Appendix 9.6 Flood Study Report, River Awbeg at Ballyhea

Comhairle Contae Chorcaí
Cork County Council

M20 Cork-Limerick Motorway Scheme

transport21 progress in motion

Flood Study Report
River Awbeg, Ballyhea

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Executive Summary

The proposed motorway crosses the Awbeg River at Ballyhea. This river is known to flood the surrounding lands Flooding in the area affects site extents of properties in the surrounding area. The aim of this flood study is to find a solution that will ensure that no perceptible increase in flooding, also known as afflux, will arise as a result of the proposed M20 scheme**.**

The structure identified to convey the watercourse under the road is a multispan bridge having a total length of 530m.

It was found that flood levels would increase by 20mm as a result of the scheme if mitigation measures were not put in place. Options to mitigate this increase (afflux) were investigated. These included extension of the viaduct, flood relief culverts, regrading and widening of the existing river channel. The recommended option is to provide a flood relief culvert downstream of the crossing point. Provision of this flood relief culvert will ensure that flood levels are not perceptibly increased in the Ballyhea area.

1.0 Introduction

The proposed M20 Cork-Limerick Motorway Scheme crosses several existing watercourses including the Awbeg River. The Awbeg River and its tributaries will require structures and/or culverts to carry their flow under the proposed scheme. This report provides details of the hydraulic assessment of the proposed structure over the Awbeg River at Ballyhea.

Approximate coordinates of proposed structure are:
E154068.57, N117986.56; E154092.59, N117997.98;
E154304.27, N117522.13; E154327.35, N117535.35

The aim of this flood study is to determine the effect the proposed motorway has on the flow in the River Awbeg and to assess if this effect is acceptable or if mitigation is necessary. The report will outline the development of the methodologies used to undertake this assessment, namely in the determination of the design flow to meet the recommendations of the Flood Study Report (FSR) and also the requirements of both the Office of Public Works (OPW) and the National Roads Authority (NRA). The design for a 530m multispan viaduct was reviewed and analysed from a flood study point of view in addition to an assessment of the requirement for mitigation against flood level increases. The report details this analysis and contains the following;

- Establishing existing flood levels and floodplain extent
- Establishing flood levels and extent due to the proposed development
- Examining possible solutions to mitigate potential flood increases

This flood study is based on the preliminary design of the M20 Cork-Limerick Motorway scheme. At detail design stage, this flood study will be reviewed to ensure that any design changes post preliminary design do not cause a perceptible increase in flood frequency or severity.

The OPW, the Environmental Protection Agency (EPA), the National Parks and Wildlife Service (NPWS), the Shannon Regional Fisheries Board (ShRFB) and the South Western Regional Fisheries Board (SWRFB) have been consulted during the design of the M20 scheme.

2.0 Description of Proposed Structure

The Awbeg River Bridge at Ch 53+935 on the proposed M20 motorway will be a multispan bridge having a total length of approximately 530m, as shown in drawing 997/01/1700/ST53/4 in Appendix A. The typical width of the structure will be 24.2m. For the purposes of this flood study, a typical pier arrangement of approximately 45m centres is assumed. The proposed motorway shall be constructed on an embankment at either end of the viaduct structure.

3.0 Flooding

3.1 Scope of Flooding Problem

The Awbeg River rises in the Ballyhoura Mountains to the East of the proposed crossing. The catchment area at the proposed M20 crossing point is 42.45km^2 as shown in Figure 3.1.

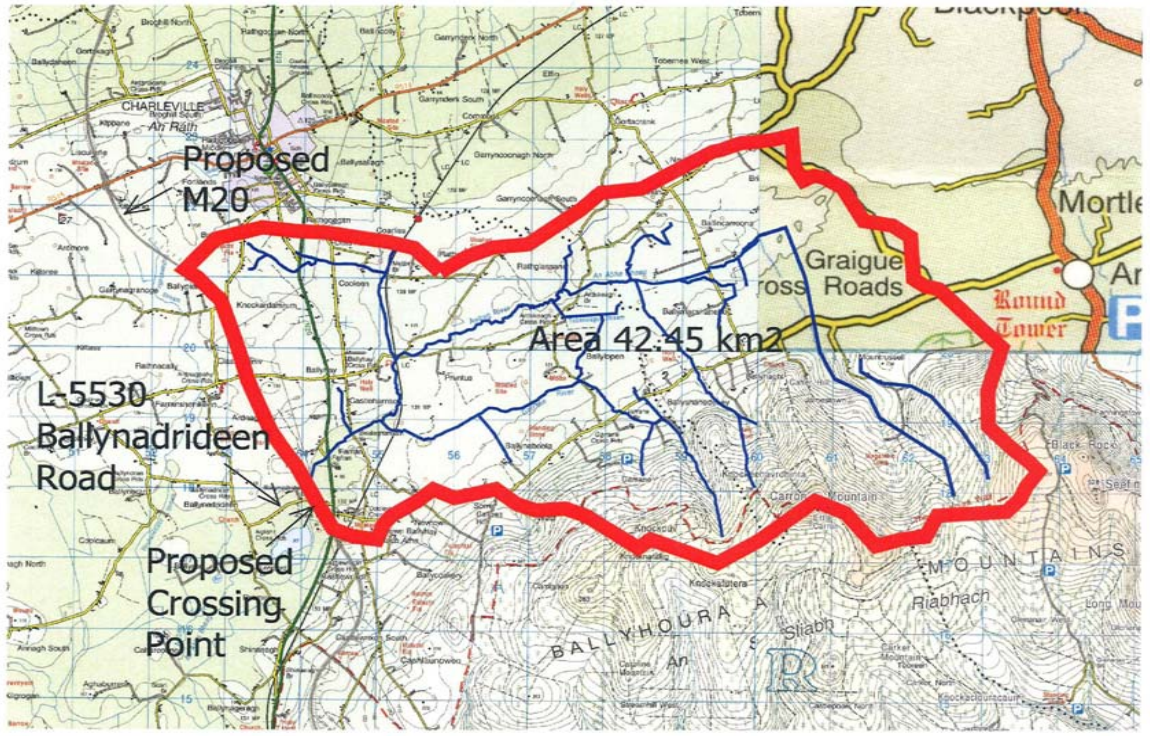


Figure 3.1 Catchment Area of Awbeg River at Ballyhea

The Awbeg River has an approximate channel width of 15 m at the proposed crossing point. OPW have indicated that this is a flood prone area. Furthermore, landowner consultation provided evidence of historical flooding in the area. The Awbeg River is known to overspill its banks up to six times per year. Flooding in the area affects site extents of residential properties in the surrounding area. The photos in Figures 3.2 and 3.3 show the extent of flooding in the Ballyhea area.

Figure 3.2 Photos of Flooding of Ballynadrideen Road (L-5530-0) adjacent to Awbeg River at Ballyhea

Figure 3.3 Photo of Flooding at Ballyhea on 20/11/2009

3.2 Causes of Flooding

There are a number of reasons for the Awbeg River flooding at Ballyhea. The Ballyhoura Mountains overlook Ballyhea village. Once the river reaches the foot of the mountains the topography flattens out leading to difficulties in draining overland flow to the river. This leads to ponding in the lands adjacent to the river. The banks of the river have been artificially bunded up in some areas along the channel in an attempt to contain the flow in the channel. However, when the river breaches its banks, there is a difficulty for flood waters to drain back into the main channel given the presence of these high bunds.

Furthermore the gradient of the river at Ballyhea is 1 in 700 and has an average velocity of 0.95m/s for a 1 in 100 year storm. Table C1 in Appendix C shows the river velocities for the pre-motorway scenario. In large floods this shallow gradient leads to difficulties in draining the increased runoff. The additional runoff cannot be conveyed downstream quickly enough and leads to the river overtopping its banks and flooding the adjacent lands.

4.0 Flood Flow Estimation

4.1 General

The following design criteria have been adopted by the design team in accordance with the FSR and the Flood Estimation Handbook (FEH).

If a catchment is gauged and there is a sufficiently long historical flow record then the FSR recommends that flood flows should be estimated by statistical flood frequency analysis methods such as Extreme Value Distribution to the data series of annual maximum flows or Peaks over Threshold (POT) flow series. Annual Maximum flow data can be obtained from the OPW or the EPA. In statistical flow estimation methods, an index flood (mean annual flood) is calculated and multiplied by a growth factor to obtain the required return period flow.

If a catchment is un-gauged the most appropriate methods for estimating design flows are described in the Flood Studies Report (1975). The method chosen should be appropriate to the size of the catchment.
Methods include:

- Mean annual flood (Qbar) by catchment characteristics plus growth curve
- FSR Unit Hydrograph and Design Storm Method

The FSR and FEH recommend that estimates of the index flood from catchment characteristics at un-gauged sites be improved by the use of index flood values calculated from river flow data recorded at gauging stations, wherever possible. The FEH also recommend that use is made of donor and/or analogue catchments to improve estimates of the index flood at un-gauged sites. A donor catchment is a catchment with a gauging station that is typically on the same river as the subject site. An analogue catchment is a catchment which is hydrologically similar to the subject site but is not necessarily on the same river.

4.2 Methodology

The FSR recommends the use of statistical flood frequency analysis where possible. The closest gauge on the River Awbeg to the Ballyhea site is approximately 30km downstream at Ballynamona Station 18004 (coordinates E165638, N107560). Given the substantial distance of the gauge from the subject site, in accordance with FEH recommendations, it was concluded that its data series would not give an accurate estimate at Ballyhea. Other flow estimation methods were therefore explored.

The methods used to derive design flow estimates for the Awbeg River at Ballyhea were:

- Qbar estimation from un-gauged methods - FSR catchment characteristic equations for un-gauged catchments
- Data transfer from gauged catchments to estimate Qbar at un-gauged sites (donor/analogue catchment analysis)

The design flow was then refined by estimating the growth curve for the Awbeg River at Ballyhea.

4.3 Un-gauged Flow Estimation

The catchment area for the Awbeg River at Ballyhea is 42.45 km^2. The most appropriate method to estimate Qbar for a catchment of this size is the FSR 6-variable catchment characteristic equation.

Flood Studies Report, 6 variable equation no.2:

$$Q = 0.0172 AREA^{0.94} STMFRQ^{0.27} S1085^{0.16} SOIL^{1.23} RSMD^{1.03} (1+LAKE)^{-0.85} \quad \text{[Equation1]}$$

where:

AREA is the catchment area (km^2).

STMFRQ (stream frequency) is the number of stream junctions per km^2 on a 1:25,000 scale map. For Ireland this can be determined from a 1inch map and converted (using a formula given in the FSR) to an equivalent 1:25,000 (2.5 inch) number.

S1085 is the slope of the main channel between 10% and 85% of its length measured from the catchment outlet (m/km).

SAAR is long-term mean annual rainfall amount in mm and 1:625,000 mapping of this parameter is available for Ireland based on meteorological records from 1941 to 1970.

R_{SMD} is a measure of rainfall excess, in mm given by 1-day R5 rainfall reduced by a weighted mean of annual soil moisture deficit (SMD). In order to obtain this value FSR maps of the 2-day R5 rainfall value and the r value which is the ratio of 1-hour R5 rainfall to 2-day R5 rainfall are used. The values obtained for the catchment are then used in conjunction with tables in the FSR for 24-hour R5 rainfall as a fraction of 2-day R5 to obtain the 24-hour (1-day) R5 rainfall. The soil moisture deficit can be determined from maps in the FSR and is subtracted from the 1-day R5 rainfall to give the R_{SMD}.

SOIL is an index of how the soil may accept infiltration and is a measure of the Winter Rainfall Acceptance Potential (WRAP). It can be determined from FSR mappings at 1:625,000 scale for Ireland. The SOIL index is based on only five classifications (very high, high, moderate, low and very low WRAP) and the mapping scale and number of categories are regarded as providing a very coarse measure of catchment runoff potential. The Flood Estimation Handbook in the UK has replaced the SOIL index by a more extensively classified and calibrated variable called HOST (Hydrology of Soil Types) provided at a grid resolution of 0.5km^2.

LAKE is an index defined as the fraction of catchment draining through lakes or reservoirs.

The characteristics for the River Awbeg catchment at Ballyhea are detailed in Table 4.1

AREA - catchment area	42.45	km^2
SAAR - standard period annual average rainfall.	1064	mm
S1 - fraction of catchment of soil class 1	0.00	-
S2 - fraction of catchment of soil class 2	28.24	-
S3 - fraction of catchment of soil class 3	0.00	-
S4 - fraction of catchment of soil class 4	0.00	-
S5- fraction of catchment of soil class 5	71.76	-
SOIL - Soil index in range 0.15 - 0.50.	0.44	-
STMFRQ - number of stream junctions as shown on the 1:25,000 map/catchment area.	0.59	no/km^2
S1085 - stream channel slope measured between two points 10 and 85% of its length.	8.17	m/km
2 day 5 year rainfall	71	mm
r - 1 hour 5 year rainfall / 2 day 5 year rainfall	0.25	-
24 hour R5 as fraction of 2 day M5	0.82	-
24 hour R5	52.45	-
Soil Moisture Deficit	5.00	mm
RSMD - net 1 day rainfall of 5 year return period.	47.5	mm
LAKE - the fraction of the catchment draining through a lake or reservoir.	0.00	-

Table 4.1 Catchment Characteristic Parameters

Using the FSR 6 variable equation (Equation 1) Qbar(estimated)$_A$ is calculated to be 13.86m^3/s.

FSR Unit Hydrograph and Design Storm Method:

Another method of estimating the design flow for un-gauged catchments is the unit hydrograph method. It is widely used in Ireland for un-gauged catchments. This method estimates the design flood hydrograph, describing the timing and magnitude of flood peak and flood volume. This method requires the catchment response characteristics (time to peak, t_p), design rainstorm characteristics (return period, storm duration, rainfall depth and profile) and catchment runoff / loss characteristics (percentage runoff influenced by SOIL type, catchment wetness index and rainfall intensity).

A flow hydrograph of the river was produced as shown in Figure 4.2. It describes the timing and magnitude of the flood peak and flood volume. The flow hydrograph calculations can be seen in Appendix B. The flood peak with 95% confidence is 70m^3/s.

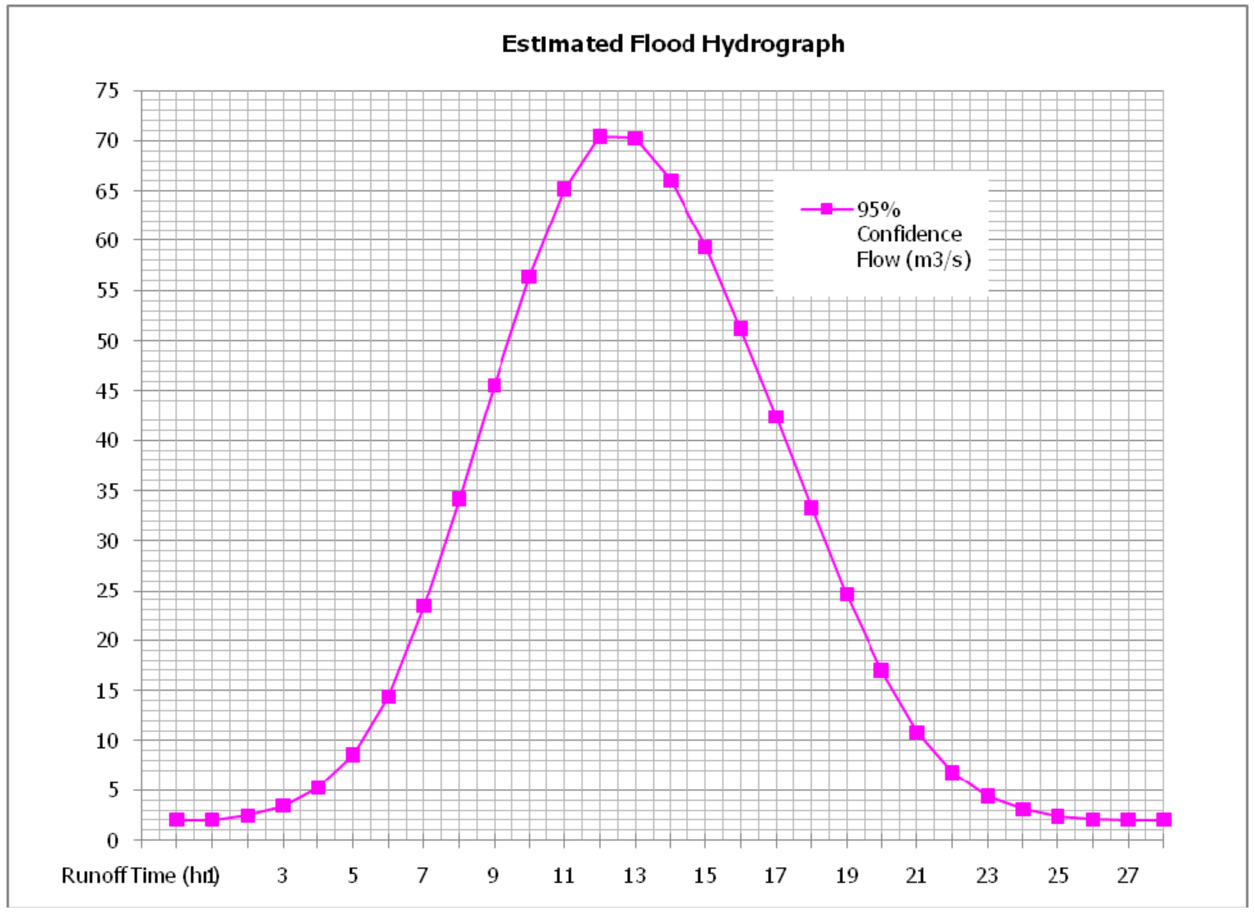


Figure 4.1 Awbeg River Flow Hydrograph

4.4 Donor/Analogue Catchment Analysis

The FEH recommends that use is made of donor and/or analogue catchments to improve estimates of the index flood at un-gauged sites. Based on the methodology of the FEH, the catchment characteristics-based estimate of Qbar at the subject site is scaled by the ratio of observed and estimated Qbar values at the donor/analogue site, so that;

$Qbar_A = Qbar(estimated)_A * Qbar(measured)_B/Qbar(estimated)_B$ [Equation2]

where subscript A refers to the subject site and subscript B refers to the donor/ analogue site.

A donor catchment assessment was undertaken using the adjacent catchment located to the north-west of the Awbeg catchment. This catchment also receives runoff from the Ballyhoura Mountains, is drained by the River Loobagh and is gauged at station 24034 (Coordinates E163231, N126306). The catchment area for the donor catchment of the Loobagh River is 54.62 km^2. The most appropriate method to estimate Qbar is the FSR-6 equation. Details are provided in Table 4.2.

AREA - catchment area	54.62	km^2
SAAR - standard period annual average rainfall.	1176	mm
S1 - fraction of catchment of soil class 1	0.00	-
S2 - fraction of catchment of soil class 2	57.40	-
S3 - fraction of catchment of soil class 3	0.00	-
S4 - fraction of catchment of soil class 4	0.00	-
S5- fraction of catchment of soil class 5	42.60	-
SOIL - Soil index in range 0.15 - 0.50.	0.39	-
STMFRQ - number of stream junctions as shown on the 1:25,000 map/catchment area.	2.05	no/km^2
S1085 - stream channel slope measured between two points 10 and 85% of its length.	7.71	m/km
2 day 5 year rainfall	71	mm
r - 1 hour 5 year rainfall / 2 day 5 year rainfall	0.25	-
24 hour R5 as fraction of 2 day M5	0.82	
24 hour R5	52.45	
Soil Moisture Deficit	5.00	mm
RSMD - net 1 day rainfall of 5 year return period.	47.5	mm
LAKE - the fraction of the catchment draining through a lake or reservoir.	0.010	-

Table 4.2 Catchment Characteristic Parameters at Loobagh Gauging Station

Using the FSR 6 variable equation (Equation2) the Qbar(estimated)$_B$ flow is calculated to be 20.33m^3/s.

Qbar (measured)$_B$ was calculated from the Annual Maximum data sets at station 24034 River Loobagh using the statistical analysis package HyfranPlus. Table 4.3 shows the annual maximum series data. Two distributions are recommended by the FSR and these are the Gumbel Extreme Value 1 (EV1) and Generalised Extreme Value (GEV) distributions. The Weibull distribution was also fitted to the data.

Table B10 and Figure B7 in Appendix B provide details of the three distributions fitted to the Annual Maximum dataset at station 24034.

HYDROMETRIC* YEAR	WATER LEVEL (mAOD-Poolbeg)	S.G. READING (m)	ESTIMATED FLOWS (m^3/s)	DATE	RELIABLE LIMIT (m^3/s)
1985	96.38	1.38	18.76	06/08/1986	13.0
1986	96.00	1.00	10.56	11/12/1986	13.0
1987	96.38	1.38	18.76	19/01/1988	13.0
1988	96.90	1.90	33.19	11/10/1988	13.0
1989	96.86	1.86	31.95	06/02/1990	13.0
1990	96.22	1.22	15.06	28/12/1990	13.0
1991	96.61	1.61	24.70	25/11/1991	13.0
1992	96.20	1.20	14.62	30/09/1993	13.0
1993	96.79	1.79	29.84	19/02/1994	13.0
1994	96.96	1.96	35.08	22/02/1995	13.0
1995	96.73	1.73	28.08	24/11/1995	13.0
1996	96.95	1.95	34.76	05/08/1997	13.0
1997	96.68	1.68	26.65	17/11/1997	13.0
1998	96.78	1.78	29.54	29/12/1998	13.0
1999	96.42	1.42	19.74	05/11/1999	13.0
2000	96.82	1.82	30.74	30/11/2000	13.0
2001	96.43	1.43	19.99	23/01/2002	13.0
2002	96.78	1.78	29.54	27/11/2002	13.0
2003	96.32	1.32	17.33	14/11/2003	13.0
2004	96.83	1.83	31.04	27/10/2004	13.0
2005	96.52	1.52	22.29	02/12/2005	13.0
2006	96.16	1.16	13.76	03/12/2006	13.0
2007	96.7	1.7	27.21	09/01/2008	13.0
2008	96.424	1.424	19.84	30/01/2009	13.0
		Average	24.30		

*The hydrometric year runs from the 1st October to the 30th September the following year. It is used instead of the calendar year because it generally contains a complete high flow season.

Table 4.3 Annual Maximum data at Gauge 24034 River Loobagh

Qbar at gauging station 24304 was chosen as the maximum of the three distributions. Table 4.4 provides details of the measured Qbar at station 24034 and the estimated Qbar on the Awbeg River at Ballyhea, all with a 95%-ile confidence interval. Using Equation 2, the annual flood Qbar at Ballyhea was determined to be 16.57m^3/s.

Mean Annual Flood	**Description**	**Mean Annual Flood (incl 95% SFE)**	**95% SFE**	*68% SFE*
m^3/s	-	m^3/s	-	-
24.30	Qbar(measured)$_B$	28.34	1.17	*1.08*
13.86	Qbar(estimated)$_A$	29.94	2.16	*1.47*
20.33	Qbar(estimated)$_B$	43.93	2.16	*1.47*
16.57	**Qbar$_A$**	**19.32**	1.17	*1.08*

Table 4.4 Estimate of Mean Annual flood using 95%-ile Confidence Interval

4.5 Growth Curve Estimation

Once the index flood, Qbar, was calculated the design flows were adjusted using growth curves for the Awbeg River in order to allow estimation of less frequent (higher return period) floods. The growth curve was then used in conjunction with Qbar to estimate flood flows for a range of return periods. There are several ways in which a growth curve may be derived, and these are described in sections 4.5.1 to 4.5.3.

4.5.1 Growth Curve from Regional Equation

The FSR provides a regional growth curve for Ireland which may be applied to any river in Ireland to produce an estimate of flow for a given return period. The growth curve ordinates for the Regional growth curve for Ireland are given in Table 4.5 and Figure 4.2.

Return period (years):	2	2.3	5	10	25	50	100
Q/Qbar:	0.95	1	1.2	1.37	1.6	1.77	1.96

Table 4.5 Growth curve derived from the FSR Regional Equation for Ireland

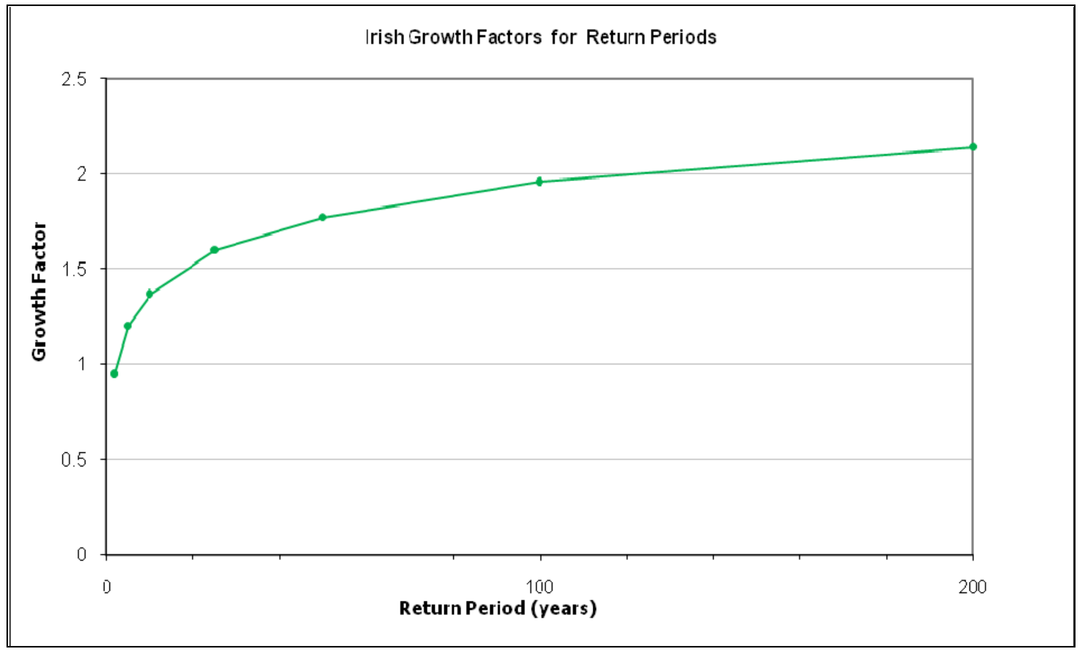


Figure 4.2 Graph of Irish Growth Factors for Different Return Periods

4.5.2 Growth curve from Donor Catchment Analysis

Where gauged data is available it is possible to estimate growth curves from observed Annual Maximum by the application of statistical distributions to the population of recorded flows. Growth curves were estimated from the Annual Maximum data sets at station 24034 River Loobagh using the statistical analysis package HyfranPlus. Two distributions are recommended by the FSR and these are the Gumbel Extreme Value 1 (EV1) and Generalised Extreme Value (GEV) distributions. The Weibull distribution was also fitted to the data. Table 4.6 provides details of the various growth curves fitted to the Annual Maximum dataset at station 24034. It is evident that the GEV and the Weibull distributions produce reasonably consistent results for each rating curve but that the EV1 distribution produces a steeper growth curve. A review of the fittings of each distribution to Annual Maximum indicated that the EV1 distribution produced a poor fit to observed data and is thought to overestimate the observed data for the higher return periods. A good fit was found for the GEV and Weibull distribution, however the growth curves are relatively flat and it was therefore decided to adopt the regional growth curve for Ireland as presented in Figure 4.2.

Return Period	GEV	Gumbel (EV1)	Weibull
100	1.50	2.04	1.60
50	1.46	1.86	1.53
20	1.39	1.62	1.42
10	1.31	1.44	1.33
5	1.20	1.25	1.21
3	1.09	1.10	1.09
2.3	1.00	1.00	1.00
2	0.96	0.96	0.96

Table 4.6 Growth curve derived from the FSR Regional Equation for Ireland

4.5.3 Pooling Group Analysis

The FEH recommends that for flow records less than the target return period but greater than 14 years a pooled analysis should be carried out with the donor site analysis being used for confirmation. This pooling group comprises of data for hydrologically similar catchments (AREA, SAAR & SOIL). The pooled group should also contain 5 times as many station years of record as the target return period (e.g. for a design return period of 1 in 100 years, 500 station years of record is required). In accordance with FEH recommendations, the pooling group analysis was undertaken based on the EPA register of gauging stations in Ireland (2007) and a total of five stations were found. Annual maximum series were only available for two out of the five stations and the record length comprised of 61 years only, which is significantly lower than the recommended 500 years of record. It was therefore decided not to pursue the pooled analysis for Irish catchments further.

A database of UK catchments is provided as part of the FEH and if the key characteristics of the study catchment are known then a pooling group may be created from this database to allow a pooled growth curve to be derived. Catchment characteristics of AREA and SAAR were calculated and while the Base Flow Index as estimated by HOST (BFIHOST) is not available for Irish catchments, this was estimated to be relatively high due to the high SOIL value. A pooling group was then derived based on recorded flows at hydrologically similar UK gauging stations and details are provided in Table 4.7.

Station	DTM AREA	SAAR	BFIHOST	URBEXT1990	No of Record Years	Note
15004	24.2	1082	0.528	0	44	
15005	42.17	1117	0.478	0		Large Reservoir
22002	60.03	1020	0.413	0	11	
49002	48.77	1076	0.643	0.0141	34	
49004	40.96	1046	0.617	0.0121	23	
51003	36.43	1153	0.586	0.0021		Suspicious Data
52014	57.34	1101	0.553	0.0001		Large Reservoir

Station	DTM AREA	SAAR	BFIHOST	URBEXT1990	No of Record Years	Note
52017	60.64	984	0.602	0.0106		Large Reservoir
52801	31.17	1163	0.58	0		Large Reservoir
56003	62.53	1171	0.528	0.0002	21	
58011	49.2	1132	0.74	0.0138		Suspicious Data
66003	69.99	1161	0.476	0.0003	26	
67009	82.5	967	0.616	0.0016	38	
205008	84.78	1016	0.403	0.0135	19	
				Total	216	

Table 4.7 Details of UK pooling group

A total of 216 record years from hydrologically similar catchments were found. This is significantly less than the required 500 record years recommended. Following consultation with the OPW, it was decided not to pursue the UK pooling group and the Irish Regional Growth Curve was adopted as shown in Figure 4.2.

4.6 Design Flow Estimate

OPW and NRA guidelines indicate that all new watercourse crossings should be designed for 1 in 100 year return period flows. This involves multiplying the Qbar by the appropriate growth factor as described in section 4.5. The Irish Regional Growth Factor for 1 in 100 year return period is 1.96.

Factors for 68% or 95% confidence should also be accounted for in the design flow. The FSR 6 variable catchment characteristic equation has a factor of 1.47 to allow for 68% confidence and 2.16 to allow for 95% confidence. The FSR advises that 95% confidence should be used in areas where there is a risk of flooding to properties and the 68% confidence factor should be used elsewhere. Given the proximity of flood waters to properties in Ballyhea, 95% confidence was adopted.

Drainage District Factors (DDF) of 1.6 were excluded due to the fact that the low embankments along the Awbeg River would be defeated during flood events and this was evident during the flood events that occurred during February and November 2009. Furthermore only a small portion of the catchment is located within the drainage district.

In line withOPW and best practice requirements, the determined design flow is subsequently increased by a factor of 20% to cater for the effects of climate change. The un-gauged FSR design flow with the 95% confidence interval and 20% climate change is 70.46m^3/s.

Gauged Flows were also estimated using the scaled Mean Annual Flood (Qbar$_A$) from the donor catchment analysis as described in Section 4.2. Due to the shortcomings of the Irish and UK pooling group analysis the Irish Regional Growth Curve was adopted to allow estimation of less frequent (higher return period) floods as shown in Table 4.8.

Return period (years):	Growth Factor	Climate Change	Design Flow
2	0.95	20%	22.0
2.3	1	20%	19.3
5	1.2	20%	27.8
10	1.37	20%	31.8
25	1.6	20%	37.1
50	1.77	20%	41.0
100	1.96	20%	45.4

Table 4.8 Design Flow Estimate including 95% confidence interval

The majority of the annual maximum data for the gauging station on the River Loobagh is extrapolated from the rating curve. The reliable limit for the gauge at the Loobagh River is approximately half the mean annual flood as seen in Table 4.3. While consultation was ongoing with the OPW, at the time of report writing, no decision had been made on the acceptability of the donor catchment analysis and for this reason, the more conservative FSR 6-variable equation with 95% confidence interval was adopted as the design flow.

4.7 Outcome

In the absence of a suitable gauge on the Awbeg River, un-gauged flow estimates were investigated. Based on FSR guidelines, the FSR 6 variable equation was determined to be the most suitable method of flow estimation at Ballyhea. Given the proximity of flood extents, during recent flood events, to properties in Ballyhea village, the most appropriate factor of safety was determined to be the 95% confidence level. The 100 year return period flow including climate change resulted to 70.5m^3/s.

Based on FEH recommendations donor/analogue catchment analysis was undertaken to improve un-gauged flow estimates at Ballyhea. The Loobagh River in the adjacent catchment to the Awbeg was determined to be a suitable donor /analogue catchment. Based on statistical flood frequency analysis, the flow in the Awbeg at Ballyhea resulted to 45.4m^3/s including 95% confidence. Given the reliable limit of the gauge is half the mean annual flood, it was determined that this estimate may be unreliable. Therefore it was concluded that the more conservative FSR 6 variable estimate should be adopted. This is to ensure beyond doubt that the worst-case scenario was designed appropriately for and to ensure that no perceptible increase in flooding resulted from construction of the M20 scheme.

5.0 Hydraulic Assessment

5.1 Background

A Hydrologic Engineering Centre-River Analysis System (HEC-RAS) 4 was used to assess the Awbeg River hydraulically. This software, developed by the US Army Corps of Engineers, allows one-dimensional steady and unsteady flow calculations to be carried out.

The program requires the following information:

- Topographic survey data of river channel and floodplain in the form of 2 dimensional cross sections
- Dimensions and elevation of relevant structures
- Upstream and downstream flow boundary conditions
- Channel and floodplain roughness coefficients

5.2 Inputs

The HEC-RAS model of the Awbeg River at Ballyhea was constructed using detailed survey information over a 2km reach length.

Cross sections were modelled every 10m from the existing structure 1km upstream of the proposed M20 crossing at L-5534 to 1km downstream of the proposed crossing. Cross sections extended 200-300m either side of the river channel to include the floodplain. Figure 5.1 illustrates the cross section plan for the analysis area.

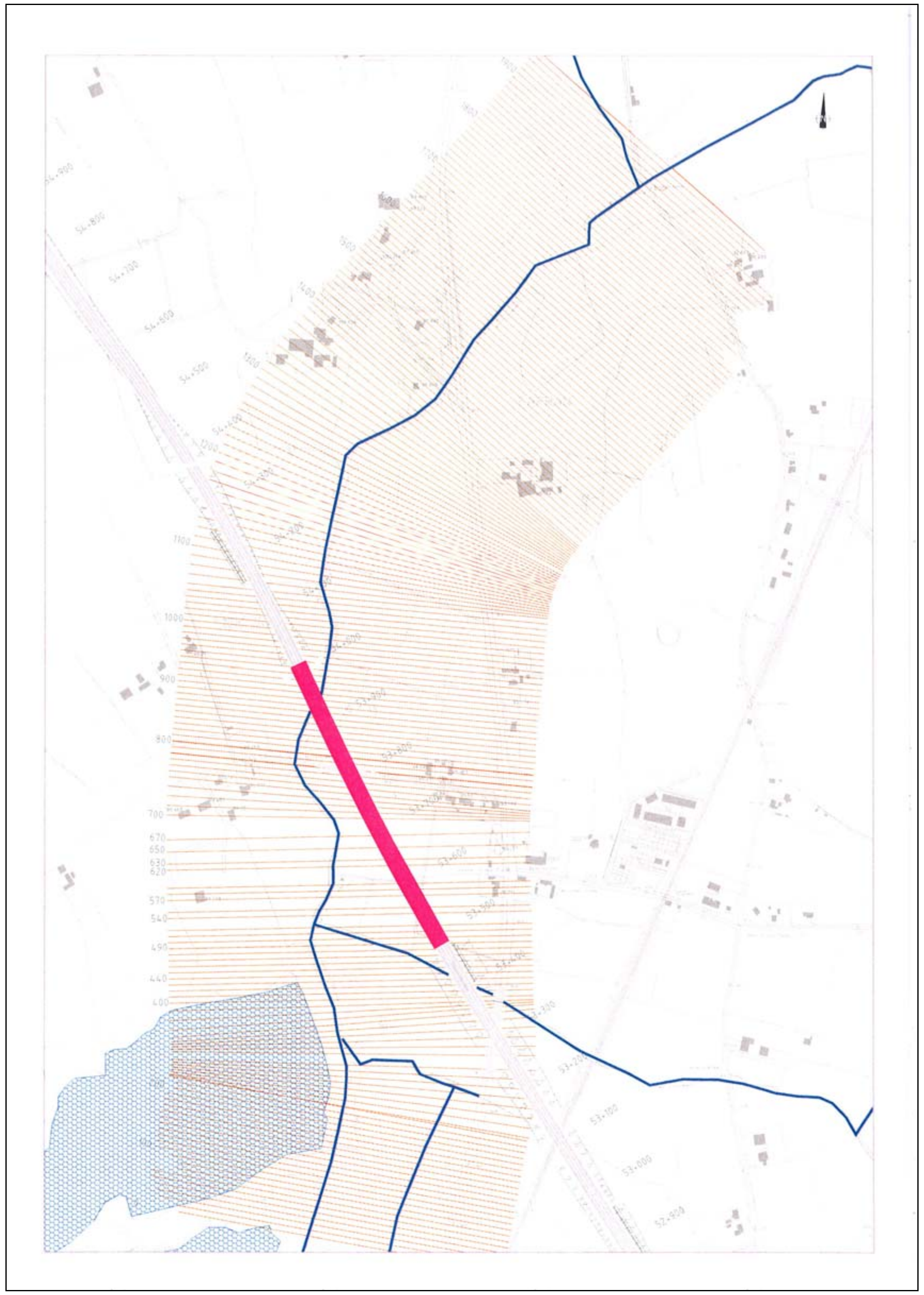


Figure 5.1 River Reach and Cross Section Plan

A manning's roughness coefficient (n) of 0.04 was assumed for the main channel and 0.06 for its overbanks based on guidance in the HEC-RAS Hydraulic Reference Manual (2002).

The HEC-RAS model was run with a flow hydrograph as shown in section 4.3 as the upstream boundary condition with a peak flow of 70m^3/s using unsteady flow analysis. The downstream boundary condition chosen was 0.013 normal depth based on the river slope.

There are two existing structures upstream of the crossing point included in the analysis - 1 no. 5.2m wide x 2.4m high arch structure to carry the existing N20 (154347.16,118490.04) and a 5.5m wide x 3m high box structure (154656.33,118786.96) for local road L-5534. A downstream structure for the L-5530 (Ballynadrideen Road) is a two arch structure 1.1m apart; 1 no. 5.4m wide x 2.35m high and 1 no. 1.8m wide x 1.77 m high.

5.3 Onsite Flow Monitoring

Two temporary hydraulic gauges were installed on the Awbeg River. The first gauge was installed at the Bealaghanattin Bridge and the second gauge some 1.2km downstream, at the Balinadrideen Bridge. The first gauge also coincides with the upstream boundary of the hydraulic model and second is used for comparison of the hydraulic modelling predictions. It should be noted that the monitoring period of these gauges does not allow verification of the 100 year design flows, however it does provide a means to calibrate the hydraulic model and provide confidence in the modelling predictions.

Figure 5.2 provides hydraulic monitoring data recorded at Bealaghanattin Bridge and Ballynadrideen Bridge. There was a time delay from the installation of the first to the second gauge which is the reason for the time data gap shown.

At time of publication it is envisaged that flow monitoring works will continue for another few months.

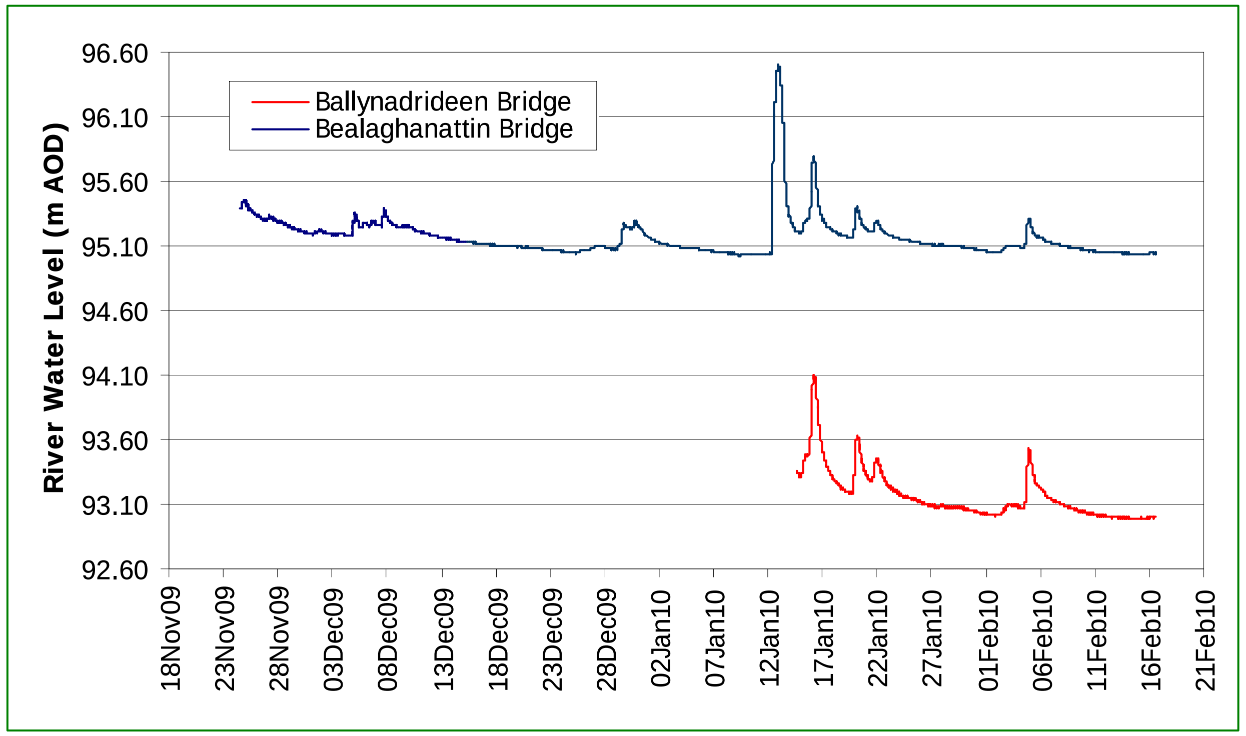


Figure 5.2 Stage Hydrograph Awbeg at Ballyhea

5.4 Modelling

Two scenarios were investigated to assess the impact of the proposed motorway and these were the existing condition (pre-motorway) and the future condition (post-motorway), as described in Section 2.
The maximum increase in water level pre-mitigation was found to be 20mm upstream of the proposed crossing point.

Figure 5.3 presents a long-section of the model showing the bridge piers and existing structures upstream and downstream of the proposed motorway crossing point. Table C1 in Appendix C indicates water levels pre-motorway and post-motorway at approximately 10m intervals along the length of the study area.

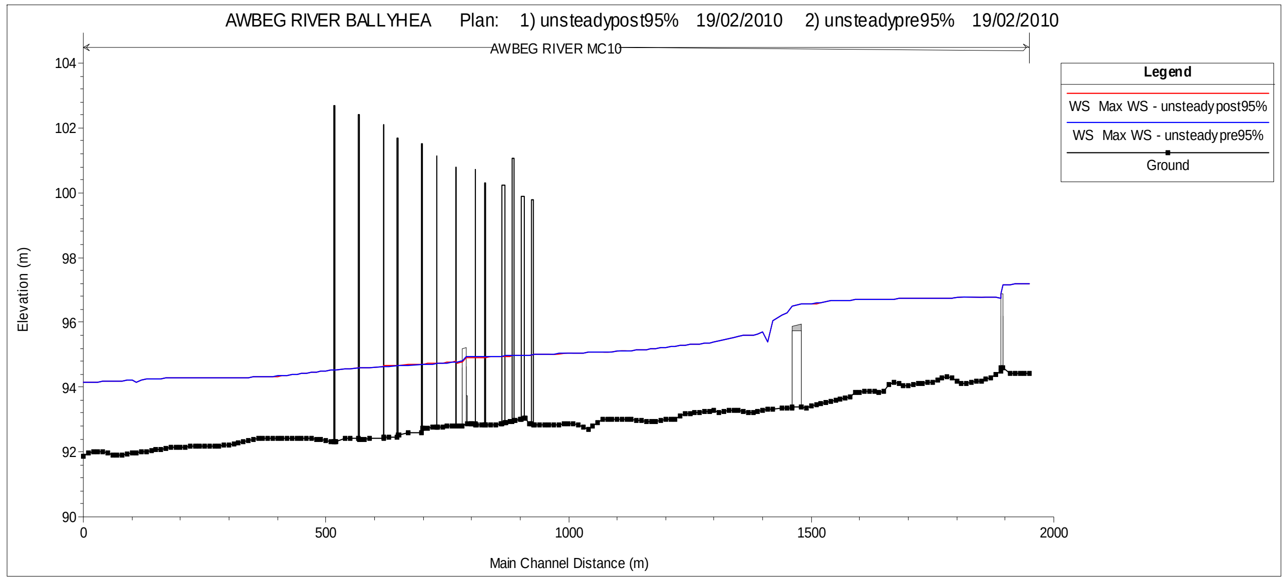


Figure 5.3 Water Profile Comparison (Pre-motorway v Post-motorway)

6.0 Mitigation Measures

The objective of this study is to ensure that construction of the M20 Scheme does not result in a perceptible increase in flood frequency or severity in the Ballyhea area in line with adherence to OPW, NRA and good practice requirements. It should however be noted that the M20 Scheme in itself will not lead to an improvement in the current situation in the Ballyhea area from a flooding point of view. A 530m structure was outlined as the length required to span the floodplain of the Awbeg at Ballyhea. Due to the close proximity of flood extents to residential properties, a solution which only results in an imperceptible increase in flood levels is required.

The viaduct structure and road embankments were modelled and analysed in detail. The result of the flooding analysis indicated a 20mm afflux. Given the location, adjacent to several residential properties, and the need for an imperceptible increase in flood levels, various mitigation measures were considered to reduce this afflux. Such mitigations options included the extension of the viaduct, upstream regrading and widening of the existing channel and also the provision of flood relief culverts.

The extension of the viaduct was considered as a mitigation proposal to alleviate the increase in flood levels but given that the afflux was 20mm other proposals took preference. Upstream regrading and widening was also considered but, as part of the channel is located inside a Candidate Special Area of Conservation (CSAC), this proposal was not the most viable. The inclusion of flood relief culverts in the design was ultimately adopted as the proposed mitigation measure. Further analysis identified a size of 1.8m x 1.8m for this flood relief culvert. This box culvert will be located under the road embankment adjacent to the southern end of the viaduct structure where the proposed embankment infringes on the flood plain.

The flood relief culvert was found to reduce the original 20mm afflux to an imperceptible level, which was the primary objective of this study. Figure 5.4 illustrates the water profiles post mitigation while Figure 5.5 illustrates the floodplain in the area pre and post motorway construction.

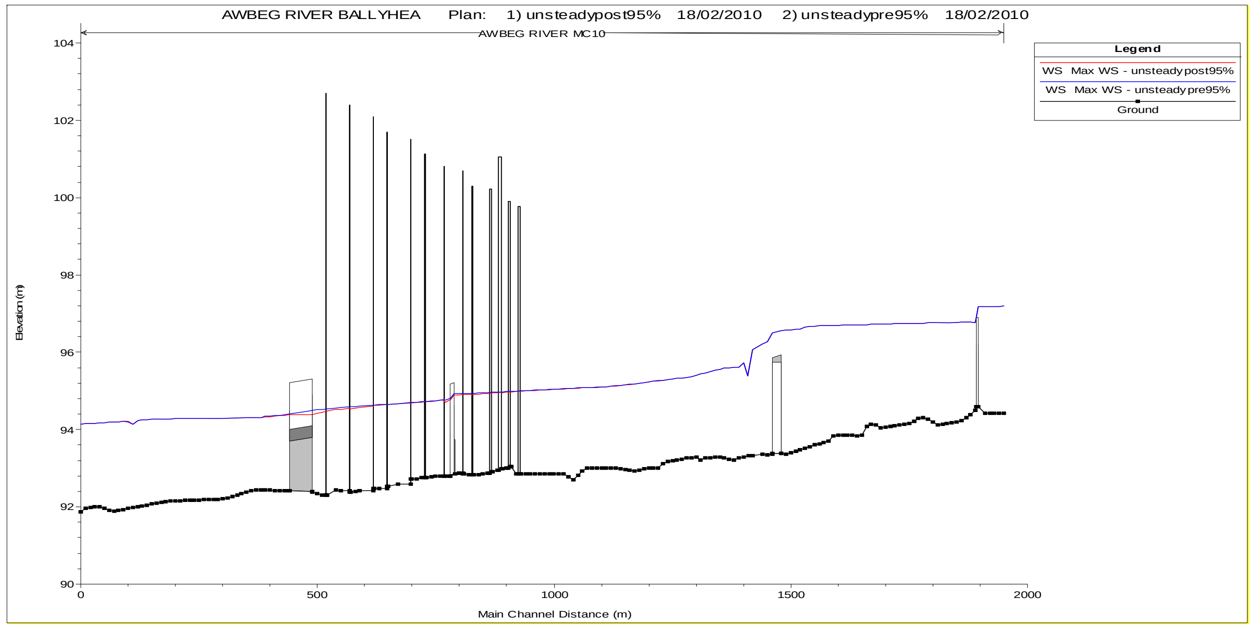


Figure 5.4 Water profiles

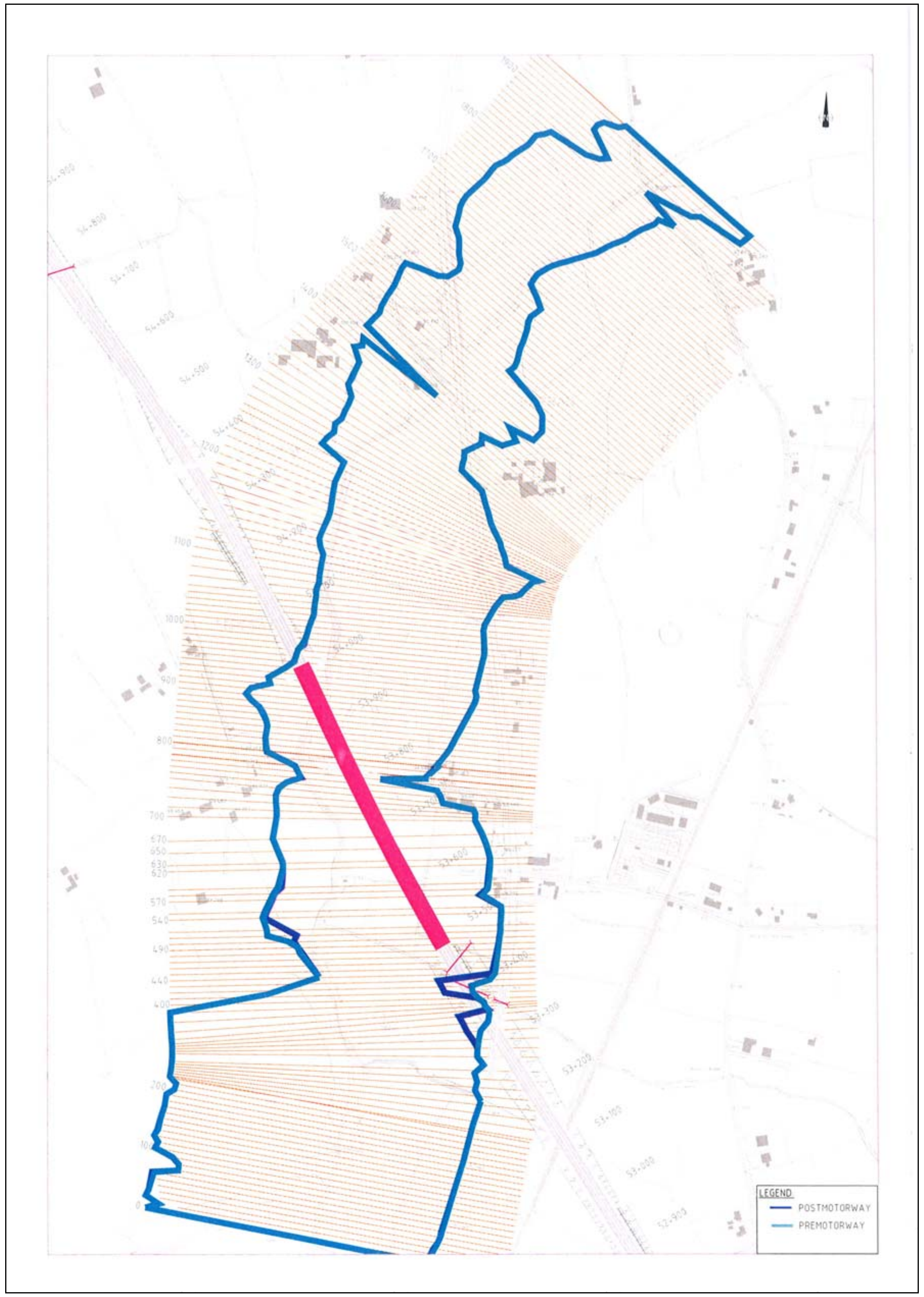


Figure 5.5 Floodplain Extents Pre-motorway and Post-motorway

7.0 Conclusion

The proposed M20 motorway crosses the Awbeg River at Ballyhea. The structure identified to convey the watercourse under the road is a multispan bridge having a total length of approximately 530m.

Hydrological calculations were undertaken and a design flow of 70.46m^3/s was determined to meet the requirements of both the FSR and FEH in addition to those of the OPW and the NRA. Hydraulic modelling was subsequently carried out using this design flow to establish the flood levels and extents of the flood plain.

The hydraulic modelling analysis indicated that flood levels would increase by 20mm as a result of the proposed motorway and structure prior to any mitigation. Given the requirement for an imperceptible increase in flood levels various mitigation measures were considered to reduce this 20mm afflux to an acceptable level.

A flood relief culvert was identified as the most viable solution and further hydraulic remodelling indicated that a 1.8m x 1.8m flood relief culvert would reduce the 20mm increase to an imperceptible level. As such, this mitigation will ensure there will be no increase in risk to flooding of properties in the area.

8.0 Glossary of Terms

AREA	Catchment area (km^2) in Equation 1
BFIHOST	Base Flow Index as estimated by HOST
CSAC	Candidate Special Area of Conservation
DDF	District Drainage Factor
EPA	Environmental Protection Agency
EV1	Gumbel Extreme Value 1
FEH	Flood Estimation Handbook
FSR	Flood Study Report
GEV	Generalised Extreme Value
HEC-RAS	Hydrologic Engineering Centres – River Analysis System
HOST	Hydrology of Soil Types
LAKE	An index of catchment draining through lakes or reservoirs
NPWS	National Parks and Wildlife Service
NRA	National Roads Authority
OPW	Office of Public Works
POT	Peaks Over Threshold
Qbar	The Mean Annual Flood
R_{smd}	A measure of rainfall excess
S1085	The slope of the main channel in Equation 1
SAAR	Long-term mean annual rainfall
SHRFB	Southern Regional Fisheries Board
SMD	Soil Moisture Deficit
SOIL	An index of how the soil may accept infiltration
STMFRQ	The number of stream junctions per km^2 in Equation 1
SWRFB	South West Regional Fisheries Board
WRAP	Winter Rainfall Acceptance Potential

9.0 References

Arup Consulting Engineers, (2003) Hydology and hydraulic Modelling Report, Office of Public Works.

Bruen M, Gebre F, Joyce T and Doyle P, (2005) ”The Flood Studies Report Un-gauged Catchment Method Underestimates for Catchments around Dublin”, National Hydrology Seminar 2005.

Cawley and Cunnane (2003) “ Comment on Estimation of Greenfield Runoff Rates “ Proceedings of the National Hydrology Seminar 2003 – Urban Hydrology Stormwater Management, IHP & ICID.

D C W Marshall & AC Bayliss (1994) “Flood Estimation for small catchments”, Hydrology Report 124, ISBN 0948540621, Institute of Hydrology, Wallingford, UK.

Design Manual for Roads & Bridges (DMRB) (1998) HA71/95 “The Effects on Flooding of Highway Construction on Floodplains”, London.

Design Manual for Roads & Bridges (DMRB) (2004) HA106/04 “Drainage of Runoff from Natural Catchments”, London.

HEC (2002) “HEC-RAS Hydraulic Reference Manual Version 3.1”, Hydrological Engineering Centre, U.S. Army Corp of Engineers 2002.

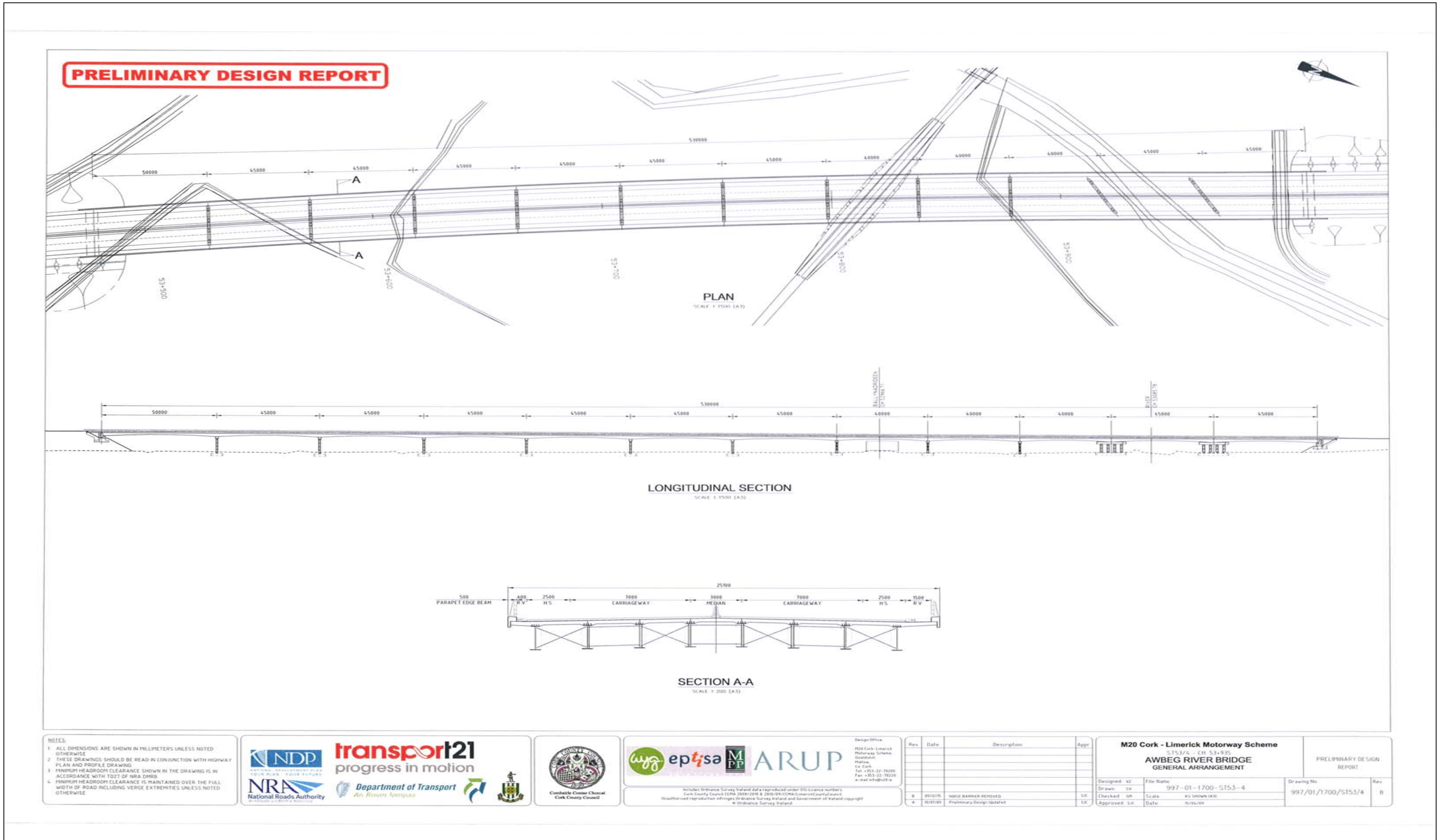
Institute of Hydrology (1999) The flood Estimation Handbook. Institute of Hydrology, Wallingford.

Lancaster J, Marshall C, (2003) “Hydological Assessment of Flood Flows on the Munster Balckwater River: A summary of techniques used to estimate flood flows at Mallow,” Paper to the Irish National Hydology Seminar.

Office of Public Works (OPW) “Construction, Replacement or Alteration of Bridges & Culverts – A Guide to Applying for Consent under Section 50 of the Arterial Drainage Act, 1945”.

Natural Environmental Research Council (NERC) (1975) “Flood Studies Report” Vols 1 to 5, London.

Appendix A Drawings



Appendix B

FSR Unit Hydrograph & Design Storm Method

Proposed M20 Crossing of the Awbeg River at Ballyhea

1 Calculate Catchment Area, Main Stream Length and Channel Slope:

Catchment Area	AREA	42.5	km^2
Main Stream Length	MSL	13.3	km
Channel Slope between 10% and 85% of the length	S1085	8.2	m/km

2 Obtain Average Annual Rainfall

SAAR 1064.0 mm

3 not required since modification of step 6

4 Calculate Percentage Urban area of the catchement

URB 0.0 %

5 URBT = 1 + URB/100 = 1.00

6 Estimate time to peak, T_p, of 1 hour unit hydrograph

$T_p = 283MSL^{0.23} S1085^{-0.33} URBT^{-2.2} SAAR^{-0.54}$ = 5.95 hr

7 Set basic data interval, T (hours) as some convenient number or fraction of hours such that T is approx. $T_p/5$

$T_p/5$ = T = 1.190 hr

Adjust 1.0 hr

8 Adjust time to peak for data interval

New T_p = oldT_p +(T-1)/2 = NEW T_p 6.00 hr

9 Estimate the recommended design storm duration

D= (1 + (SAAR/1000))T_p D 12.38 hours

Adjust storm duration so that it is an odd multiple of the time step, T = 11.00 hours

10 Establish required flood return period for the design and corresponding rainstorm return period SRP (years)

Return Periods (years)	
Flood	Rain
2.33	2
5	8
10	17
20	35
30	50
50	81
100	140
250	300
500	520
1000	1000

Table B1: Relationship between return periods of precipitation and flood peaks

flood return period 100 year

rainstorm return period 140 year

11 Calculate areal rainfall amount P, for the required return period and storm duration

2-day R5 calculated from maps in FSR 71.00

r is the ratio between 1 hour and 2 day rainfall amounts of 5 year return period and is calculated from maps in FSR

= 25.00%

r - FSR factor to estimate rainfall amount for different storm durations See Table B2. 62.00

The 5 year return period rainfall of duration 11 hours is 62% of the 2 day rainfall amount

= 44.02 mm

The corresponding amount for a return period of 140 years can be determined by a double interpolation of the table of growth factors. See Table B3.

Rainstorm return period - growth factor = 1.79

Required Return period rainfall = required 5 year return period rainfall x growth factor = 78.80 mm

An areal reduction factor is interploated from Table in FSR. See Table B4.

Areal Reduction Factor = 0.93

P, Required Areal Rainfall Amount = Areal Reduction factor x required return period rainfall

= 73.63 mm

r	R_5 Rainfall amounts as percentages of 2 day R_5												
%	1 min	2 min	5 min	10 min	15 min	30 min	1hr	2hr	4hr	6hr	12hr	24hr	48hr
12	0.85	1.4	2.7	4.2	5.4	8.1	12	18	26	33	49	72	106
15	1.2	2.1	3.8	5.7	7.2	10.4	15	21	30	37	53	75	106
18	1.6	2.8	5	7.4	9.1	12.9	18	25	34	41	56	77	106
21	2.1	3.5	6.3	9.1	11.2	15.4	21	28	38	45	59	79	105
24	2.5	4.3	7.6	11	13.4	18.1	24	32	41	48	63	82	106
27	3	5	9	12.9	15.5	20.7	27	35	45	51	66	83	106
30	3.4	5.7	10.3	14.8	17.7	23.3	30	38	48	54	68	85	106
33	3.8	6.5	11.7	16.7	19.9	26	33	41	51	57	70	86	106
36	4.1	7.2	13	18.6	22.1	28.7	36	44	54	60	73	88	106
39	4.6	7.9	14.5	20.6	24.5	31.5	39	47	57	63	75	89	106
42	5	8.7	16	22.7	26.9	34.3	42	51	60	66	77	91	106
45	5.4	9.5	17.4	24.7	29.2	37.1	45	53	63	68	79	92	106

Table B2: FSR Factors to estimate rainfall amounts for different storm durations

R5 (mm)	Growth factors (to multiply by R5)					
	R2	R10	R20	R50	R100	R1000
0.5	0.76	1.14	1.3	1.51	1.71	2.54
2	0.76	1.15	1.31	1.54	1.75	2.65
5	0.76	1.16	1.34	1.62	1.86	2.94
10	0.75	1.18	1.38	1.69	1.97	3.25
15	0.75	1.18	1.38	1.7	1.98	3.28
20	0.76	1.18	1.37	1.66	1.93	3.14
25	0.77	1.17	1.36	1.64	1.89	3.03
30	0.78	1.17	1.35	1.61	1.85	2.92
40	0.79	1.16	1.33	1.56	1.77	2.72
50	0.8	1.15	1.3	1.52	1.72	2.57
75	0.82	1.13	1.26	1.45	1.62	2.31
100	0.83	1.12	1.24	1.4	1.54	2.12
150	0.84	1.1	1.2	1.33	1.45	1.9
200	0.85	1.09	1.18	1.3	1.4	1.79
500	0.86	1.08	1.14	1.2	1.27	1.52
1000	0.86	1.07	1.12	1.18	1.23	1.42

Table B3: Growth Factors Scotland and Northern Ireland

Duration D (hours)	Area A (km2)									
	1	5	10	30	100	300	1000	3000	###	30000
0.02	0.76	0.61	0.52	0.4	0.27	-	-	-	-	-
0.03	0.84	0.72	0.65	0.53	0.39	-	-	-	-	-
0.08	0.9	0.82	0.76	0.65	0.51	0.38	-	-	-	-
0.17	0.93	0.87	0.83	0.73	0.59	0.47	0.32	-	-	-
0.25	0.94	0.89	0.85	0.77	0.64	0.53	0.39	0.29	-	-
0.50	0.95	0.91	0.89	0.82	0.72	0.62	0.51	0.41	0.31	-
1.00	0.96	0.93	0.91	0.86	0.79	0.71	0.62	0.53	0.44	0.35
2.00	0.97	0.95	0.93	0.9	0.84	0.79	0.73	0.65	0.55	0.47
3.00	0.97	0.96	0.94	0.91	0.87	0.83	0.78	0.71	0.62	0.54
6.00	0.98	0.97	0.96	0.93	0.9	0.87	0.83	0.79	0.73	0.67
24.00	0.99	0.98	0.97	0.96	0.94	0.92	0.89	0.86	0.83	0.80
48.00	-	0.99	0.98	0.97	0.96	0.94	0.91	0.88	0.86	0.82
96.00	-	-	0.99	0.98	0.97	0.96	0.93	0.91	0.88	0.85
192.00	-	-	-	0.99	0.98	0.97	0.95	0.92	0.90	0.87
600.00	-	-	-	-	0.99	0.98	0.97	0.95	0.93	0.91

Table B4: Areal Reduction Factors

12 Estimate the design catchment wetness index from Figure 6.44 of the FSR. See Figure B1

CWI 124.00

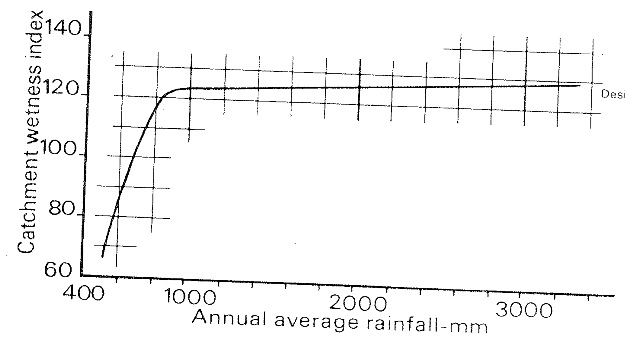


Figure B1: Catchment Wetness Index v Annual Average Rainfall

13 Calculate Soil Index

S_1	0.00
S_2	0.28
S_3	0.00
S_4	0.00
S_5	0.72
$SOIL = 0.15S_1+0.3S_2+0.4S_3+0.45S_4+0.5S_5$	0.44

14

Calculate the standard percentage runoff SPR (%) and hence the percentage Runoff, PR, (%)

$SPR=10S_1+30S_2+37S_3+47S_4+53S_5$	46.50
$DPR_{CWI} = 0.25(CWI-125)$	-0.25
$DPR_{RAIN} = 0.45(P-40)0.7$	5.27 for P>40mm
$DPR_{RAIN} = 0$	0 for P<=40mm
DPR_{RAIN}	5.27
$PR_{RURAL} = SPR + DPR_{CWI} + DPR_{RAIN}$	51.53
$PR_{total} = PR_{RURAL}(1-0.3URBAN) + 70(0.3URBAN)$	51.53%

15 **If only the peak flow is required then the curve number, CN determined from Figure 6.64 in the FSR. See Figure B2.**

CN	29.00	where	T_p/T	6.00
$q = CN \times AREA \times PR_{TOTAL}/T \times 10^5$	0.47		D/T	11

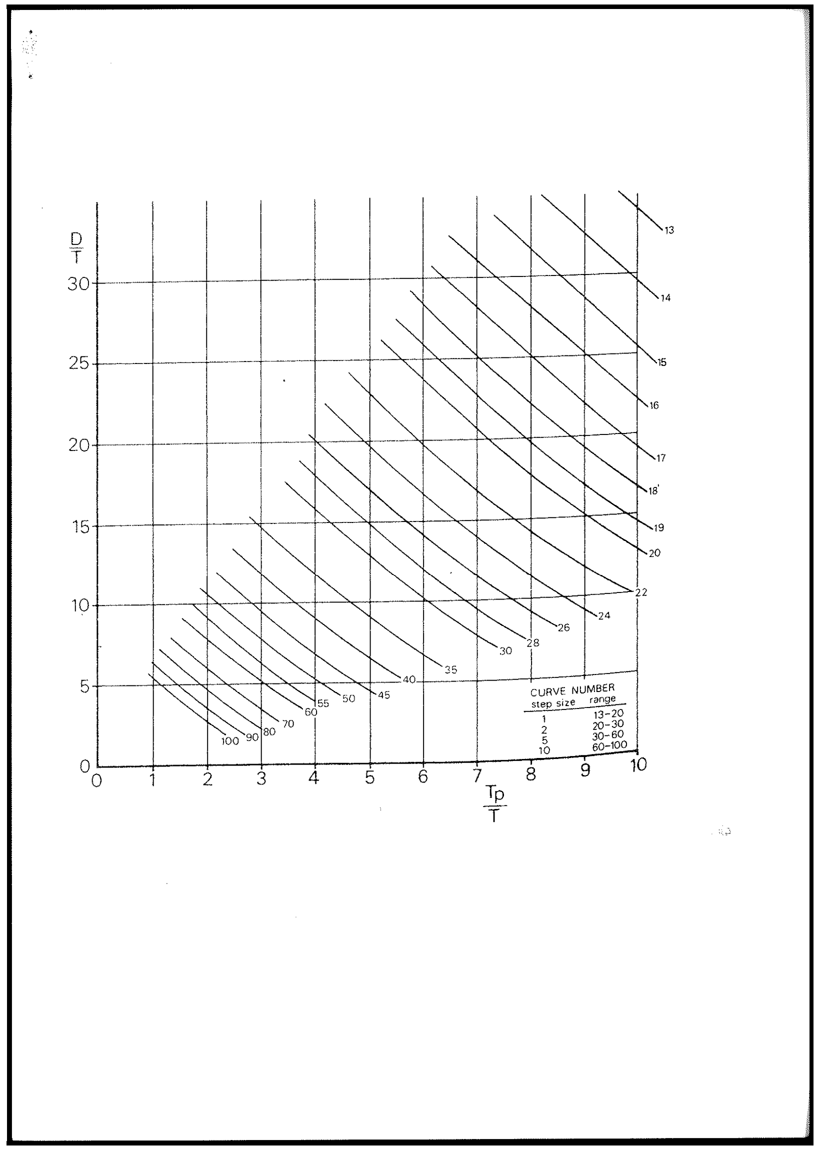


Figure B2: Curve Number

16 **If full hydrograph is required then the rainfall amount, P, is distributed over the storm duration, D, according to a chosen profile from the FSR (Table B5). See Table B6 and B7 for calculation of Rainstorm shape and Figure B3 for graph of Effective Rain versus Time.**

Cumul % rain	Cumul % duration
0%	0%
10%	4%
24%	10%
45%	20%
72%	40%
85%	60%
94%	80%
100%	100%

Table B5: 75% Winter rain storm profiles

Time (hr)	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00
% cumula-tive duration	0	(11/11)* (100)	(9/11)* (100)	(7/11)* (100)	(5/11)* (100)	(3/11)* (100)	(1/11)* (100)	(3/11)* (100)	(5/11)* (100)	(7/11)* (100)	(9/11)* (100)	(11/11)* (100)
%cumul-ative duration	0	100.0%	81.82%	63.64%	45.45%	27.27%	9.09%	27.27%	45.45%	63.64%	81.82%	100.00%
%cumul-ative rain	0	100.00%	94.55%	86.64%	75.55%	54.82%	21.88%	54.82%	75.55%	86.64%	94.55%	100.00%
%Rain	0	2.73%	3.95%	5.55%	10.36%	16.47%	21.88%	16.47%	10.36%	5.55%	3.95%	2.73%

Table B6: Design Rainstorm Shape

Time (hours)	Rain (mm) = P x (%Rain)	Effective Rain (mm) = Rain x PRTOTAL
0.00	0.00	0.00
1.00	2.01	1.03
2.00	2.91	1.50
3.00	4.08	2.10
4.00	7.63	3.93
5.00	12.13	6.25
6.00	16.11	8.30
7.00	12.13	6.25
8.00	7.63	3.93
9.00	4.08	2.10
10.00	2.91	1.50
11.00	2.01	1.03
0.00	0.00	0.00
0.00	0.00	0.00
0.00		0.00
	SUM= 73.63 = P	

Table B7: Design Rainstorm Shape

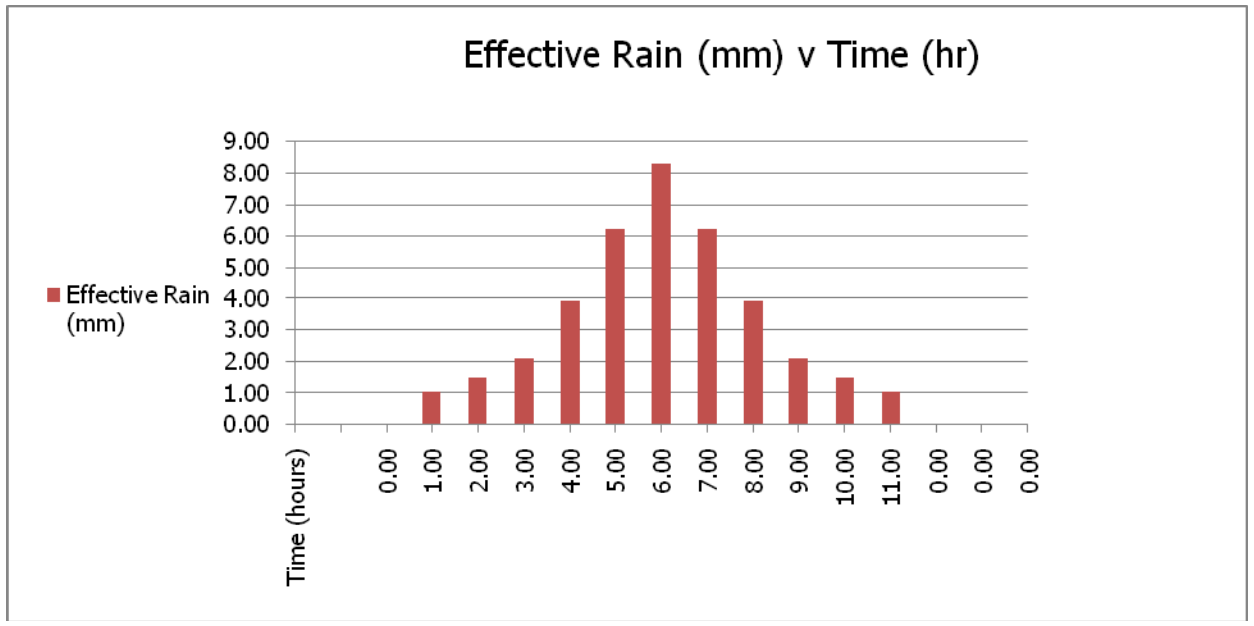


Figure B3: Graph of Effective Rain v Time

17 A triangular unit hydrograph is constructed

The Peak of the unit hydrograph is, Q_P =(220 x AREA)/(1000 x T_P) = 1.56 m^3/s per mm of effective rain

The time base of the unit hydrograph, TB =2.52*Tp = 15.12

The individual ordinate, hi of the triangular unit hydrograph for each time step, ti can be then calculated

$h_i = (Q_p/T_p)t_i$ for $t_i \leq T_p$

$h_i = Q_p(TB-t_i)/(TB-T_p)$ for $T_p \leq t_i \leq TB$

Time (Hr) ti	UH (m3/s per mm) hi
0.00	0.00
1.00	0.26
2.00	0.52
3.00	0.78
4.00	1.04
5.00	1.30
6.00	1.56
7.00	1.39
8.00	1.22
9.00	1.04
10.00	0.87
11.00	0.70
12.00	0.53
13.00	0.36
14.00	0.19
15.00	0.02
16.00	-0.15

Table B8: Unit Hydrograph

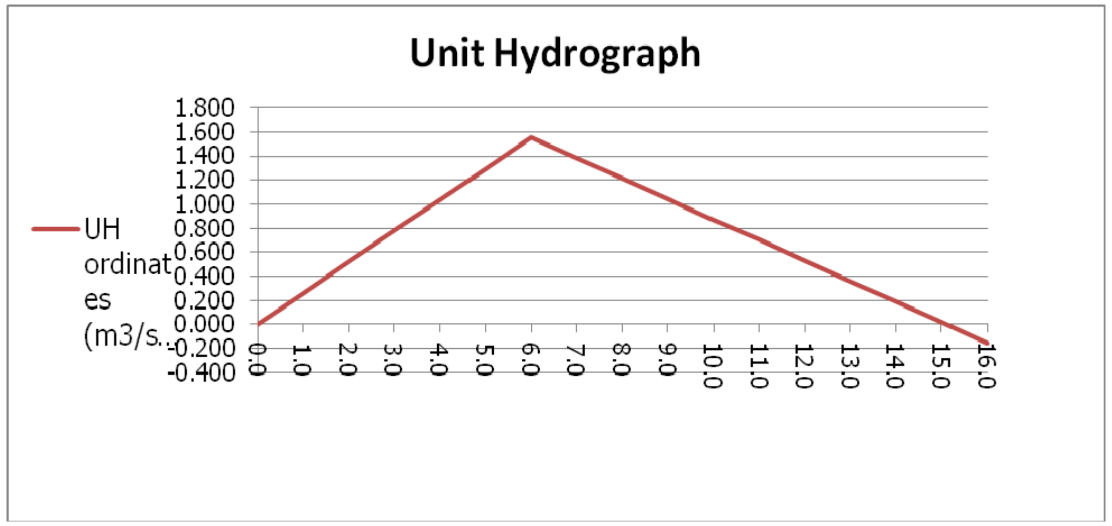


Figure B4: Unit Hydrograph

18 Hydrograph Calculations Table

Table B9: Hydrograph Values

Runoff Time (hr)	UH ordinates (m^3/s per mm)	Runoff (m^3/s) i.e Convolute effective rain with unit hydrograph	Total Discharge (m^3/s) = Runoff + Base flow)	Time (hours)	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	0.00
				Rain (mm)	0.00	2.01	2.91	4.08	7.63	12.13	16.11	12.13	7.63	4.08	2.91	2.01	0
				Effective R (mm)	0.00	1.03	1.50	2.104	3.93	6.25	8.30	6.25	3.93	2.10	1.50	1.03	0
				95% Confidence Interval on Total Discharge (m3/s) = Runoff + Base flow)													
0	0.00	0.00	1.36	2.04	0.00												
1	0.26	0.00	1.36	2.04	0.00	0.00											
2	0.52	0.27	1.62	2.44	0.00	0.27	0.00										
3	0.78	0.93	2.28	3.43	0.00	0.54	0.39	0.000									
4	1.04	2.13	3.49	5.24	0.00	0.81	0.78	0.546	0.00								
5	1.30	4.35	5.71	8.59	0.00	1.07	1.17	1.092	1.02	0.00							
6	1.56	8.20	9.55	14.37	0.00	1.34	1.56	1.637	2.04	1.62	0.00						
7	1.39	14.19	15.55	23.39	0.00	1.61	1.95	2.183	3.06	3.24	2.15	0.00					
8	1.22	21.37	22.72	34.18	0.00	1.43	2.34	2.729	4.08	4.86	4.31	1.62	0.00				
9	1.04	28.92	30.27	45.53	0.00	1.26	2.08	3.275	5.10	6.48	6.46	3.24	1.02	0.00			
10	0.87	36.10	37.46	56.35	0.00	1.08	1.82	2.915	6.12	8.10	8.61	4.86	2.04	0.55	0.00		
11	0.70	41.99	43.35	65.2	0.00	0.90	1.57	2.556	5.45	9.73	10.77	6.48	3.06	1.09	0.39	0.00	
12	0.53	45.46	46.82	70.42	0.00	0.73	1.31	2.197	4.78	8.66	12.92	8.10	4.08	1.64	0.78	0.27	
13	0.36	45.36	46.71	70.27	0.00	0.55	1.05	1.838	4.11	7.59	11.50	9.73	5.10	2.18	1.17	0.54	
14	0.19	42.57	43.93	66.07	0.00	0.37	0.80	1.479	3.44	6.53	10.09	8.66	6.12	2.73	1.56	0.81	
15	0.02	38.09	39.45	59.33	0.00	0.20	0.54	1.120	2.76	5.46	8.67	7.59	5.45	3.27	1.95	1.07	
16	0.00	32.71	34.06	51.24	0.00	0.02	0.29	0.761	2.09	4.39	7.25	6.53	4.78	2.92	2.34	1.34	
17	0.00	26.83	28.19	42.4		0.00	0.03	0.402	1.42	3.33	5.84	5.46	4.11	2.56	2.08	1.61	
18	0.00	20.76	22.11	33.26			0.00	0.043	0.75	2.26	4.42	4.39	3.44	2.20	1.82	1.43	
19	0.00	15.03	16.39	24.65				0.000	0.08	1.19	3.00	3.33	2.76	1.84	1.57	1.26	
20	0.00	9.94	11.30	16.99					0.00	0.13	1.59	2.26	2.09	1.48	1.31	1.08	
21	0.00	5.87	7.22	10.86						0.00	0.17	1.19	1.42	1.12	1.05	0.90	
22	0.00	3.17	4.52	6.8							0.00	0.13	0.75	0.76	0.80	0.73	
23	0.00	1.58	2.93	4.41								0.00	0.08	0.40	0.54	0.55	
24	0.00	0.70	2.06	3.1									0.00	0.04	0.29	0.37	
25	0.00	0.23	1.58	2.38										0.00	0.03	0.20	
26	0.00	0.02	1.38	2.07											0.00	0.02	
27	0.00	0.00	1.36	2.04												0.00	
28	0.00	0.00	1.36	2.04													

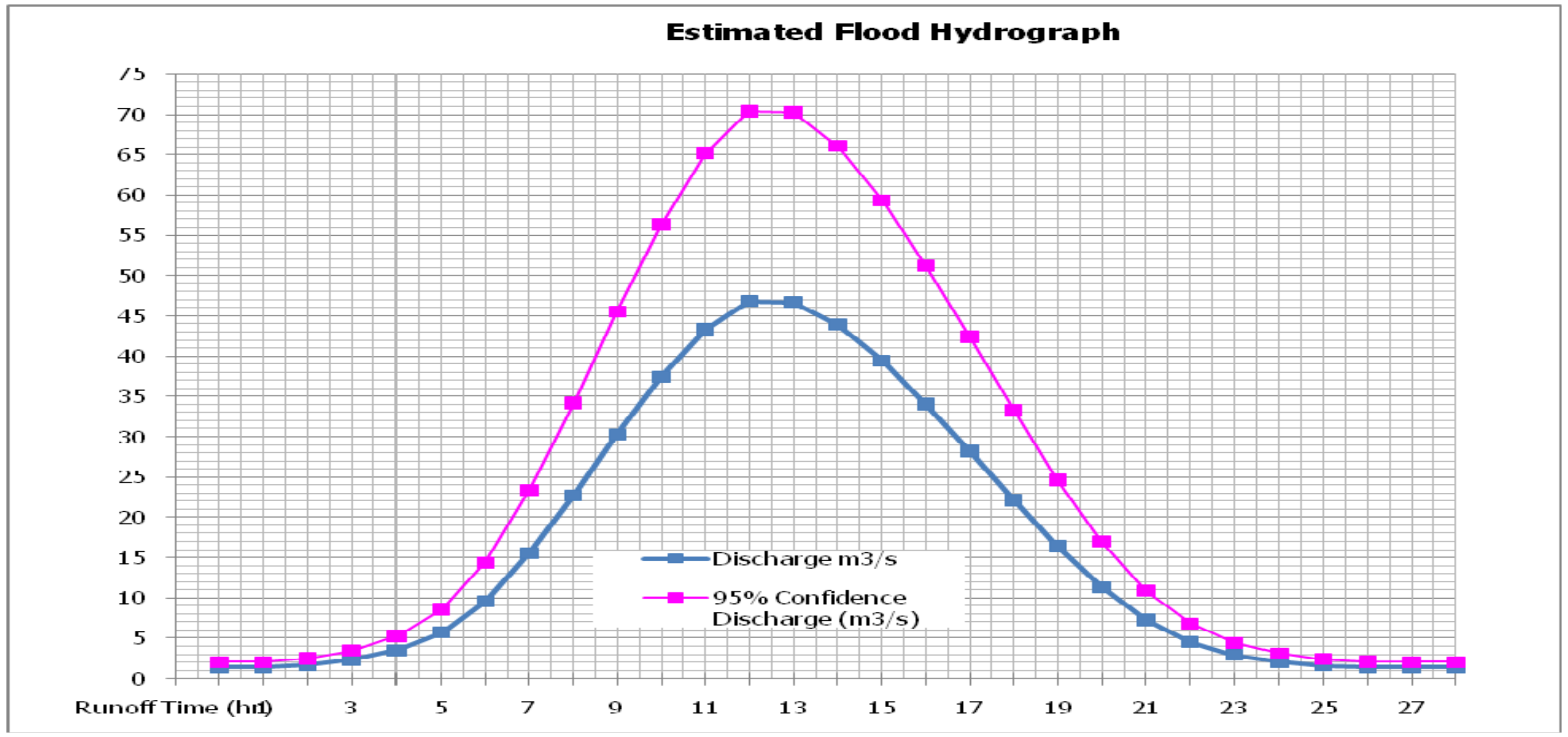


Figure B5: Hydrograph

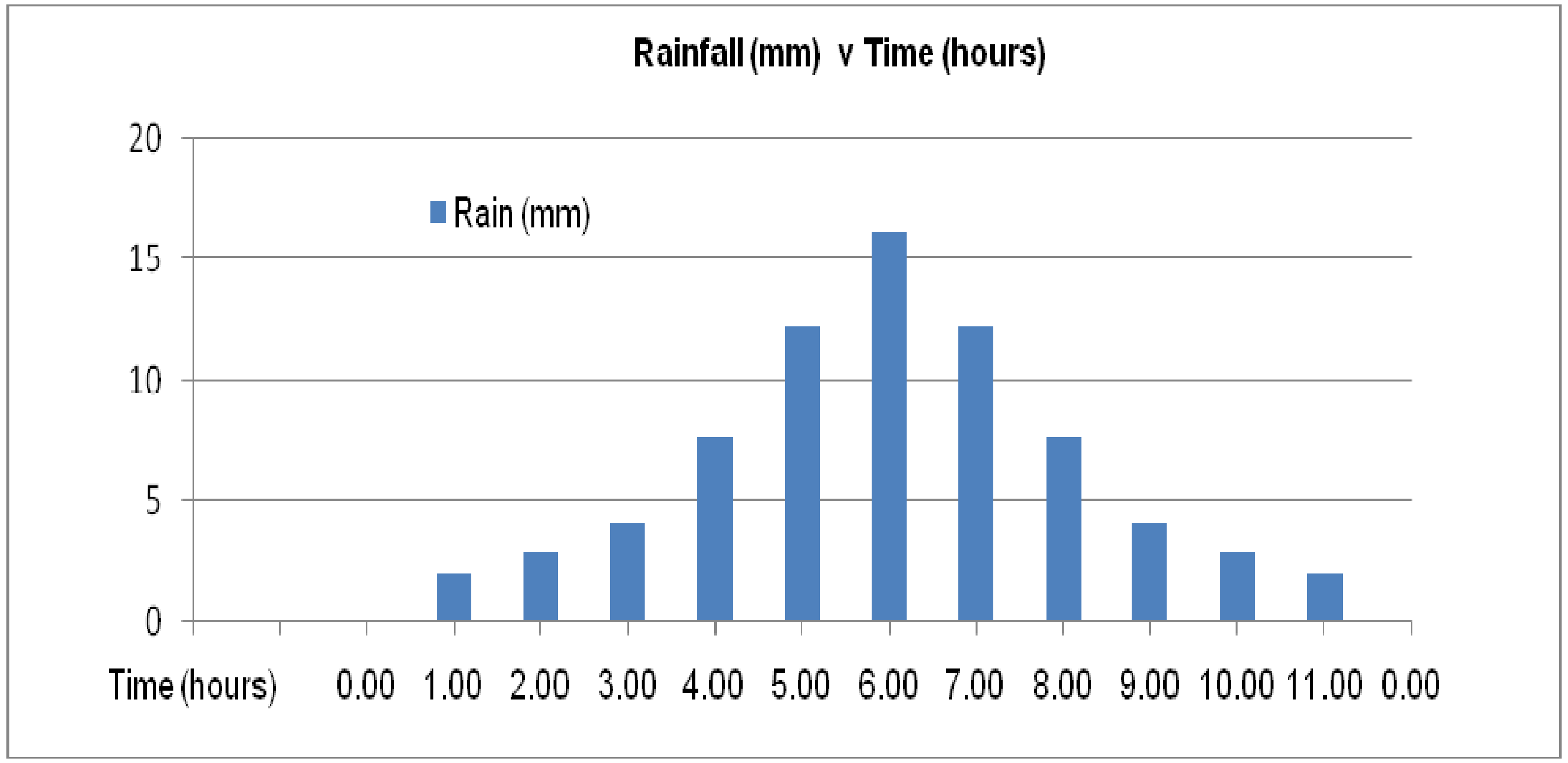


Figure B6: Graph of Rainfall v Time

Statistical Flood Frequency Analysis at Station 24034

GEV (Method of weighted moments)

Number of observations 24

Parameters
alpha 7.892293
k 0.398358
u 22.061175

Quantiles
q = F(X) : non-exceedance probability
Return Period, T = 1/(1-q)

T (years)	q	XT	Standard deviation	Confidence interval (95%) Lower Limit	Higher Limit	
10000	0.9999	41.4	4.98	N/D	N/D	1.60714286
2000	0.9995	40.9	4.47	N/D	N/D	1.58773292
1000	0.999	40.6	4.19	N/D	N/D	1.57608696
200	0.995	39.5	3.33	N/D	N/D	1.53338509
100	0.99	38.7	2.9	33	44.4	1.50232919
50	0.98	37.7	2.45	32.9	42.5	1.46350932
20	0.95	35.8	1.91	32.1	39.5	1.38975155
10	0.9	33.8	1.66	30.5	37	1.3121118
5	0.8	31	1.62	27.8	34.1	1.20341615
3	0.6667	28	1.69	24.7	31.4	1.08695652
2.3	0.55001	25.76	1.732	22.32	29.16	1
2	0.5	24.8	1.75	21.3	28.2	0.96273292
1.4286	0.3	20.5	1.84	16.9	24.1	0.79580745
1.25	0.2	17.9	1.98	14.1	21.8	0.69487578
1.1111	0.1	14.3	2.38	9.58	18.9	0.55512422
1.0526	0.05	11.2	2.94	5.45	17	0.43478261
1.0204	0.02	7.76	3.77	0.364	15.2	0.30124224
1.0101	0.01	5.47	4.44	-3.23	14.2	0.21234472
1.005	0.005	3.38	5.11	-6.64	13.4	0.13121118
1.001	0.001	-0.911	6.66	-14	12.1	-0.03536491
1.0005	0.0005	-2.57	7.31	-16.9	11.8	-0.09976708
1.0001	0.0001	-6.11	8.79	-23.3	11.1	-0.23718944

Gumbel (Method of weighted moments)

Number of observations 24

Parameters
u 20.76061
alpha 6.119562

Quantiles
q = F(X) : non-exceedance probability
Return Period, T = 1/(1-q)

T	q	XT	Standard deviation	Confidence interval (95%) Lower Limit	Higher Limit	
10000	0.9999	77.1	10.3	57	97.3	2.99301242
2000	0.9995	67.3	8.46	50.7	83.9	2.61257764
1000	0.999	63	7.69	48	78.1	2.44565217
200	0.995	53.2	5.88	41.6	64.7	2.06521739
100	0.99	48.9	5.11	38.9	58.9	1.89829193
50	0.98	44.6	4.35	36.1	53.2	1.73136646
20	0.95	38.9	3.35	32.4	45.5	1.51009317
10	0.9	34.5	2.61	29.4	39.7	1.33928571
5	0.8	29.9	1.92	26.2	33.7	1.16071429
3	0.6667	26.3	1.49	23.4	29.2	1.02096273
2.3	0.55001	23.99	1.357	21.37	26.61	0.93128882
2	0.5	23	1.3	20.5	25.5	0.89285714
1.4286	0.3	19.6	1.39	16.9	22.3	0.76086957
1.25	0.2	17.8	1.54	14.8	20.9	0.69099379
1.1111	0.1	15.7	1.79	12.1	19.2	0.60947205
1.0526	0.05	14	2.01	10.1	18	0.54347826
1.0204	0.02	12.4	2.25	8	16.8	0.48136646
1.0101	0.01	11.4	2.41	6.7	16.1	0.44254658
1.005	0.005	10.6	2.54	5.57	15.5	0.41149068
1.001	0.001	8.93	2.81	3.43	14.4	0.34666149
1.0005	0.0005	8.35	2.9	2.65	14	0.32414596
1.0001	0.0001	7.17	3.1	1.09	13.3	0.27833851

Weibull (Method of moments)

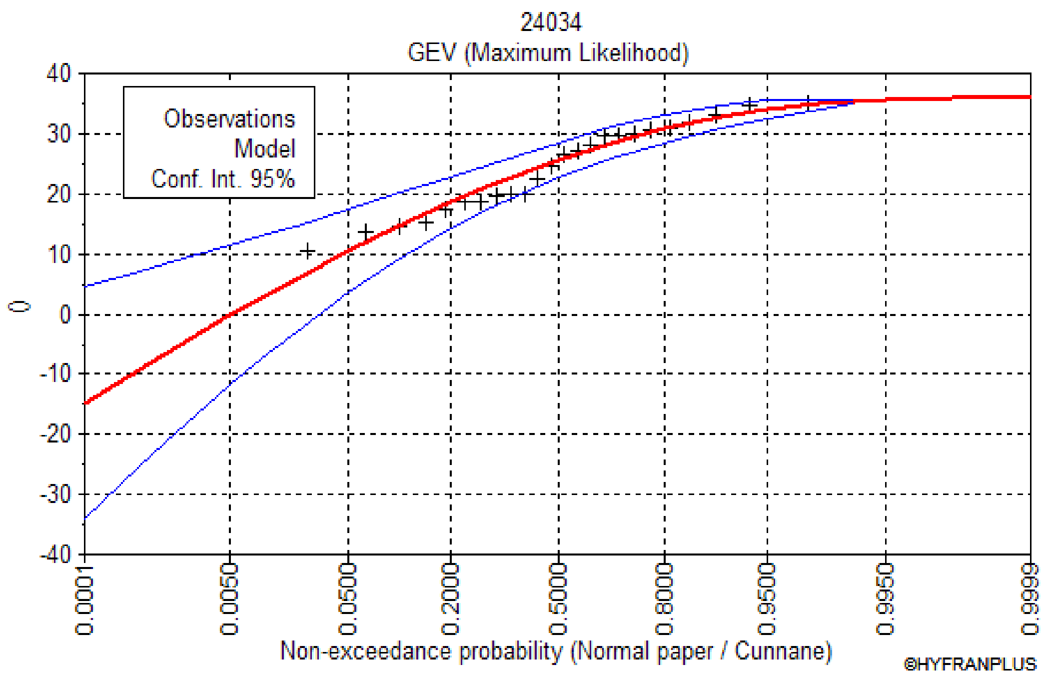
Number of observations 24

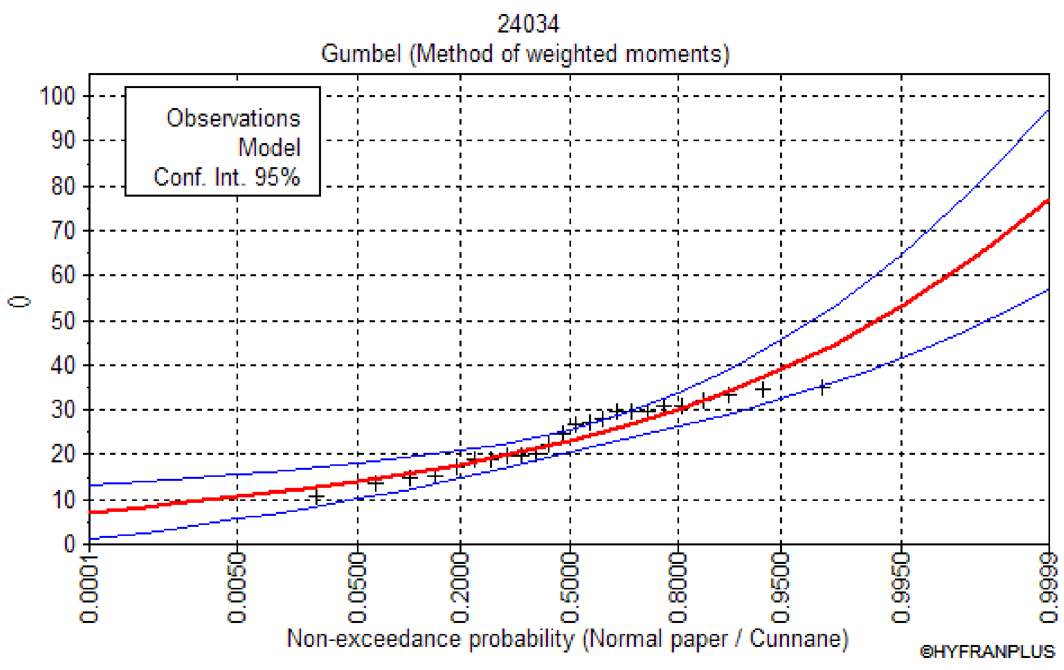
Parameters
alpha 26.909697
c 3.722662

Quantiles
q = F(X) : non-exceedance probability
Return Period, T = 1/(1-q)

T	q	XT	Standard deviation	Confidence interval (95%) Lower Limit	Higher Limit	
10000	0.9999	48.9	3.02	42.9	54.8	1.89829193
2000	0.9995	46.4	2.66	41.2	51.6	1.80124224
1000	0.999	45.2	2.5	40.3	50.1	1.75465839
200	0.995	42.1	2.11	38	46.3	1.63431677
100	0.99	40.6	1.95	36.7	44.4	1.57608696
50	0.98	38.8	1.79	35.3	42.3	1.50621118
20	0.95	36.1	1.59	33	39.3	1.40139752
10	0.9	33.7	1.49	30.8	36.6	1.30822981
5	0.8	30.6	1.44	27.8	33.4	1.1878882
3	0.6667	27.6	1.47	24.7	30.5	1.07142857
2.3	0.55001	25.36	1.526	22.32	28.33	0.98447205
2	0.5	24.4	1.55	21.3	27.4	0.94720497
1.4286	0.3	20.4	1.67	17.1	23.7	0.79192547
1.25	0.2	18	1.73	14.6	21.4	0.69875776
1.1111	0.1	14.7	1.76	11.2	18.2	0.57065217
1.0526	0.05	12.1	1.74	8.71	15.5	0.4697205
1.0204	0.02	9.43	1.65	6.21	12.7	0.36607143
1.0101	0.01	7.82	1.55	4.78	10.9	0.30357143
1.005	0.005	6.49	1.44	3.67	9.31	0.25194099
1.001	0.001	4.21	1.16	1.93	6.49	0.16343168
1.0005	0.0005	3.49	1.05	1.44	5.55	0.13548137
1.0001	0.0001	2.27	0.807	0.685	3.85	0.08812112

Table B10:Station 24034 -Results of Fitting





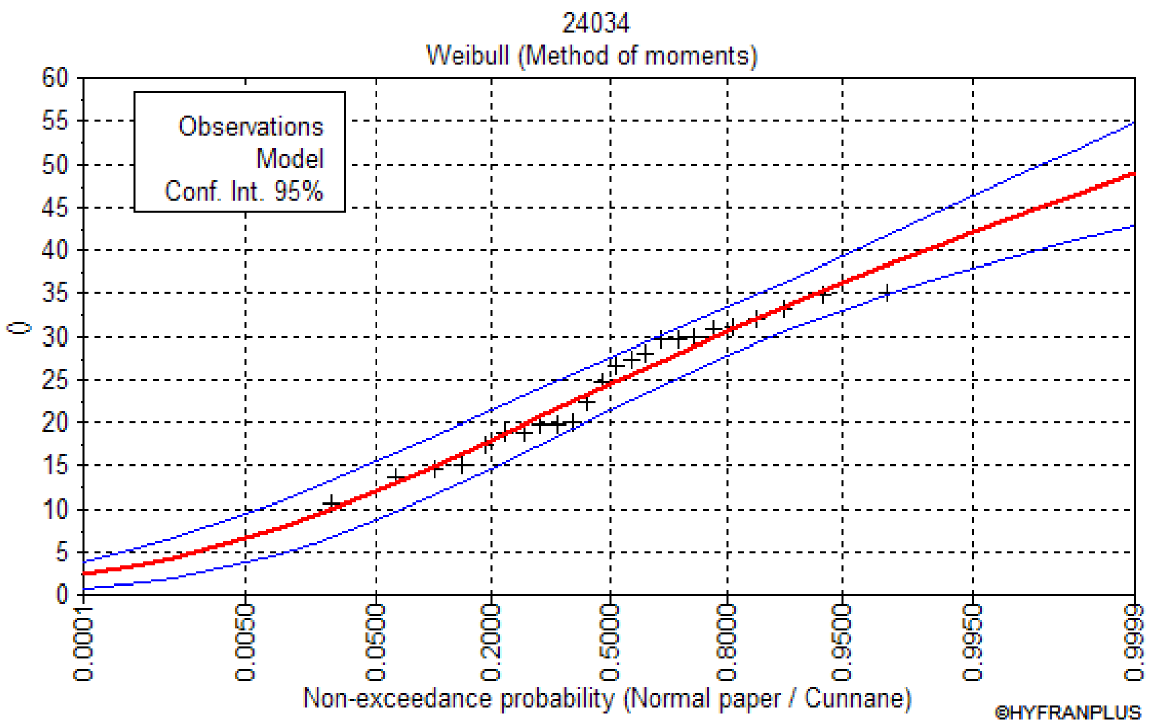


Figure B7: Station 24034 Graph of Fitting

Appendix C

Table C1 Pre-motorway and Post-motorway Results

River Station	Profile	Q Total Pre-motorway (m3/s)	Q Total Post-motorway (m3/s)	Water Surface Elevation Pre-motorway (m)	Water Surface Elevation Post-motorway (m)	AFFLUX (Increase in Water levels)	Velocity Channel Pre-motorway (m/s)	Velocity Channel Post-motorway (m/s)
1950	Max WS	70.41	70.41	97.19	97.19	**0**	0.45	0.45
1940	Max WS	70.41	70.41	97.19	97.19	**0**	0.51	0.51
1930	Max WS	70.41	70.41	97.18	97.18	**0**	0.61	0.61
1920	Max WS	70.41	70.4	97.18	97.18	**0**	0.78	0.78
1910	Max WS	70.41	70.4	97.17	97.17	**0**	0.79	0.79
1900		Culvert Inlet	Culvert Inlet	96.89	96.89	**0**	1.39	1.39
		Culvert Outlet	Culvert Outlet	96.94	96.94	**0**	1.39	1.39
1890	Max WS	70.33	70.33	96.76	96.76	**0**	2.63	2.63
1880	Max WS	70.33	70.34	96.78	96.78	**0**	2.1	2.1
1870	Max WS	70.34	70.33	96.78	96.78	**0**	1.81	1.81
1860	Max WS	70.33	70.33	96.77	96.77	**0**	1.63	1.63
1850	Max WS	70.33	70.33	96.77	96.77	**0**	1.47	1.47
1840	Max WS	70.34	70.33	96.77	96.77	**0**	1.08	1.09
1830	Max WS	70.33	70.33	96.77	96.77	**0**	0.9	0.9
1820	Max WS	70.33	70.33	96.76	96.76	**0**	0.73	0.73
1810	Max WS	70.33	70.33	96.76	96.76	**0**	0.67	0.67
1800	Max WS	70.33	70.33	96.76	96.76	**0**	0.63	0.63
1790	Max WS	70.33	70.33	96.76	96.76	**0**	0.62	0.62
1780	Max WS	70.33	70.33	96.75	96.75	**0**	0.56	0.56
1770	Max WS	70.33	70.33	96.75	96.75	**0**	0.51	0.51
1760	Max WS	70.33	70.33	96.75	96.75	**0**	0.49	0.49
1750	Max WS	70.33	70.33	96.75	96.74	**-0.01**	0.47	0.47
1740	Max WS	70.33	70.33	96.74	96.74	**0**	0.49	0.49
1730	Max WS	70.33	70.33	96.74	96.74	**0**	0.5	0.5
1720	Max WS	70.33	70.33	96.74	96.74	**0**	0.52	0.52
1710	Max WS	70.33	70.33	96.73	96.73	**0**	0.54	0.54
1700	Max WS	70.33	70.33	96.73	96.73	**0**	0.55	0.55
1690	Max WS	70.33	70.33	96.73	96.73	**0**	0.55	0.55
1680	Max WS	70.33	70.33	96.73	96.72	**-0.01**	0.59	0.59
1670	Max WS	70.33	70.33	96.72	96.72	**0**	0.68	0.68
1660	Max WS	70.33	70.33	96.71	96.71	**0**	0.75	0.75
1650	Max WS	70.33	70.33	96.71	96.71	**0**	0.81	0.81
1640	Max WS	70.33	70.33	96.71	96.71	**0**	0.74	0.74
1630	Max WS	70.33	70.33	96.7	96.7	**0**	0.62	0.62
1620	Max WS	70.33	70.33	96.7	96.7	**0**	0.6	0.6
1610	Max WS	70.33	70.33	96.7	96.7	**0**	0.58	0.58
1600	Max WS	70.33	70.33	96.7	96.69	**-0.01**	0.68	0.68
1590	Max WS	70.33	70.33	96.69	96.69	**0**	0.77	0.77
1580	Max WS	70.33	70.33	96.69	96.69	**0**	0.7	0.7
1570	Max WS	70.33	70.33	96.69	96.69	**0**	0.69	0.69
1560	Max WS	70.33	70.33	96.68	96.68	**0**	0.7	0.7
1550	Max WS	70.33	70.33	96.68	96.68	**0**	0.76	0.76
1540	Max WS	70.33	70.33	96.67	96.67	**0**	0.92	0.92
1530	Max WS	70.33	70.33	96.65	96.65	**0**	1.32	1.32
1520	Max WS	52.26	52.53	96.6	96.6	**0**	1.42	1.43
1510	Max WS	51.91	52.42	96.59	96.59	**0**	1.51	1.53
1500	Max WS	51.78	52.35	96.58	96.58	**0**	1.46	1.48
1490	Max WS	51.73	52.06	96.57	96.57	**0**	1.28	1.29
1480	Max WS	51.17	51.42	96.56	96.56	**0**	1.26	1.26
1470		Culvert Inlet	Culvert Inlet	95.74	95.74	**0**	0.43	0.43
		Culvert Outlet	Culvert Outlet	95.74	95.74	**0**	0.43	0.43
1460	Max WS	70.33	70.33	96.5	96.49	**-0.01**	1.81	1.82
1450	Max WS	54.27	54.13	96.28	96.28	**0**	2.3	2.31
1440	Max WS	70.33	70.33	96.21	96.21	**0**	1.65	1.64
1420	Max WS	70.33	70.33	96.06	96.06	**0**	2.29	2.28
1410	Max WS	49.47	48.27	95.39	95.39	**0**	3.28	3.19
1400	Max WS	70.32	70.33	95.72	95.72	**0**	1.85	1.85
1390	Max WS	70.32	70.32	95.62	95.62	**0**	2.46	2.46
1380	Max WS	70.32	70.32	95.61	95.61	**0**	2.06	2.06
1370	Max WS	70.32	70.32	95.6	95.6	**0**	1.69	1.69
1360	Max WS	70.32	70.32	95.59	95.59	**0**	1.46	1.46
1350	Max WS	70.32	70.32	95.56	95.56	**0**	1.59	1.59
1340	Max WS	70.31	70.31	95.53	95.53	**0**	1.49	1.49
1330	Max WS	70.31	70.32	95.5	95.5	**0**	1.57	1.57
1320	Max WS	70.3	70.31	95.46	95.46	**0**	1.68	1.68
1310	Max WS	70.3	70.31	95.43	95.43	**0**	1.53	1.53
1300	Max WS	70.3	70.31	95.4	95.4	**0**	1.56	1.57
1290	Max WS	70.3	70.3	95.37	95.37	**0**	1.51	1.51
1280	Max WS	70.29	70.3	95.35	95.35	**0**	1.24	1.24
1270	Max WS	70.29	70.3	95.34	95.33	**-0.01**	1.09	1.09
1260	Max WS	70.29	70.3	95.32	95.32	**0**	0.99	0.99
1250	Max WS	70.29	70.3	95.31	95.31	**0**	1.01	1.01
1240	Max WS	70.29	70.3	95.3	95.3	**0**	1.05	1.05
1230	Max WS	70.29	70.29	95.28	95.28	**0**	1.14	1.14
1220	Max WS	70.28	70.3	95.26	95.26	**0**	1.17	1.17
1210	Max WS	70.28	70.3	95.25	95.25	**0**	1.16	1.17

River Station	Profile	Q Total Pre-motorway (m3/s)	Q Total Post-motorway (m3/s)	Water Surface Elevation Pre-motorway (m)	Water Surface Elevation Post-motorway (m)	AFFLUX (Increase in Water levels)	Velocity Channel Pre-motorway (m/s)	Velocity Channel Post-motorway (m/s)
1200	Max WS	70.28	70.29	95.23	95.23	**0**	1.19	1.2
1190	Max WS	70.28	70.29	95.21	95.21	**0**	1.21	1.22
1180	Max WS	70.28	70.29	95.2	95.2	**0**	1.24	1.24
1170	Max WS	70.28	70.29	95.18	95.18	**0**	1.19	1.2
1160	Max WS	70.27	70.29	95.17	95.17	**0**	1.13	1.13
1150	Max WS	70.27	70.29	95.15	95.15	**0**	1.06	1.06
1140	Max WS	70.26	70.28	95.14	95.14	**0**	1.04	1.05
1130	Max WS	70.27	70.29	95.13	95.13	**0**	1.01	1.01
1120	Max WS	70.26	70.29	95.12	95.12	**0**	0.93	0.93
1110	Max WS	70.26	70.28	95.11	95.11	**0**	0.92	0.92
1100	Max WS	70.26	70.28	95.1	95.1	**0**	0.84	0.84
1090	Max WS	70.25	70.28	95.1	95.09	**-0.01**	0.75	0.75
1080	Max WS	70.26	70.28	95.09	95.09	**0**	0.67	0.67
1070	Max WS	70.25	70.28	95.09	95.08	**-0.01**	0.67	0.67
1060	Max WS	70.25	70.28	95.08	95.08	**0**	0.67	0.67
1050	Max WS	70.25	70.28	95.07	95.07	**0**	0.74	0.74
1040	Max WS	70.25	70.28	95.07	95.07	**0**	0.75	0.75
1030	Max WS	70.25	70.28	95.06	95.06	**0**	0.75	0.75
1020	Max WS	70.24	70.28	95.06	95.05	**-0.01**	0.71	0.71
1010	Max WS	70.24	70.28	95.05	95.05	**0**	0.73	0.73
1000	Max WS	70.24	70.28	95.04	95.04	**0**	0.77	0.78
990	Max WS	70.24	70.28	95.04	95.04	**0**	0.77	0.78
980	Max WS	70.23	70.27	95.03	95.03	**0**	0.78	0.78
970	Max WS	70.24	70.28	95.02	95.02	**0**	0.76	0.76
960	Max WS	70.24	70.27	95.02	95.02	**0**	0.79	0.77
950	Max WS	70.23	70.27	95.01	95.01	**0**	0.8	0.81
940	Max WS	70.23	70.27	95	95	**0**	0.79	0.8
930	Max WS	70.23	70.27	95	95	**0**	0.78	0.79
921			Bridge Inlet		95			0.34
			Bridge Outlet		94.99			0.34
920	Max WS	70.23	70.27	94.99	94.99	**0**	0.79	0.8
910	Max WS	70.23	70.27	94.99	94.98	**-0.01**	0.79	0.8
909			Bridge Inlet		94.98			0.34
			Bridge Outlet		94.98			0.32
900	Max WS	70.23	70.28	94.98	94.97	**-0.01**	0.75	0.76
890	Max WS	70.22	70.27	94.97	94.97	**0**	0.8	0.81
881			Bridge Inlet		94.97			0.34
			Bridge Outlet		94.96			0.34
880	Max WS	70.22	70.27	94.97	94.96	**-0.01**	0.78	0.8

River Station	Profile	Q Total Pre-motorway (m3/s)	Q Total Post-motorway (m3/s)	Water Surface Elevation Pre-motorway (m)	Water Surface Elevation Post-motorway (m)	AFFLUX (Increase in Water levels)	Velocity Channel Pre-motorway (m/s)	Velocity Channel Post-motorway (m/s)
870	Max WS	70.22	70.27	94.96	94.95	**-0.01**	0.72	0.74
869			Bridge Inlet		94.95			0.35
			Bridge Outlet		94.95			0.35
860	Max WS	70.22	70.27	94.95	94.94	**-0.01**	0.73	0.75
850	Max WS	70.22	70.27	94.95	94.94	**-0.01**	0.72	0.74
840	Max WS	70.22	70.27	94.94	94.93	**-0.01**	0.73	0.75
830	Max WS	70.22	70.27	94.94	94.92	**-0.02**	0.74	0.76
829			Bridge Inlet		94.92			0.37
			Bridge Outlet		94.92			0.32
820	Max WS	70.22	70.27	94.93	94.92	**-0.01**	0.64	0.66
810	Max WS	70.22	70.27	94.93	94.92	**-0.01**	0.56	0.57
801			Bridge Inlet		94.92			0.29
			Bridge Outlet		94.91			0.3
800	Max WS	70.22	70.27	94.93	94.91	**-0.02**	0.57	0.56
799	Max WS	70.22	70.27	94.93	94.91	**-0.02**	0.57	0.56
790		Culvert Inlet	Culvert Inlet	94.63	94.63	**0**	0.45	0.43
		Culvert Outlet	Culvert Outlet	94.6	94.6	**0**	0.45	0.43
780	Max WS	70.21	70.27	94.81	94.78	**-0.03**	1.83	1.89
779	Max WS	70.22	70.27	94.81	94.78	**-0.03**	1.8	1.86
770	Max WS	70.21	70.27	94.77	94.73	**-0.04**	1.97	2.14
769			Bridge Inlet		94.76			1.01
			Bridge Outlet		94.8			0.56
760	Max WS	70.21	70.27	94.76	94.77	**0.01**	1.24	1.2
750	Max WS	70.2	70.27	94.75	94.76	**0.01**	1.02	1
740	Max WS	70.21	70.27	94.74	94.75	**0.01**	0.92	0.9
730	Max WS	70.2	70.26	94.73	94.74	**0.01**	0.92	0.9
729			Bridge Inlet		94.74			0.4
			Bridge Outlet		94.74			0.37
720	Max WS	70.2	70.27	94.72	94.73	**0.01**	0.84	0.82
710	Max WS	70.2	70.27	94.71	94.72	**0.01**	0.82	0.79
700	Max WS	70.19	70.26	94.7	94.71	**0.01**	0.84	0.81
679			Bridge Inlet		94.71			0.38
			Bridge Outlet		94.71			0.35
670	Max WS	70.19	70.27	94.67	94.69	**0.02**	0.91	0.87
650	Max WS	70.18	70.26	94.66	94.67	**0.01**	0.8	0.77
639			Bridge Inlet		94.67			0.34
			Bridge Outlet		94.67			0.33

River Station	Profile	Q Total Pre-motorway (m3/s)	Q Total Post-motorway (m3/s)	Water Surface Elevation Pre-motorway (m)	Water Surface Elevation Post-motorway (m)	AFFLUX (Increase in Water levels)	Velocity Channel Pre-motorway (m/s)	Velocity Channel Post-motorway (m/s)
630	Max WS	70.18	70.27	94.64	94.66	**0.02**	0.74	0.72
620	Max WS	70.18	70.26	94.64	94.65	**0.01**	0.76	0.73
599			Bridge Inlet		94.65			0.34
			Bridge Outlet		94.65			0.37
590	Max WS	70.18	70.26	94.61	94.61	**0**	1	0.99
580	Max WS	70.18	70.26	94.6	94.6	**0**	0.99	0.98
570	Max WS	70.18	70.26	94.58	94.59	**0.01**	0.94	0.93
559			Bridge Inlet		94.59			0.41
			Bridge Outlet		94.59			0.34
550	Max WS	70.17	70.26	94.57	94.58	**0.01**	0.85	0.83
540	Max WS	70.17	70.26	94.56	94.57	**0.01**	0.92	0.9
520	Max WS	70.17	70.26	94.53	94.54	**0.01**	1.03	1
519			Bridge Inlet		94.54			0.47
			Bridge Outlet		94.54			0.47
510	Max WS	70.17	70.26	94.52	94.53	**0.01**	1.06	1.04
500	Max WS	70.16	70.25	94.5	94.51	**0.01**	1.14	1.12
490	Max WS	70.16	70.25	94.48	94.49	**0.01**	1.28	1.26
480	Max WS	70.16	70.25	94.47	94.47	**0**	1.2	1.36
470	Max WS	70.16	70.25	94.45	94.46	**0.01**	1.06	1.12
460	Max WS	70.16	70.25	94.44	94.43	**-0.01**	1.08	1.3
450	Max WS	70.15	70.25	94.42	94.41	**-0.01**	1.09	1.29
440	Max WS	70.15	70.25	94.4	94.39	**-0.01**	1.07	1.2
430	Max WS	70.15	70.24	94.39	94.37	**-0.02**	1.1	1.15
420	Max WS	70.13	70.25	94.37	94.36	**-0.01**	1.07	1.09
410	Max WS	70.14	70.23	94.36	94.34	**-0.02**	1.07	1.05
400	Max WS	70.14	70.23	94.35	94.33	**-0.02**	0.98	1.01
390	Max WS	70.13	70.23	94.34	94.32	**-0.02**	0.91	0.96
380	Max WS	70.11	70.23	94.31	94.31	**0**	1.25	1.25
370	Max WS	70.12	70.22	94.31	94.31	**0**	0.77	0.77
360	Max WS	70.11	70.22	94.31	94.31	**0**	0.55	0.55
350	Max WS	70.11	70.22	94.31	94.31	**0**	0.46	0.46
340	Max WS	70.11	70.22	94.3	94.3	**0**	0.44	0.44
330	Max WS	70.1	70.22	94.3	94.3	**0**	0.4	0.4
320	Max WS	70.11	70.21	94.3	94.3	**0**	0.43	0.43
310	Max WS	70.1	70.21	94.29	94.29	**0**	0.42	0.42
300	Max WS	70.1	70.22	94.29	94.29	**0**	0.41	0.41
290	Max WS	70.11	70.21	94.29	94.29	**0**	0.39	0.39
280	Max WS	70.1	70.21	94.29	94.29	**0**	0.38	0.38
270	Max WS	70.1	70.21	94.29	94.29	**0**	0.37	0.37
260	Max WS	70.1	70.21	94.29	94.29	**0**	0.36	0.36
250	Max WS	70.1	70.2	94.29	94.29	**0**	0.35	0.34
240	Max WS	70.1	70.2	94.28	94.28	**0**	0.34	0.34
230	Max WS	70.1	70.21	94.28	94.28	**0**	0.35	0.35
220	Max WS	70.1	70.21	94.28	94.28	**0**	0.38	0.38
210	Max WS	70.1	70.21	94.28	94.28	**0**	0.26	0.26
200	Max WS	70.1	70.21	94.28	94.28	**0**	0.33	0.33
190	Max WS	70.1	70.21	94.28	94.28	**0**	0.4	0.39
180	Max WS	70.1	70.2	94.28	94.28	**0**	0.48	0.48
170	Max WS	70.09	70.21	94.27	94.27	**0**	0.64	0.64
160	Max WS	70.1	70.21	94.26	94.27	**0.01**	0.72	0.71
150	Max WS	70.1	70.21	94.26	94.26	**0**	0.64	0.64
140	Max WS	70.09	70.2	94.26	94.26	**0**	0.7	0.69
130	Max WS	70.1	70.21	94.26	94.26	**0**	0.64	0.64
120	Max WS	70.1	70.2	94.23	94.22	**-0.01**	1.27	1.28
110	Max WS	70.09	70.2	94.14	94.15	**0.01**	1.8	1.8
100	Max WS	70.09	70.2	94.2	94.2	**0**	0.82	0.83
90	Max WS	70.1	70.2	94.21	94.21	**0**	0.82	0.82
80	Max WS	70.09	70.2	94.19	94.19	**0**	1.11	1.12
70	Max WS	70.09	70.2	94.19	94.19	**0**	1.58	1.58
60	Max WS	70.09	70.2	94.19	94.19	**0**	1.98	1.98
50	Max WS	70.09	70.2	94.17	94.17	**0**	1.57	1.57
40	Max WS	70.09	70.2	94.18	94.18	**0**	0.47	0.47
30	Max WS	70.09	70.2	94.16	94.16	**0**	1.16	1.16
20	Max WS	70.09	70.2	94.16	94.16	**0**	0.98	0.99
10	Max WS	70.09	70.2	94.16	94.16	**0**	0.63	0.63
0	Max WS	70.09	70.2	94.14	94.14	**0**	0.76	0.77

Table C2 Pre-motorway and Proposed Solution Results

River Station	Profile	Q Total Pre-motorway (m3/s)	Q Total Post-motorway (m3/s)	Water Surface Elevation Pre-motorway (m)	Water Surface Elevation Post-motorway (m)	AFFLUX (Increase in Water levels)	Velocity Channel Pre-motorway (m/s)	Velocity Channel Post-motorway (m/s)
1950	Max WS	70.41	70.41	97.19	97.19	**0**	0.45	0.45
1940	Max WS	70.41	70.41	97.19	97.19	**0**	0.51	0.51
1930	Max WS	70.41	70.41	97.18	97.18	**0**	0.61	0.61
1920	Max WS	70.4	70.41	97.18	97.18	**0**	0.78	0.78
1910	Max WS	70.41	70.4	97.17	97.17	**0**	0.79	0.79
1900		Culvert Inlet	Culvert Inlet	96.89	96.89	**0**	1.39	1.39
		Culvert Outlet	Culvert Outlet	96.94	96.94	**0**	1.39	1.39
1890	Max WS	70.33	70.33	96.76	96.76	**0**	2.63	2.63
1880	Max WS	70.33	70.33	96.79	96.78	**0**	2.1	2.1
1870	Max WS	70.34	70.33	96.78	96.78	**0**	1.81	1.81
1860	Max WS	70.34	70.33	96.77	96.77	**0**	1.63	1.63
1850	Max WS	70.33	70.33	96.77	96.77	**0**	1.47	1.47
1840	Max WS	70.34	70.33	96.77	96.77	**0**	1.08	1.09
1830	Max WS	70.33	70.33	96.77	96.77	**0**	0.9	0.9
1820	Max WS	70.33	70.33	96.77	96.76	**0**	0.73	0.73
1810	Max WS	70.33	70.33	96.76	96.76	**0**	0.67	0.67
1800	Max WS	70.33	70.33	96.76	96.76	**0**	0.63	0.63
1790	Max WS	70.33	70.33	96.76	96.76	**0**	0.62	0.62
1780	Max WS	70.33	70.33	96.75	96.75	**0**	0.56	0.56
1770	Max WS	70.33	70.33	96.75	96.75	**0**	0.51	0.51
1760	Max WS	70.33	70.33	96.75	96.75	**0**	0.49	0.49
1750	Max WS	70.33	70.33	96.75	96.74	**0**	0.47	0.47
1740	Max WS	70.33	70.33	96.74	96.74	**0**	0.49	0.49
1730	Max WS	70.33	70.33	96.74	96.74	**0**	0.5	0.5
1720	Max WS	70.33	70.33	96.74	96.74	**0**	0.52	0.52
1710	Max WS	70.33	70.33	96.73	96.73	**0**	0.54	0.54
1700	Max WS	70.33	70.33	96.73	96.73	**0**	0.55	0.55
1690	Max WS	70.33	70.33	96.73	96.73	**0**	0.55	0.55
1680	Max WS	70.33	70.33	96.73	96.73	**0**	0.59	0.59
1670	Max WS	70.33	70.33	96.72	96.72	**0**	0.68	0.68
1660	Max WS	70.33	70.33	96.72	96.71	**0**	0.75	0.75
1650	Max WS	70.33	70.33	96.71	96.71	**0**	0.81	0.81
1640	Max WS	70.33	70.33	96.71	96.71	**0**	0.74	0.74
1630	Max WS	70.33	70.33	96.71	96.70	**0**	0.62	0.62
1620	Max WS	70.33	70.33	96.70	96.70	**0**	0.6	0.6
1610	Max WS	70.33	70.33	96.70	96.70	**0**	0.58	0.58
1600	Max WS	70.33	70.33	96.70	96.70	**0**	0.68	0.68
1590	Max WS	70.33	70.33	96.69	96.69	**0**	0.77	0.77
1580	Max WS	70.33	70.33	96.69	96.69	**0**	0.7	0.7
1570	Max WS	70.33	70.33	96.69	96.69	**0**	0.69	0.69
1560	Max WS	70.33	70.33	96.68	96.68	**0**	0.7	0.7
1550	Max WS	70.33	70.33	96.68	96.68	**0**	0.76	0.76
1540	Max WS	70.33	70.33	96.67	96.67	**0**	0.92	0.92
1530	Max WS	70.33	70.33	96.65	96.65	**0**	1.32	1.32
1520	Max WS	52.26	52.53	96.60	96.60	**0**	1.42	1.43
1510	Max WS	51.91	52.42	96.59	96.59	**0**	1.51	1.53
1500	Max WS	51.78	52.36	96.58	96.58	**0**	1.46	1.48
1490	Max WS	51.73	52.06	96.57	96.57	**0**	1.28	1.29
1480	Max WS	51.17	51.42	96.56	96.56	**0**	1.26	1.26
1470		Culvert Inlet	Culvert Inlet	95.74	95.74	**0**	0.43	0.43
		Culvert Outlet	Culvert Outlet	95.74	95.74	**0**	0.43	0.43
1460	Max WS	70.33	70.33	96.50	96.49	**0**	1.81	1.82
1450	Max WS	54.26	54.13	96.28	96.28	**0**	2.3	2.31
1440	Max WS	70.33	70.33	96.22	96.21	**0**	1.65	1.64
1420	Max WS	70.33	70.33	96.06	96.06	**0**	2.29	2.28
1410	Max WS	49.46	48.26	95.39	95.39	**0**	3.28	3.19
1400	Max WS	70.32	70.32	95.72	95.72	**0**	1.85	1.85
1390	Max WS	70.32	70.32	95.62	95.62	**0**	2.46	2.46
1380	Max WS	70.32	70.32	95.61	95.61	**0**	2.06	2.06
1370	Max WS	70.32	70.32	95.60	95.60	**0**	1.69	1.69
1360	Max WS	70.32	70.32	95.59	95.59	**0**	1.46	1.46
1350	Max WS	70.32	70.32	95.56	95.56	**0**	1.59	1.59
1340	Max WS	70.31	70.32	95.53	95.53	**0**	1.49	1.49
1330	Max WS	70.31	70.32	95.50	95.50	**0**	1.57	1.57
1320	Max WS	70.3	70.31	95.46	95.46	**0**	1.68	1.69
1310	Max WS	70.3	70.31	95.44	95.43	**0**	1.53	1.53
1300	Max WS	70.3	70.31	95.40	95.40	**0**	1.56	1.57
1290	Max WS	70.29	70.31	95.37	95.37	**0**	1.51	1.51
1280	Max WS	70.29	70.3	95.35	95.35	**0**	1.24	1.24
1270	Max WS	70.29	70.3	95.34	95.33	**0**	1.09	1.09
1260	Max WS	70.29	70.3	95.32	95.32	**0**	0.99	0.99
1250	Max WS	70.29	70.3	95.31	95.31	**0**	1.01	1.01
1240	Max WS	70.29	70.3	95.30	95.30	**0**	1.05	1.05
1230	Max WS	70.29	70.3	95.28	95.28	**0**	1.14	1.14
1220	Max WS	70.28	70.3	95.26	95.26	**0**	1.17	1.18
1210	Max WS	70.28	70.3	95.25	95.25	**0**	1.17	1.17
1200	Max WS	70.28	70.29	95.23	95.23	**0**	1.19	1.2
1190	Max WS	70.28	70.3	95.22	95.21	**0**	1.21	1.22
1180	Max WS	70.28	70.29	95.20	95.20	**0**	1.24	1.25
1170	Max WS	70.28	70.29	95.18	95.18	**0**	1.19	1.2
1160	Max WS	70.27	70.29	95.17	95.17	**0**	1.13	1.14
1150	Max WS	70.27	70.29	95.16	95.15	**0**	1.06	1.07
1140	Max WS	70.27	70.29	95.14	95.14	**0**	1.04	1.05
1130	Max WS	70.26	70.29	95.13	95.13	**0**	1.01	1.02
1120	Max WS	70.26	70.29	95.12	95.12	**0**	0.93	0.94
1110	Max WS	70.25	70.28	95.11	95.11	**0**	0.92	0.92
1100	Max WS	70.26	70.28	95.10	95.10	**0**	0.84	0.85
1090	Max WS	70.26	70.29	95.10	95.09	**-0.01**	0.75	0.75
1080	Max WS	70.25	70.28	95.09	95.09	**0**	0.67	0.68
1070	Max WS	70.25	70.28	95.09	95.08	**0**	0.67	0.67
1060	Max WS	70.25	70.28	95.08	95.07	**-0.01**	0.67	0.68
1050	Max WS	70.24	70.28	95.07	95.07	**-0.01**	0.74	0.75
1040	Max WS	70.25	70.28	95.07	95.06	**0**	0.75	0.76

River Station	Profile	Q Total Pre-motorway (m3/s)	Q Total Post-motorway (m3/s)	Water Surface Elevation Pre-motorway (m)	Water Surface Elevation Post-motorway (m)	AFFLUX (Increase in Water levels)	Velocity Channel Pre-motorway (m/s)	Velocity Channel Post-motorway (m/s)
1030	Max WS	70.24	70.28	95.06	95.06	**-0.01**	0.75	0.76
1020	Max WS	70.24	70.28	95.06	95.05	**-0.01**	0.71	0.72
1010	Max WS	70.24	70.28	95.05	95.05	**-0.01**	0.73	0.74
1000	Max WS	70.24	70.28	95.04	95.04	**-0.01**	0.77	0.78
990	Max WS	70.23	70.28	95.04	95.03	**-0.01**	0.77	0.78
980	Max WS	70.24	70.28	95.03	95.02	**-0.01**	0.78	0.79
970	Max WS	70.23	70.27	95.02	95.02	**-0.01**	0.76	0.77
960	Max WS	70.24	70.28	95.02	95.01	**-0.01**	0.79	0.78
950	Max WS	70.23	70.28	95.01	95.00	**-0.01**	0.8	0.81
940	Max WS	70.23	70.28	95.01	95.00	**-0.01**	0.79	0.81
930	Max WS	70.23	70.28	95.00	94.99	**-0.01**	0.78	0.8
921			Bridge Inlet		94.99			0.35
			Bridge Outlet		94.99			0.34
920	Max WS	70.23	70.28	94.99	94.98	**-0.01**	0.79	0.81
910	Max WS	70.23	70.27	94.99	94.97	**-0.01**	0.79	0.81
909			Bridge Inlet		94.98			0.34
			Bridge Outlet		94.97			0.33
900	Max WS	70.22	70.28	94.98	94.97	**-0.02**	0.75	0.77
890	Max WS	70.22	70.27	94.97	94.96	**-0.02**	0.8	0.82
881			Bridge Inlet		94.96			0.34
			Bridge Outlet		94.96			0.35
880	Max WS	70.22	70.28	94.97	94.95	**-0.02**	0.78	0.81
870	Max WS	70.22	70.27	94.96	94.94	**-0.02**	0.72	0.75
869			Bridge Inlet		94.94			0.35
			Bridge Outlet		94.94			0.35
860	Max WS	70.22	70.28	94.96	94.94	**-0.02**	0.73	0.76
850	Max WS	70.22	70.27	94.95	94.93	**-0.02**	0.72	0.75
840	Max WS	70.22	70.27	94.94	94.92	**-0.02**	0.73	0.76
830	Max WS	70.22	70.27	94.94	94.91	**-0.02**	0.74	0.77
829			Bridge Inlet		94.92			0.37
			Bridge Outlet		94.92			0.33
820	Max WS	70.22	70.27	94.93	94.91	**-0.02**	0.64	0.67
810	Max WS	70.22	70.27	94.93	94.91	**-0.02**	0.56	0.57
801			Bridge Inlet		94.91			0.29
			Bridge Outlet		94.91			0.31
800	Max WS	70.22	70.27	94.93	94.90	**-0.02**	0.57	0.56
799	Max WS	70.22	70.27	94.93	94.90	**-0.03**	0.57	0.57
790		Culvert Inlet	Culvert Inlet	94.63	94.63		0.45	0.41
		Culvert Outlet	Culvert Outlet	94.60	94.60		0.45	0.41
780	Max WS	70.21	70.27	94.81	94.77	**-0.04**	1.83	1.92
779	Max WS	70.21	70.27	94.81	94.77	**-0.04**	1.8	1.88
770	Max WS	70.2	70.27	94.77	94.71	**-0.06**	1.96	2.2
769			Bridge Inlet		94.75			1.04

River Station	Profile	Q Total Pre-motorway (m3/s)	Q Total Post-motorway (m3/s)	Water Surface Elevation Pre-motorway (m)	Water Surface Elevation Post-motorway (m)	AFFLUX (Increase in Water levels)	Velocity Channel Pre-motorway (m/s)	Velocity Channel Post-motorway (m/s)
			Bridge Outlet		97.78			0.58
760	Max WS	70.21	70.27	94.76	94.76	**-0.01**	1.23	1.25
750	Max WS	70.2	70.27	94.75	94.74	**-0.01**	1.02	1.03
740	Max WS	70.2	70.27	94.74	94.73	**-0.01**	0.92	0.93
730	Max WS	70.2	70.27	94.73	94.72	**-0.01**	0.92	0.94
729			Bridge Inlet		94.72			0.41
			Bridge Outlet		94.72			0.38
720	Max WS	70.19	70.27	94.72	94.71	**-0.01**	0.84	0.85
710	Max WS	70.19	70.27	94.71	94.70	**-0.01**	0.82	0.83
700	Max WS	70.19	70.27	94.70	94.69	**-0.01**	0.83	0.85
679			Bridge Inlet		94.69			0.39
			Bridge Outlet		94.69			0.37
670	Max WS	70.18	70.27	94.67	94.66	**-0.01**	0.9	0.93
650	Max WS	70.18	70.27	94.66	94.65	**-0.01**	0.79	0.81
639			Bridge Inlet		94.65			0.35
			Bridge Outlet		94.65			0.34
630	Max WS	70.18	70.27	94.64	94.63	**-0.01**	0.74	0.77
620	Max WS	70.17	70.27	94.64	94.62	**-0.01**	0.75	0.78
599			Bridge Inlet		94.62			0.36
			Bridge Outlet		94.62			0.4
590	Max WS	70.17	70.27	94.61	94.57	**-0.04**	1	1.09
580	Max WS	70.17	70.27	94.60	94.56	**-0.04**	0.98	1.09
570	Max WS	70.17	70.27	94.59	94.54	**-0.04**	0.93	1.04
559			Bridge Inlet		94.55			0.45
			Bridge Outlet		94.55			0.37
550	Max WS	70.17	70.27	94.57	94.52	**-0.05**	0.84	0.94
540	Max WS	70.16	70.27	94.56	94.51	**-0.05**	0.91	1.03
520	Max WS	70.16	70.27	94.54	94.48	**-0.06**	1.02	1.17
519			Bridge Inlet		94.48			0.54
			Bridge Outlet		94.48			0.54
510	Max WS	70.16	70.27	94.52	94.45	**-0.07**	1.05	1.26
500.001	Max WS	70.16	70.26	94.51	94.42	**-0.08**	1.13	1.41
490	Max WS	70.16	70.26	94.49	94.39	**-0.10**	1.27	1.67
465			Culvert Inlet		94.42			0.45
			Culvert Outlet		94.41			0.43
440	Max WS	70.15	70.26	94.40	94.39	**-0.01**	1.07	1.2
430	Max WS	70.14	70.25	94.39	94.37	**-0.01**	1.1	1.15
420	Max WS	70.14	70.25	94.37	94.36	**-0.01**	1.07	1.1
410	Max WS	70.13	70.25	94.36	94.35	**-0.01**	1.07	1.05
400	Max WS	70.13	70.24	94.35	94.33	**-0.01**	0.98	1.01
390	Max WS	70.11	70.24	94.34	94.32	**-0.01**	0.9	0.96
380	Max WS	70.11	70.24	94.31	94.31	**0**	1.25	1.25

River Station	Profile	Q Total Pre-motorway (m3/s)	Q Total Post-motorway (m3/s)	Water Surface Elevation Pre-motorway (m)	Water Surface Elevation Post-motorway (m)	AFFLUX (Increase in Water levels)	Velocity Channel Pre-motorway (m/s)	Velocity Channel Post-motorway (m/s)
370	Max WS	70.11	70.23	94.31	94.31	**0**	0.77	0.77
360	Max WS	70.11	70.24	94.31	94.31	**0**	0.55	0.55
350	Max WS	70.11	70.23	94.31	94.31	**0**	0.46	0.46
340	Max WS	70.1	70.23	94.30	94.30	**0**	0.44	0.44
330	Max WS	70.11	70.23	94.30	94.30	**0**	0.4	0.4
320	Max WS	70.11	70.22	94.30	94.30	**0**	0.43	0.43
310	Max WS	70.1	70.23	94.29	94.30	**0**	0.42	0.42
300	Max WS	70.1	70.22	94.29	94.29	**0**	0.41	0.41
290	Max WS	70.1	70.22	94.29	94.29	**0**	0.39	0.39
280	Max WS	70.1	70.23	94.29	94.29	**0**	0.38	0.38
270	Max WS	70.1	70.23	94.29	94.29	**0**	0.37	0.37
260	Max WS	70.1	70.23	94.29	94.29	**0**	0.36	0.36
250	Max WS	70.1	70.23	94.29	94.29	**0**	0.35	0.34
240	Max WS	70.1	70.22	94.28	94.29	**0**	0.34	0.34
230	Max WS	70.1	70.22	94.28	94.28	**0**	0.34	0.35
220	Max WS	70.1	70.22	94.28	94.28	**0**	0.38	0.38
210	Max WS	70.1	70.22	94.28	94.28	**0**	0.26	0.26
200	Max WS	70.1	70.22	94.28	94.28	**0**	0.33	0.33
190	Max WS	70.09	70.22	94.28	94.28	**0**	0.4	0.39
180	Max WS	70.09	70.22	94.28	94.28	**0**	0.48	0.48
170	Max WS	70.09	70.22	94.27	94.27	**0**	0.64	0.64
160	Max WS	70.09	70.22	94.27	94.27	**0**	0.72	0.71
150	Max WS	70.09	70.22	94.26	94.26	**0**	0.64	0.64
140	Max WS	70.09	70.22	94.26	94.26	**0**	0.7	0.69
130	Max WS	70.09	70.22	94.26	94.26	**0**	0.64	0.64
120	Max WS	70.09	70.22	94.23	94.23	**0**	1.27	1.28
110	Max WS	70.09	70.22	94.15	94.15	**0**	1.8	1.8
100	Max WS	70.09	70.22	94.20	94.20	**0**	0.82	0.83
90	Max WS	70.09	70.22	94.21	94.21	**0**	0.82	0.82
80	Max WS	70.09	70.22	94.19	94.19	**0**	1.11	1.12
70	Max WS	70.09	70.22	94.19	94.19	**0**	1.58	1.58
60	Max WS	70.09	70.22	94.19	94.19	**0**	1.98	1.98
50	Max WS	70.09	70.22	94.17	94.17	**0**	1.57	1.57
40	Max WS	70.09	70.22	94.18	94.18	**0**	0.47	0.47
30	Max WS	70.09	70.22	94.16	94.16	**0**	1.16	1.16
20	Max WS	70.09	70.22	94.16	94.16	**0**	0.98	0.99
10	Max WS	70.09	70.21	94.16	94.16	**0**	0.63	0.63
0	Max WS	70.09	70.22	94.14	94.14	**0**	0.76	0.77