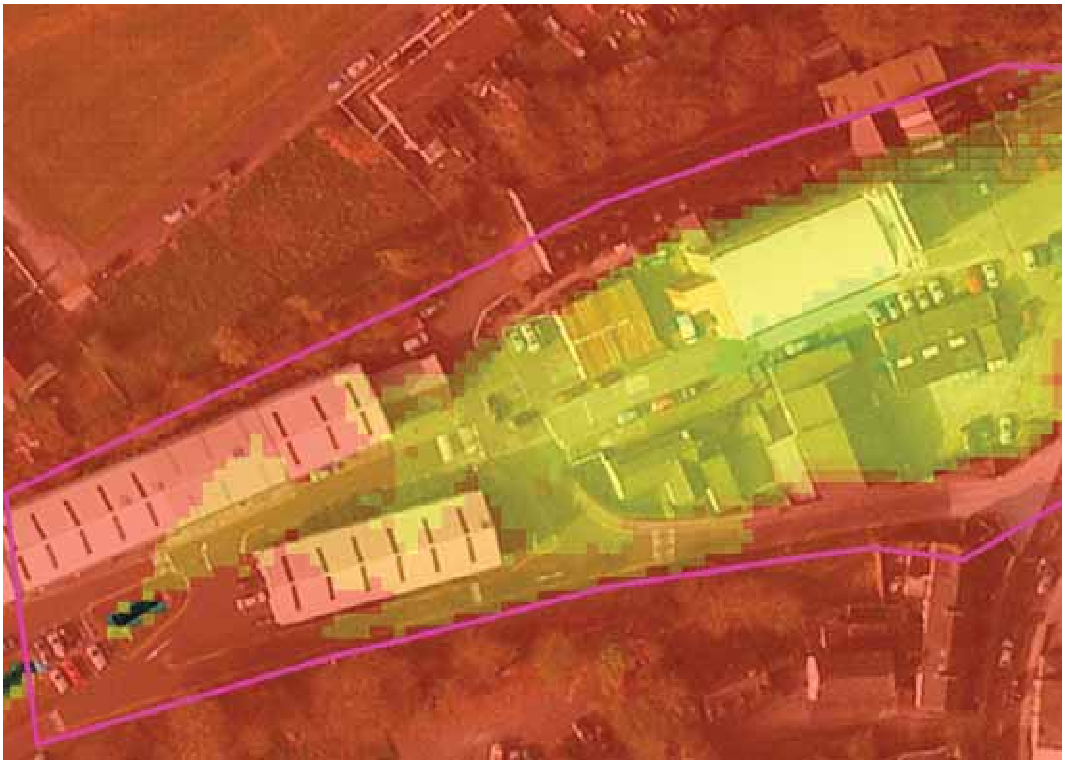
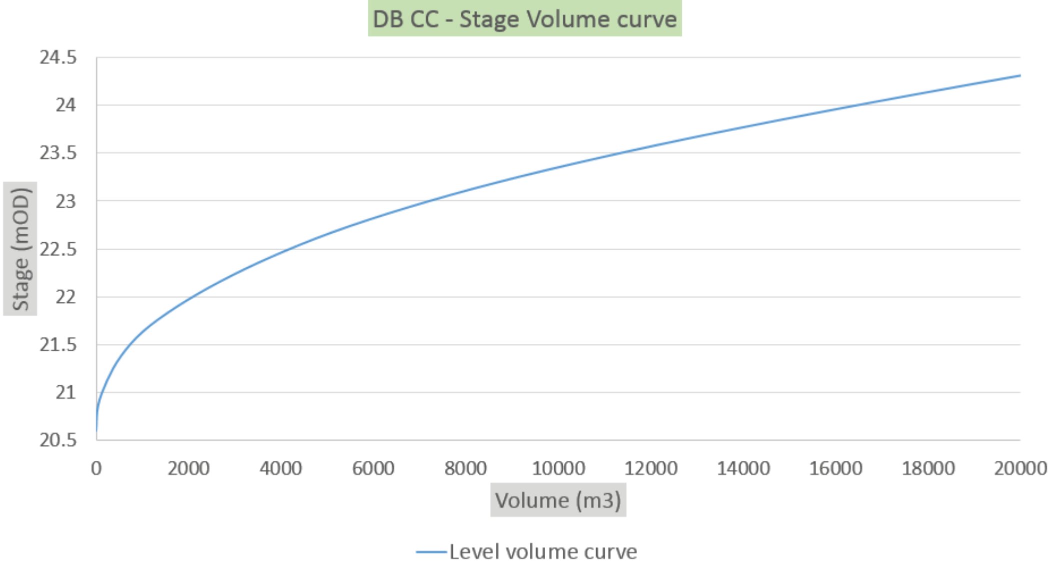


Figure 61: Stage-volume curve for Donnybrook Commercial Centre



Flood maps for both the Q100 and Q1000 scenarios have been produced by taking a horizontal projection of 21.6mOD and 23.4mOD, respectively, through the Lidar dataset. The area bounded with ground elevations less than the respective design flood level is defined as the flood extent for that return period event.

It is noted that utilising a stage-volume curve to produce flood extent maps represents a more simplified approach that the approach used for Douglas (i.e. utilising the results of a detailed 2D hydraulic model). Given that the floodplain in Donnybrook Commercial Centre is contained due to its topography, this approach is deemed appropriate.

It is noted that this approach to estimating the flood extent in Donnybrook has been agreed with the Project Steering Committee.