Cork County Council

Douglas Flood Relief Scheme (Including Togher Culvert)

Togher Hydraulics Report

234335-00

Issue 1 | 19 May 2017

Job number 234335-00

Ove Arup & Partners International Ltd

Arup
One Albert Quay
Cork
T12 X8N6
Ireland
www.arup.com

ARUP

Document Verification

ARUP

Job title	Douglas Flood Relief Scheme (Including Togher Culvert)	**Job number**	234335-00
Document title	Togher Hydraulics Report	**File reference**	
Document ref	234335-00		

Revision	**Date**	**Filename**	234335_DRAFT Togher Hydraulics_20160222.docx		
Draft 1	23 Feb 2016	**Description**	First draft		
			Prepared by	Checked by	Approved by
		Name	Kevin Barry	Ken Leahy	Ken Leahy
		Signature			
Issue	19 May 2017	**Filename**	234335_Togher Hydraulics_Issue1.docx		
		Description			
			Prepared by	Checked by	Approved by
		Name	Kevin Barry	Dave Twomey	Ken Leahy
		Signature	Kevin Barry	David Twomey	[illegible]
		Filename			
		Description			
			Prepared by	Checked by	Approved by
		Name			
		Signature			
		Filename			
		Description			
			Prepared by	Checked by	Approved by
		Name			
		Signature			

Issue Document Verification with Document ✓

Contents

			Page
Executive Summary			**1**
1	**Introduction**		**3**
	1.1	Context	3
	1.2	Scope of the Hydraulic Modelling	4
	1.3	Study Areas	4
2	**Data Collection**		**9**
	2.1	Mapping	9
	2.2	River Survey Data	9
	2.3	Digital Terrain Model	9
	2.4	Model Calibration Event Data	10
	2.5	Topographic Dataset	10
	2.6	Additional Datasets	10
3	**Design Hydrology**		**11**
	3.1	Hydrological Estimation Undertaken as Part of the Study	11
	3.2	Low Flows in the Hydrograph	12
	3.3	Urban Drainage Network	12
	3.4	Fluvial Tidal Joint Probability	12
4	**Single Culvert Option - Hydraulic Model Build**		**13**
	4.1	Introduction	13
	4.2	Common Elements to Both the Single Culvert and Open Channel Hydraulic Models	13
	4.3	Schematisation of the Single Culvert Model	15
	4.4	Entrance and Exit Head Losses of the Culvert	17
	4.5	Manning's n – Single Culvert Option	18
	4.6	Additional Structures in the Model	19
	4.7	Hydraulic Model Results - Single Culvert Option	19
	4.8	Model Results – Trash Screen Blockage	21
5	**Open Channel Option – Hydraulic Model Build**		**24**
	5.1	Schematisation of the Open Channel Model	24
	5.2	Preliminary Assessment of Required Open Channel Dimensions	27
	5.3	Open Channel - Section 50 Requirements	29
	5.4	Proposed Cross Section Dimensions Based on the Preliminary Assessment	31
	5.5	Manning's n – Open Channel Model	31

5.6 Representation of the Culverts Along the Open Channel in the Hydraulic Model 31
5.7 Open Channel Hydraulic Model Results 32
5.8 Size of Channel Required to Meet Section 50 Requirements 34

6 Discussion and Conclusion 35

Appendices

Appendix A

Hydraulic Model Results

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 in Togher between Lehenaghmore Industrial Estate and Greenwood Estate which offer the required standard of protection. Two separate measures are considered: (1) Single Culvert, and (2) Open Channel with associated culvert crossings.
- Flood alleviation measures along the Tramore River/Ballybrack stream in Douglas which offers 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 Togher. The hydraulic analysis for Douglas is detailed in a separate hydraulic report.

The Tramore River flows through Togher and is culverted over most of its length through the reach. The river enters the culvert in Lehenaghmore Industrial Estate and exits it adjacent to Griffin Pianos in Greenwood Estate at the bottom of Togher Road.

Two separate 1D ISIS hydraulic models of the Tramore River were developed to simulate both of the proposed flood relief measures. As it is not within the scope of the work to consider the existing scenario, a hydraulic model of the existing scenario has not been developed.

The models are not calibrated against any historic data. The validity of the model has therefore been ensured through reliance on good practice in modelling and selection of appropriate model parameters.

The results of the single culvert hydraulic model indicates that a rectangular culvert of dimensions 3m*1.4m is not surcharged by the Section 50 Q100 design flow at any point along its length.

The freeboard maintained within the culvert varies. For the Design Q100 flow it varies from 0.5m to 0.98m. For the Section 50 design flow it varies from 0.2m to 0.85m.

Peak velocities within the culvert are high. For the Q100 design flow the peak velocity is circa 5.9m/s. For the Section 50 Q100 design flow the peak velocity is circa 6.65m/s. Careful attention to detail will therefore be required as part of the detailed design of the culvert.

A 67% blockage of the trash screen at the upstream face of the proposed single culvert was considered. The results of the model indicate that a blockage of this magnitude will result in significant increases in the water level upstream. Direct defences immediately upstream of the culvert for a length of approximately 50m are therefore required.

The open channel cross section considered in the hydraulic model consists of a vertical right bank and a 60˚sloped left bank. The width of the top of the channel varies from circa 3.3m to 4.3m and the depth varies throughout the reach.

The results of the open channel hydraulic model indicate that design Q100 flow is conveyed through the reach without any surcharging of the five culverts. The freeboard at the entrances to the culverts varies from 220m to 820mm. The freeboard at the exits of the culverts varies from 150mm to 470mm.

The results of the model indicate that the Section 50 design flow will result in surcharging of the culverts. A minimum freeboard of 300mm to the top of the bank however is achieved throughout the reach. An exception to this occurs immediately upstream of the first culvert where the freeboard is 140mm. At this location some additional direct defences can be incorporated into the works to maintain adequate freeboard.

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 option in Togher which involved the replacement of the existing under-capacity culvert with a new single 3.0m * 1.4m rectangular culvert extending from Lehenaghmore Industrial Estate to Greenwood Estate.

A preliminary assessment of the proposed option undertaken as part of this project indicated that the culvert may be undersized in light of the revised hydrological assessment of the Tramore catchment which was undertaken as part of this project.

The preliminary investigation also indicated that a predominantly open channel may offer a viable alternative flood relief measure for Togher.

Arup has therefore been asked to assess the sizing of the single culvert option and also to consider the open channel option as part of the project and undertake engineering options assessment of both. It is noted that the Lee CFRAM project only considered the single culvert option.

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 Draft Hydraulics report is produced as part of Stage I of the project and details the hydraulic analysis undertaken as part of the study for Togher.

The reader is referred to the following Stage I reports which are to be read in conjunction with this hydraulics report:

- Douglas Flood Relief Scheme (Including Togher Culvert) – Final Hydrology Report.
- Douglas Flood Relief Scheme (Including Togher Culvert) – Douglas Options Report.
- Douglas Flood Relief Scheme (Including Togher Culvert) – Togher Options Report.

1.2 Scope of the Hydraulic Modelling

The purpose of this report is to detail the hydraulic modelling analysis carried out as part of Stage I of the project for Togher. The scope of the work is to develop a dynamic 1D hydraulic model of the Tramore River through Togher that simulates the 1 in 100 year flood event for two separate flood relief measures:

- Single culvert.
- Open Channel with associated culvert crossings.

The results of the hydraulic model are to inform the development of a flood relief scheme for Togher that offers the required standard of protection.

The models do not simulate out-of-bank floodplain flow and only simulate the flow in the channel and culvert network. This approach is justified given that the objective of the model is to access flood relief options for Togher and this can be correctly accessed through consideration of the design water levels in the channel: once the water level exceeds the level of either the left or right bank in the model (whichever is lowest) flooding will occur and this is sufficient to determine the suitability of the measure being considered.

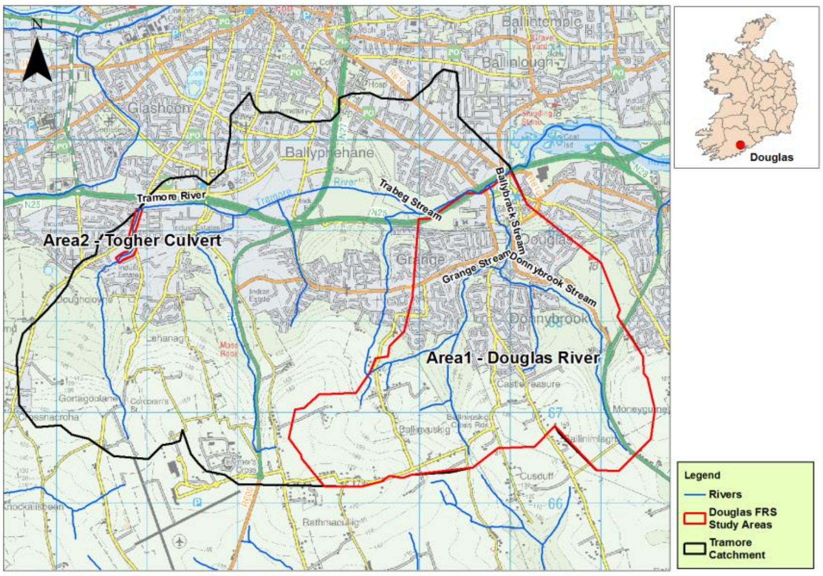
It is not within the scope of the work to consider the existing scenario in Togher. A hydraulic model of the existing scenario has therefore not been developed.

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):

- Douglas (the reader is referred to the accompanying Douglas Hydraulic report for a description of this study area);
- Togher.

Figure 1: Douglas Flood Relief Scheme Study Areas



The area of Togher relevant to this study is between Lehenaghmore Industrial Estate and Greenwood Estate as indicated in Figure 2.

The Tramore River flows through Togher and is culverted over most of its length through the reach. The river enters the culvert in Lehenaghmore Industrial Estate (Figure 3) and exits it adjacent to Griffin Pianos in Greenwood Estate at the bottom of Togher Road as indicated in Figure 4.

Figure 2: Area of Togher relevant to the study. The red arrow indicates the direction of flow of the Tramore River

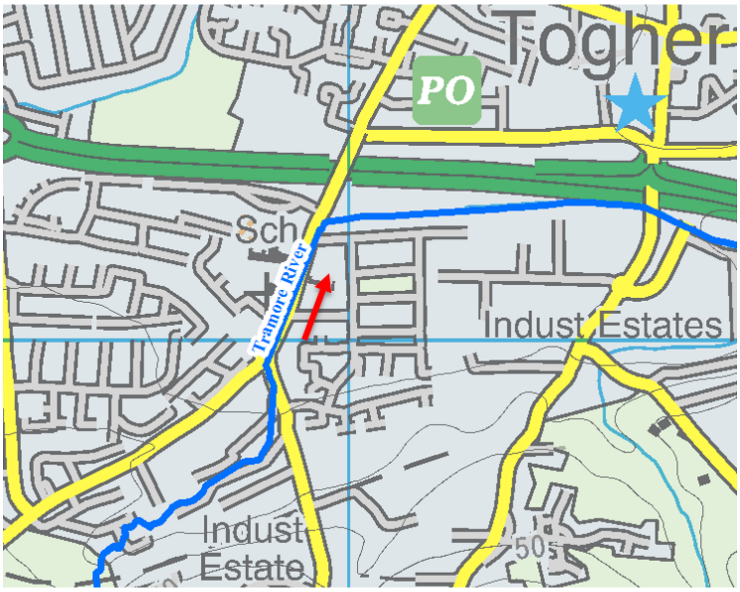


Figure 3: Existing trash screen at entrance to culvert in Lehenaghmore Industrial Estate

Figure 4: Exit of culvert adjacent to Griffin Pianos (red building on the left of photo). This photo is taken looking upstream.

There are two open channel sections along the reach as indicated in Figure 5:

- Upstream of the Roundabout on Togher Road (circa 40m in length) - a photograph of this reach is presented in Figure 6. The photograph is taken looking upstream. The water in the channel is not visible in the photo due to the heavy vegetation on both banks of the channel.
- Upstream of the entrance to Greenwood Estate (circa 15m in length) - a photograph of this reach is presented in Figure 7. The photograph is taken looking upstream.

The alignment of the culvert/open channel as presented in Figure 5 is indicative and does not necessarily represent the actual alignment.

Figure 5: Schematic of the existing Togher Culvert and Open Channel

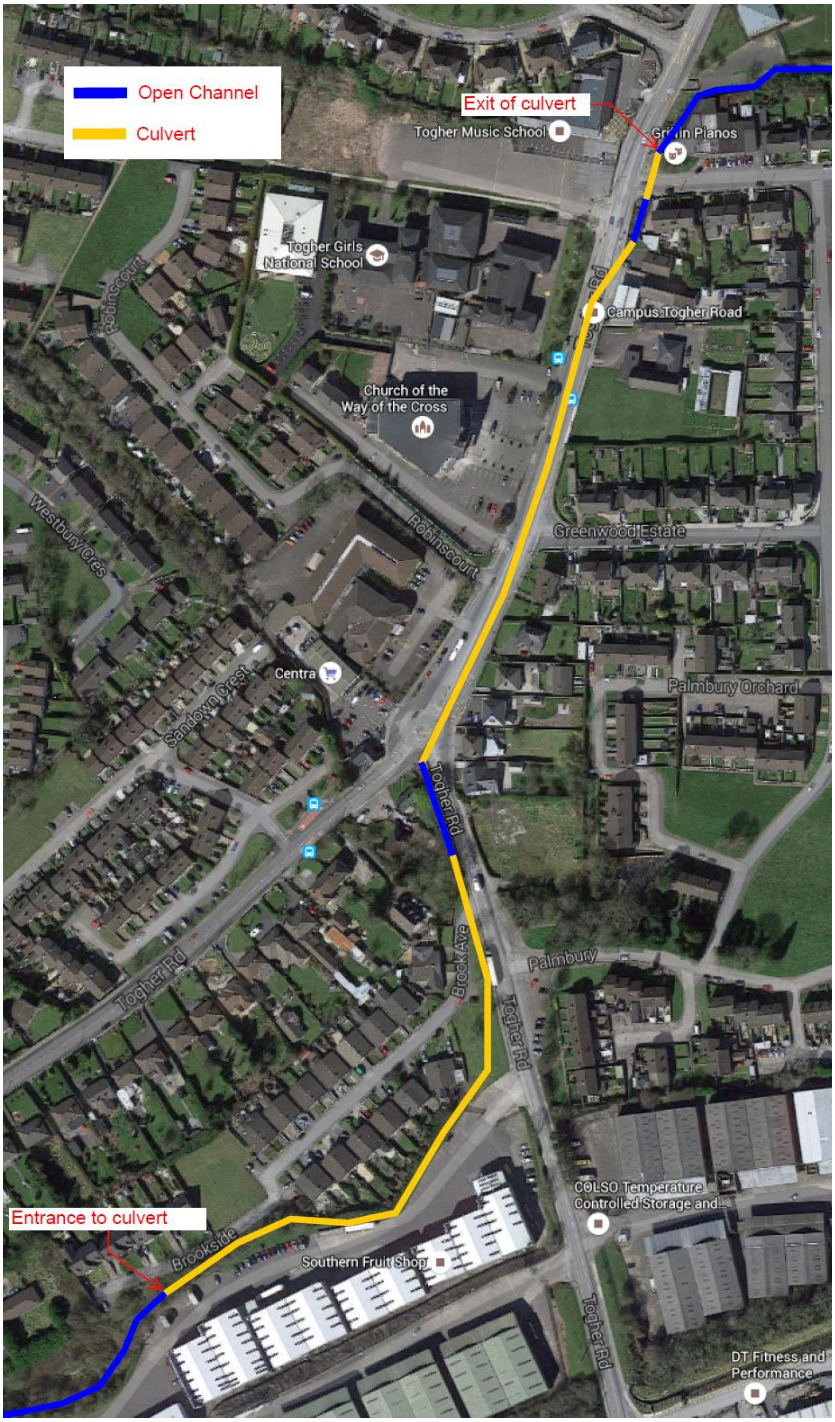


Figure 6: Open channel section immediately upstream of the roundabout on Togher Road.

Figure 7: Open channel section at downstream end of the reach.

2 Data Collection

This chapter details the datasets used in the construction and running of the Togher 1D models.

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).

2.2 River Survey Data

The 1D element of the hydraulic models have used channel and structure cross sectional survey data from the 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.

2.3 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 has been used in the study to define the ground elevations along the route of the existing culvert and adjacent areas.

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 m2. 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.

2.4 Model Calibration Event Data

The hydraulic models have not been calibrated against recorded data as there are no in-bank measurements of water level and/or current speed available from within the channel to compare against model results. Further it is noted that it is not in the scope of work to develop a model of the existing scenario which would allow a calibration be made should relevant calibration data have been available.

It has not been possible to compare results from the model to historic flood data from Togher as the model does not simulate out of bank flow.

The validity of the model has therefore been ensured through reliance on good practice in modelling and selection of appropriate model parameters.

2.5 Topographic Dataset

A topographic survey of the route of the existing culvert in Togher and its adjacent areas was undertaken by Cork County Council and provided to Arup. The data was used to confirm existing ground levels along the route.

2.6 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 Douglas and Togher Draft Final Hydrology Report.

3 Design Hydrology

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.

The reader is referred to the accompanying Douglas and Togher Hydrology Report for a detailed description of this work.

The design flows and Section 50 design flows estimated by the study for the Hydrological Estimation Point relevant to Togher (HEP_09) are presented in Figure 8. The location of the HEP is plotted in Figure 8.

The design flows estimated at HEP_09 were not inserted into the model at the geographical location of the HEP, but instead it was inserted at the upstream end of the reach as indicated by the green arrow in Figure 8.

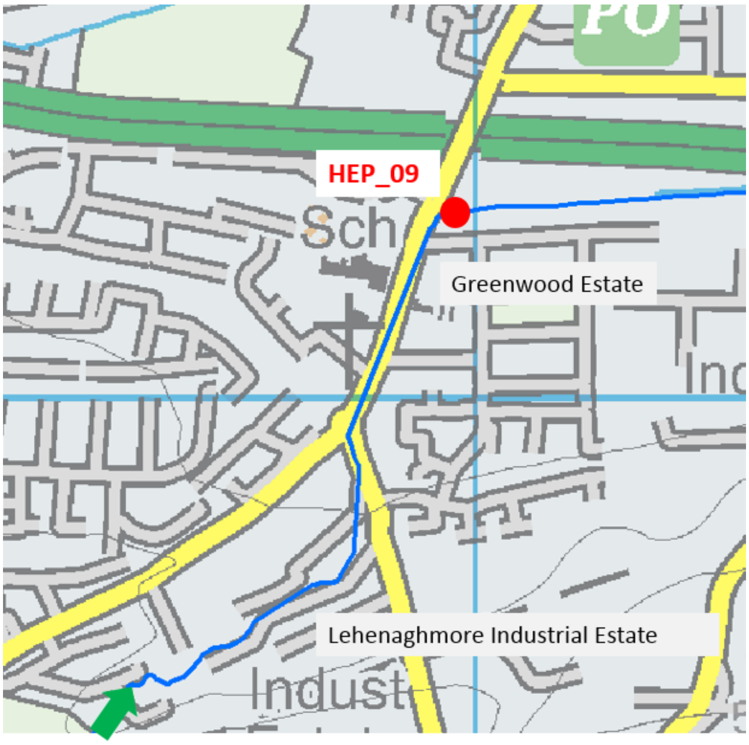
This is a conservative approach that has been adopted to ensure that the design flow is never underestimated in the model and also to simplify the hydraulic model build.

There are no other hydrological boundaries in the model. The downstream boundary of the model was modelled with a normal depth unit.

Table 1: Design Runs for HEP_09

Return Period (years)	**HEP_09 – Design flow (m3/s)**	**HEP_09 – S50 Design flow (m3/s)**
2 (Qmed)	2.97	4.33
5	3.98	5.81
10	4.72	6.89
25	5.94	8.67
50	6.65	9.71
100	7.60	11.1

Figure 8: HEP_09 location



3.2 Low Flows in the Hydrograph

A minimum flow of $1m^3/s$ was applied to the hydrographs to ensure hydraulic model stability at the start of the run.

3.3 Urban Drainage Network

The urban drainage network in Togher 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.

Addressing the drainage network as part of the overall solution to flooding in Togher however is addressed in the Options Report.

3.4 Fluvial Tidal Joint Probability

A tidal-fluvial joint probability analysis was carried out as part of the Lee CFRAM Study. The results however are not relevant to Togher as the tide does not influence water levels in Togher.

4 Single Culvert Option - Hydraulic Model Build

4.1 Introduction

Two separate one-dimensional models of the Tramore River through Togher have been developed to access both the single culvert and open channel flood relief options. The models have been developed in ISIS Professional 1D (v3.7) software.

This chapter details the development of the single culvert hydraulic model. Chapter 5 details the development of the open channel hydraulic model.

There are a number of elements common to the development of both models. To avoid repetition, these common elements are detailed only once in the report in the following section and include:

- Development from the Lee CFRAM model.
- Model extents.
- Labelling system.
- Model resolution.

4.2 Common Elements to Both the Single Culvert and Open Channel Hydraulic Models

4.2.1 Development from the Lee CFRAM Hydraulic Model

A hydraulic model of the Tramore River 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.

Both of the Togher FRS hydraulic models were developed from the Lee CFRAM hydraulic model. They are a modified version of the model which meets the needs of the current project.

The development of the model can be summarised as:

- <u>Removal of the 2D domain</u> – The 2D domain that formed part of the Lee CFRAMS model was removed for our model as it is not required given the scope of work;
- <u>Removal of hydraulic units which model the existing scenario</u> – The Lee CFRAM model was developed to assess the existing scenario through Togher. To simulate both of the proposed options, the Lee CFRAM model was modified so as to represent the proposed options.

Consequently, a number of cross sections and structures from the Lee CFRAM model were removed and replaced with units that represent the geometry of the two options considered as part of this project. These units include rectangular conduit units, culvert inlet and outlet units, Bernoulli Loss units and river section (open channel units);

- 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 Togher FRS model as they are not required;
- Model Parameters – A number of the model parameters used in the Lee CFRAM model were changed in the Togher model. These include channel roughness and structure coefficients.

4.2.2 Model Extents

The extent of both the single culvert model and the open channel hydraulic model is presented in Figure 9 with the blue line. The red marks in the figure indicate the upstream and downstream extent of the existing culvert through Togher (ignoring the two short open channel sections). The Irish National Grid (ING) coordinates of the extent are presented in Figure 10.

Figure 9: Extents of the Togher 1D model presented with the blue line.

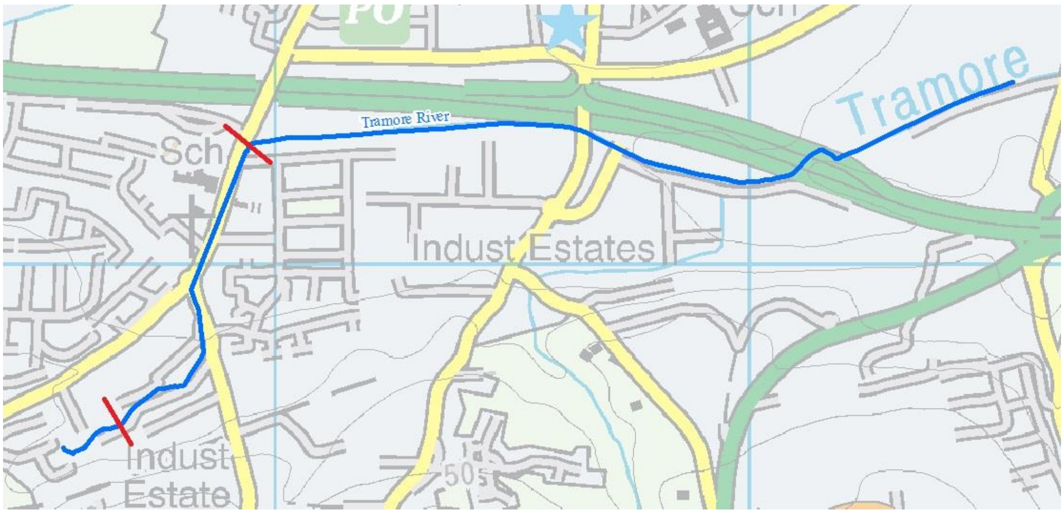


Figure 10: Extents of the Togher FRS model. All coordinates are in Irish National Grid.

Watercourse	Model Upstream Extent		Model Downstream Extent	
Tramore River	165557	68613	167571	69385

4.2.3 Labelling System of Both Models

The nodes for both models (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.

4.2.4 Model Resolution

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

4.3 Schematisation of the Single Culvert Model

4.3.1 Alignment of the Culvert

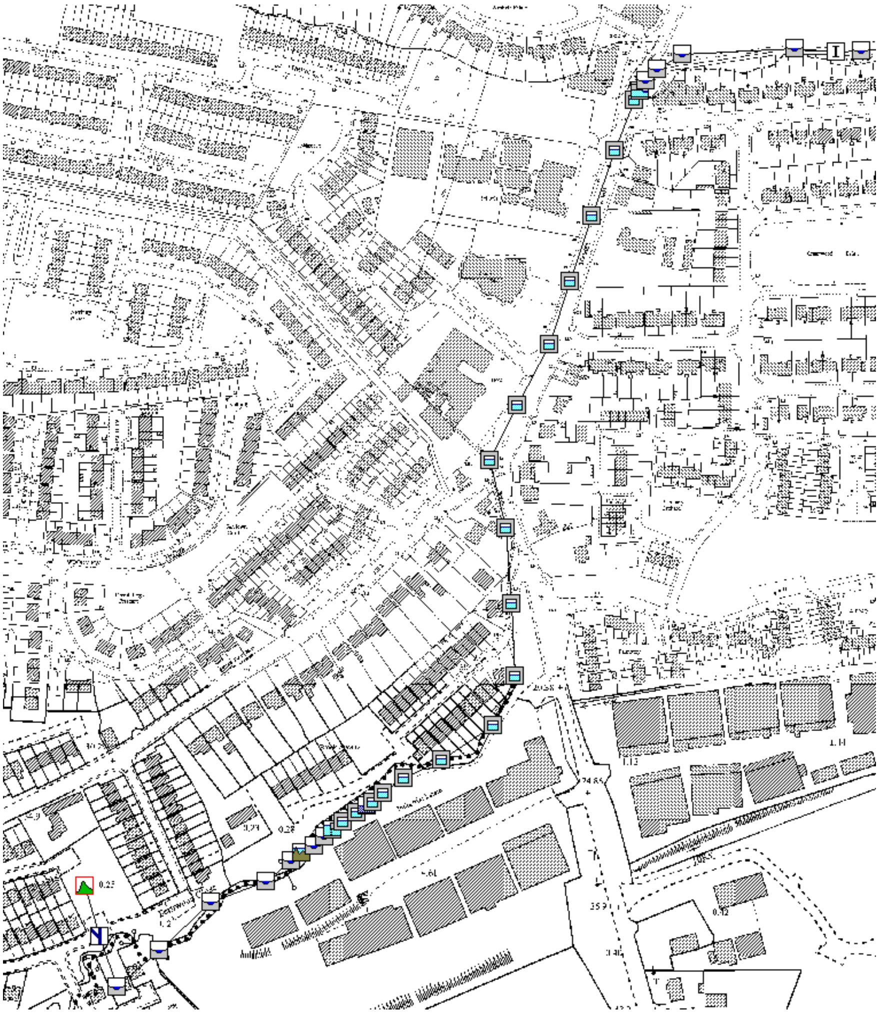
A schematic of the single culvert hydraulic model is presented in Figure 11. It can be seen from the figure that the single culvert is modelled by a series of rectangular conduit units from the upstream to the downstream end of the reach. A culvert inlet unit is included at the top of the reach to correctly account for the inlet head losses. A culvert outlet unit is included at the downstream end to model the exit head losses.

It has been assumed in the model that the culvert is aligned along the same route as the existing culvert which is predominately along the left lane of Togher Road. Following this route the length of the culvert is approximately 645m.

The option of aligning the culvert along a different route through Togher is discussed in the Togher Options report.

The conduit units are spaced at approximate intervals of 50m. The internal dimensions of the culvert and selection of model parameters are discussed in Section 4.3.3 of the report.

Figure 11: Togher Single Culvert model

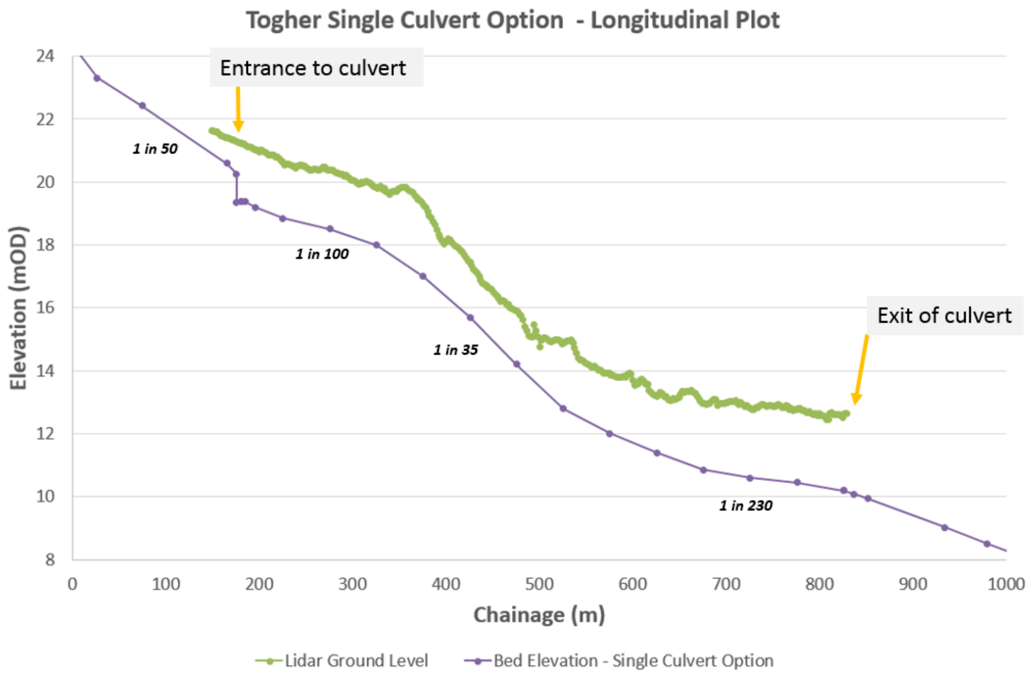


4.3.2 Slope of the Culvert

The slope of the single culvert follows existing ground levels. A longitudinal plot of the route is presented in Figure 12. Average slopes of different sections of the reach are indicated in the figure.

As discussed in Section 4.3.1, the actual alignment of the culvert may diverge from the alignment assumed in the hydraulic model. This however is unlikely to affect the longitudinal slope of the culvert as the existing ground levels do not vary significantly across Togher Road.

Figure 12: Longitudinal Plot of the culvert



4.3.3 Dimensions of the Single Culvert

A preliminary assessment of the required size of the culvert was first undertaken using the 'Initial assessment of discharge capacity for rectangular culverts' methodology as detailed in CIRIA Manual C689 'Culvert design and operation guide'.

Our analysis suggests that the existing channel upstream of the culvert proposed by the Lee CFRAM (3m*1.4m rectangular culvert) would reach bank full level with a flow of 13.2m^3/s. As this flow is greater than the design flow for the scheme, the culvert proposed by the Lee CFRAM may be suitably dimensioned.

A more detailed and comprehensive assessment was undertaken using the hydraulic model and is discussed in Section 4.7 of the report.

4.4 Entrance and Exit Head Losses of the Culvert

The single culvert has been modelled through the inclusion of sixteen separate rectangular conduit units in the model. A culvert inlet has been specified at the upstream end and a culvert outlet unit has been defined at the exit. Appropriate head loss parameters are defined for both units as indicated in Figure 13.

A trash screen at the inlet has been included in the model through use of the Trash Screen option in the Culvert inlet unit. A sensitivity on the formation of blockages of the trash screen has been undertaken as part of the work and is detailed in Section 4.8 of the report.

Figure 13: Culvert inlet and outlet parameters

Culvert Inlet	Value
K	0.486
M	0.667
Culvert Inlet	0.025
Y	0.865
Ki	0.5
Headloss Type	Static
Rev. Flow Mode	Calculated
Trash Screen	**Value**
Screen Width	3.0m
Bar Proportion	0.3
Head Loss Coeff.	1.5
Blockage	varies
Culvert outlet	**Value**
Head Loss Coeff.	1
Headloss Type	Static

4.5 Manning's n – Single Culvert Option

The roughness values of the open channel sections of the 1D model (from both upstream and downstream of the single culvert) 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.

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.

Typical values used in the study are presented in the following figure.

Figure 14: Culvert inlet and outlet parameters

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 roughness values of the single culvert in the model has been defined for three separate parts of each cross section:

- The invert (bottom of culvert).
- The side walls and
- The soffit (roof of the culvert).

A manning value of 0.015 was used for all three sections for each of the conduit units through the full reach of the single culvert. This corresponds to a smooth concrete finish on the inside of the culvert.

4.6 Additional Structures in the Model

Three bridges located downstream of the existing culvert in Togher have been included in the both the single culvert and open channel hydraulic models to ensure any backwater from the bridges them is accounted for in the model.

The bridges have been modelled using the Bridge ARCH unit in ISIS 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 bridge has been accounted for through the use of a spill unit in the 1D domain of the model. The dimensions of the bridges have been taken from the surveyed data.

There are no weirs in the model.

4.7 Hydraulic Model Results - Single Culvert Option

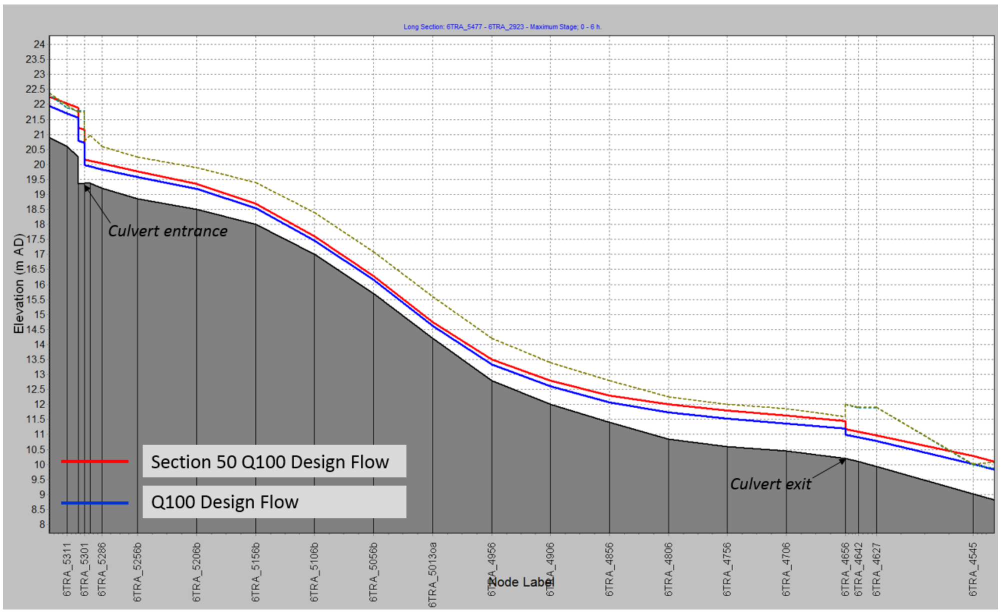
Figure 15 presents the longitudinal plot of the peak water level throughout the length of the proposed single culvert. It can be seen from the figure that the proposed culvert is not surcharged by either the Q100 design flow or the section 50 Q100 design flow at any point along its length.

The freeboard maintained within the culvert varies:

- For the Q100 design flow the freeboard varies from 0.5m to 0.98m.
- For the Section 50 Q100 design flow the freeboard varies from 0.2m to 0.85m.

It can be seen from the figure that the Section 50 water level is marginally above the level of the bank immediately upstream of the entrance to the culvert and also at the very end of the reach (6TRA_4545).

Figure 15: Longitudinal plot of maximum water level



Velocity time series from cross section 6TRA_5013 are presented in Figure 16. This location corresponds to the steepest section of the culvert and the likely location of the highest velocities. It can be seen from the figure that the peak velocities for both of the model runs are very high:

- For the Q100 design flow the peak velocity is circa 5.9m/s;
- For the S50 Q100 design flow the peak velocity is circa 6.65m/s.

Careful attention to detail will be required as part of the detailed design of the culvert. The reader is referred to the accompanying Options report for further detail.

The flow is supercritical in the culvert. The results of the model indicate that the transition from super critical to sub critical flow occurs downstream of cross section 6TRA_4806. The flow becomes super critical on entering the culvert at cross section 6TRA_5301.

Figure 16: Velocity Timeseries for cross section 6TRA_5013

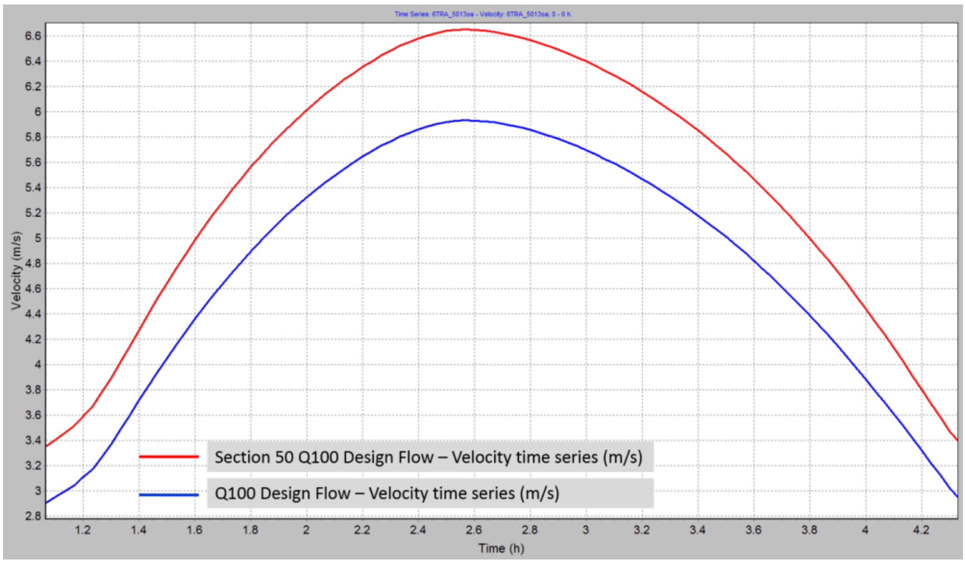
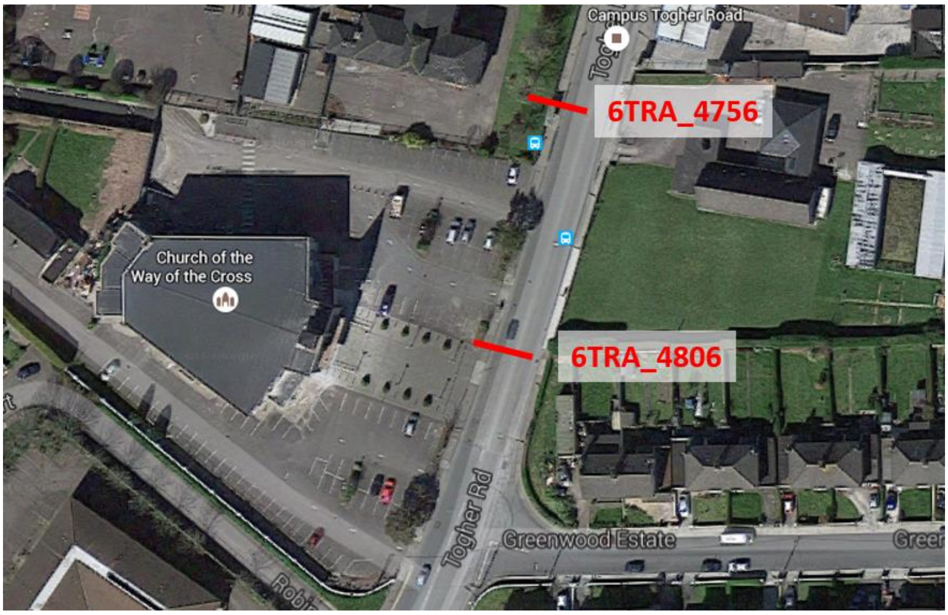


Figure 17: Location of change from supercritical to subcritical flow



4.8 Model Results – Trash Screen Blockage

The Environment Agency's 'Trash and Security Screen Guide 2009' report recommends that a sensitivity analysis on trash screen blockages is considered as part of the design of trash screens. Two blockage value are recommended in the report: 30% and 67%. The model was therefore re-run assuming that the trash screen at the upstream face of the culvert is 67% blocked.

The model was re-run assuming that the trash screen at the upstream face of the culvert is 67% blocked. This value was selected based on guidance in the blockage values of 30% and 67% as part of a sensitivity analysis.

Figure 18 presents the longitudinal plot of the peak water level in the vicinity of the upstream face of the culvert and Figure 19 presents the peak water levels at cross section 6TRA_5306. It can be seen from the figures that the 67% blockages result in significant increases in the water level:

- The Q100 design water level increases from 21.56m OD to 22.05m OD – an increase of 0.49m.
- The S50 Q100 design water level increases from 21.88m OD to 22.78m OD – an increase of 0.9m.

It is noted that the model does not allow any water to spill over the top of the culvert and neither does it allow water to spill over the left or right bank of the cross sections.

The elevated water levels will require direct defences to be constructed upstream of the culvert for a length of approximately 50m. The consequences of this are discussed in the accompanying Togher Options report.

Figure 18: Longitudinal plot of peak water level at the entrance to the culvert

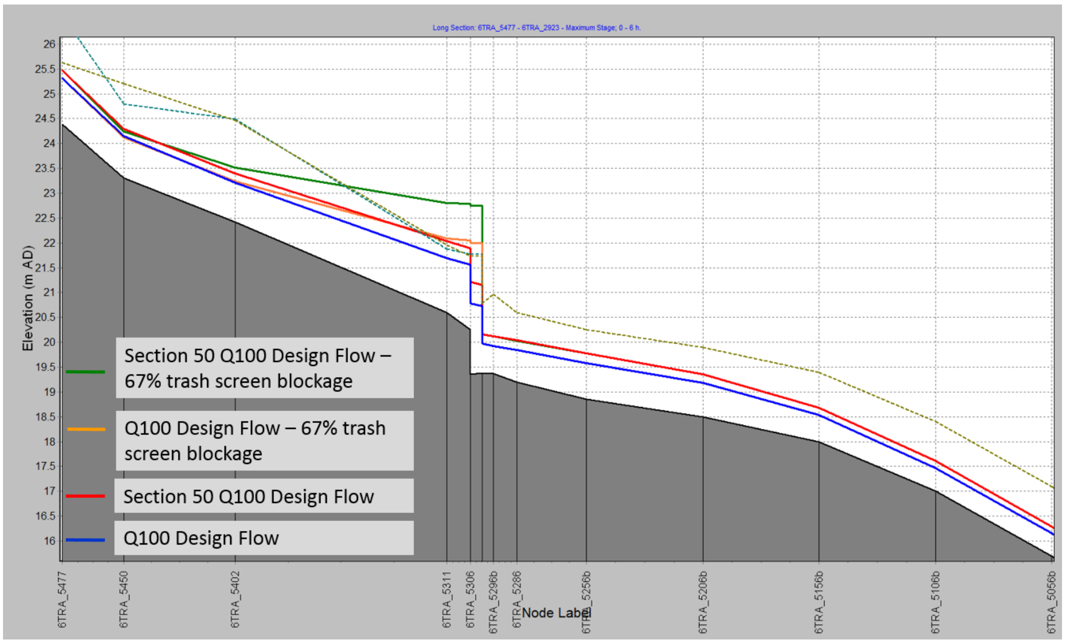
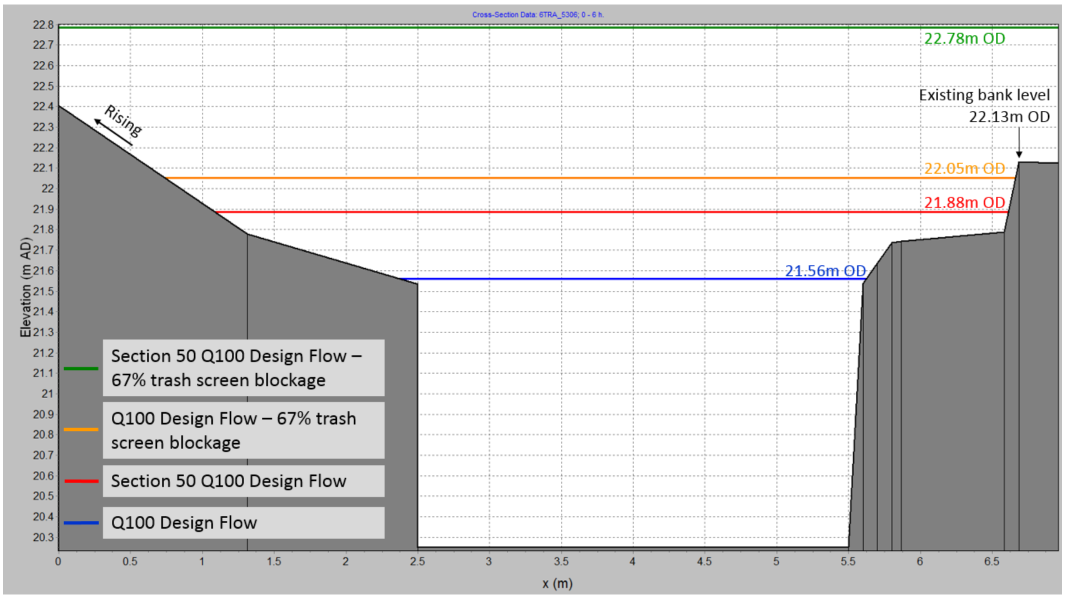


Figure 19: Cross section 6TRA_5306 – peak water levels



5 Open Channel Option – Hydraulic Model Build

This section details the development of the hydraulic model of the open channel option for Togher. It is noted that the following aspects of the model build have been detailed in Section 4.2:

- Development of the model from the Lee CFRAM model.
- Model extents.
- Labelling Systems.
- Model Resolution.

5.1 Schematisation of the Open Channel Model

5.1.1 Alignment of the Open Channel

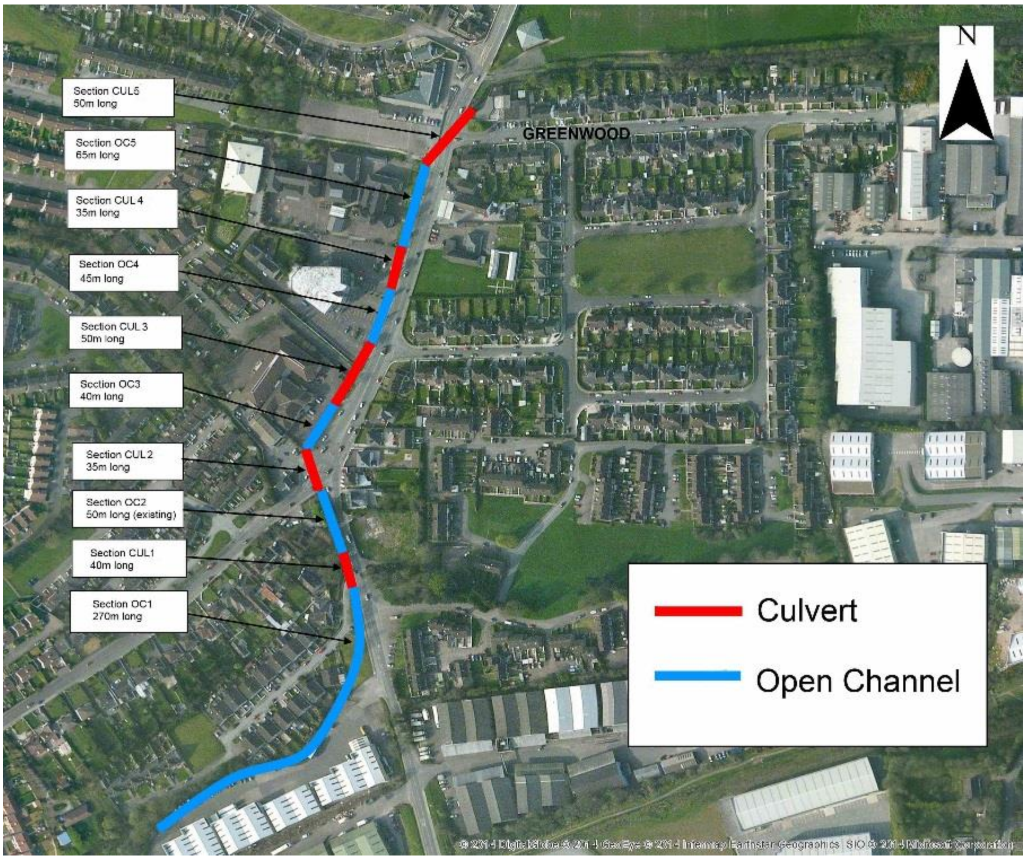
A sketch of the proposed open channel option is presented in Figure 20. The thickness of the line in the drawing is indicative and does not represent the scaled width of the channel. It can be seen from the figure that the option consists of replacing the existing culvert with a new open channel incorporating five separate culverts to facilitate access to properties and public roads in Togher.

The open channel sections will vary in length from between 40m and 270m. The culverted sections will vary in length from between 35m and 50m.

The alignment of the channel is constrained through the entire reach by Togher road and existing properties and there is little scope to align it differently. An exception to this however is through the green area immediately downstream of the entrance to Southern Fruits. The alignment of the channel in the model is along the footpath which it is selected to maximise the social amenity of the open channel.

The reader is referred to the accompanying Togher Options report for a detailed description of the open channel alignment.

Figure 20: Proposed alignment of the open channel option (not to scale).



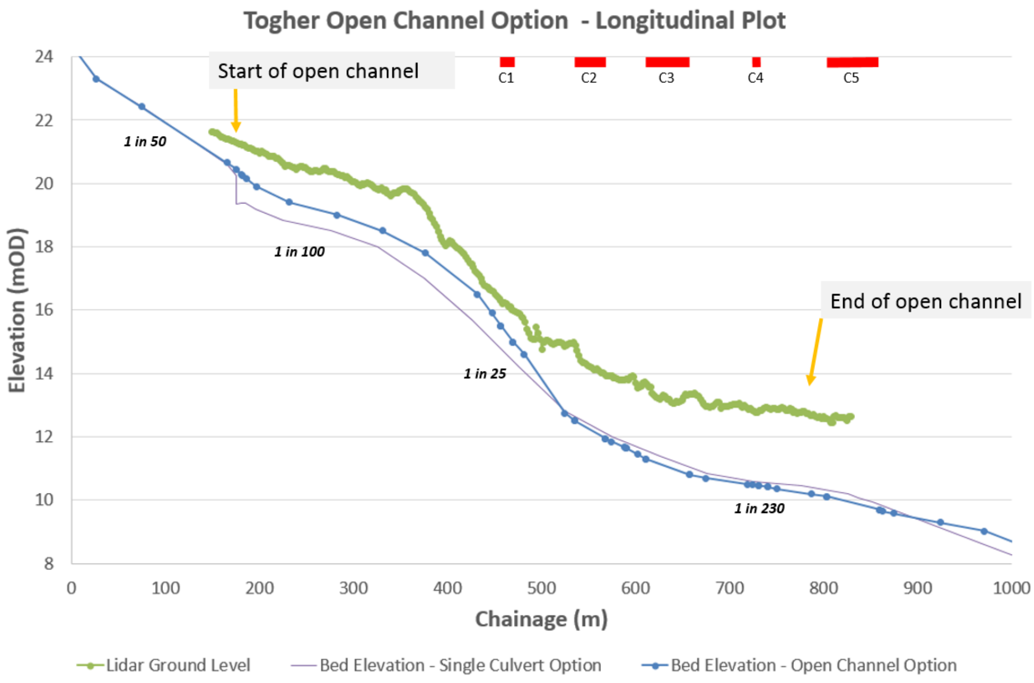
5.1.2 Slope of the Open Channel Bed

To minimise the need for excessive cut and fill the slope of the bed of the open channel will generally follow the slope of the existing ground levels. It is noted however that the design may require local variations in the slope to manage the expected high velocities.

A longitudinal plot of the route is presented in Figure 21. The location of the five culverts along the route are marked on the figure by the thick red lines. The average slope of different sections of the reach are indicated. To allow a direct comparison between the two options considered as part of the study, the slope of the single culvert option (which was originally presented in Figure 12) is also indicated on the figure.

Adequate cover is required over these culvert sections to accommodate existing services. We have assumed a cover of 1.2m over the soffit level of the culverts.

Figure 21: Longitudinal Plot of the open channel



5.1.3 Open Channel Geometry

There are a number of items related to the design of the open channel geometry which need to be considered:

- The desire to minimise land take along the reach.
- Aesthetic considerations.
- Low flows for ecological considerations.
- Cross sectional area for conveying the design flood event.

It is proposed to incorporate a vertical reinforced wall for the right bank of the channel throughout the full reach. It is proposed to incorporate a 60˚sloped bank for the left hand side of the channel where space allows. This approach will minimise land-take while maximising the amenity value of the channel.

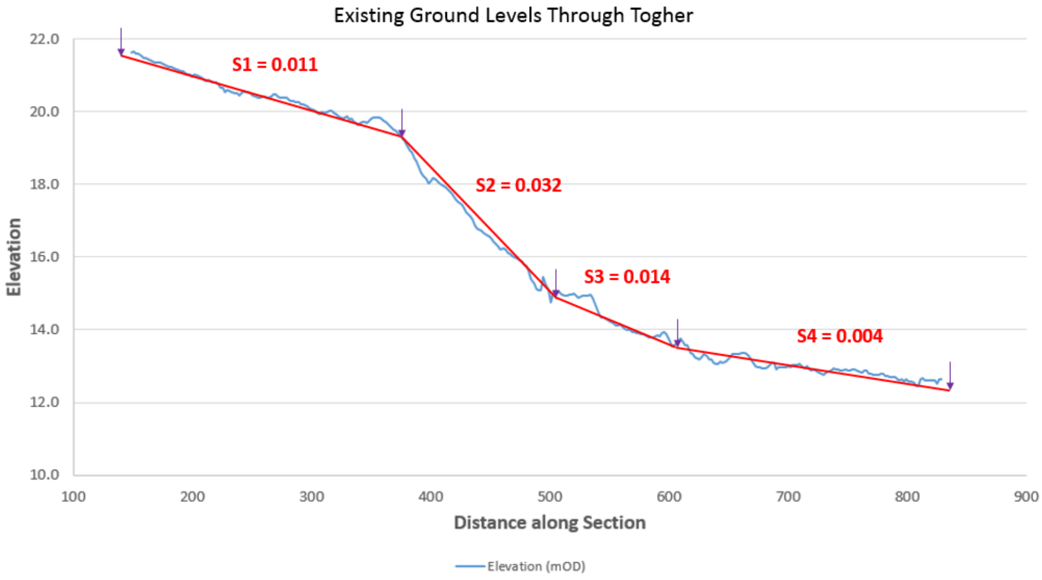
A low flow section within the channel is required to maintain ecologically appropriate low flows. It is therefore proposed to construct a meandering low flow section within the open channel.

The cross sectional area of the channel is guided by flooding requirements. A preliminary assessment of the required size of open channel was undertaken using Manning's equation and is detailed in the following section of the report. A more detailed assessment of the required channel sizing was undertaken using the hydraulic model and is presented in Section 5.7.

5.2 Preliminary Assessment of Required Open Channel Dimensions

Existing ground levels of the reach were examined to assess the likely slope of the open channel. Based on this analysis the reach was divided into four sections as indicated in Figure 22.

Figure 22: Existing ground levels through Togher (blue line). The approximate slopes are superimposed on the data (red line and red labels)



A Manning's equation calculation was then performed on each of the four sections to determine the depth of water associated with the design flood event. From this an estimate of the bed level of the open channel was calculated from:

Bed level = ground level – freeboard – cover to culverts - depth of water

It was assumed that the channel was 3m wide, rectangular in shape and that the Manning's value throughout the reach was 0.035. A screenshot of the calculation is presented in Figure 23.

A longitudinal plot of the bed levels calculated from the preliminary assessment are presented in Figure 24. The bed level presented with the orange line assumes no cover to the culverts and considers the design Q100 flow. It is applicable to the upstream part of the reach in Southern Fruits where there are no culvert requirements.

The bed level presented with the grey line in Figure 24 assumes a 1.2m cover to the culverts and considers the design section 50 flow. It is applicable to the downstream part of the reach.

A preliminary estimate of the required bed level through the entire reach can be determined by considering both of these datasets together. This combined dataset is indicated by the thick blue line in Figure 25.

Figure 23: Manning's equation calculations

Simple Mannings calcs to act as a check on the Hydraulic Modelling results					
ASSUME A RECTANGULAR CHANNEL					
	S50 Flows				
	1st Section - S50	**2nd Section - S50**	**3rd Section - S50**	**4th Section - S50**	**4th Section - S50 (end)**
Cross section data					
Width =	3.00	3.00	3.00	3.00	
Widening (m) =	0.00	0.00	0.00	0.00	
Maximum Width =	3.00	3.00	3.00	3.00	
Required depth to give design Q (m) =	**1.497**	**1.013**	**1.368**	**2.208**	**2.208**
Parameters					
Slope (S)	0.011	0.032	0.014	0.004	
Roughness (n)	0.035	0.035	0.035	0.035	
Hydraulic Parameters					
Area of flow (m2)	4.49	3.04	4.10	6.62	
Wetted Perimeter (m)	5.99	5.03	5.74	7.42	
Flow rate in channel (m3/s)	11.10	11.10	11.10	11.10	
Existing ground level at start of reach	21.64	19.20	15.05	13.61	12.64
Assuming no culverts					
Freeboard (m) =	0.30				
Cover to culverts (m) =	1.200				
PRELIMINARY Bed Level =	18.643	16.688	12.182	9.902	8.932
nces along Tramore River (for plotting)	149	378.25	506.48	606.02	828.90

Figure 24: Preliminary assessment of required bed levels. The location of the five culverts are indicated on the figure

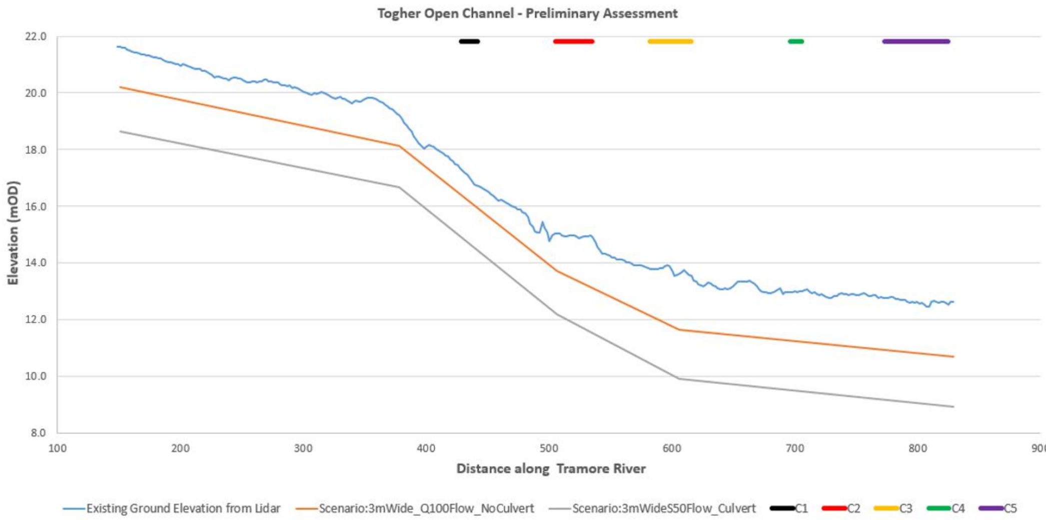
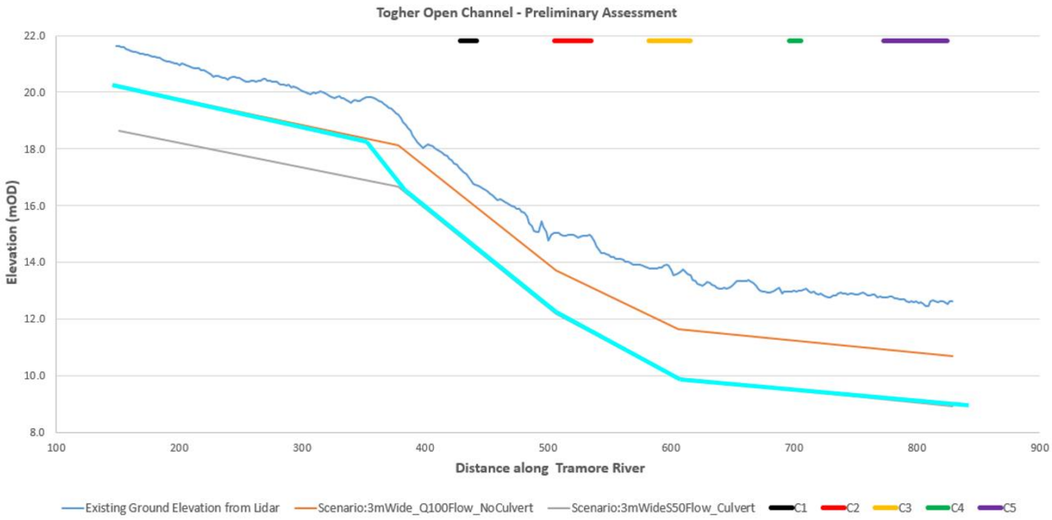


Figure 25: Preliminary assessment of required bed levels – merging of the two different datasets



It can be seen from Figure 25 that the depth of channel at the downstream end for the scenario that considers the section 50 design flow and a 1.2m cover to the culverts is approximately 3.7m. This is a significant depth of channel which may be impractical to implement.

A channel wider than 3m would increase the flow area and therefore reduce the need for a deeper channel. A 4m wide channel for the downstream end has therefore also been assessed. The results of the analysis are presented in Figure 26.

It can be seen that for the design Section 50 flows incorporating a 4m wide section for the downstream end requires a 3.1m deep channel. This is still a significant depth of channel that may be impractical to implement.

5.3 Open Channel - Section 50 Requirements

Section 50 requirements for culverts differ from Section 50 requirements for bridges as it recognised by OPW that given the relatively small cross sectional area of culvert openings it may be impractical for these requirements to be met.

Further it is noted that Section 50 requirements are intended to ensure a conservative approach to one off culverts/bridges where the wider impacts may not necessarily be understood. In the context of a flood relief scheme, where the entire affected reach is being considered and modelled, it may be reasonable to relax the Section 50 requirements whilst still ensuring a robust solution.

Over the course of this project, OPW has advised Arup that for culverts the following guidelines should be considered:

- Ideally the maximum net head loss over the length of the culvert is 0.1m.
- Drowning of the outlet of the culvert is permitted.

- Surcharging of the inlet to the culvert is also allowed in the design flood condition provided that all head losses including entry losses are taken into account in the analysis.
- As a consequence, there is no requirement for freeboard in the culvert provided all appropriate head losses are properly accounted for.
- Velocities should not exceed 1.5m/s within the culvert except where this is unavoidable because of the natural gradient of the watercourse.

Therefore, while it is desirable to reduce the net head losses to less than 0.1m and have freeboard within the culvert, it is not an absolute requirement.

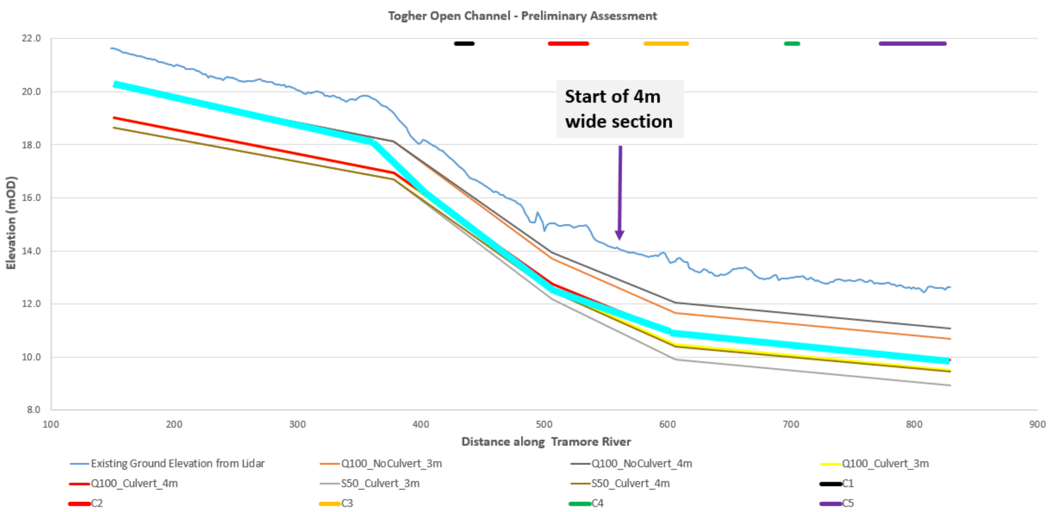
We therefore propose to design the open channel to meet the freeboard and cover requirements for the design Q100 flows and not the design Section 50 flows as they are not practical to implement. Our design will however ensure that the arrangement can pass the Section 50 flow with a minimum of 300mm freeboard below bank level.

Figure 26 presents the bed level of the open channel calculated from the preliminary analysis for the proposed design of the open channel. It can be seen the required depth of channel at the downstream end is 2.75m for the proposed arrangements.

Is it noted that the channel width goes from 3m to 4m wide in between the second and third culverts.

The extent of surcharging, if any, of the culverts for the design Section 50 flow is estimated from the hydraulic modelling and is discussed in Section 5.7. This will determine if freeboard requirements are met in the channel and if a refinement of the design is necessary.

Figure 26: Proposed bed level of the open channel from the preliminary assessment

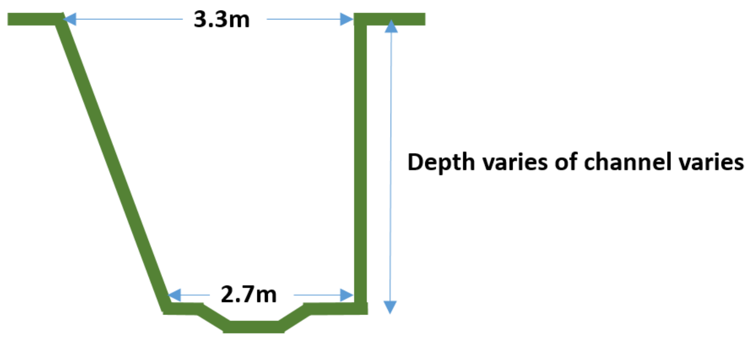


5.4 Proposed Cross Section Dimensions Based on the Preliminary Assessment

An indicative cross section of the open channel hydraulic model is presented in Figure 27. It can be seen from the figure that to minimise land take the width of the channel bed is set at 2.7m. The width of the top of the sections is set at 3.3m. The width of at the downstream end of the reach is 4.3m.

The low flow section is indicated in the cross section plot. The actual dimensioning of this low flow section is to be finalised in the detailed design stage of the project.

Figure 27: Indicative cross section of the open channel reach



5.5 Manning's n – Open Channel Model

The roughness values of the model follow the same values as detailed in Section 4.5. The Manning's values for the open channel section were selected to represent the likely finishes of the bed and side slopes.

5.6 Representation of the Culverts Along the Open Channel in the Hydraulic Model

The five culverts that form part of the Open Channel option model have been modelled through use of rectangular conduit units in ISIS. The entrance and exit head losses into and out of the culverts were modelled using the Bernoulli Loss unit and not the standard culvert inlet/outlet units. The Bernoulli Loss unit was selected as it allows different head losses to be specified at different water levels in the channel whereas as the standard Culvert Inlet and Culvert Outlet units apply a constant head loss to the inlet and outlet flow regardless of the depth of water in the channel.

The five culverts are to have the same dimensions as the open channels upstream and downstream of them. From a hydraulics perspective they will therefore act as "flat slabs" over the open channel. There will therefore be no entrance head loss into the culvert when the water level is below the soffit level of the culvert. A head loss will only occur when the water level hits the soffit level of the culvert.

In a similar manner there will be no exit head loss when the water level is below the soffit level of the exit of the culvert.

There are no weirs in the model.

5.7 Open Channel Hydraulic Model Results

The model was used to simulate both the design Q100 and design section 50 flows through the reach. For the first simulation of the model the bed levels were set according to the results of the preliminary analysis as reported in the previous section.

Preliminary design runs of the hydraulic model indicated that the design Q100 flow exceeds the capacity of the channel at the upstream part of the reach in Southern Fruits. The results also indicate the second culvert along the reach is surcharged.

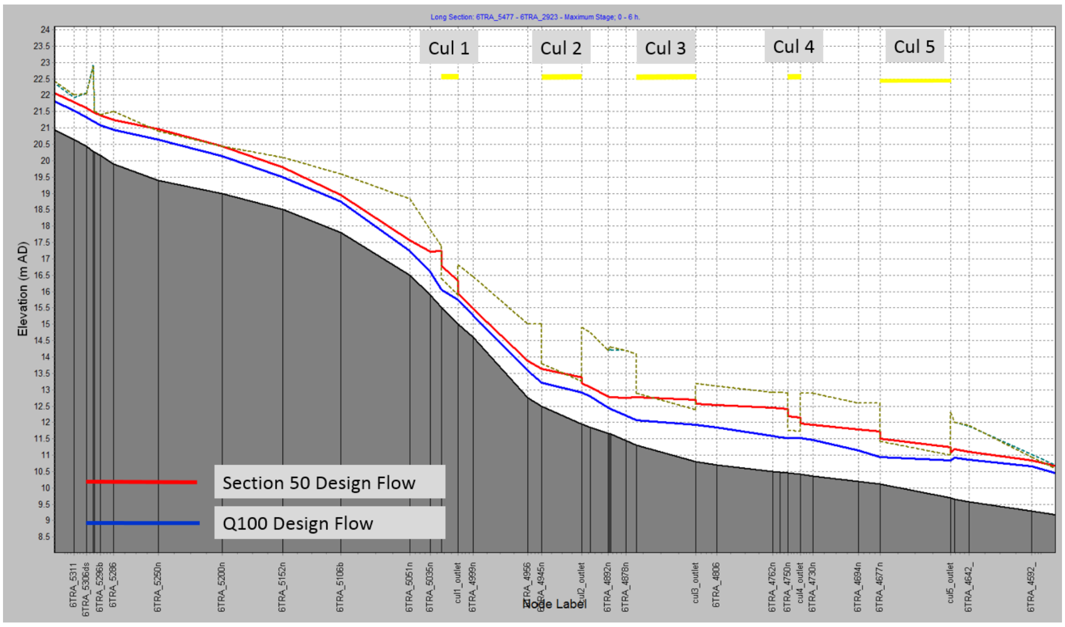
Preliminary runs for the design section 50 flow indicate more severe surcharging of the second culvert, out-of-bank flow in Southern Fruits and surcharging of the first culvert along the reach.

The geometry of the open channel was therefore modified to address these issues and the following modifications were undertaken:

- The bed level in the upstream section of Southern Fruits was lowered by approximately 300mm.
- The bed level immediately upstream of the first culvert was lowered by approximately 250mm. Consequently the bed is steeper through this reach than in the original model.
- The assumed cover over the first culvert was reduced from 1.2m to 1m – this assumption allowed the soffit level of the culvert be increased by 0.2m. Given the absence of significant services in this part of the reach an assumed cover 1m is considered feasible.
- The bed level upstream and downstream of the second culvert and the invert level of the same culvert were reduced by approximately 250mm.

Figure 28 presents the longitudinal profile of maximum water level for the refined model for both the Q100 (blue line) and Section 50 (red line) design flows. The location of the five culverts are indicated on the figure.

Figure 28: Longitudinal Profile of Maximum water level through the reach



It can be seen from the figure that the design Q100 flow is conveyed through the reach without any surcharging of the culverts. The freeboard varies through the reach:

- The minimum freeboard offered in the open channel section is approximately 250mm (within Southern Fruits);
- The freeboard offered at the upstream and downstream faces of the various culverts in the model are listed in Table 2.

Table 2: Freeboard at the upstream and downstream faces of the culvert – Design Q100 flow

	Freeboard - upstream face	**Freeboard - downstream face**
Culvert 1	340mm	150mm
Culvert 2	580mm	340mm
Culvert 3	820mm	470mm
Culvert 4	220mm	200mm
Culvert 5	480mm	150mm

It can be seen that the freeboard at the entrances to the culverts varies from 220m to 820mm. It can also be seen that the freeboard at the exits of the culverts varies from 150mm to 470mm.

The results of the model presented in Figure 28 indicate that the Section 50 flow is surcharging most of the culverts. The freeboard offered at the upstream and downstream faces of the various culverts in the model are listed in Table 3.

Negative numbers indicate the extent of the surcharging over the soffit.

Table 3: Freeboard at the upstream and downstream faces of the culvert – Section 50 flow

	Freeboard - upstream face	Freeboard - downstream face
Culvert 1	-372mm	-436mm
Culvert 2	136mm	-130mm
Culvert 3	140mm	-290mm
Culvert 4	-430mm	-430mm
Culvert 5	-86mm	-247mm

While the model does indicate surcharging at the culverts the water level is not out-of-bank at any point along the reach. A minimum freeboard of 300mm is maintained throughout the open channel/culverted reach. There is however one exception to this: immediately upstream of the first culvert the freeboard is 140mm. At this location some additional direct defences can be incorporated into the works to maintain adequate freeboard.

It can be seen from the results that the Section 50 flow is out of bank in Southern Fruits. Section 50 flows however are not relevant at this location as no culverts are to be constructed along this reach.

5.8 Size of Channel Required to Meet Section 50 Requirements

The manning's equation spreadsheet was used to determine the size of channel at the downstream end of the reach that would be required to ensure that Section 50 requirements are strictly adhered to (i.e. minimum freeboard of 300mm throughout the length of the culvert).

The modified bed levels as presented in Figure 28 were used in the analysis. The width of the channel was increased until the cross sectional area was sufficient to ensure that Section 50 requirements were met.

The results of the analysis indicated that a channel width of 7.5m is required at the downstream end to strictly meet with Section 50 requirements.

6 Discussion and Conclusion

Two separate 1D ISIS hydraulic models of the Tramore River through Togher were developed to simulate both of the flood relief measures proposed as part of the study:

- Single culvert.
- Open Channel with associated culvert crossings.

The results of the single culvert model indicate that a single rectangular culvert of dimensions 3m*1.4m is not surcharged by the Section 50 Q100 design flow at any point along its length. The freeboard maintained within the culvert varies from 0.5m to 0.98m for the Design Q100 flow and from 0.2m to 0.85m for the Section 50 design flow.

Peak velocities within the culvert are high and vary from circa 5.9m/s (Q100 design flow) to 6.65m/s (Section 50 flow). Careful attention to detail will therefore be required as part of the detailed design of the culvert.

Direct defences are required immediately upstream of the culvert for a length of approximately 50m to address elevated water levels that may occur in the event of a blockage of the trash screen.

The results of the open channel hydraulic model indicate that the design Q100 flow can be conveyed through the reach without any surcharging of the five culverts required as part of the design. The freeboard at the entrances to the five culverts varies from 220m to 820mm. The freeboard at the exits of the five culverts varies from 150mm to 470mm.

The results of the model indicate that the Section 50 flow will result in surcharging of the culverts. A minimum freeboard of 300mm to the top of the bank will be maintained throughout the open channel/culverted reach. An exception to this however occurs immediately upstream of the first culvert where the freeboard is 140mm. At this location some additional direct defences can be incorporated into the works to maintain adequate freeboard.

Appendix A

Hydraulic Model Results

A1.1 Single Culvert Model – no Blockage

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Velocity (m/s)
6TRA_5477	25.309	7.592	4.177
6TRA_5450	24.149	7.591	1.914
6TRA_5402	23.206	7.594	2.713
6TRA_5311	21.692	7.596	1.615
6TRA_5306	21.56	7.596	1.898
6TRA_5306ds	20.784	7.596	1.746
6TRA_5301	20.722	7.596	1.867
6TRA_5301ia	19.979	7.596	4.226
6TRA_5296b	19.928	7.596	3.401
6TRA_5286	19.837	7.596	3.974
6TRA_5256b	19.574	7.596	3.498
6TRA_5206b	19.181	7.596	3.717
6TRA_5156b	18.537	7.595	4.714
6TRA_5106b	17.472	7.595	5.365
6TRA_5056b	16.162	7.594	5.476
6TRA_5013oa	14.627	7.593	5.932
6TRA_4956	13.338	7.593	4.707
6TRA_4906	12.601	7.591	4.208
6TRA_4856	12.061	7.59	3.827
6TRA_4806	11.725	7.591	2.892
6TRA_4756	11.536	7.592	2.704
6TRA_4706	11.357	7.592	2.791
6TRA_4656	11.19	7.592	2.558
6TRA_4653	10.984	7.592	1.587
6TRA_4642	10.898	7.593	2.315
6TRA_4627	10.773	7.592	1.816
6TRA_4545	10.011	7.592	2.526
6TRA_4500	9.556	7.591	2.185
6TRA_4457b	9.27	7.589	1.575
6TRA_4372	8.855	7.589	1.56
6TRA_4273	8.45	7.588	1.669
6TRA_4169	7.99	7.586	1.622
6TRA_4112	7.784	7.585	1.458
6TRA_4036	7.309	7.585	1.984
6TRA_3938	6.556	7.584	2.159

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Velocity (m/s)
6TRA_3932	6.553	7.584	1.691
6TRA_3901	6.439	7.583	1.548
6TRA_3901i1	6.387	7.583	1.659
6TRA_3870	6.365	7.581	1.166
6TRA_3870i1	6.332	7.58	1.26
6TRA_3884	6.312	7.582	1.844
6TRA_3884d	6.312	7.582	1.844
6TRA_3884Bu	6.312	7.582	0.672
6TRA_3884Spu	6.312	0	0.672
6TRA_3884Bd	6.312	7.582	0.672
6TRA_3884Spd	6.312	0	0.672
6TRA_3847	6.278	7.58	1.415
6TRA_3847d	6.278	7.58	1.415
6TRA_3847Bu	6.278	7.58	0.543
6TRA_3847Spu	6.278	0	0.543
6TRA_3847Bd	6.278	7.58	0.543
6TRA_3847Spd	6.278	0	0.543
6TRA_3847i1	6.231	7.58	1.463
6TRA_3847i2	6.18	7.58	1.53
6TRA_3813	6.122	7.579	1.627
6TRA_3732	6.025	7.572	0.977
6TRA_3732Bu	6.025	7.572	0.912
6TRA_3732Spu	6.025	0	0.912
6TRA_3732Bd	6.012	7.572	0.912
6TRA_3732d	6.012	7.572	0.978
6TRA_3732Spd	6.012	0	0.912
6TRA_3720	5.936	7.57	1.335
6TRA_3623	5.856	7.563	0.788
6TRA_3559	5.851	7.556	0.474
6TRA_3513	5.792	7.554	0.927
6TRA_3502	5.751	7.554	1.224
6TRA_3502Bu	5.751	7.554	1.377
6TRA_3502Spu	5.751	0	1.377
6TRA_3502Bd	5.712	7.554	1.377
6TRA_3502d	5.712	7.554	1.342
6TRA_3502Spd	5.712	0	1.377
6TRA_3397	5.051	7.554	2.131
6TRA_3309	4.64	7.551	1.458

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Velocity (m/s)
6TRA_3194	4.431	7.548	0.873
6TRA_3100	4.306	7.543	0.933
6TRA_3009	4.071	7.542	1.167
6TRA_2923	3.674	7.541	1.516

A1.2 Single Culvert Model – 67% Blockage

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Velocity (m/s)
6TRA_5477	25.308	7.592	4.185
6TRA_5450	24.119	7.592	2.011
6TRA_5402	23.241	7.593	2.561
6TRA_5311	22.091	7.592	1.615
6TRA_5306	22.053	7.591	1.479
6TRA_5306ds	22.001	7.591	0.871
6TRA_5301	21.993	7.591	0.886
6TRA_5301ia	19.979	7.591	4.226
6TRA_5296b	19.928	7.591	3.401
6TRA_5286	19.837	7.591	3.974
6TRA_5256b	19.573	7.591	3.498
6TRA_5206b	19.181	7.59	3.716
6TRA_5156b	18.537	7.589	4.713
6TRA_5106b	17.472	7.588	5.363
6TRA_5056b	16.162	7.588	5.475
6TRA_5013oa	14.627	7.588	5.93
6TRA_4956	13.338	7.589	4.706
6TRA_4906	12.601	7.589	4.207
6TRA_4856	12.061	7.59	3.827
6TRA_4806	11.725	7.589	2.891
6TRA_4756	11.536	7.589	2.703
6TRA_4706	11.356	7.589	2.791
6TRA_4656	11.189	7.588	2.557
6TRA_4653	10.984	7.588	1.587
6TRA_4642	10.897	7.588	2.314
6TRA_4627	10.773	7.588	1.816
6TRA_4545	10.01	7.586	2.526
6TRA_4500	9.556	7.586	2.184
6TRA_4457b	9.27	7.586	1.574
6TRA_4372	8.855	7.586	1.56

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Velocity (m/s)
6TRA_4273	8.45	7.584	1.669
6TRA_4169	7.99	7.583	1.622
6TRA_4112	7.784	7.583	1.457
6TRA_4036	7.309	7.581	1.984
6TRA_3938	6.556	7.58	2.158
6TRA_3932	6.553	7.58	1.691
6TRA_3901	6.439	7.58	1.548
6TRA_3901i1	6.387	7.58	1.659
6TRA_3870	6.365	7.579	1.166
6TRA_3870i1	6.331	7.579	1.26
6TRA_3884	6.312	7.579	1.844
6TRA_3884d	6.312	7.579	1.844
6TRA_3884Bu	6.312	7.579	0.672
6TRA_3884Spu	6.312	0	0.672
6TRA_3884Bd	6.312	7.579	0.672
6TRA_3884Spd	6.312	0	0.672
6TRA_3847	6.278	7.578	1.415
6TRA_3847d	6.278	7.578	1.415
6TRA_3847Bu	6.278	7.578	0.543
6TRA_3847Spu	6.278	0	0.543
6TRA_3847Bd	6.278	7.578	0.543
6TRA_3847Spd	6.278	0	0.543
6TRA_3847i1	6.231	7.578	1.463
6TRA_3847i2	6.18	7.577	1.53
6TRA_3813	6.122	7.577	1.627
6TRA_3732	6.025	7.568	0.977
6TRA_3732Bu	6.025	7.568	0.912
6TRA_3732Spu	6.025	0	0.912
6TRA_3732Bd	6.012	7.568	0.912
6TRA_3732d	6.012	7.568	0.978
6TRA_3732Spd	6.012	0	0.912
6TRA_3720	5.936	7.567	1.335
6TRA_3623	5.856	7.559	0.788
6TRA_3559	5.851	7.554	0.473
6TRA_3513	5.792	7.552	0.927
6TRA_3502	5.751	7.552	1.225
6TRA_3502Bu	5.751	7.552	1.377
6TRA_3502Spu	5.751	0	1.377

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Velocity (m/s)
6TRA_3502Bd	5.712	7.552	1.377
6TRA_3502d	5.712	7.552	1.339
6TRA_3502Spd	5.712	0	1.377
6TRA_3397	5.05	7.549	2.13
6TRA_3309	4.64	7.549	1.458
6TRA_3194	4.431	7.544	0.873
6TRA_3100	4.306	7.541	0.933
6TRA_3009	4.071	7.538	1.167
6TRA_2923	3.674	7.538	1.516

A1.3 Open Channel Model – 67% Blockage

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Velocity (m/s)
6TRA_5477	25.305	7.58	4.086
6TRA_5450	24.136	7.581	1.925
6TRA_5402	23.215	7.583	2.62
6TRA_5311	21.522	7.589	1.986
6TRA_5306ds	21.33	7.589	2.792
6TRA_5301	21.201	7.589	2.654
6TRA_5301ia	21.18	7.589	2.742
6TRA_5296b	21.093	7.589	2.701
6TRA_5286	20.941	7.59	2.476
6TRA_5250n	20.633	7.591	2.06
6TRA_5200n	20.134	7.593	2.247
6TRA_5152n	19.502	7.594	2.581
6TRA_5106b	18.749	7.595	2.749
6TRA_5051n	17.25	7.595	3.538
6TRA_5035n	16.594	7.595	3.801
6TRA_5026n	16.059	7.595	4.396
cul1_inlet	16.059	7.595	4.527
6TRA_5011n	15.756	7.595	3.275
cul1_outlet	15.756	7.595	3.347
6TRA_4999n	15.267	7.595	3.949
6TRA_4956	13.569	7.595	3.23
6TRA_4945n	13.216	7.595	3.455
cul2_inlet	13.216	7.595	3.536
cul2_outlet	12.916	7.594	2.622
6TRA_4913n	12.916	7.594	2.577
6TRA_4906	12.8	7.594	2.804

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Velocity (m/s)
6TRA_4892n	12.449	7.594	3.412
6TRA_4891n	12.422	7.594	2.932
6TRA_4890n	12.403	7.594	2.583
6TRA_4878n	12.201	7.594	2.627
6TRA_4870n	12.077	7.594	2.405
cul3_inlet	12.077	7.594	2.444
cul3_outlet	11.929	7.592	1.681
6TRA_4823n	11.929	7.592	1.663
6TRA_4806	11.838	7.591	1.717
6TRA_4762n	11.595	7.589	1.785
6TRA_4756	11.554	7.588	1.821
6TRA_4750n	11.534	7.588	1.745
cul4_inlet	11.534	7.588	1.766
6TRA_4740n	11.523	7.588	1.7
cul4_outlet	11.523	7.588	1.72
6TRA_4730n	11.455	7.587	1.788
6TRA_4694n	11.145	7.585	2.073
6TRA_4677n	10.942	7.584	2.272
cul5_inlet	10.942	7.584	2.307
6TRA_4653_	10.931	7.58	0.959
6TRA_4642_	10.861	7.579	1.337
6TRA_4656_	10.851	7.58	1.63
cul5_outlet	10.851	7.58	1.648
6TRA_4592_	10.667	7.575	1.51
6TRA_4545_	10.137	7.578	2.544
6TRA_4500_	9.587	7.579	2.214
6TRA_4457b_	9.268	7.581	1.56
6TRA_4372_	8.854	7.584	1.545
6TRA_4273	8.448	7.585	1.655
6TRA_4169	7.99	7.584	1.604
6TRA_4112	7.788	7.583	1.436
6TRA_4036	7.309	7.579	1.958
6TRA_3932	6.551	7.574	1.673
6TRA_3938	6.548	7.575	2.146
6TRA_3901	6.436	7.571	1.538
6TRA_3901i1	6.386	7.57	1.639
6TRA_3870	6.362	7.568	1.161
6TRA_3870i1	6.329	7.568	1.253

Model Cross Section	Max Stage (mOD)	Max Flow (m^3/s)	Max Velocity (m/s)
6TRA_3884	6.313	7.569	1.818
6TRA_3884d	6.313	7.569	1.818
6TRA_3884Bu	6.313	7.569	0.672
6TRA_3884Spu	6.313	0	0.672
6TRA_3884Bd	6.313	7.569	0.672
6TRA_3884Spd	6.313	0	0.672
6TRA_3847	6.276	7.569	1.406
6TRA_3847d	6.276	7.569	1.406
6TRA_3847Bu	6.276	7.569	0.543
6TRA_3847Spu	6.276	0	0.543
6TRA_3847Bd	6.276	7.569	0.543
6TRA_3847Spd	6.276	0	0.543
6TRA_3847i1	6.23	7.569	1.451
6TRA_3847i2	6.18	7.569	1.515
6TRA_3813	6.122	7.57	1.609
6TRA_3732	6.024	7.568	0.963
6TRA_3732Bu	6.024	7.568	0.912
6TRA_3732Spu	6.024	0	0.912
6TRA_3732Bd	6.011	7.568	0.912
6TRA_3732d	6.011	7.568	0.964
6TRA_3732Spd	6.011	0	0.912
6TRA_3720	5.937	7.567	1.319
6TRA_3623	5.856	7.56	0.783
6TRA_3559	5.851	7.552	0.472
6TRA_3513	5.793	7.546	0.92
6TRA_3502	5.753	7.545	1.211
6TRA_3502Bu	5.753	7.545	1.377
6TRA_3502Spu	5.753	0	1.377
6TRA_3502Bd	5.716	7.545	1.377
6TRA_3502d	5.716	7.545	1.306
6TRA_3502Spd	5.716	0	1.377
6TRA_3397	5.046	7.542	2.111
6TRA_3309	4.64	7.545	1.445
6TRA_3194	4.431	7.545	0.868
6TRA_3100	4.305	7.542	0.929
6TRA_3009	4.07	7.535	1.161
6TRA_2923	3.673	7.529	1.502