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Report for **ARROW Energy Major Pipelines**

ABP Flood Impact Assessment Study

ABP No: 08-GHD-02-0003

REV 0

Rev No.	Author	Reviewer		Approved for Issue		
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1. Introduction

1.1 Project Overview

The Arrow Bowen Pipeline (ABP) will transport coal seam gas from the Bowen Basin in Queensland to a proposed LNG facility to be located on Curtis Island near Gladstone. A map of the pipeline route is provided in Appendix 1.

The proposed ABP system will consist of a 610 km long, 42” OD steel transmission pipeline comprising approximately 477 km of main pipeline and approximately 133 km of lateral pipelines.

The purpose of this desktop flood study of the transmission pipeline route is to identify locations where significant lengths may be subjected to inundation by floodwaters. This information is to be used to assess buoyancy control requirements for the pipeline.

1.2 Scope and Methodology

This document repeats the exercise of the Surat Gladstone Pipeline flood study according to the same methodology adopted for the production of the March 2010 GHD report.

The ABP desktop flood study used a range of data, including:

- The proposed pipeline route (Revision D) and distances (provided by Arrow Energy Pty Ltd);
- Regional topographic maps (provided by Arrow Energy Pty Ltd);
- Stream gauging data;
- 10 m interval contour data (provided by Arrow Energy Pty Ltd).

The short timeframe has meant it has only been possible to undertake an overview assessment of flood levels and extents focussed on crossings of major waterways and where the proposed pipeline route follows the alignment of waterways and drainage paths.

The following methodology was used to estimate the 100 year Average Recurrence Interval (ARI) flood levels and inundation extents:

100 year ARI flood discharges were estimated using the Department of Transport and Main Roads (DTMR) regional flood estimation method or flood frequency analysis of stream gauging data (where this information was available).

100 year ARI flood levels were estimated from the calculated values of 100 year ARI flood discharge using either a HEC-RAS model incorporating stream height gauging data and available topography data or assessment of topographic data only.

Lengths of the pipeline inundated by the 100 year ARI flood event were determined from the estimated 100 year ARI flood levels using the 10 m interval contour data.

The March 2010 study benefitted from the accuracy of LIDAR data supplemented by ground surveys of major crossings. However, for this project, the topographic data supplied is only to a 10 m contour. This means the modelling of flood levels and extent will be of lower accuracy than was the case with the earlier study.

The flood discharges, levels and extents identified in this report should again be considered as indicative only. It is recommended that more detailed flooding investigations be undertaken as part of detailed design.

2. Topography and Drainage

The proposed gas transmission pipeline route (Revision D) is shown in Appendix A and has a total main pipeline length of 477 km. The pipeline runs in a south westerly direction to the proposed LNG facility to be located on Curtis Island near Gladstone.

Although there are a number of creeks of varying size encountered, the Isaac River, Mackenzie River and Fitzroy River are the only major waterways crossed by this part of the pipeline. The Isaac and the Mackenzie Rivers flow into the Fitzroy River which discharges into the Pacific Ocean between Rockhampton and Gladstone. River Basins traversed by the ABP are provided in Table 1

Ground elevations are mainly within the range 10 m to 660 m Australian Height Datum (AHD).

Locations where the Revision D pipeline route crosses major waterways or floodplain areas have been identified in this Preliminary Flood Study. This flood study is a Preliminary Flood Study, based on coarse 10 m interval topographic data along the pipeline route. The final locations assessed as being potentially susceptible to significant flood inundation are listed in Appendix B.

Table 1 River Basins crossed by ABP route

Pipeline Distance (km)	River basin
0 - 6	Bowen / Broken
6 - 37	Belyando / Suttor
37 - 346	Nogoa / Mackenzie
346 - 469	Fitzroy River (Qld)
469 - 477	Calliope River

3. Hydrologic Assessment

3.1 Overview

Hydrologic calculations were undertaken to estimate the 100 year ARI peak catchment discharges at the flood prone locations listed in Appendix B, for input to hydraulic calculations of flood levels (refer Section 4).

The following methods were used:

The DTMR regional flood estimation method was applied to the catchments devoid of any stream gauging data.

Flood frequency analysis was used in preference to the DTMR method for catchments that have available stream gauging data.

3.2 DTMR Regional Flood Estimation Method

The DTMR has recently developed a new flood estimation method for Queensland catchments (Palmen and Weeks, 2009). The flood estimation method provides regression equations that allow the prediction of the peak flood discharge (Q) for catchments without stream flow gauging data. The equations allow the prediction of the peak flood discharge for the 2, 5, 10, 20, 50 and 100 year ARI flood events as a function of the catchment area (A) and 50 year ARI 72 hour duration design storm rainfall intensity (I72hr,50yr).

The regression equations were developed from flood frequency analyses of data from 289 stream flow gauging stations in Queensland.

The equation for the 100 year ARI peak flood discharge (Q100) is:

$$\mathrm{Log}_{10}Q_{100} = 0.847 + 0.644\log_{10}A + 0.899\log_{10}I_{72hr,50yr}$$

Catchment areas were determined based on topographic maps provided by Arrow Energy Pty Ltd. The 50 year ARI 72 hour duration design storm rainfall intensity was determined for each catchment using the Bureau of Meteorology On-Line IFD internet site. The estimated 100 year ARI peak flood discharges are provided in Appendix B.

The stated accuracy of the DTMR regression equations is shown in Table 2. For the 100 year ARI flood event, only 32% of the 289 gauged catchments had a predicted flood discharge from the regression equation that was within ±20% of the value derived from the more accurate flood frequency analysis. It must be recognised that there is considerable uncertainty in estimating the magnitude of the 100 year ARI flood discharge when the duration of stream flow gauging data is in most cases significantly less than 100 years.

Table 2 Accuracy of DTMR flood estimation equations (Table 3 of Palmen and Weeks (2009))

ARI	Adjusted r^2	Root Mean Squared Error	Percentage of Stations within ± 20% of target
2	0.577	± 82%	30%
5	0.630	± 57%	30%
10	0.638	± 49%	31%
20	0.627	± 50%	35%
50	0.584	± 52%	34%
100	0.537	± 56%	32%

3.3 Flood Frequency Analysis

A design flood discharge of a specified recurrence interval can be estimated from stream flow gauging data using a flood frequency analysis. This type of analysis is likely to provide the most accurate estimate of flood peak discharge provided it is based on stream flow gauging data of a sufficient length and reliability. This procedure involves:

- Determination of the annual maximum flood discharge in each year;
- Ranking of annual maximum flood discharges in descending order;
- Fitting a probability distribution to the ranked annual maximum flood discharges;
- The Log Pearson Type III distribution is the recommended probability distribution for flood frequency analyses in Australia (IEAust, 1999).

3.3.1 Comparison of DTMR and Flood Frequency Analysis Methods

To assess the accuracy of the DTMR method in determining peak flood discharges for ungauged catchments the method was compared with the results of the more accurate flood frequency analysis method using the stream flow gauging data from a number gauged catchments within the study area.

Stream flow gauging data is available for a number of the waterways crossed by the ABP route (refer Table 3). The stream flow gauging stations are operated by the Queensland Department of Environment and Resource Management (DERM).

Estimates of the 100 year ARI peak flood discharges were obtained at the stream gauging station locations using the DTMR regional flood estimation method (described in Section 3.2) and flood frequency analysis (fitted Log Pearson Type III distribution). The comparison of the predicted flood discharges from the two methods is shown in Table 3.

For one out of the three catchments assessed (33.33%) the DTMR method yielded a 100 year ARI flood discharge that was 42% larger than the flood frequency analysis value. For the other two, the DTMR method yielded a 100 year ARI flood discharge that was 13% and 50% lower than the flood frequency analysis value.

It is evident that the accuracy of the DTMR flood estimation method is quite variable; however this method was adopted for those catchments in the study area where stream gauge data was un-available.

Table 3 Detail of stream flow gauging stations for waterways crossed by ABP route

4	Station Name	Distance from ABP	Catchment Area	Period of Record	Maximum Recorded Flow	Maximum Recorded Depth
			(km^2)		(m^3/s)	(m)
120304A	Suttor R at Eaglefield	50 km downstream	1,890	1967 to current	1,595	12.87
130402A	Isaac R at Burton Gorge	7 km upstream	551	1964 to 1988	777	7.24
130401A[1]	Isaac R at Yatton	17 km upstream	19,719	1962 to current	20,844	19.27
130003B[1]	Fitzroy R at Riverslea	76 km upstream	131,385	1974 to current	14,532	27.96
130004A	Raglan Ck at Old Station	23 km upstream	389	1963 to current	1,471	12.64

[1] DTMR/flood frequency analysis method flow comparison not undertaken since the catchment area is too large for the former method.

Table 4 Comparison of 100 year peak discharges predicted using DTMR method and flood frequency analysis

Station No	Station Name	Catchment Area (km^2)	100 year ARI Peak Discharge (m^3/s) DTMR Method	Flood Frequency Analysis	% Difference (DTMR Method to Flood Frequency Analysis)
120304A	Suttor R at Eaglefield	1,890	3,115	2,196	42%
130402A	Isaac R at Burton Gorge	551	1,408	1,627	-13%
130004A	Raglan Ck at Old Station	389	2,058	4.118	-50%

3.3.2 Estimation of Flood Discharges at ABP Location Using Flood Frequency Analysis

For those catchments for which stream flow gauging data is available, the 100 year ARI flood discharge at the ABP crossing locations was estimated from the flood frequency analysis results instead of the DTMR method.

The flood discharge at the ABP crossing locations (Q100,ABP) was estimated by scaling the flood discharge values at the stream gauging stations (Q100,GS) according to the ratio of catchment areas at the two locations as follows (exponent from DTMR equation):

$$Q_{100,ABP} = Q_{100,GS} \times (A_{ABP} / A_{GS})^{0.644}$$

The scaled 100 year ARI flood discharges at the ABP locations are indicated in Appendix B. Appendix B also indicates which catchments the DTMR method was used for and which catchments the flood frequency analysis results were used for.

4. Hydraulic Assessment

4.1 Overview

1-D HEC-RAS models were used to estimate the flood levels at all but one (Pipeline lateral Dysart Rev D, *refer Appendix B*) flood prone locations. These models incorporated information from the stream gauge data (where available) and available topography data. Details are provided in Appendix B.

The length of the pipeline route that will be potentially inundated by the 100 year ARI flood event was then determined by superimposing the estimated flood levels onto a representation of the land surface obtained from the provided topographic data.

HEC-RAS modelling was not undertaken for locations where the topographic data was insufficient. At these locations the flood inundation extent was estimated directly from the topographic survey data.

4.2 Flood Level Estimation

4.2.1 1D HEC-RAS Modelling

Flood levels at a majority of crossing locations were estimated using the HEC-RAS one-dimensional hydraulic modelling software (refer Appendix B). The HEC-RAS hydraulic model for the crossings was constructed using the following information:

Cross sections of waterways were extracted from the 10 m contour topographic data at the crossing locations.

In the absence of a field assessment or appropriate photographic evidence of channel roughness/vegetation conditions, a uniform Manning's roughness value of 0.07 was applied to all cross sections.

100 year ARI peak discharges were mostly determined using the stream gauge data. Where stream gauge data was unavailable, DTMR regional flood estimation method was used.

The estimated 100 year ARI flood levels at the crossing locations are provided in Appendix B which also indicates the flood level estimation method adopted for each flood prone location.

4.2.2 Assessment of Waterway Topography

Flood levels were not determined at location where Pipeline lateral Dysart Rev D crosses Stephens creek. This is because the topographic data was insufficient and too coarse and indicated that the pipeline will be subject to flood inundation (i.e. without the need for hydrologic and hydraulic calculations). At this location the flood inundation extent was inferred from the 10 m contour topographic data, the proximity of the waterway and the downstream HEC-RAS model at confluence of Stephens creek and Isaac River (Refer Appendix B).

4.3 Flood Inundation Extent Estimation

The extent of the pipeline route that will be potentially inundated by the 100 year ARI flood event was then determined by superimposing the estimated flood levels (refer Section 4) onto a representation of the land surface derived from the available topographic data. The estimated flood inundation extents are shown in Appendix B.

5. Conclusions and Recommendations

A desktop flood study using industry-accepted hydrologic and hydraulic methods has been conducted on the first 610 km (approx.) of the proposed ABP to identify locations where significant lengths of the pipeline may be flooded. This information will be utilised for the purpose of assessment of buoyancy controls for the pipeline.

The following information was identified in the flood study and is summarised in Appendix B:

- 11 locations along the proposed pipeline route where significant lengths of the pipeline may be subject to flood inundation;
- 100 year ARI flood discharges and levels at these crossing locations;
- Lengths of the pipeline at these locations that will be potentially inundated by the 100 year ARI flood event.

The short period available to complete the flood study meant it was only possible to undertake an overview assessment of flood levels.

The methods used for the estimation of flood discharges and levels are simplistic in nature and accordingly the flood results determined in this study should be considered indicative only. Furthermore, the absence of higher resolution topographic, LIDAR and ground survey data has greatly reduced the accuracy of the results compared with the March 2010 study.

While this flood study was focussed only on identifying locations where significant lengths of the pipeline may be inundated there are numerous other locations where shorter lengths are likely to be flooded.

It is recommended that more detailed flooding investigations be undertaken as part of detailed design.

6. References

- GHD Pty Ltd (2010), Report for Surat Gladstone Pipeline Preliminary Engineering – Preliminary Flood Study. Document No. 08-GHD-3-02-0021 Rev 3. March 2010.
- The Institution of Engineers, Australia (1999), Australian Rainfall and Runoff: A Guide to Flood Estimation. Volume 1. Barton, ACT.
- Palmen, L.B. and Weeks, W.D (2009). Regional Flood Frequency for Queensland using the Quantile Regression Technique. Paper provided by Department of Transport and Main Roads.

7. Disclaimer

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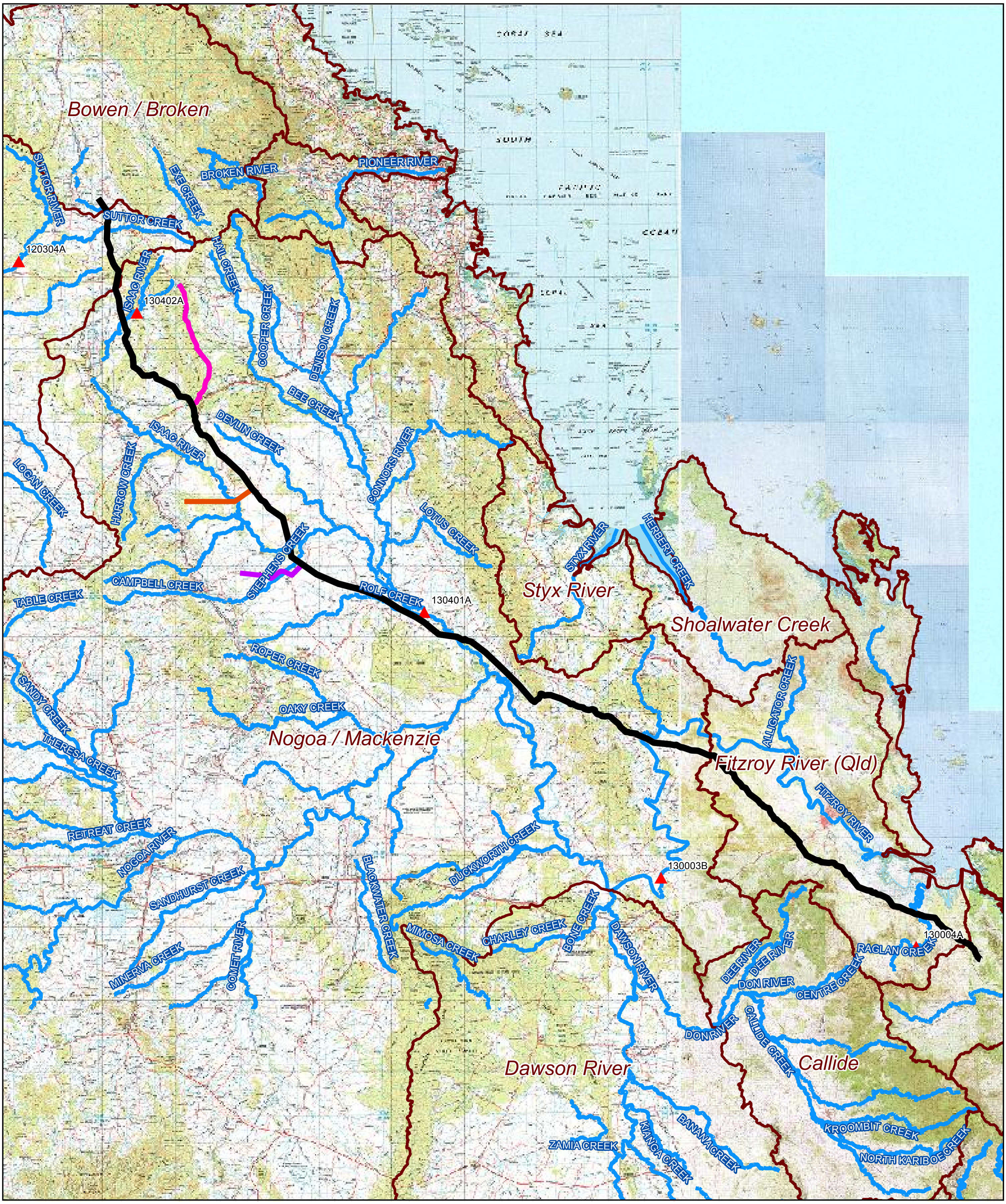
The opinions, conclusions and any recommendations in this Report are based on assumptions made by GHD described in this Report (refer section 5) .GHD disclaims liability arising from any of the assumptions being incorrect.

Appendix A

ABP Preliminary Engineering Flood Study Locality Map



LEGEND

- ▲ Stream gauges (DERM)
- Arrow Bowen Pipeline (Revision D)
- ABP-Lateral-Dysart-RevD
- Major Waterways
- ABP-Lateral-Saraji-RevD
- River basin
- ABP-Lateral-Elphinstone-RevD

Paper Size A3

0 6,500 13,000 26,000 39,000 52,000

Metres

Horizontal Datum: GDA 1994
Grid: GCS GDA 1994

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Arrow Energy
ABP Preliminary Engineering Flood Study

Locality Map
Arrow Bowen Pipeline

Job Number	41-24306
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Date	26 Sep 2011

Figure 1

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Data source: DERM, Stream Gauges, River Basin; ARROW, Major waterways, Bowen Gladstone pipeline, Topographic maps. 2011. Created by:Akamal

Appendix B

ABP Preliminary Engineering Flood Study Results

ABP Distance (Rev D)	Waterway	Location Description	Catchment Area (km^2)	100 yr ARI flow (m^3/s)	Flow Estimation Method	100 yr ARI Flood Level (m AHD)	Flood Level Estimation Method	Pipe Inundation length (m)
12.17	Suttor Creek	Pipeline crosses waterway	450	1,236	DTMR method	320.89	HEC-RAS model	1,148
50.33	Isaac River	Pipeline crosses waterway	615	1,746	Scaled from upstream stream gauging station "Burton Gorge"	286.58	HEC-RAS model	1,280
168.13	Stephens Creek and Isaac River	Pipeline crosses waterway	7,064.7	17,932	Scaled from downstream stream gauging station "Yatton"	152.27	HEC-RAS model	13,996
212.65	Rolf Creek	Pipeline crosses waterway	1,320	3,132	DTMR method	117.54	HEC-RAS model	2,426
238.75	Isaac River	Pipeline crosses waterway	21,265	36,461	Scaled from stream gauging station "Yatton"	110.84	HEC-RAS model	26,590
255.92	Isaac River	Pipeline runs parallel to waterway	74,825	81,979	Scaled from upstream stream gauging station "Yatton"	-	HEC-RAS model	12,625
273.62	Mackenzie River	Pipeline runs parallel to waterway	74,825	81,979	Scaled from upstream stream gauging station "Yatton"	-	HEC-RAS model	5,119
319.53	Fitzroy River	Pipeline crosses waterway	133,545	30,298	Scaled from upstream stream gauging station "Riverslea"	42.97	HEC-RAS model	6,565

ABP Distance (Rev D)	Waterway	Location Description	Catchment Area (km^2)	100 yr ARI flow (m^3/s)	Flow Estimation Method	100 yr ARI Flood Level (m AHD)	Flood Level Estimation Method	Pipe Inundation length (m)
447.63	Raglan Creek	Pipeline crosses waterway	681	5,906	Scaled from upstream stream gauging station "old Station"	14.57	HEC-RAS model	6,425
	Isaac River	Pipeline lateral Saraji Rev D crosses waterway	5,611.7	15,460	Scaled from downstream stream gauging station "Yatton"	173.60	HEC-RAS model	7,431
	Stephens Creek	Pipeline lateral Dysart Rev D crosses waterway	1,453	3,332	DTMR method	-	Conservative Estimate only, based on topography	11,072

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