

Appendix 9.5 Flood Study Report, River Awbeg at Buttevant



Comhairle Contae Chorcaí
Cork County Council

M20 Cork-Limerick Motorway Scheme

transport21
progress in motion

Flood Study Report River Awbeg, Buttevant



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Executive Summary

The proposed motorway crosses the Awbeg River at Buttevant. The river regularly breaches its banks at the location of the crossing but the river flow and overbank flow is generally contained within the confines of the valley which is quite well defined. The aim of this flood study is to determine the effect the proposed motorway has on the flow in the river and to assess if this effect is acceptable or if mitigation is necessary.

The structure identified to convey the watercourse under the road is a multi-span bridge having a total length of 110m.

It was found that flood levels would increase by 10mm as a result of the proposed crossing. Furthermore, it was found that there was no increased risk of properties flooding due to the structure. It is therefore recommended that the 110m multi-span bridge will adequately accommodate the design flow and that no further mitigation measures are necessary.

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 Buttevant. The structure identified to convey the watercourse under the road is a multi-span bridge having a total length of 110m.

Approximate coordinates of the proposed structure are:

E156056.92, N108255.36; E156083.49, N108256.77;
E156087.31, N108148.12; E156060.71, N108147.97

A study was undertaken to ensure that this structure was sufficient to adequately convey the design flow without increasing flood risk on properties or increasing water levels, also known as afflux, outside the limits allowed by responsible bodies such as the Office of Public Works (OPW) or the National Roads Authority (NRA).

The main elements of the report include:

- Establishing the design flow for the Awbeg River
- Establishing existing flood levels and floodplain extent
- Establishing flood levels and extent due to the proposed development
- Assessing the need for mitigation

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

It is anticipated that the Awbeg River Bridge at Ch 43+470 on the proposed M20 motorway will be a multi-span bridge having a total length of approximately 110m, as shown in drawing 997/01/1700/ST43/2 in Appendix A. The bridge abutments are located on either side of the flood plain. The typical width of the structure will be 24.2m. For the purposes of this flood study, a typical pier arrangement of approximately 30m centres is assumed.

3.0 Flooding

3.1 Scope of Flooding Problem

The Awbeg River rises in the Ballyhoura Mountains to the east of the proposed M20. It generally flows south-east picking up a number of tributaries before crossing the existing N20 and subsequently the proposed M20 at Ch. 53+900 near the village of Ballyhea. The catchment area at the proposed Ballyhea crossing point is 42.45km². A separate flood study has been prepared for this crossing point. From there the Awbeg winds south and flows through the town of Buttevant, 13km south of Ballyhea. It crosses the existing N20 again just to the north of Buttevant and south of Buttevant it takes a sharp turn to the east and crosses the proposed M20 for the second time. The catchment of the river at the proposed crossing point at Buttevant is estimated to be 193 km² and the channel width is approximately 13m. Refer to Figure 3.1 for catchment area map.

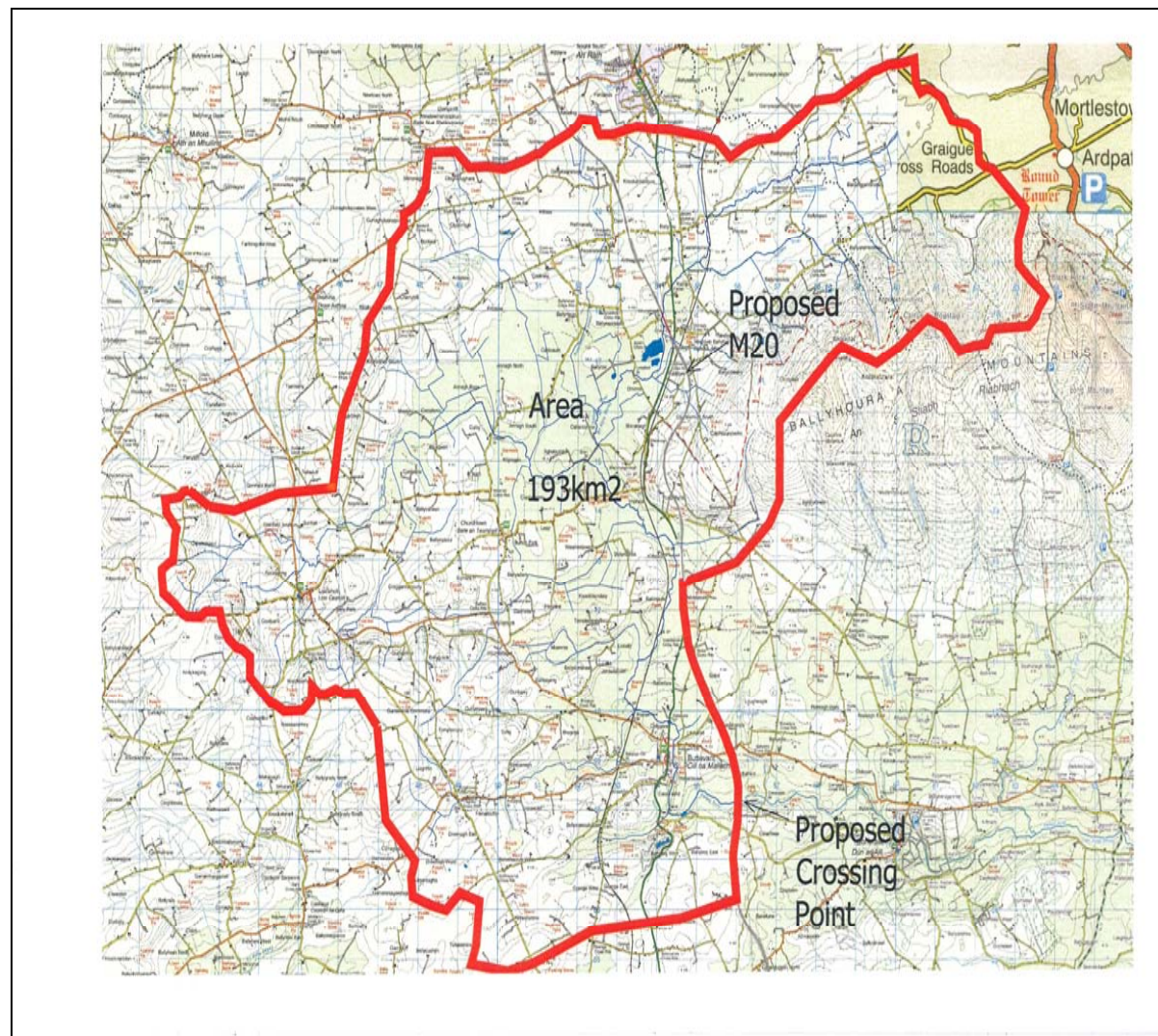


Figure 3.1 Catchment Area of Awbeg River at Buttevant

The OPW have indicated that this is a flood prone area. Furthermore, landowner consultation provided evidence of historical flooding in the area.

3.2 Causes of Flooding

There are a number of reasons for the Awbeg River flooding at Buttevant. The Ballyhoura Mountains overlook the low lying town of Buttevant. The flat topography to the North of Buttevant leads to difficulties in draining overland flow to the river. As a result water ponds regularly in the lands adjacent to the river, upstream of the crossing point. Furthermore the gradient of the river at Buttevant is extremely shallow and estimated to be 1 in 900. During flood events, this shallow gradient leads to the river overtopping its banks as the increased runoff cannot be conveyed downstream quickly enough. It should be noted that the flood waters at the crossing point, south of Buttevant town are contained within the confines of the valley as can be seen in Figure 3.2.



Figure 3.2 Photos of Flooding of Floodplain of River Awbeg at Buttevant

4.0 Flood Flow Estimation

4.1 General

The following design criteria have been adopted by the design team in accordance with the Flood Studies Report (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 Buttevant site is approximately 12km downstream at Ballynamona Station 18004 (coordinates E165638, N107560).

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

- Qbar estimation from un-gauged methods - FSR catchment characteristic equations for un-gauged catchments

- Donor / Analogue Catchment Analysis

The design flow was then refined by estimating the growth curve for the Awbeg River at Buttevant and applying it to Qbar.

4.3 Un-gauged Flow Estimation

The catchment area for the Awbeg River at Buttevant is 193 km². 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:

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

where:

AREA is the catchment area (km²).

STMFRQ (stream frequency) is the number of stream junctions per km² 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 0.5km².

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

Details of the catchment characteristic parameters are provided in Table 4.1.

AREA - catchment area	193.02	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	65.72	-
S3 - fraction of catchment of soil class 3	0.00	-
S4 - fraction of catchment of soil class 4	12.49	-
S5- fraction of catchment of soil class 5	21.78	-
SOIL - Soil index in range 0.15 - 0.50.	0.36	-
STMFRQ - number of stream junctions as shown on the 1:25,000 map/catchment area.	0.73	no/km ²
S1085 - stream channel slope measured between two points 10 and 85% of its length.	1.73	m/km
2 day 5 year rainfall	64	mm
r - 1 hour 5 year rainfall / 2 day 5 year rainfall	0.26	-
24 hour R5 as fraction of 2 day M5	0.83	-
24 hour R5	47.86	-
Soil Moisture Deficit	5.00	mm
RSMD - net 1 day rainfall of 5 year return period.	42.9	mm
LAKE - the fraction of the catchment draining through a lake or reservoir.	0.006	-

Table 4.1 Catchment Characteristic Parameters

Using the FSR 6 variable equation (Equation 1) $Q_{bar}(estimated)_A$ is calculated to be 33.2m³/s.

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

Q_{bar} at the subject site is scaled by the ratio of observed and estimated Q_{bar} values at the donor/analogue site, so that;

$$Q_{bar}_A = Q_{bar}(estimated)_A * Q_{bar}(measured)_B / Q_{bar}(estimated)_B \quad [Equation2]$$

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 gauged station 18004. The catchment area for the donor catchment is 324 km². The most appropriate method to estimate Q_{bar} is the FSR-6 variable equation. Details of the catchment characteristics are provided in Table 4.2.

AREA - catchment area	324.00	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	62.12	-
S3 - fraction of catchment of soil class 3	0.00	-
S4 - fraction of catchment of soil class 4	22.91	-
S5- fraction of catchment of soil class 5	14.97	-
SOIL - Soil index in range 0.15 - 0.50.	0.36	-
STMFRQ - number of stream junctions as shown on the 1:25,000 map/catchment area.	0.55	no/km ²
S1085 - stream channel slope measured between two points 10 and 85% of its length.	1.71	m/km
2 day 5 year rainfall	64	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	47.28	-
Soil Moisture Deficit	5.00	mm
RSMD - net 1 day rainfall of 5 year return period.	42.3	mm
LAKE - the fraction of the catchment draining through a lake or reservoir.	0.010	-

Table 4.2 Catchment Characteristic Parameters at Gauge 18004 Ballynamona

Using the FSR 6 variable equation (Equation2) the $Q_{bar}(estimated)_B$ flow is calculated to be $49.5m^3/s$.

$Q_{bar}(measured)_B$ was calculated from the Annual Maximum data sets at station 18004 on the River Awbeg 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.

HYDROMETRIC* YEAR	WATER LEVEL (mAOD-Poolbeg)	S.G. READING (m)	ESTIMATED FLOWS (m ³ /s)	DATE	RELIABLE LIMIT (m ³ /s)
1955	56.77	1.69	32	35	26/09/1956
1956	57.03	1.95	39.8	35	01/01/1957
1957	56.76	1.68	31.8	35	03/09/1958
1958	-	-	-	35	01/01/1900
1959	56.75	1.67	31.5	35	26/12/1959
1960	56.88	1.8	35.2	35	03/10/1960
1961	56.79	1.71	32.6	35	19/05/1962
1962	56.7	1.62	30.1	35	10/02/1963
1963	56.88	1.8	35.2	35	17/08/1964
1964	-	-	-	35	13/12/1964
1965	57.03	1.95	39.8	35	20/02/1966
1966	56.73	1.65	30.9	35	23/02/1967
1967	56.62	1.54	27.9	35	09/01/1968
1968	57.42	2.34	52.7	35	13/01/1968
1969	56.73	1.65	30.9	35	17/02/1970
1970	-	-	-	35	01/01/1900
1971	-	-	-	35	01/01/1900
1972	56.74	1.66	31.2	35	18/02/1973
1973	56.81	1.73	33.2	35	01/12/1973
1974	56.66	1.59	29.1	35	26/01/1975
1975	56.66	1.58	29	35	30/01/1976
1976	56.59	1.52	27.2	35	23/12/1976
1977	56.63	1.56	28.3	35	22/02/1978
1978	56.74	1.66	31.2	35	07/12/1978
1979	56.78	1.7	32.3	35	24/12/1979
1980	56.73	1.65	30.9	35	03/11/1980
1981	56.69	1.62	29.9	35	29/12/1981
1982	56.75	1.67	31.5	35	09/11/1982
1983	56.83	1.76	33.9	35	16/12/1983
1984	56.62	1.54	27.9	35	09/02/1985
1985	56.35	1.27	21	35	07/08/1986
1986	56.58	1.5	26.8	35	13/12/1986
1987	56.75	1.67	31.5	35	03/02/1988
1988	56.79	1.72	32.8	35	11/10/1988
1989	56.86	1.78	34.6	35	06/02/1990
1990	56.58	1.5	26.8	35	01/01/1991
1991	56.49	1.41	24.5	35	25/11/1991
1992	56.38	1.31	21.8	35	14/09/1991
1993	56.77	1.69	32	35	15/01/1994
1994	56.82	1.74	33.5	35	10/03/1995

HYDROMETRIC* YEAR	WATER LEVEL (mAOD-Poolbeg)	S.G. READING (m)	ESTIMATED FLOWS (m ³ /s)	DATE	RELIABLE LIMIT (m ³ /s)
1995	56.77	1.7	32.2	35	08/01/1996
1996	56.62	1.54	27.9	35	05/08/1997
1997	56.74	1.66	31.2	35	08/01/1998
1998	56.78	1.71	32.5	35	30/12/1998
1999	56.62	1.54	27.9	35	25/12/1999
2000	56.92	1.84	36.4	35	06/11/2000
2001	56.59	1.5	26.8	35	02/12/2002
2002	56.66	1.57	28.7	35	27/11/2002
2003	56.19	1.1	17.1	35	12/03/2004
2004	56.79	1.7	32.3	35	29/10/2004
2005	56.49	1.4	24.2	35	03/11/2005
2006	56.54	1.45	25.5	35	30/12/2006
		Average	30.7		

*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 18004 Ballynamona

Appendix B provides details of the three distributions fitted to the Annual Maxima dataset at station 18004.

For annual maximum flow records of 48 years the FEH recommends to measure Q_{bar} . Q_{bar} at the subject site was estimated using Equation 2. Table 4.4 provides details of measured and estimated Q_{bars} at station 18004 and at the subject site with a 68%-ile confidence interval.

Mean Annual Flood	Description	Mean Annual Flood (incl 95% SFE)	68% SFE	95% SFE
m ³ /s	-	m ³ /s	-	-
31.20	$Q_{bar}(measured)_B$	30.89	0.99	1.03
33.19	$Q_{bar}(estimated)_A$	48.78	1.47	2.16
49.49	$Q_{bar}(estimated)_B$	72.74	1.47	2.16
20.92	Q_{bar}_A	20.71		

Table 4.4 Estimate of Mean Annual flood

4.5 Growth Curve Estimation

Once the index flood, Q_{bar} , 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 Q_{bar} 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 section 4.5.1 and 4.5.2.

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 4.1.

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

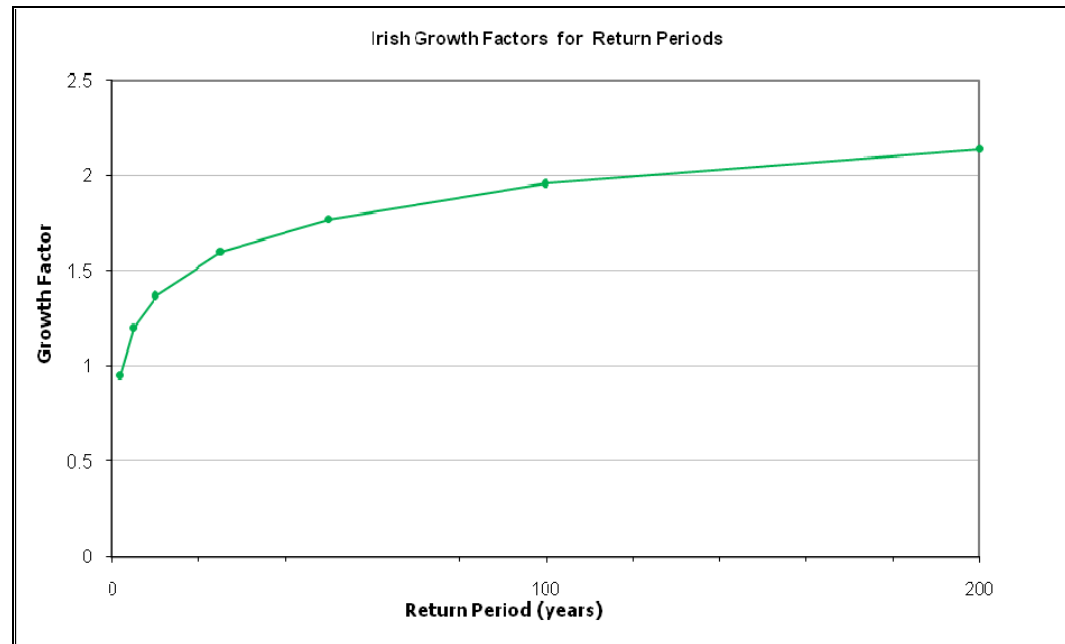


Figure 4.1 Graph of Irish Growth Factors for Different Return Periods

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 18004 on the Awbeg River 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 18004. The growth curves are relatively flat and it was therefore decided to adopt the more conservative regional growth factor for Ireland as presented in Figure 4.1.

Return Period	GEV	Gumbel (EV1)	Weibull
100	1.36	1.51	1.29
50	1.31	1.42	1.26
20	1.25	1.31	1.21
10	1.19	1.22	1.17
5	1.11	1.12	1.11
3	1.05	1.05	1.05
2.3	1.00	1.00	1.00
2	0.98	0.98	0.98

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

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 mean annual flood (Q_{bar}) 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. Refer to Table 4.5 and Figure 4.1.

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. As no properties are at risk of flooding at the Buttevant crossing point, 68% confidence was adopted.

A Drainage District Factors (DDF) of 1.6 was included as the majority of channels in the catchment are located within a drainage district.

In line with OPW 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 68% confidence interval and 20% climate change is 115m³/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. The Irish Regional Growth Curve was applied to Qbar to allow estimation of less frequent (higher return period) floods as shown in Table 4.7.

Return period (years):	Growth Factor	Climate Change	Design Flow
2	0.95	20%	38
2.3	0.99	20%	21
5	1.2	20%	48
10	1.37	20%	55
25	1.6	20%	64
50	1.77	20%	70
100	1.96	20%	78

Table 4.7 Design Flow Estimate including 95% confidence interval

4.7 Outcome

The FSR recommends that if a catchment is gauged then design flows should be calculated from statistical flood frequency analysis. In the absence of a gauge at the subject site, the FEH recommends that use is made of donor and/or analogue catchments to improve estimates of the index flood at un-gauged sites. The catchment at the crossing point is hydraulically similar to that at Ballynamona (Gauging Station 18004). Refer to Tables 4.1 and 4.2 respectively. Based on FSR and FEH recommendations, the close proximity of gauging station 18004 and the similarity of the catchments hydraulically make it a suitable donor catchment for flow estimations at Buttevant. It was therefore concluded that the donor catchment estimation method with a resultant flow of 78m³/s at the Buttevant site was the most suitable design flow estimate.

5.0 Hydraulic Assessment

5.1 Background

A Hydrologic Engineering Centre-River Analysis System (HEC-RAS) 4 was used to assess the flood impact of the Awbeg River. 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 Buttevant was constructed using survey information and aerial topography data over a 1.4km reach length.

The river was represented using cross sections that were generated at 10m intervals and include the existing structure 700m downstream of the proposed M20 crossing at L-5565. Cross sections extended 200-300m either side of the river channel to include the floodplain. Figure 5.2 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 78m³/s design flow using steady flow analysis. The downstream boundary condition chosen was 0.001 normal depth based on the river slope. There is also an existing structure downstream of the crossing point included in the analysis: 2 no. 7.7m wide x 2.5m high box structures to carry the local road L5565.

5.3 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 10mm upstream of the proposed crossing point.

Figure 5.4 presents a long-section of the model showing the bridge piers and existing structure 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.

There is no perceptible increase in flood extents due to the scheme. Refer to Figures 5.4 for floodplain extents pre-motorway and post-motorway. The minor increase in water level does not result in an increase of flood risk and no properties are affected. Therefore no mitigation measures were deemed necessary.



Figure 5.4 Floodplain Extents Pre-motorway and Post-motorway

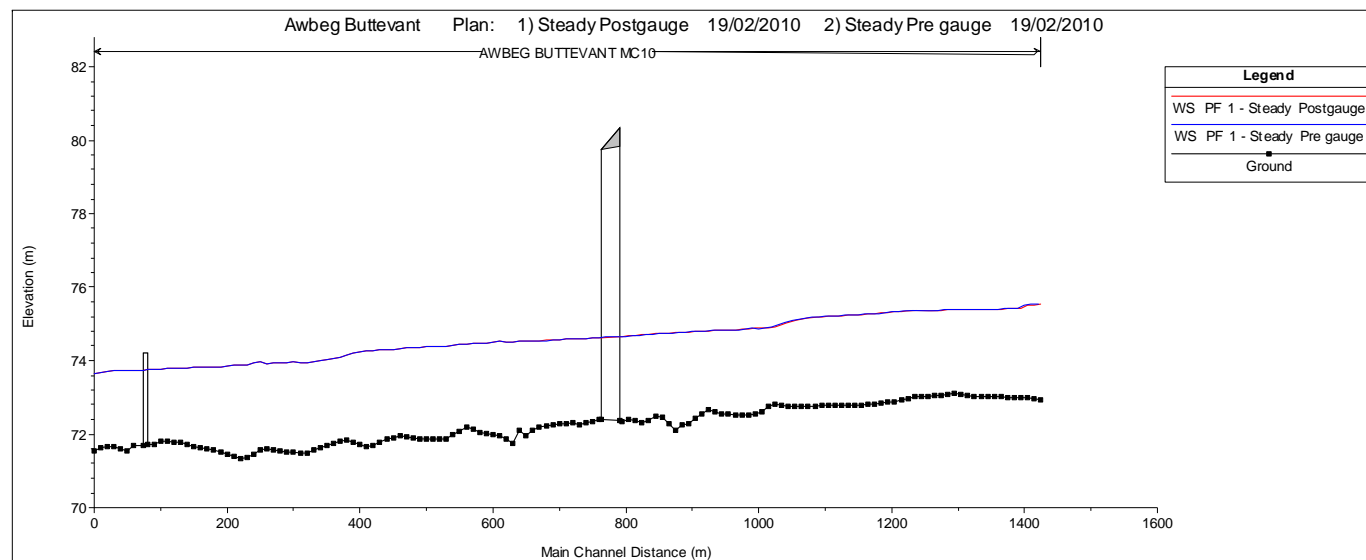


Figure 5.4 Water Profile Comparison (Pre-motorway v Post-motorway)

6.0 Conclusion

The proposed M20 motorway crosses the Awbeg River at Buttevant. The structure identified to convey the watercourse under the road is a multi-span bridge having a total length of approximately 110m.

Hydrological calculations were undertaken and a design flow of 78m³/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 10mm as a result of the proposed motorway and structure. This does not cause an increased risk of flooding to properties and is well within the guidelines outlined by the OPW and the NRA. It was therefore concluded that no additional flood mitigation measures were required.

7.0 Glossary of Terms

AREA	Catchment area (km ²) in Equation 1
BFIHOST	Base Flow Index as estimated by HOST
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

8.0 References

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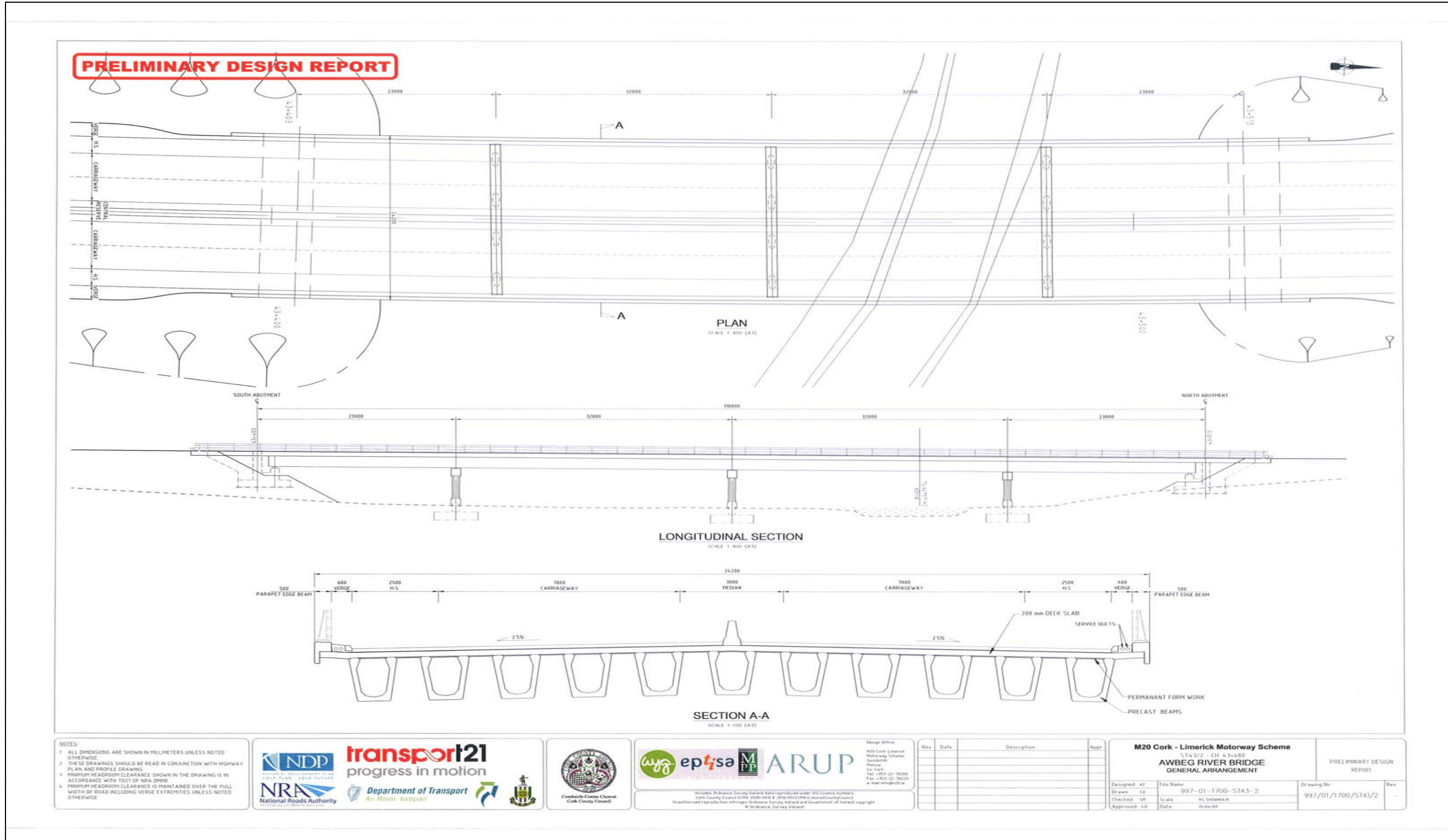
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Appendix A - Drawings



Appendix B

Statistical Flood Frequency Analysis at Station 18004

GEV (Method of weighted moments)							Gumbel (Method of weighted moments)						Weibull (Method of moments)							
Number of observations 47							Number of observations 47						Number of observations 47							
Parameters alpha 4.49564 k 0.21108 u 28.9493							Parameters u 28.5436 alpha 3.82801						Parameters alpha 32.929 c 6.78694							
Quantiles q = F(X) : non-exceedance probability T = 1/(1-q)							Quantiles q = F(X) : non-exceedance probability T = 1/(1-q)						Quantiles q = F(X) : non-exceedance probability T = 1/(1-q)							
T	q	XT	Standard deviation	Confidence interval (95%)		GF	T	q	XT	Standard deviation	Confidence interval (95%)		GF	T	q	XT	Standard deviation	Confidence interval (95%)		GF
10000	0.9999	47.2	5.09	N/D	N/D	1.52	10000	0.9999	63.8	4.55	54.9	72.7	2.09	10000	0.9999	45.7	3.95	37.9	53.4	1.43
2000	0.9995	46	4.13	N/D	N/D	1.48	2000	0.9995	57.6	3.75	50.3	65	1.89	2000	0.9995	44.4	3.6	37.3	51.4	1.39
1000	0.999	45.3	3.68	N/D	N/D	1.46	1000	0.999	55	3.4	48.3	61.7	1.80	1000	0.999	43.8	3.43	37.1	50.5	1.37
200	0.995	43.3	2.61	38.2	48.4	1.39	200	0.995	48.8	2.6	43.7	53.9	1.60	200	0.995	42.1	2.99	36.2	48	1.32
100	0.99	42.2	2.16	37.9	46.4	1.36	100	0.99	46.2	2.26	41.7	50.6	1.51	100	0.99	41.2	2.77	35.8	46.7	1.29
50	0.98	40.9	1.74	37.5	44.3	1.31	50	0.98	43.5	1.92	39.7	47.2	1.42	50	0.98	40.3	2.52	35.3	45.2	1.26
20	0.95	38.9	1.26	36.4	41.3	1.25	20	0.95	39.9	1.48	37	42.8	1.31	20	0.95	38.7	2.14	34.5	42.9	1.21
10	0.9	37	1.01	35	39	1.19	10	0.9	37.2	1.15	34.9	39.4	1.22	10	0.9	37.2	1.81	33.7	40.8	1.17
5	0.8	34.7	0.871	33	36.4	1.11	5	0.8	34.3	0.846	32.6	35.9	1.12	5	0.8	35.3	1.4	32.6	38.1	1.11
3	0.6667	32.6	0.809	31.1	34.2	1.05	3	0.6667	32	0.657	30.7	33.3	1.05	3	0.6667	33.4	1.05	31.3	35.4	1.05
2.3	0.55001	31.13	0.7761	29.63	32.66	1.00	2.3	0.55001	30.53	0.6003	29.37	31.76	1.00	2.3	0.55001	31.86	0.8582	30.18	33.51	1.00
2	0.5	30.5	0.762	29	32	0.98	2	0.5	29.9	0.576	28.8	31.1	0.98	2	0.5	31.2	0.776	29.7	32.7	0.98
1.4286	0.3	28.1	0.725	26.7	29.5	0.90	1.4286	0.3	27.8	0.619	26.6	29	0.91	1.4286	0.3	28.3	0.764	26.8	29.8	0.89
1.25	0.2	26.7	0.738	25.3	28.1	0.86	1.25	0.2	26.7	0.687	25.4	28.1	0.87	1.25	0.2	26.4	0.94	24.6	28.2	0.83
1.1111	0.1	24.8	0.833	23.2	26.5	0.80	1.1111	0.1	25.4	0.8	23.8	26.9	0.83	1.1111	0.1	23.6	1.28	21.1	26.1	0.74
1.0526	0.05	23.4	0.982	21.5	25.3	0.75	1.0526	0.05	24.3	0.898	22.6	26.1	0.80	1.0526	0.05	21.3	1.57	18.2	24.3	0.67
1.0204	0.02	21.8	1.21	19.5	24.2	0.70	1.0204	0.02	23.3	1.01	21.4	25.3	0.76	1.0204	0.02	18.5	1.85	14.9	22.2	0.58
1.0101	0.01	20.8	1.39	18.1	23.6	0.67	1.0101	0.01	22.7	1.07	20.6	24.8	0.74	1.0101	0.01	16.7	2.01	12.8	20.7	0.52
1.005	0.005	20	1.57	16.9	23.1	0.64	1.005	0.005	22.2	1.13	19.9	24.4	0.73	1.005	0.005	15.1	2.11	10.9	19.2	0.47
1.001	0.001	18.2	1.98	14.3	22.1	0.58	1.001	0.001	21.1	1.25	18.7	23.6	0.69	1.001	0.001	11.9	2.23	7.54	16.3	0.37
1.0005	0.0005	17.6	2.15	13.4	21.8	0.57	1.0005	0.0005	20.8	1.3	18.2	23.3	0.68	1.0005	0.0005	10.7	2.23	6.38	15.1	0.34
1.0001	0.0001	16.2	2.51	11.3	21.1	0.52	1.0001	0.0001	20	1.38	17.3	22.8	0.66	1.0001	0.0001	8.48	2.16	4.25	12.7	0.27

Table B1: Station 18004- Results of Fitting

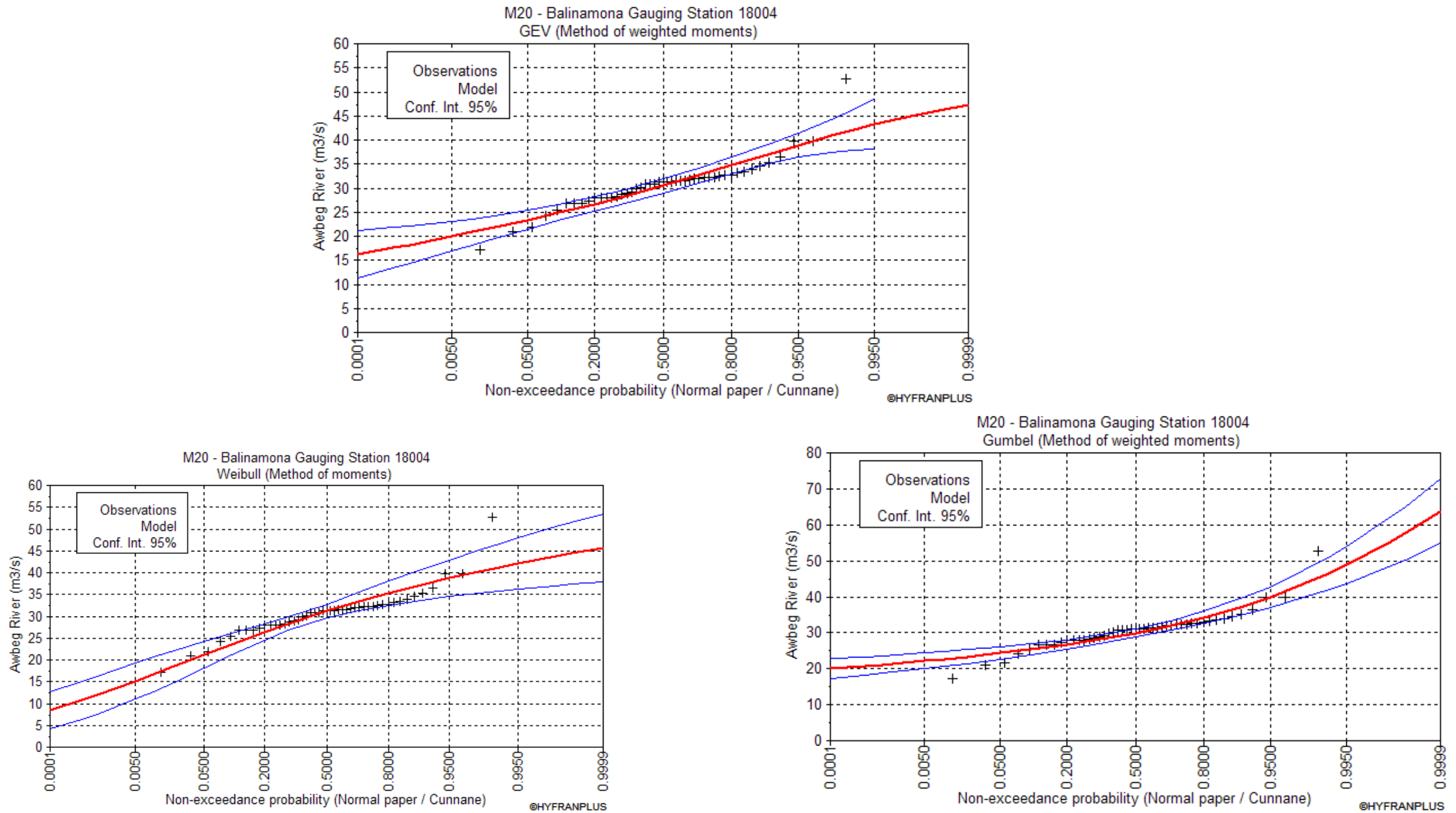


Figure B1: Station 18004 Graph of Fitting

Appendix C

Results

River Station	Q Total Pre-motorway (m ³ /s)	Q Total Post-motorway (m ³ /s)	Water Surface Elevation Pre-motorway (m)	Water Surface Elevation Post-motorway (m)	AFFLUX (Increase in Water levels) (mm)	Channel Velocity Pre-motorway (m/s)	Channel Velocity Post-motorway (m/s)
1420	78	78	75.62	75.63	0.01	1.54	1.54
1410	78	78	75.62	75.63	0.01	1.33	1.3
1400	78	78	75.61	75.61	0	1.3	1.29
1390	78	78	75.55	75.55	0	1.82	1.82
1380	78	78	75.54	75.54	0	1.75	1.75
1370	78	78	75.53	75.53	0	1.68	1.68
1360	78	78	75.52	75.52	0	1.6	1.6
1350	78	78	75.51	75.51	0	1.51	1.51
1340	78	78	75.51	75.51	0	1.41	1.41
1330	78	78	75.5	75.5	0	1.34	1.34
1320	78	78	75.5	75.5	0	1.3	1.3
1310	78	78	75.49	75.49	0	1.21	1.21
1300	78	78	75.49	75.49	0	1.1	1.09
1290	78	78	75.49	75.49	0	1	1
1280	78	78	75.48	75.48	0	1.06	1.06
1270	78	78	75.47	75.47	0	1.13	1.13
1260	78	78	75.47	75.47	0	1.09	1.09
1250	78	78	75.46	75.46	0	1.04	1.04
1240	78	78	75.46	75.46	0	1	0.99
1230	78	78	75.45	75.45	0	0.95	0.94
1220	78	78	75.44	75.45	0.01	0.92	0.92
1210	78	78	75.44	75.44	0	0.97	0.97
1200	78	78	75.43	75.43	0	1.09	1.08
1190	78	78	75.41	75.41	0	1.22	1.22
1180	78	78	75.39	75.39	0	1.3	1.29
1170	78	78	75.37	75.37	0	1.33	1.33
1160	78	78	75.36	75.36	0	1.31	1.31
1150	78	78	75.35	75.35	0	1.32	1.32
1140	78	78	75.34	75.34	0	1.35	1.35
1130	78	78	75.33	75.33	0	1.35	1.35
1120	78	78	75.31	75.32	0.01	1.35	1.35
1110	78	78	75.3	75.31	0.01	1.36	1.35
1100	78	78	75.29	75.3	0.01	1.34	1.34
1090	78	78	75.28	75.28	0	1.38	1.38
1080	78	78	75.27	75.27	0	1.36	1.36
1070	78	78	75.26	75.26	0	1.39	1.39
1060	78	78	75.23	75.23	0	1.55	1.55
1050	78	78	75.19	75.19	0	1.75	1.74
1040	78	78	75.15	75.15	0	1.89	1.89

River Station	Q Total Pre-motorway (m ³ /s)	Q Total Post-motorway (m ³ /s)	Water Surface Elevation Pre-motorway (m)	Water Surface Elevation Post-motorway (m)	AFFLUX (Increase in Water levels) (mm)	Channel Velocity Pre-motorway (m/s)	Channel Velocity Post-motorway (m/s)
1030	78	78	75.11	75.11	0	2.06	2.05
1020	78	78	75.05	75.06	0.01	2.21	2.21
1010	78	78	75.02	75.03	0.01	2.17	2.16
1000	78	78	75.01	75.02	0.01	1.94	1.93
990	78	78	75.01	75.01	0	1.77	1.77
980	78	78	74.99	74.99	0	1.74	1.73
970	78	78	74.97	74.98	0.01	1.73	1.73
960	78	78	74.96	74.97	0.01	1.65	1.65
950	78	78	74.96	74.96	0	1.62	1.61
940	78	78	74.94	74.95	0.01	1.61	1.6
930	78	78	74.94	74.94	0	1.45	1.44
920	78	78	74.93	74.94	0.01	1.47	1.46
910	78	78	74.92	74.93	0.01	1.38	1.38
900	78	78	74.92	74.92	0	1.3	1.29
890	78	78	74.9	74.9	0	1.32	1.31
880	78	78	74.88	74.89	0.01	1.37	1.36
870	78	78	74.88	74.88	0	1.3	1.3
860	78	78	74.87	74.87	0	1.37	1.36
850	78	78	74.86	74.86	0	1.39	1.38
840	78	78	74.85	74.85	0	1.37	1.36
830	78	78	74.84	74.84	0	1.37	1.36
820	78	78	74.82	74.82	0	1.42	1.41
810	78	78	74.8	74.81	0.01	1.43	1.42
800	78	78	74.79	74.8	0.01	1.38	1.36
790	78	78	74.78	74.79	0.01	1.36	1.34
780	78	Bridge Inlet	-	74.78	-	-	0.8
770	78	Bridge Outlet	-	74.75	-	-	0.79
760	78	78	74.76	74.76	0	1.28	1.27
750	78	78	74.74	74.74	0	1.29	1.27
740	78	78	74.73	74.73	0	1.33	1.31
730	78	78	74.72	74.72	0	1.31	1.3
720	78	78	74.71	74.71	0	1.28	1.28
710	78	78	74.71	74.71	0	1.15	1.15
700	78	78	74.69	74.7	0.01	1.19	1.19
690	78	78	74.68	74.68	0	1.26	1.26
680	78	78	74.67	74.67	0	1.22	1.18
670	78	78	74.66	74.66	0	1.21	1.21
660	78	78	74.65	74.65	0	1.23	1.23
650	78	78	74.65	74.65	0	1.16	1.16
640	78	78	74.64	74.64	0	1.19	1.19
630	78	78	74.64	74.64	0	1.08	1.08
620	78	78	74.63	74.63	0	0.94	0.95
610	78	78	74.64	74.64	0	0.6	0.6
600	78	78	74.63	74.63	0	0.65	0.65
590	78	78	74.61	74.61	0	1.04	1.04

River Station	Q Total Pre-motorway (m ³ /s)	Q Total Post-motorway (m ³ /s)	Water Surface Elevation Pre-motorway (m)	Water Surface Elevation Post-motorway (m)	AFFLUX (Increase in Water levels) (mm)	Channel Velocity Pre-motorway (m/s)	Channel Velocity Post-motorway (m/s)
580	78	78	74.59	74.59	0	1.25	1.26
570	78	78	74.58	74.58	0	1.19	1.19
560	78	78	74.57	74.57	0	1.14	1.13
550	78	78	74.56	74.56	0	1.24	1.24
540	78	78	74.53	74.53	0	1.39	1.39
530	78	78	74.5	74.5	0	1.55	1.55
520	78	78	74.5	74.5	0	1.4	1.4
510	78	78	74.5	74.5	0	1.31	1.31
500	78	78	74.5	74.5	0	1.24	1.24
490	78	78	74.49	74.49	0	1.19	1.19
480	78	78	74.48	74.48	0	1.24	1.24
470	78	78	74.47	74.47	0	1.22	1.22
460	78	78	74.45	74.45	0	1.3	1.3
450	78	78	74.43	74.43	0	1.36	1.36
440	78	78	74.43	74.43	0	1.26	1.28
430	78	78	74.42	74.42	0	1.26	1.26
420	78	78	74.4	74.4	0	1.32	1.32
410	78	78	74.39	74.39	0	1.37	1.37
400	78	78	74.37	74.37	0	1.41	1.41
390	78	78	74.34	74.34	0	1.51	1.51
380	78	78	74.28	74.28	0	1.77	1.77
370	78	78	74.24	74.24	0	1.9	1.9
360	78	78	74.21	74.21	0	1.95	1.95
350	78	78	74.18	74.18	0	1.97	1.97
340	78	78	74.14	74.14	0	2.03	2.03
330	78	78	74.11	74.11	0	2.02	2.02
320	78	78	74.08	74.08	0	2.06	2.06
310	78	78	74.08	74.08	0	1.89	1.89
300	78	78	74.09	74.09	0	1.74	1.74
290	78	78	74.08	74.08	0	1.69	1.69
280	78	78	74.07	74.07	0	1.7	1.7
270	78	78	74.06	74.06	0	1.65	1.65
260	78	78	74.05	74.05	0	1.65	1.65
250	78	78	74.07	74.07	0	1.24	1.24
240	78	78	74.07	74.07	0	1.19	1.19
230	78	78	74.02	74.02	0	1.5	1.5
220	78	78	74.01	74.01	0	1.49	1.49
210	78	78	74	74	0	1.46	1.46
200	78	78	73.98	73.98	0	1.53	1.53
190	78	78	73.96	73.96	0	1.58	1.58
180	78	78	73.95	73.95	0	1.55	1.55
170	78	78	73.95	73.95	0	1.43	1.43
160	78	78	73.95	73.95	0	1.32	1.32
150	78	78	73.94	73.94	0	1.28	1.28
140	78	78	73.93	73.93	0	1.3	1.3
130	78	78	73.93	73.93	0	1.25	1.25

River Station	Q Total Pre-motorway (m ³ /s)	Q Total Post-motorway (m ³ /s)	Water Surface Elevation Pre-motorway (m)	Water Surface Elevation Post-motorway (m)	AFFLUX (Increase in Water levels) (mm)	Channel Velocity Pre-motorway (m/s)	Channel Velocity Post-motorway (m/s)
120	78	78	73.92	73.92	0	1.26	1.26
110	78	78	73.91	73.91	0	1.17	1.17
100	78	78	73.91	73.91	0	1.11	1.11
90	78	78	73.9	73.9	0	1.11	1.11
80	Culvert Inlet	Culvert Inlet	73.89	73.89	0	0.82	0.82
70	Culvert Outlet	Culvert Outlet	73.89	73.89	0	0.82	0.82
60	78	78	73.87	73.87	0	1.21	1.21
50	78	78	73.87	73.87	0	1.12	1.12
40	78	78	73.87	73.87	0	1	1
30	78	78	73.86	73.86	0	0.98	0.98
20	78	78	73.85	73.85	0	1.1	1.1
10	78	78	73.82	73.82	0	1.27	1.27
0	78	78	73.8	73.8	0	1.38	1.38

Table C1 Pre-motorway and Post-motorway Results

