Hydrology Report

Flood Risk Management Study – Lower Barwon River and Lower Moorabool River

Corangamite CMA, City of Greater Geelong and Golden Plains Shire Council

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1 INTRODUCTION

Corangamite CMA in partnership with the City of Greater Geelong and Golden Plains Shire Council engaged Water Technology to undertake the Lower Barwon and Lower Moorabool Rivers Flood Risk Management Study. The overall objective of this project is to review and revise existing flooding information and produce detailed flood mapping for a range of flood modelling scenarios within the study area. The project will undertake a definitive flood investigation for the floodplain reaches within the study area, including collation of available relevant data, a comprehensive hydrological assessment, determination of robust flood levels, velocities, depths and extents for a range of design flood events. The project will develop an improved understanding of flood behaviour to enable improved land use planning and emergency response.

This document is the second of a series of technical reports which will be prepared during the study. This report documents the hydrological analysis.

2 PROJECT AREA

The study area is defined by the lower reaches of the Barwon River and the Moorabool River to the mouth of the Barwon River including Waurn Ponds creek and a number of small tributaries (Figure 2-1). The study area extends as far upstream as the Batesford streamflow gauge on the Moorabool River and the Pollocksford streamflow gauge on the Barwon River.

The Barwon River and Moorabool River are large river systems with a combined catchment area of 5,130 km^2. The Barwon River catchment is the larger of the two systems with a catchment area of approximately 2,800 km^2 upstream of the Moorabool confluence whilst the Moorabool River has a catchment area of approximately 1,150 km^2. Of note is the Woady Yaloak River diversion into the Barwon River. This waterway normally drains into Lake Corangamite, but during floods is diverted into Warrambine Creek and into the Barwon River upstream of Inverleigh. The Woady Yaloak River catchment area is approximately 1,360 km^2. A number of tributaries such as Waurn Ponds Creek and Armstrong Creek flow into the Barwon River within the study area along with several other smaller creeks.

The various catchment area sizes of the major rivers and various tributaries often result in the catchment responding to storm events at different time scales. The smaller urban catchments respond quickly to intense storm events, with the larger rural catchments responding later with the peak of the flood occurring sometime after the smaller catchments.

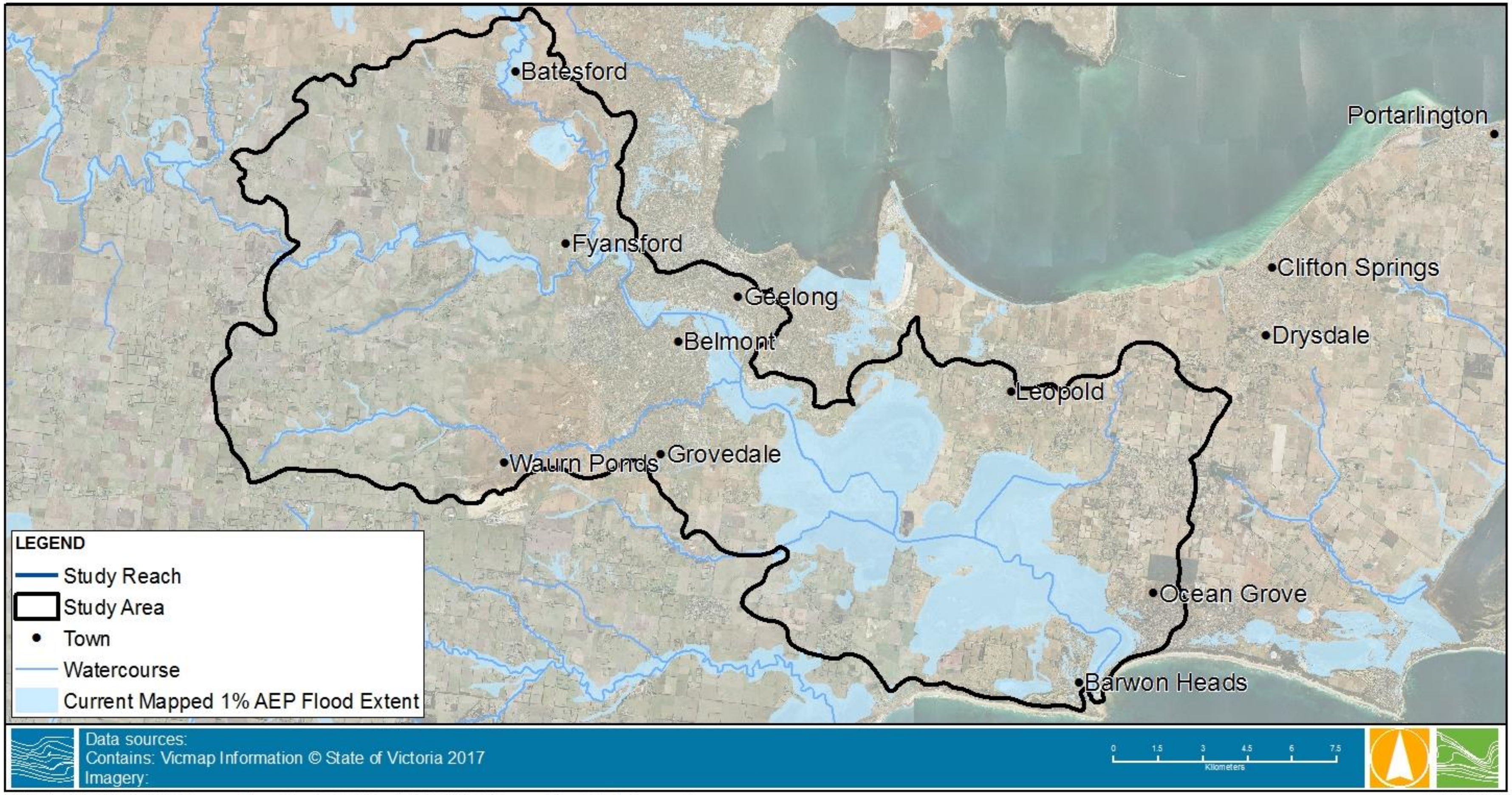

FIGURE 2-1 STUDY AREA

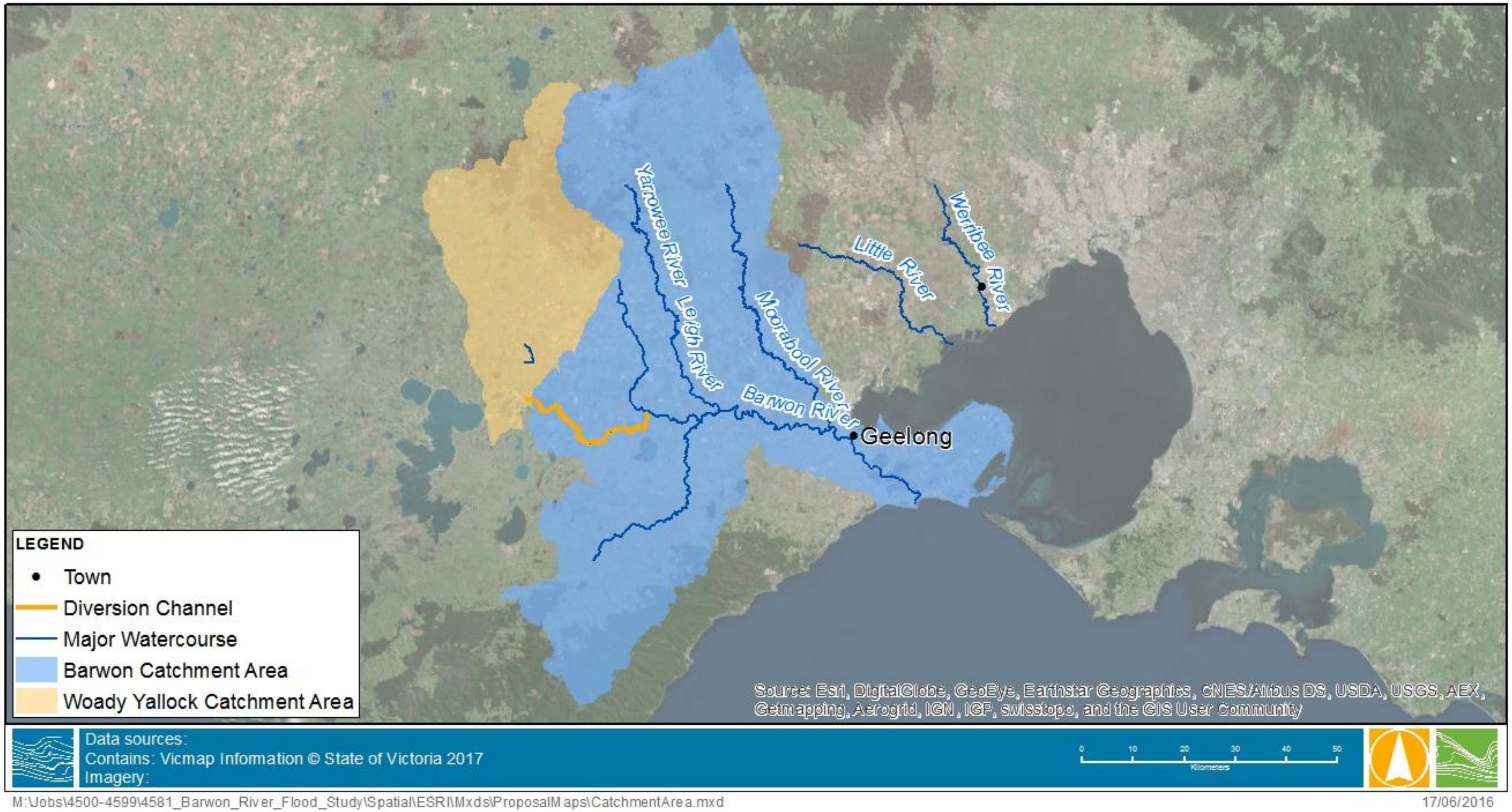

FIGURE 2-2 CATCHMENT MAP

3 REPORTING

This document is the second of a series of technical reports which will be prepared during the study. The reporting stages are outlined below:

- Site Visit, Inception and Data Collation Report (Completed)
- Hydrology Report (This document)
- Hydraulics Modelling and Calibration Reporting
- Flood Warning and Intelligence Assessment
- Planning Scheme Amendment Documentation
- Mitigation Assessment Report
- Municipal Flood Emergency Plan
- Final Flood Investigation Report

This report documents the hydrological analysis. The purpose of this document is to present the methodology, analysis and results of the catchment hydrology for the study area. This information will be used as the key input to the hydraulic model and subsequent flood mapping. This report will be submitted for review by the DELWP review panel. On completion of the review and approval process the hydraulic design modelling will be completed and the remaining flood intelligence and mitigation stages will follow.

4 HYDROLOGY

4.1 Overview

The primary aim of the hydrological analysis undertaken for this project included:

- Determining design event peak flows and hydrographs for input to the hydraulic model at the model boundaries primarily the Barwon River from Pollocksford, the Moorabool River at Batesford, Waurn Ponds Creek and a number of small local tributaries.
- Design Events included the 50%, 20%,10%, 5%, 2%, 1%, 0.5%, 0.2% AEP flood events, probable Maximum flood (PMF) and climate change scenarios.
- Determine historic flows and streamflow data available for calibration of the hydraulic model.

To achieve these aims, the hydrological assessment was separated into three components (Figure 4-1):

- Flood Frequency Analysis (FFA) – Which included analysis of the Barwon River at both the Pollocksford and Geelong gauges and the Moorabool River at Batesford.
- Waurn Ponds Creek RORB model.
- Rain on grid modelling of the small local tributaries.

The rainfall on grid modelling of the local tributaries allows mapping of the smaller tributaries right to the top of their catchment. This was a requirement of the scope and adds significant benefit to the outcomes of the project.

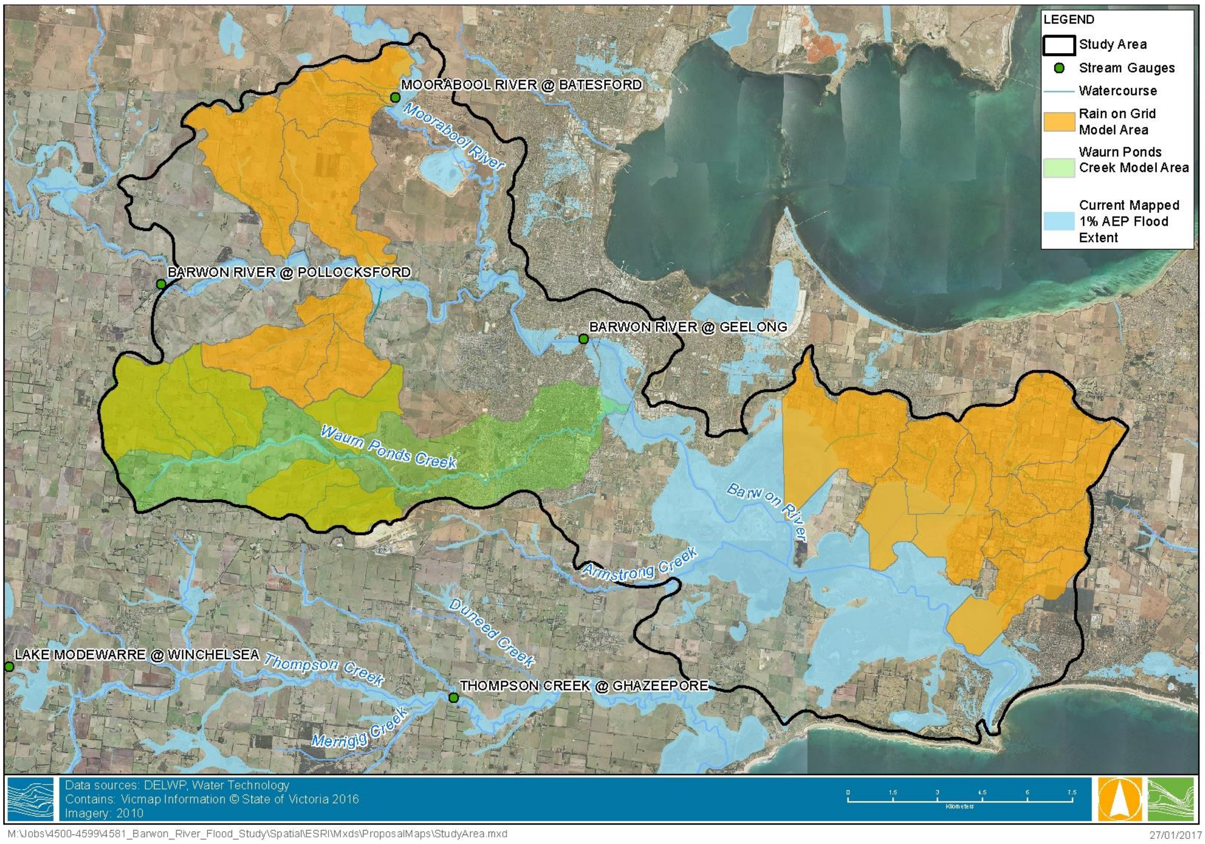

FIGURE 4-1 MODEL AREAS

4.2 Availability and Quality of Gauge Data

The availability of the streamflow data at the three key gauge locations within the study area is summarised below in Table 4-1, with each gauge described in more detail below in this section.

TABLE 4-1 STREAMFLOW GAUGE DATA SUMMARY

Gauge Station Number	Gauge Name	Catchment Area (km^2)	Status	Record
233200	Barwon River @ Pollocksford	2,713	Active	1908 – Present
232202	Moorabool River @ Batesford	1,088	Active	1908 - Present
233217	Barwon River @ Geelong	3,925	Active	1956 – Present

4.2.1 Barwon River at Pollocksford

The Barwon River gauge at Pollocksford (site No. 233200) is located within a relatively narrow confined section of the Barwon River. At this location the size of the upstream catchment is estimated to be approximately 2,713 km². Gauging at this location commenced in 1906, with the gauge itself having moved several times since records began. Table A-2 summarises the various locations of the gauge over the period of record. Table A-3 identifies the variation in the gauge zero datum at the various sites.

While the gauge record at this location extends from 1906 to current day, there is a significant period of 'no record' from 1922 to 1969. This is observed in the continuous height and flow data as displayed on the DELWP Water Information Monitoring System[2] and is clearly shown in Figure 4-4.

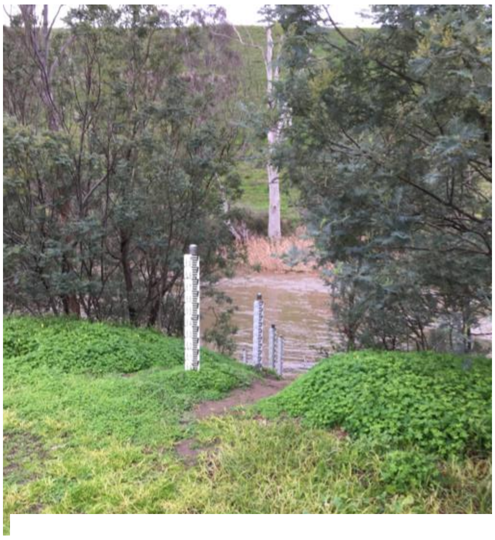

FIGURE 4-2 GAUGE LOCATION

TABLE 4-2 BARWON RIVER AT POLLOCKSFORD GAUGE DESCRIPTION

Record Period	Location	Control Structure	Recorder
1906 - 1922	Site A	Gravel and Clay	Manual Daily Readings
1922 - 1969	No Record	No Record	No Record
1969 - 1972	Site B	Rock and Boulders	Recorder
1972 - Current	Site B	Concrete Hump	Recorder

TABLE 4-3 BARWON RIVER AT POLLOCKSFORD GAUGE ELEVATION AT ZERO HEIGHT

Record Period	Gauge Height at Zero
May 1969 to July 1986	24.074 Meters AHD
July 1986 to October 1986	24.156 Meters AHD
October 1986 to Current	24.074 Meters AHD

The current rating table at this location was last updated in October 2012 (Figure 4-3). A significant portion of the rating table is extrapolated. The reliability of the rating table based on the stage height is shown in Table 4-4. The maximum gauged event for construction of the rating curve was measured at 8.998 m which occurred on 7/11/1995. Larger stage heights have been recorded over the gauges history, with the 1909 and 1995 events recording levels 9.601 and 9.054 m respectively. Figure 4-5 shows all historic gauging measurements completed. The scatter in the gauging points for lower flows most likely represents the difference in the river heights gauged at the Site A and B locations over the gauges history.

Given that there was a gauging measurement completed during a high flow event in 1995, with a stage height of 8.998 m, the rating curve is likely more accurate than the description provided in Figure 4-4. The rating curve quality codes state that the rating curve is extrapolated beyond a stage height of 5.50 m. It is likely that this extrapolation is reasonably accurate given the high flow gauging that has been used to extrapolate the curve through.

TABLE 4-4 POLLOCKSFORD GAUGE RATING TABLE RELIABILITY

Gauge Stage Range (m)	Reliability Description
0.2 – 3.21	Reliable
3.21 – 3.59	Rating Extrapolated within x1.5 max flow
3.59 – 5.50	Rating based on measurements > 20 years old
5.50 – 9.1	Rating table extrapolated

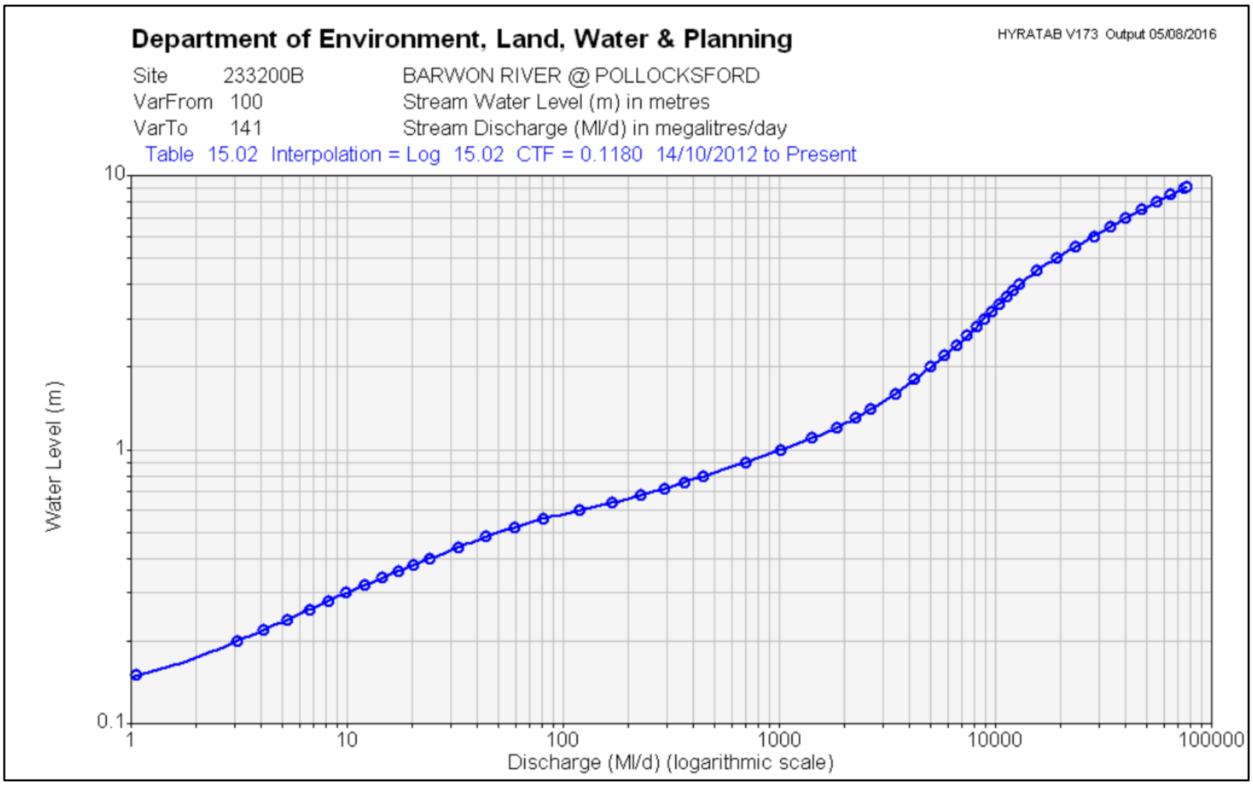

FIGURE 4-3 BARWON RIVER @ POLLOCKSFORD GAUGE RATING CURVE

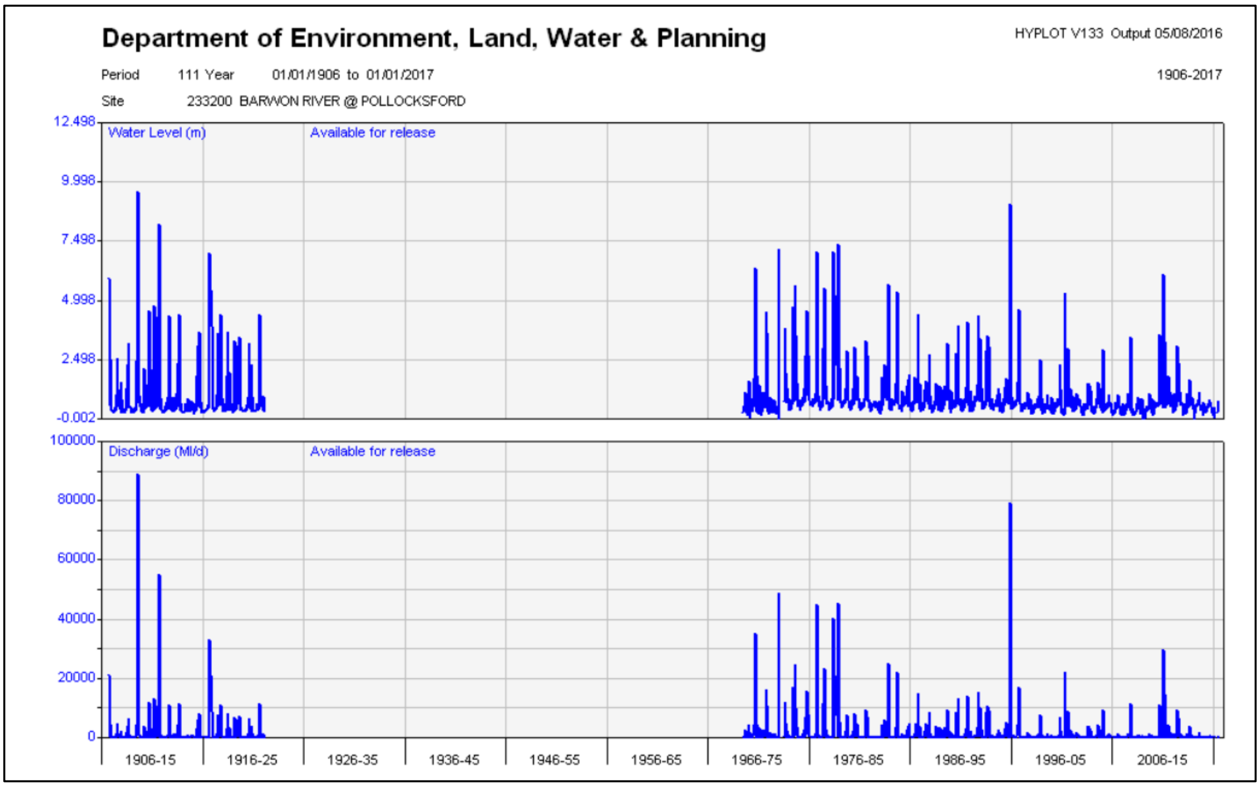

FIGURE 4-4 BARWON RIVER @ POLLOCKSFORD GAUGE RECORD

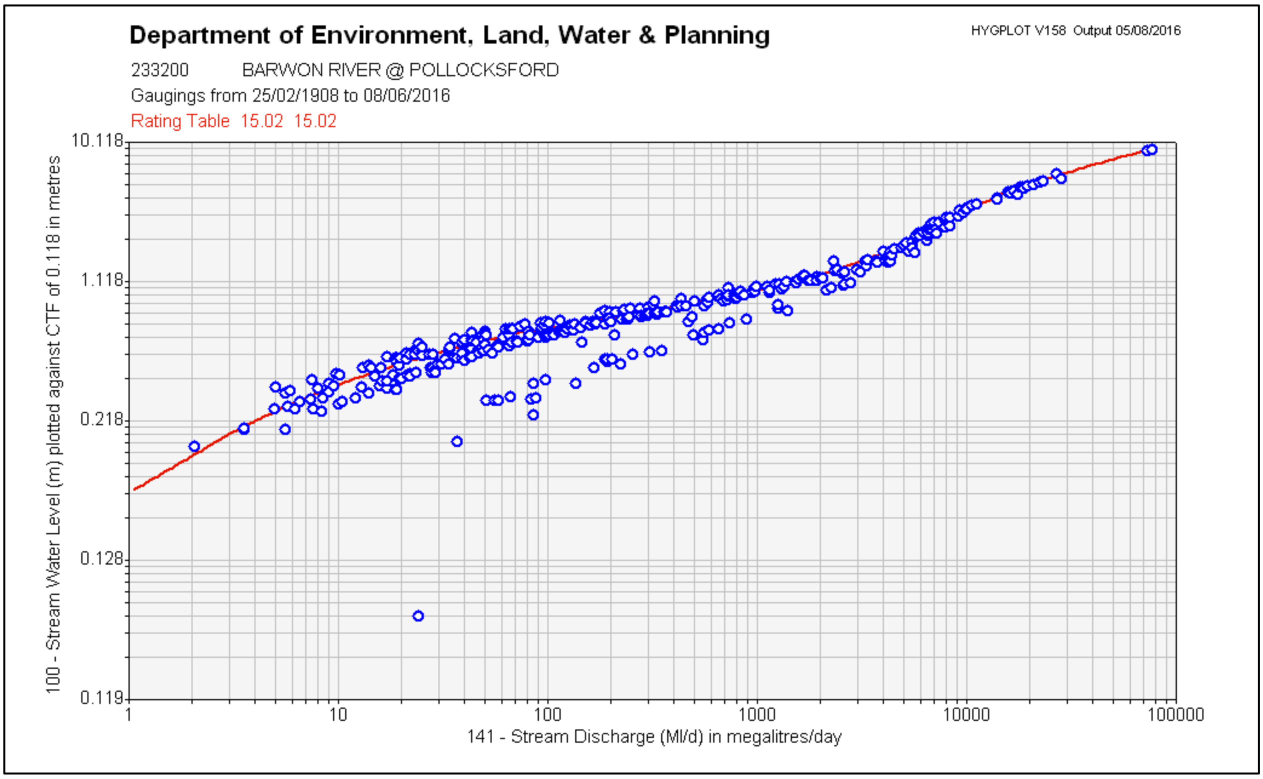

FIGURE 4-5 BARWON RIVER @ POLLOCKSFORD GAUGE ALL HISTORICAL GAUGINGS

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The quality of the available data varies throughout the record. Early records were taken manually daily, while more recent stream flow and height is recorded automatically and instantaneously. The quality codes of the available data as provided by DEWLP are shown in Table 4-5 and Figure 4-6 below.

TABLE 4-5 QUALITY CODES

Quality Code	Quality Data Description
1	Unedited data
2	Good quality data - minimal editing required. Drift correction
8	Pool reading only - no flow condition.
9	Pool dry, no data collected
10	Data transposed from recorder chart.
15	Minor editing. >+/-10mm drift correction
26	Daily read records (see additional quality info)
50	Medium editing >+/-30mm drift correction, significant single spike removal etc.
76	Reliable non-linear interpolation using other data sources, not a correlation.
100	Irregular data, Use with caution. Beyond QC=50 or unexplained
104	Records manually estimated.
147	Rating based on measurements older than 20 years
149	Rating extrapolated within 1.5x Max Qm
150	Rating extrapolated due to insufficient gauging (see additional quality info)
160	Stage backed-up by downstream influence (see additional quality info)
255	No data exists

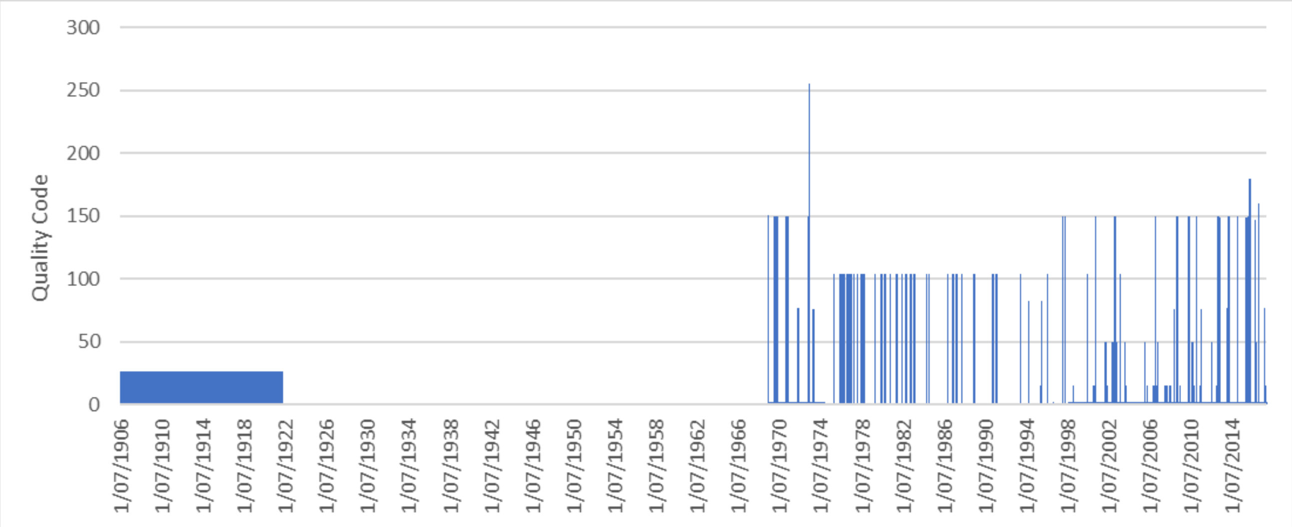

FIGURE 4-6 DATA QUALITY RECORD

4.2.2 Moorabool River at Batesford Gauge

The Moorabool River gauge (site No. 232202) is located at the Midland Hwy in Batesford. The highway bridge is a dual carriageway. The upstream catchment at the gauge location is approximately 1,088 km².

The location of the gauge at Batesford has moved several times over the period of record and this is summarised in Table 4-6. Site A is the original location immediately downstream of the Midland Highway bridge, with the gauge moving to Site B, 2.5 km downstream (referred to as "Lynnburn"), and then moving back to Site A.

TABLE 4-6 MOORABOOL RIVER @ BATESFORD GAUGE DESCRIPTION

Record Period	Location	Control	Recorder
1908 - 1921	Site A	Gravel	Manual Daily Readings
1922-1944	No Record	No Record	No Record
1945-1953	Site A	Gravel	Manual Daily Readings
1953-1957	Site B	Concrete Weir	Manual Daily Readings
1959 – 1967	Site A	Concrete Weir	Recorder
1967- Current	Site A	Concrete Weir	Recorder

Table A-6 shows the gauge zero for Site A, applicable since 1959.

TABLE 4-7 MOORABOOL RIVER @ BATESFORD GAUGE ELEVATION AT ZERO HEIGHT

Record Period	Gauge Height at Zero
1959 to Current	17.11 Meters AHD

The gauge record extends from 1908 to present, however a large amount of data from 1921 to 1945 and 1953 to 1959 is absent from the record. This is observed in the continuous height and flow data as displayed on the DELWP Water Information Management System and is shown in Figure A-5 .

The current gauge rating curve is shown in Figure 4-8. The upper portion of the rating table is extrapolated. The reliability of the rating table based on the stage height is shown in . The maximum gauging was measured at 4.247 m on 20/11/1978. Since 1959 7 events larger than the maximum gauged flow have been recorded, with the 1995 event the largest at 5.440 m. A stage height of 6.096 m was recorded in 1952 at Site A, however this was prior to the concrete weir being installed at the gauging location, so there is some uncertainty regarding how this height corresponds to the current day heights.

All historical gaugings can be observed along with the current rating curve in Figure 4-9. The gaugings showing some scatter at the lower end, however this does not impact on the flood flow record.

The rating curve does not appear to extend out to cover some of the largest events recorded, with the rating curve stopping at 4.80 m. It is likely that the extrapolated rating curve is of reasonable quality as it has the gauged event at 4.247 m to extrapolate through. The reliability of the flow estimates for the 1995 and 1952 events are uncertain as they exceed the rating curve and were most likely based on estimates using an unofficial extrapolation of the existing rating curve at the time or from hand calculations.

TABLE 4-8 BATESFORD GAUGE RATING TABLE RELIABILITY

Gauge Stage Range	Reliability Description
0.40 – 1.60	Reliable
1.61 – 2.39	Rating extrapolated within 1.5 x max flow
2.40 – 4.80	Rating table based on measurement greater than 20 years old

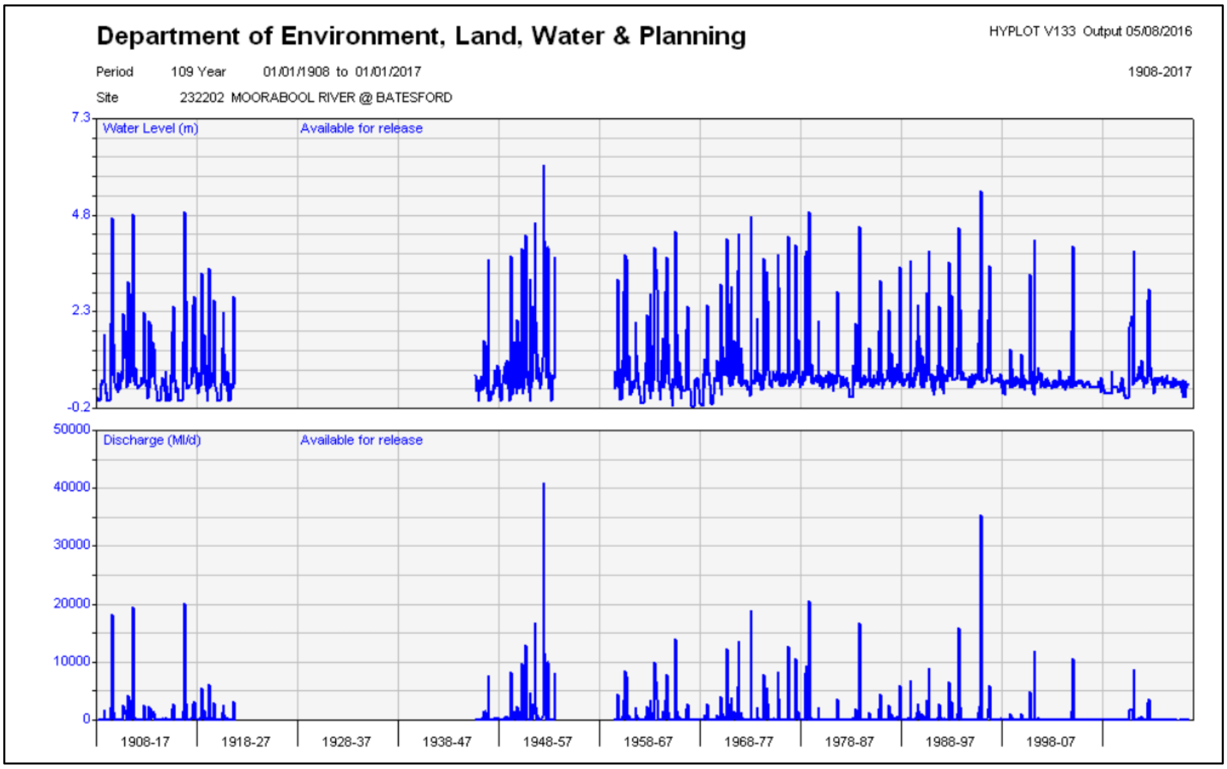

FIGURE 4-7 MOORABOOL RIVER @ BATESFORD GAUGE RECORD

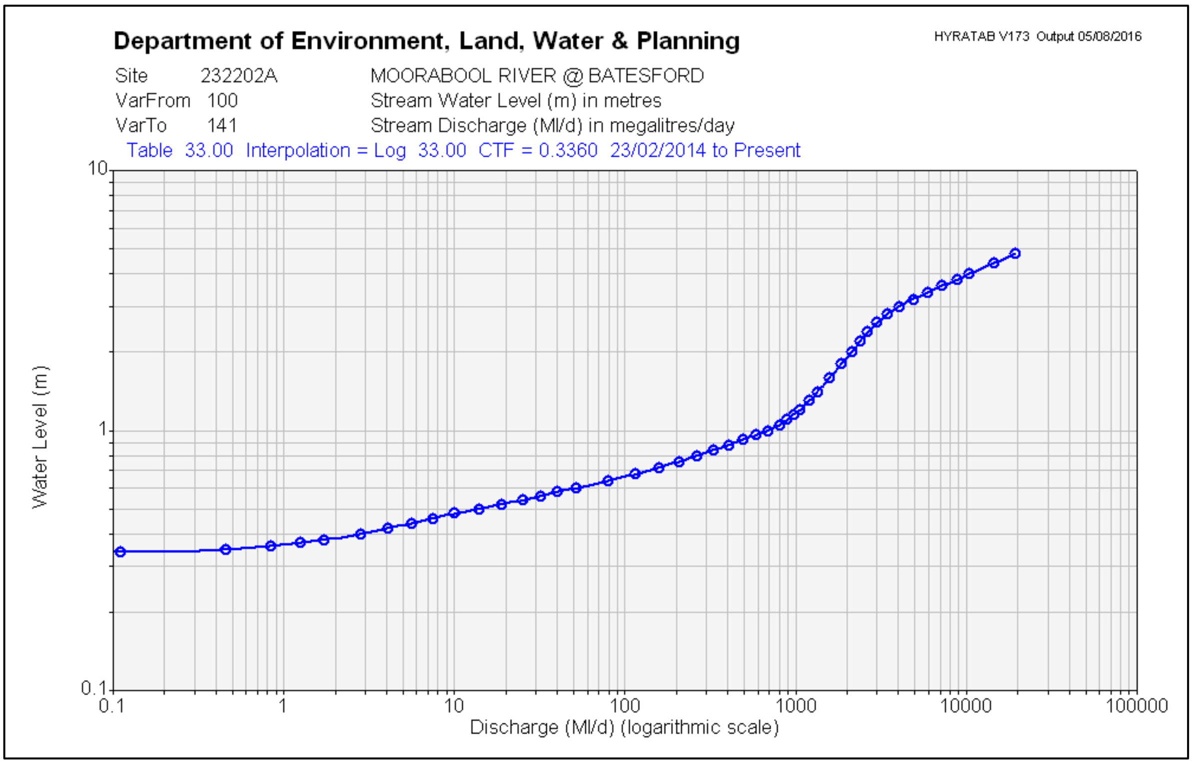

FIGURE 4-8 MOORABOOL RIVER @ BATESFORD GAUGE RATING CURVE

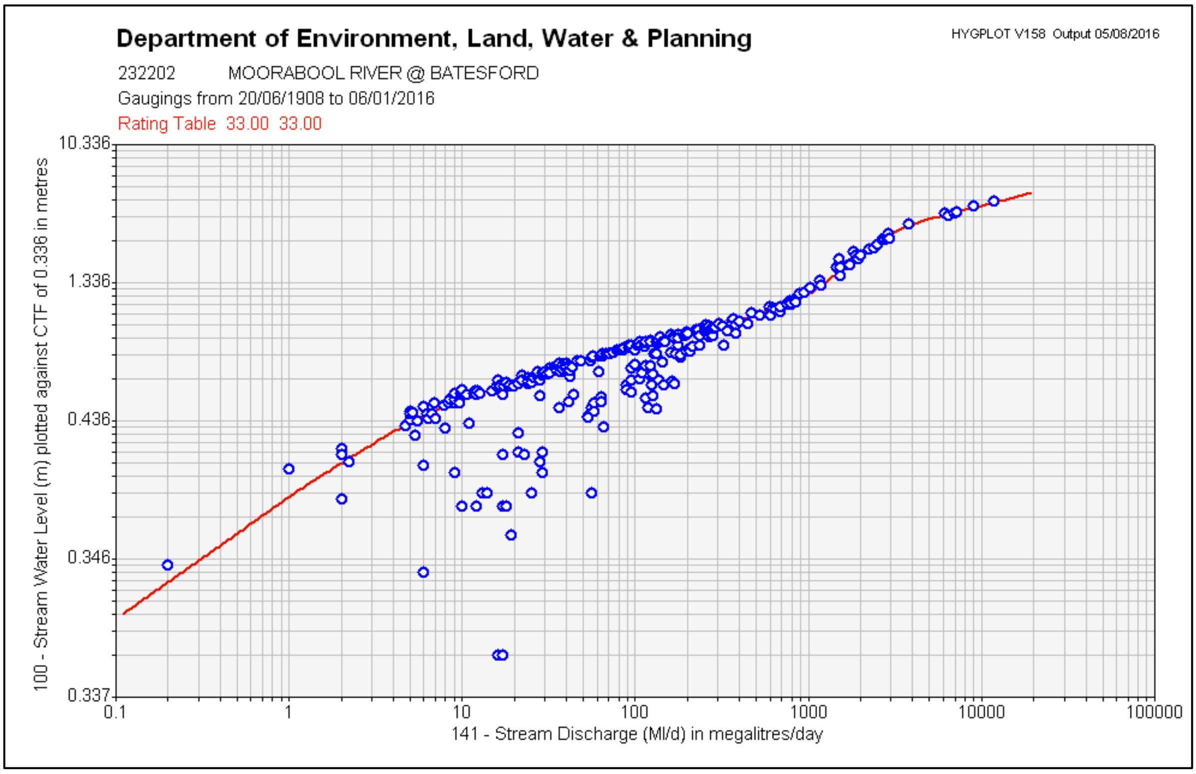

FIGURE 4-9 MOORABOOL RIVER @ BATESFORD GAUGE ALL HISTORICAL GAUGINGS

The quality of the available data varies throughout the record. Early records were taken manually daily, while more recent stream flow and height is recorded automatically and instantaneously. The quality codes of the available data as provided by DEWLP are shown in Table 4-9 and Figure 4-10 below.

TABLE 4-9 QUALITY CODES

Quality Code	Quality Data Description
1	Unedited data
2	Good quality data - minimal editing required. Drift correction
11	Raw data used for operational purposes. (Not validated)
15	Minor editing. >+/-10mm drift correction
26	Daily read records (see additional quality info)
50	Medium editing >+/-30mm drift correction, significant single spike removal etc.
76	Reliable non-linear interpolation using other data sources, not a correlation.
77	Correlation with other station, same variable only.
82	Linear interpolation across gap in records. (<0.5 day)
104	Records manually estimated.
147	Rating based on measurements older than 20 years
149	Rating extrapolated within 1.5x Max Qm
150	Rating extrapolated due to insufficient gaugings (see additional quality info)
151	Data lost due to natural causes / vandalism (see additional quality info)
160	Stage backed-up by downstream influence (see additional quality info)
180	Data not recorded, equipment malfunction.
255	No data exists

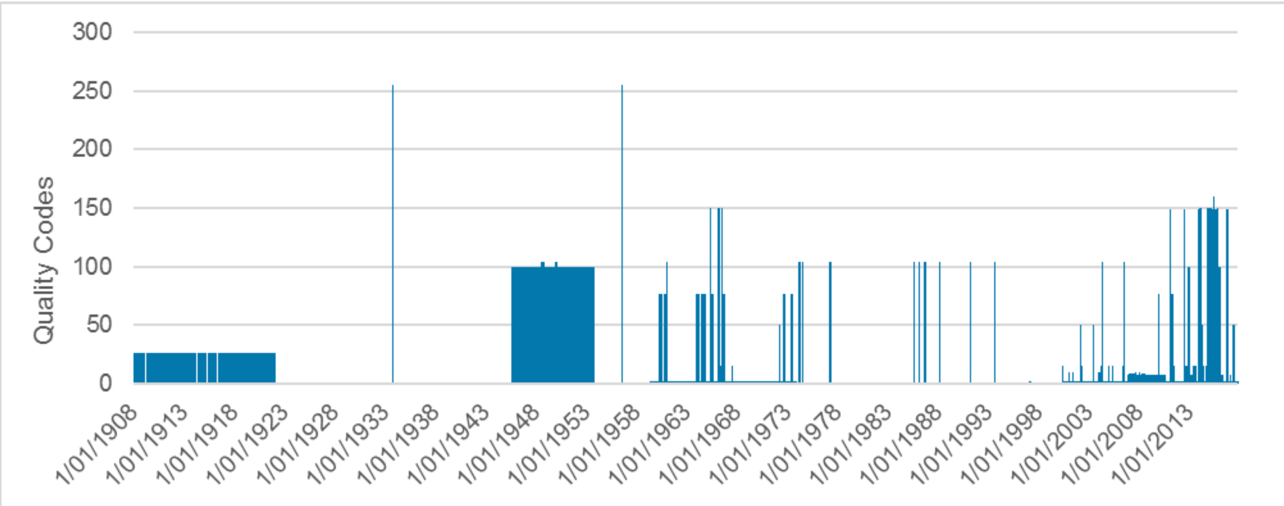

FIGURE 4-10 QUALITY CODE RECORD

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4.2.3 Barwon River at Geelong (McIntyre Bridge)

The Barwon River gauge at Geelong, colloquially referred to as the McIntyre Bridge gauge (Site No. 233217) is located within the main rowing mile of the Barwon River through Geelong. The upstream catchment at this point is estimated to be 3,925 km².

Gauging of the Barwon River through Geelong has occurred at a number of locations throughout this reach of the river. Records indicate at least four different sites have been used to record river height and flow data over the past 55 years. This data is shown in Figure A-8 . The four known sites are described in Table A-8 .

The current site is located at McIntyres Bridge in Newtown, on a section of the river where it becomes less confined, with a small floodplain on the southern bank.

TABLE 4-10 GAUGE PERIOD AND LOCATION

Record Period	Location	Control	Recorder
1960-1985	Site A - At the Princess Highway Bridge	Natural	Manual Readings – Flood Only
1961-1969	Site B - Ford at the Railway Bridge, Tucker Street Breakwater	Concrete Ford	Manual Readings – Daily
1978-1985	Site C - Downstream of Queens park Bridge (400meters)	Natural - Gravel	Recorder
1977-current	Site D - McIntyre Bridge (Current location)	Natural	Recorder

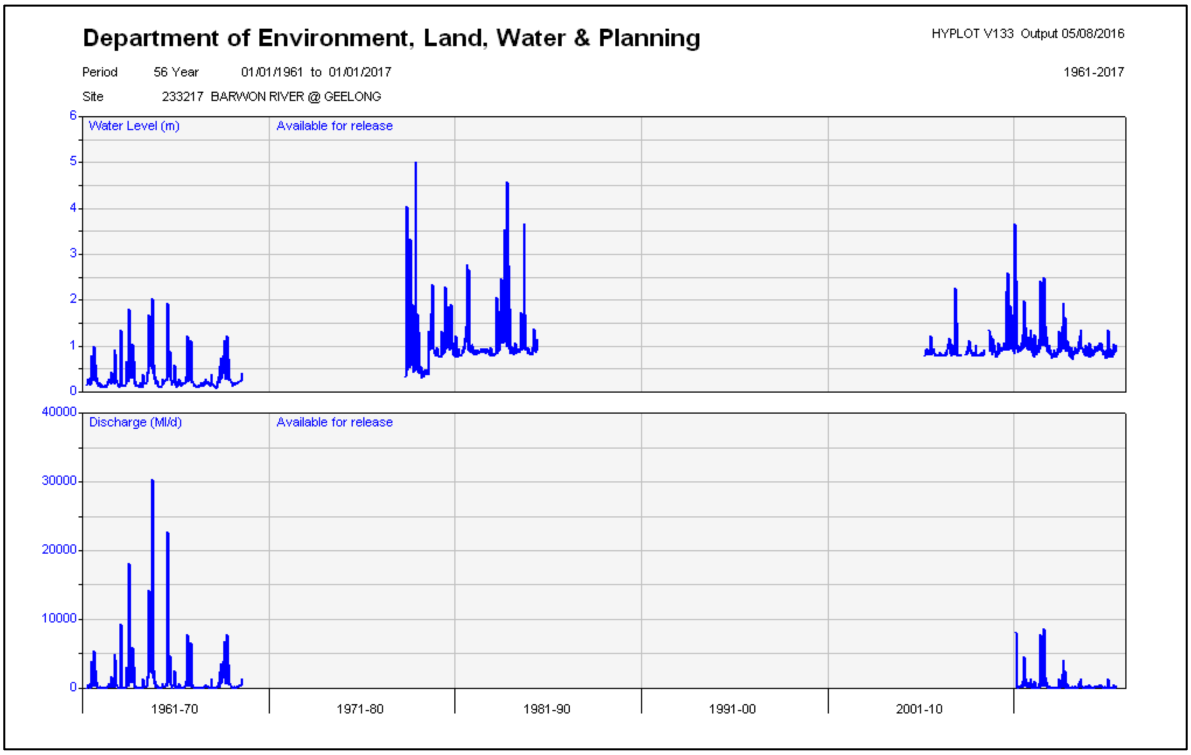

FIGURE 4-11 BARWON RIVER @ GEELONG GAUGE RECORD

The rating table for the Barwon River gauge at Geelong is based on relatively few gauging events spread across multiple site locations. For this reason, it is considered that the rating curve may be somewhat unreliable. The current rating curve is shown in Figure 4-12, with the rating curve and all historic gauging events shown in Figure 4-13. The upper portion of the rating table is extrapolated. The reliability of the rating table based on the stage height is shown in Table 4-11. The maximum gauged measurement at this location was taken at a stage height of 4.054 m which occurred on 7/2/1973.

Given the lack of gauging, the rating curve at this location is uncertain at high flood flows. Having regard for this further investigation of the rating curve in relation to recorded stage height levels will be undertaken as part of the hydraulic modelling component of this study.

TABLE 4-11 BARWON RIVER AT GEELONG GAUGE RATING TABLE RELIABILITY

Gauge Stage Range	Reliability Description
1 – 2.4	Reliable
2.4 – 3.19	Rating Extrapolating within x 1.5 max flow
3.2– 4.8	Rating based on measurements > 20 years old
4.8 – 5.6	Rating table extrapolated

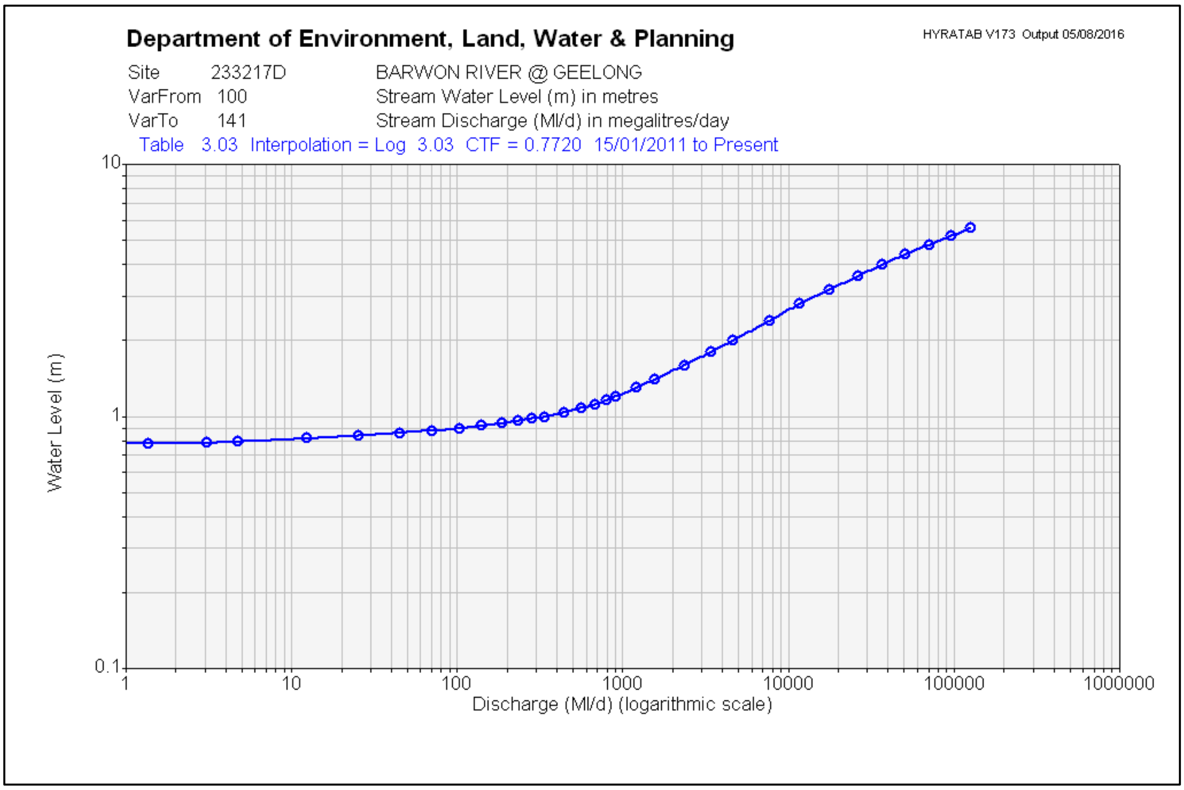

FIGURE 4-12 BARWON RIVER @ GEELONG GAUGE RATING CURVE

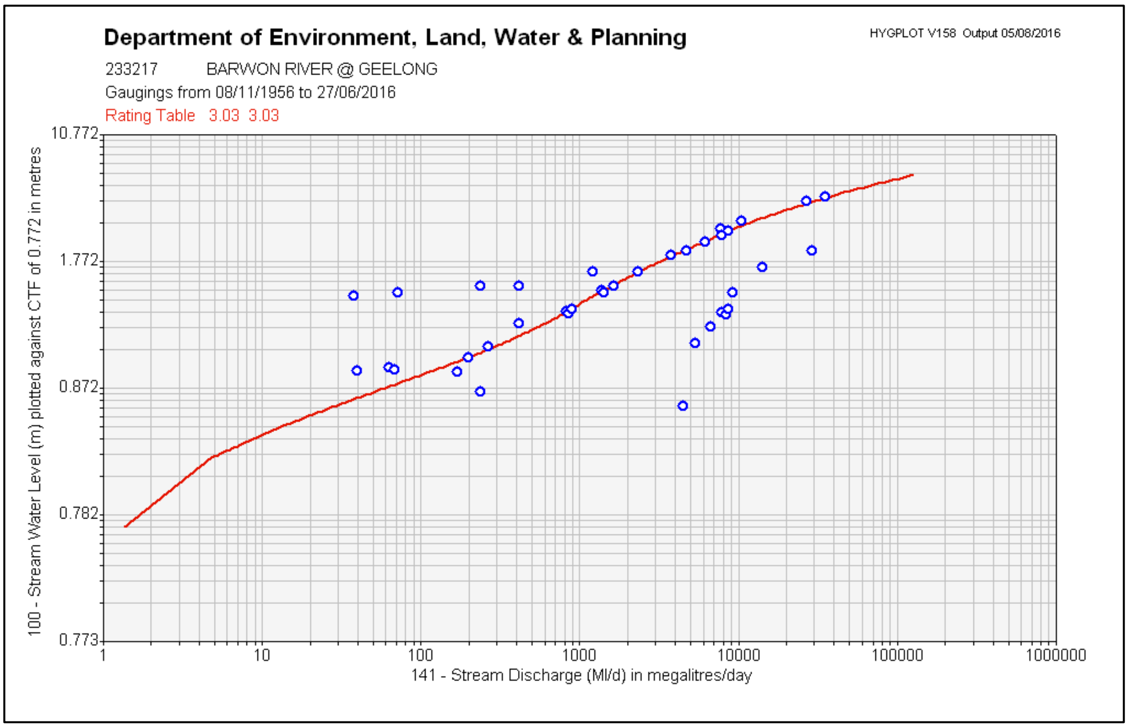

FIGURE 4-13 BARWON RIVER @ GEELONG GAUGE ALL HISTORIC GAUGINGS

4.3 Drainage Schemes

A number of formal drainage schemes exist within the greater Barwon catchment which have altered natural drainage patterns within the catchment. The two major schemes within this region include:

- Lake Corangamite and Woady Yaloak Diversion Scheme
- Lake Colac and Lough Calvert Drainage Scheme

The Woady Yaloak drainage scheme was established in 1959 as a flood mitigation scheme following several years of flooding during 1950-1953. The scheme was aimed at controlling the water levels within Lake Corangamite to ensure a reduced flood risk for surrounding properties. The diversion provides a very minor peak inflow into the Barwon River via Warrambine Creek above Inverleigh. This diversion is intrinsic in the gauge record since 1959. The flow it contributes is very small and has no real impact on the gauge flow at Geelong.

The Lough Calvert drainage scheme initially commenced in 1953 under similar circumstance to the Woady Yaloak Scheme. The Lough Calvert scheme was established as a flood mitigation scheme to protect rural properties around the perimeter of Lake Colac and the Lough Calvert.

4.4 Catchment Storage

The Barwon River catchment provides for the major water supply in the region including Geelong. A number of regulated storages operate within the catchment. The most significant of these being:

- West Barwon Dam (Capacity: 38,056 ML), and
- Wurdee Boluc (Capacity: 21,504 ML)

The West Barwon Dam is located in the upper Barwon River catchment within the Otways (Figure 4-14). The dam is managed by Barwon Water and is used as the main water storage for the Geelong area. Works to construct the West Barwon reservoir were begun in 1959 by the Geelong Waterworks and Sewerage Trust. The reservoir was completed in 1965.

The reservoir has a catchment area of 51 sq.km² and has a capacity of 21,504 ML. When capacity of the dam is reached excess water spills via a concrete spillway chute to the West Barwon River. Water from West Barwon Dam is also diverted to Wurdee Boluc Reservoir via a concrete lined diversion channel. Water is stored at Wurdee Boluc prior to treatment and distribution to the greater Geelong area for portable water usage.

A number of additional storages are also noted within the Leigh River catchment, a major inflow to the Barwon River. These include the White Swan Reservoir, Gong Gong Reservoir and Lake Wendouree.

Similarly, to the Moorabool River catchment farm dams, diversion and groundwater extraction greatly influence flows within the river. This is reflected in the observed condition of the river upstream and downstream of the water supply storages as noted in the Corangamite Index of Stream Condition Report. Natural storage including numerous lakes and wetlands within the Barwon Catchment also play an important role in defining the sensitivity of the catchment runoff following significant rainfall events.

The Barwon catchment is identified as a fully-allocated catchment and as such is subject to an environmental entitlement. This entitlement is managed by the Corangamite CMA as part of the environmental water reserve on behalf of the Victorian Environmental Water Holder.

The Moorabool River catchment is heavily regulated with numerous significant storages located on the west and east branches of the river. The key major water storages within the Moorabool Catchment and their respective capacities are:

- Moorabool Reservoir (Capacity: 6,141 ML)
- Wilson Reservoir (Capacity: 1,067 ML)
- Korweinguboora Reservoir (Capacity: 2,083 ML)
- Bostock Reservoir (Capacity: 7,410 ML)
- Lal Lal Reservoir (Capacity: 59,540 ML)

The location of these storages are shown in Figure 4-15. Of the numerous storages located within this catchment the Lal Lal Reservoir is the largest. Lal Lal Reservoir is located within the upper Moorabool River catchment on the West Branch of the Moorabool River. Lal Lal Reservoir is also known as Bungal Dam and is managed jointly by Barwon Water and Central Highlands Water as an important water supply for Ballarat, Geelong and districts. Flows from the Lal Lal Reservoir are shared by Barwon Water, Central Highlands Water and the Environment under a bulk entitlement. The releases from Lal Lal Reservoir under environmental flows are managed by the Corangamite Catchment Management Authority through a seasonal watering proposal. The reservoir has a catchment area of 230 km² and has a capacity of 59,540 ML. The structure itself was constructed in 1972. Once at capacity, the dam spills via a significant concrete lined chute to the Moorabool River West Branch. Water levels in the reservoir have fluctuated significantly since its construction. In addition to the significant regulated storage within this catchment, harvesting of water from farm dams, licenced offtakes and groundwater usage also influences available flow generated within the river. It has been estimated that the catchment contains more than 4,000 dams with an estimated storage capacity of 14,000ML[1]. It is important to note that the Moorabool River is subject to an environmental entitlement which is managed by the CCMA.

It is important to note that the catchment area upstream of the two major storages is relatively minor in comparison to the total catchment areas of the respective river systems (Table 4-12). The distributed storages throughout both the Moorabool and Barwon catchments do impact on runoff in the rivers, with the smaller more frequent floods impacted more than larger floods.

TABLE 4-12 STORAGE CATCHMENT DETAILS

River Catchment	Total Catchment Area to Gauge (km^2)	Storage Name	Storage Capacity (ML)	Catchment Area Upstream of Storage (km^2)
Moorabool River	1,088 @ Batesford	Lal Lal	50,540	260
Barwon River	2,713 @ Pollocksford	West Barwon Wurdee Boluc	38,056 21,504	51

[1] Jacobs (2015), Moorabool River Flows Study Update.

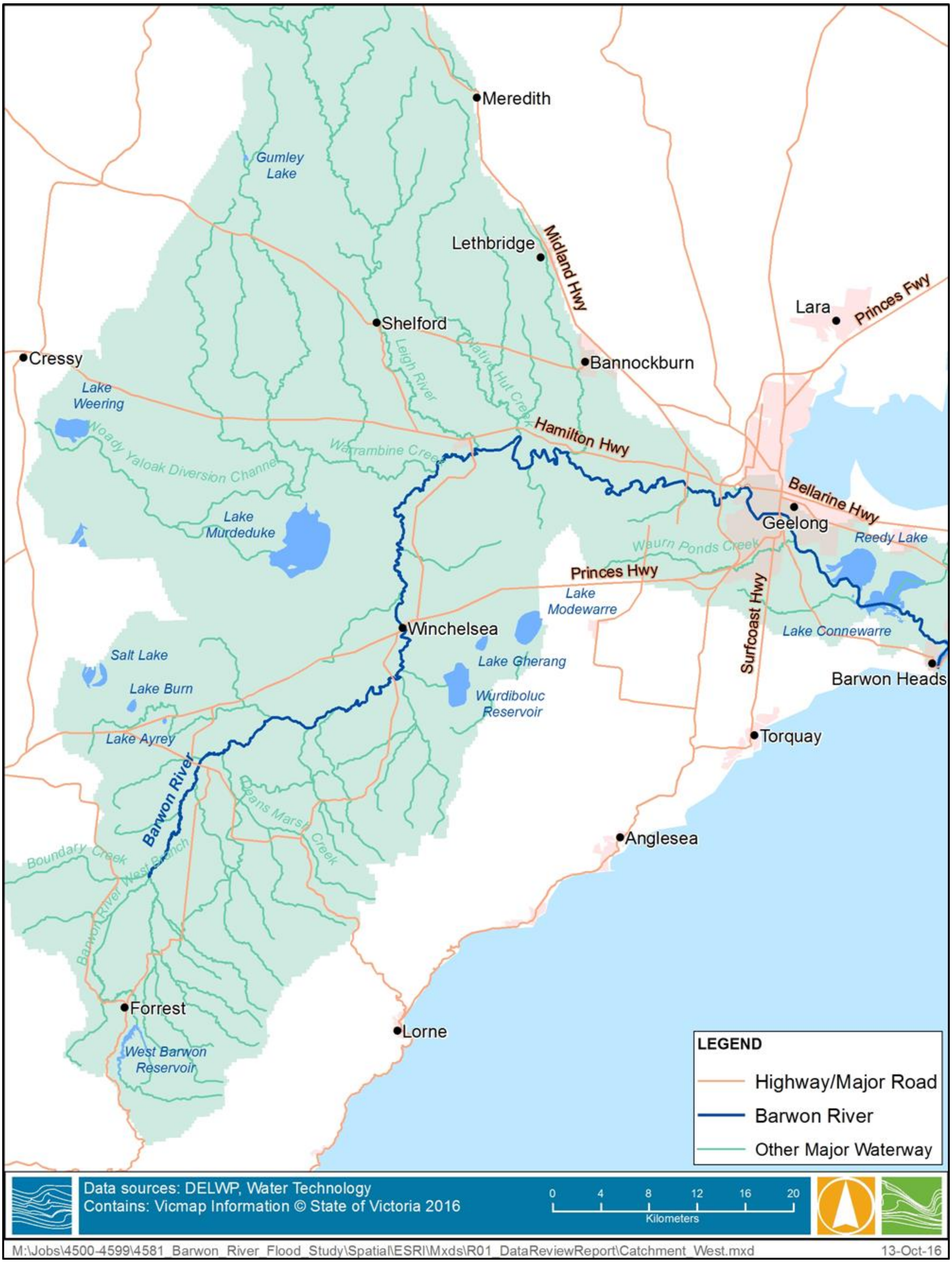

FIGURE 4-14 BARWON CATCHMNENT STORAGES

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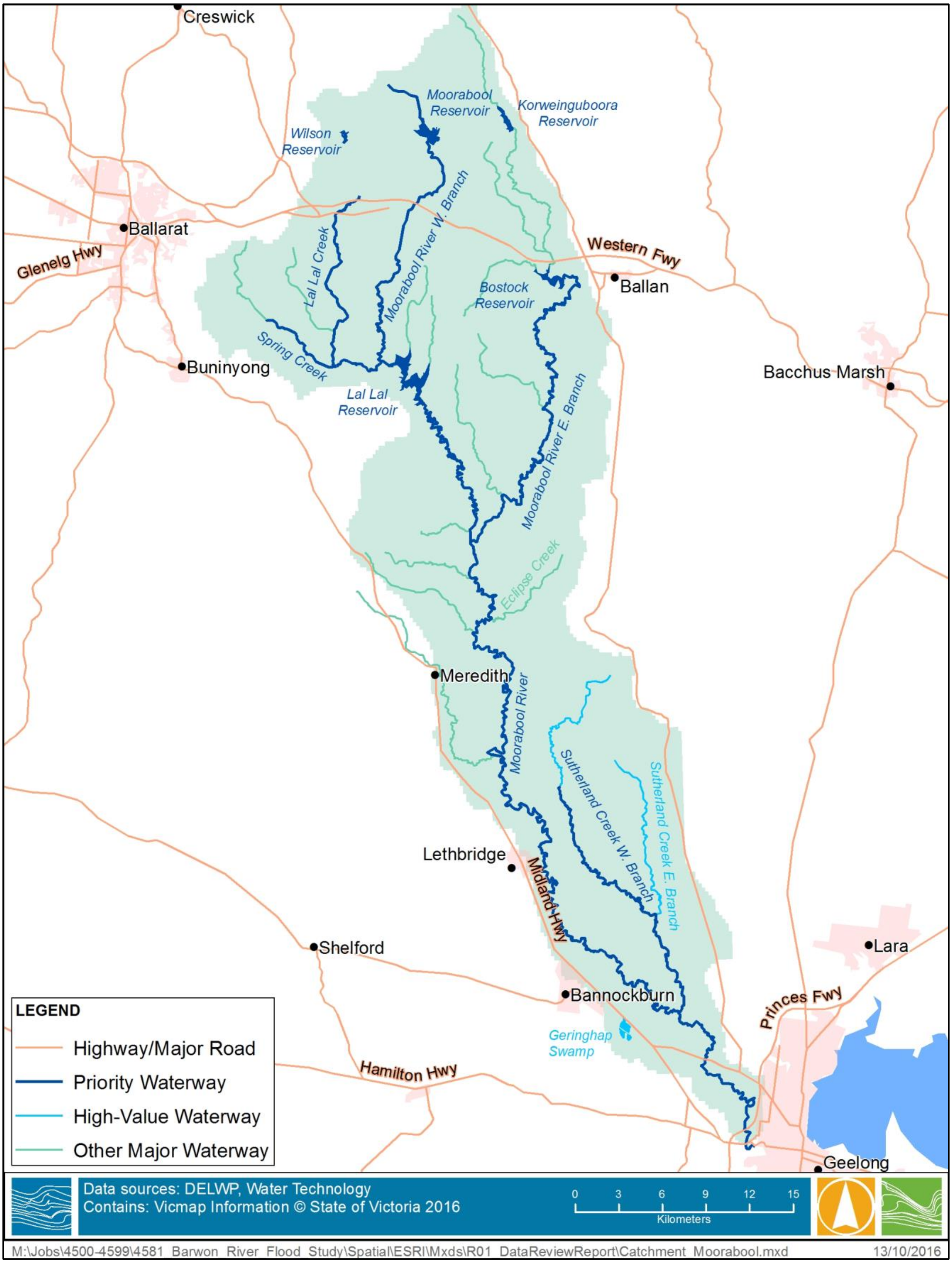
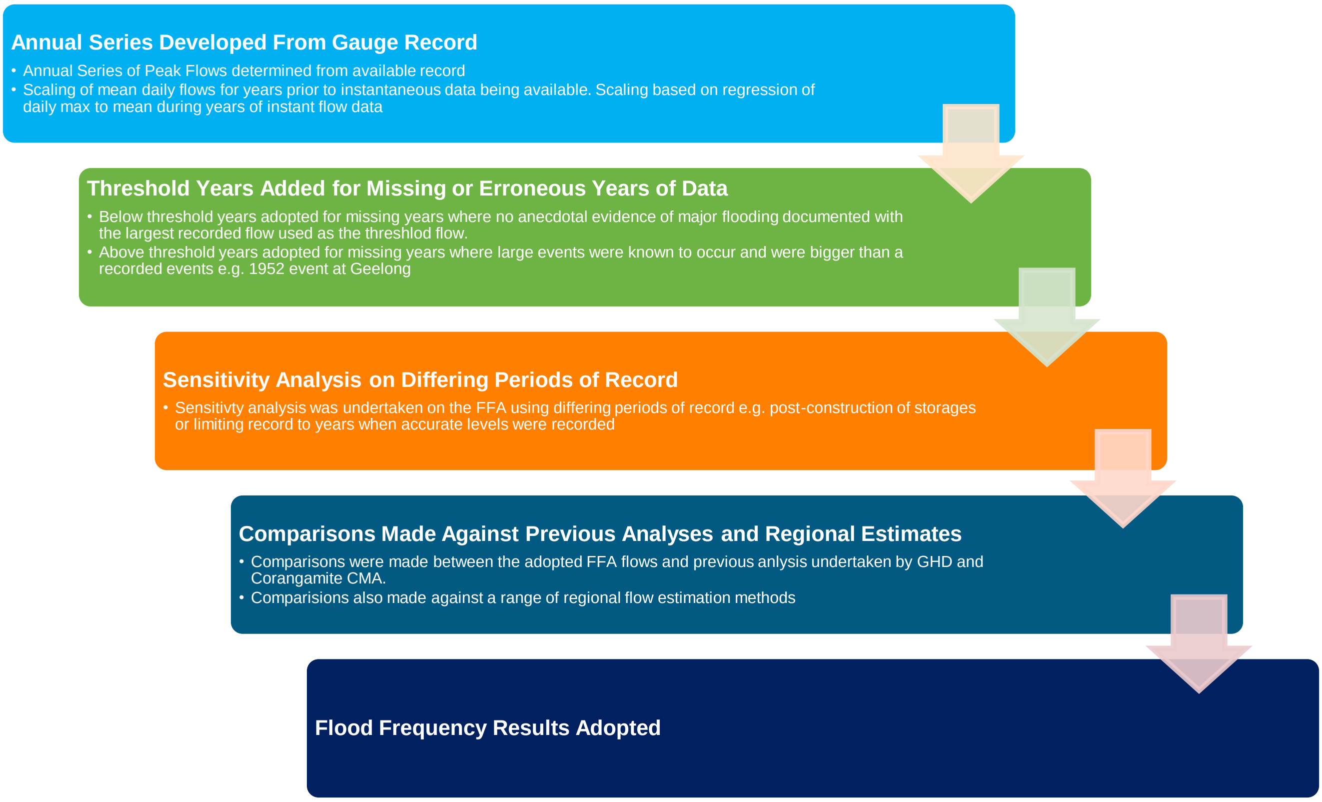


FIGURE 4-15 MOORABOOL CATCHMENT STORAGES

4.5 Flood Frequency Analysis

4.5.1 Overview

A consistent approach to flood frequency analysis was taken across the analyses undertaken on the three gauge records at Barwon River at Pollocksford, Barwon River at Geelong (McIntyre Bridge) and the Moorabool River at Batesford. The approach is consistent with methods described in Australian Rainfall and Runoff 2016. The approach is summarised in the graphic below:



A summary of the results of the analyses are provided below with additional technical detail provided in Appendix B to Appendix D. Where the approach varied from the general steps described above this is detailed.

4.6 Barwon River at Pollocksford Flood Frequency Analysis

4.6.1 Approach and Assumptions

Flood frequency analysis was undertaken on available streamflow data from the Barwon River at Pollocksford gauge (233200). Whilst the Pollocksford gauge has a long period of flow record, dating back to 1906, a significant period of missing data exists between 1923 to 1968. The gauge has moved four times, but it has remained within the same short reach of river upstream of the Pollocksford Road bridge.

Continuous good quality gauge data is available for 47 years (1969 to current). The gauge record at this location provides a good upstream flow record of noted large floods experienced on the Barwon River through Geelong. Notably absent from the period of record is a recorded flow or stage height from the largest event in living memory, 1952. The catchment of the Barwon River upstream of Pollocksford is noted as having significant catchment storage.

Two significant coupled storages exist in the upper Barwon Catchment, those being the West Barwon Dam with a capacity of 38,056 ML and Wurdee Boluc with a capacity of 21,504 ML. Whilst the dams are significant, the catchments which feed these dams are very small compared with the entire catchment area upstream of Pollocksford.

TABLE 4-13 SUMMARY OF FFA FOR THE BARWON RIVER AT POLLOCKSFORD GAUGE

Gauge: Barwon River at Pollocksford (233200)	
Period of Gauge Record:	64 years from 1906-1922 and 1969-2015
Missing Data:	46 years from 1922-1969
Thresholds Applied:	45 years below 79,029 ML/day was adopted (based on the largest recorded flow at this location in 1995), 1 year above this threshold (representing the large 1952 event which is ungauged)
Other adjustments to record:	None
Sensitivity Analysis	■ Post construction of storages: 1972-2015 ■ Full Record: 1906-2015 (Adopted – impact of upstream storages is minimal given small catchment area of storages compared to total Barwon catchment area)
Adopted Distribution	Log Pearson 3
Previous Analyses	Corangamite CMA (2015), GHD (2016)

4.6.2 Adopted Annual Series

The adopted annual series for the Barwon River at Pollocksford FFA is provided below. The table presents the years and adopted peak flows.

TABLE 4-14 ADOPTED ANNUAL SERIES FOR THE BARWON RIVER AT POLLOCKSFORD

Year	Peak Flow (ML/d)	Year	Peak Flow (ML/d)	Year	Peak Flow (ML/d)
1906	21,200	1974*	24,536	1996*	16,859
1907	5,200	1975*	15,877	1997*	1,715
1908	6,321	1976*	45,026	1998*	7,558
1909	89,084	1977*	23,389	1999*	1,279
1910	11,965	1978*	45,247	2000*	6,985
1911	54,990	1979*	7,586	2001*	21,924
1912	11,070	1980*	8,210	2002*	1,491
1913	11,325	1981*	9,114	2003*	3,957
1914	889	1982*	245	2004*	4,420
1915	7,898	1983*	25,002	2005*	9,227
1916	35,500	1984*	21,940	2006*	1,267

Year	Peak Flow (ML/d)	Year	Peak Flow (ML/d)	Year	Peak Flow (ML/d)
1917	11,202	1985*	4,648	2007*	11,287
1918	7,898	1986*	14,811	2008*	742
1919	7,138	1987*	8,264	2009*	1,429
1920	6,321	1988*	3,761	2010*	11,042
1921	11,325	1989*	9,160	2011*	29,460
1922	1,242	1990*	12,952	2012*	9,190
1969	2,566	1991*	13,970	2013*	3,682
1970	35,351	1992*	15,204	2014*	1,560
1971	16,008	1993*	10,727	2015*	381
1972	1,782	1994*	2,616		
1973*	48,722	1995*	79,030		

The * next to the years denotes those flows used as part of the post construction of dams FFA (presented in Appendix B).

4.6.3 Adopted Flood Frequency Results

The adopted results of the FFA is provided in Table 4-15 below and is based on the annual series for the full period of record. The results show a 1% AEP peak flow of 99,568 ML/d with 5-95% confidence limits of 69,670 ML/d to 167,815 ML/d. These confidence limits are considered reasonable based on experience with other FFA analyses.

TABLE 4-15 ADOPTED PEAK FLOWS – BARWON RIVER AT POLLOCKSFORD

Design Event (AEP)	Full Record Log Pearson III with Low Flow Censoring		
	Peak Flow (ML/d)	Lower Confidence Limit (ML/d)	Upper Confidence Limit (ML/d)
50%	9,182	7,010	12,053
20%	24,063	18,777	31,009
10%	38,004	29,665	48,963
5%	54,149	41,542	73,354
2%	78,702	57,828	119,120
1%	99,568	69,670	167,815
0.5%	122,294	80,366	231,120
0.2%	155,267	92,686	344,555
PMF	1,453,594		

Water Technology determined that the censored LP3 distribution of the full available record was the preferred option based on the following:

- The full record provided a much longer period of record for assessment which reduces the uncertainty and confidence limits of the analysis.

- The full records enable the inclusion of a number of significant historical floods including 1909, 1911, 1973, 1978, 1976, 1995, with the addition of the missing 1952 event as a peak above threshold.
- The Log Pearson 3 distribution with censoring provides the best fit across all AEPs with confidence limits within a reasonable range.
- The flows produced by this assessment are similar to previous FFA assessments undertaken by Corangamite CMA (2015) and GHD (2016) for the more frequent event and are 9-12% higher for the 1% AEP event.

The FFA at this location also included a 4-day volume analysis in order to derive design hydrographs for each of the proposed flood events to be modelled. This assessment produced proposed hydrograph shapes for the adopted peak flows based on representation of the flow-volume relationship of previous flood events on the Barwon River at Pollocksford. The adopted design hydrographs are shown in Figure B-28, Appendix B.

4.6.4 Comparison to Previous Studies

Both Corangamite CMA (2015) and GHD (2016) has previously undertaken Flood Frequency Analysis for this gauge based on a reduced record and shortened series (1972-2014). A comparison of these results with the current adopted design flows at this location is shown in . It is noted that the difference in the generated flows is low. The greatest difference of 15-19% is for the 1% AEP (100 year ARI), which is likely a result of a number of factors including the longer annual series record including a number of additional high flow events, the low flow censoring and the inclusion of the flow threshold results.

TABLE 4-16 FFA COMPARISON – BARWON RIVER AT POLLOCKSFORD

AEP	CCMA (2015) ML/d	GHD (2016) ML/d	Water Technology ML/d	Difference to CCMA % (+/-)	Difference to GHD % (+/-)
20%	23,200	23,700	24,063	+ 4	+ 2
10%	35,800	36,800	38,004	+ 11	+ 3
5%	50,800	51,300	54,159	+ 7	+ 6
2%	73,100	72,100	78,702	+ 8	+ 9
1%	91,400	88,900	99,568	+ 9	+ 12

4.6.5 Comparison to Regional Estimates

The Barwon River catchment at Pollocksford is calculated at 2713 km^2. A number of regional estimated peak flows shown in Table 4-17 of the 1% AEP design flow indicate various peak flow estimates for comparison. It can be seen that the adopted FFA lies between the range of estimates and is closest to the rational method estimates. The adopted 1% AEP flow is considerably lower than the RFFE tool, but the tool is known to have poor accuracy in many locations.

TABLE 4-17 1% AEP REGIONAL ESTIMATES

Catchment Area	Rational Method (Adams Method)	Vicroads Rational Method	Hydrologic Recipes – Rural Estimate **(Grayson, 1996)** p107	RFFE (AR&R, 2016)	**Water Technology FFA (2017)**
2713km^2	81,659 ML/d	81,593 ML/d	168,064 ML/d	207,360 ML/d	**99,568 ML/d**

4.7 Moorabool River at Batesford Flood Frequency Analysis

4.7.1 Approach and Assumptions

Flood frequency analysis was undertaken on available streamflow data from the Moorabool River at Batesford gauge (232202). Whilst the Batesford gauge has a long period of flow record, dating back to 1908, a significant period of missing data exists between 1922 to 1944. The gauge has moved several times, but it has stayed within the same river reach immediately downstream of the Midland Highway bridge at Batesford.

Continuous good quality gauge data is available for 66 years (1945 to current). The gauge record at this location provides a good upstream flow record of noted large floods experienced on the Moorabool River and on the Barwon River through Geelong. The Moorabool River catchment upstream of Batesford is noted as having significant catchment storage. The majority of these storages are located in the upper catchment around the Ballarat region. The most significant of these storages being the Lal Lal Reservoir which has a capacity of 59,540 ML. Analysis undertaken by Corangamite CMA has determined that in large flood events the upstream storages results in a reduction of approximately 20% of the peak flow at Batesford.

TABLE 4-18 SUMMARY OF FFA FOR THE MOORABOOL RIVER AT BATESFORD GAUGE

Gauge: Moorabool River at Batesford (232202)	
Period of Gauge Record:	80 years from 1908-1921 and 1945-2015
Missing Data:	28 years from 1922-1944
Thresholds Applied:	29 years below 56,500 ML/day was adopted (based on the scaled, largest recorded flow as this location)
Other adjustments to record:	None
Sensitivity Analysis	■ Post construction of storages: 1973-2015, 43 years of record with modified record from 1960-1972 included from CCMA analysis (Adopted) ■ Full Record: 1906-2015, 80 years of record
Adopted Distribution	Log Pearson 3
Previous Analyses	Corangamite CMA (2015), GHD (2016)

4.7.2 Adopted Annual Series

The adopted annual series for the Moorabool River at Batesford FFA is provided below. Note that years prior to 1960 were not adopted in the final analysis due to the impact of upstream storages constructed in the early 1970s. Missing years were included as below threshold years.

TABLE 4-19 ADOPTED ANNUAL SERIES FOR THE MOORABOOL RIVER AT BATESFORD

Year	Peak Flow (ML/d)	Year	Peak Flow (ML/d)	Year	Peak Flow (ML/d)
1908	2,459	1963*	9,957***	1990*	8,828
1909	25,231	1964*	7,867***	1991*	2,669
1910	3,456	1965*	14,028***	1992*	6,629

Year	Peak Flow (ML/d)	Year	Peak Flow (ML/d)	Year	Peak Flow (ML/d)
1911	27,045	1966*	2,676***	1993*	15,851
1912	3,503	1967*	46***	1994*	188
1913	3,088	1968*	2,726***	1995*	35,401
1914	467	1969*	772***	1996*	5,970
1915	3,792	1970*	12,244***	1997*	123
1916	27,985	1971*	13,605***	1998*	1,095
1917	4,382	1972*	1,294***	1999*	957
1918	7,480	1973*	18,904	2000*	4,965
1919	8,464	1974*	7,753	2001*	11,804
1920	3,503	1975*	8,338	2002*	35
1921	4,382	1976*	12,634	2003*	245
1945	307	1977*	10,559	2004*	1,495
1946	10,495	1978*	20,578	2005*	10,624
1947	677	1979*	2,101	2006*	14
1948	929	1980*	182	2007*	40
1949	11,431	1981*	3,510	2008*	185
1950	17,888	1982*	59	2009*	45
1951	23,189	1983*	16,670	2010*	1,979
1952*	40,608**	1984*	1,322	2011*	8,739
1953	11,160	1985*	4,367	2012*	3,706
1959	3,701	1986*	2,522	2013*	63
1960*	8,462	1987*	5,831	2014*	88
1961*	2,159***	1988*	6,810	2015*	69
1962*	2421***	1989*	2,742		

The * next to the years denotes those flows used as part of the partial record of dams FFA (adopted series).
** 1952 peak determined from CCMA modelling, assumes storages in situ
*** modified record to account for storages, gauged flows scaled down by 20%, based on CCMA analysis

4.7.3 Adopted Flood Frequency Results

The adopted results of the FFA is provided in Table 4-20 below and is based on the partial annual series as shown in Table 4-19 to account for the impact of upstream storages. The results show a 1% AEP peak flow of 36,927 ML/d with 5-95% confidence limits of 26,266 ML/d to 57,776 ML/d. These confidence limits are considered reasonable based on experience with other FFA analyses.

TABLE 4-20 ADOPTED PEAK FLOWS – MOORABOOL RIVER AT BATESFORD

Design Event (AEP)	Full Record Log Pearson III with Low Flow Censoring (m^3/s)		
	Peak Flow (ML/d)	Lower Confidence Limit (ML/d)	Upper Confidence Limit (ML/d)
50%	3,221	2,204	4,553
20%	8,771	6,923	11,699

10%	14,012	10,981	18,524
5%	20,071	15,387	26,594
2%	29,222	21,660	41,023
1%	36,927	26,266	57,776
0.5%	45,237	30,612	80,127
0.2%	45,236	35,689	117,936
PMF	1,453,594		

Water Technology determined that the censored LP3 distribution of the partial record was the preferred option based on the following:

- CCMA analysis indicates the upstream storages reduce peak flows at Batesford by approximately 20% in large flood events .
- The LP3 distribution with censoring provides the best fit across AEPs with confidences limits within a reasonable range.
- The flows produced by this assessment are lower than previous catchment analysis and former flood frequency analysis undertaken by the Corangamite CMA (2015), and approximately 20% lower than estimates by GHD (2016) .

The FFA at this location also included a 4-day volume analysis in order to derive design hydrographs for each of the proposed flood events to be modelled. This assessment produced proposed hydrograph shapes for the adopted peak flows based on representation of the flow volume relationship of previous flood events on the Moorabool River at Batesford.

4.7.4 Comparison to Previous Studies

Both Corangamite CMA (2015) and GHD (2016) has previously undertaken Flood Frequency Analysis for this gauge. A comparison of these results with the current adopted design flows at this location is shown in Table 4-21. It is noted that the estimates are approximately 15-20% lower than the CCMA estimates and approximately 30% lower than the GHD estimates. The differences are largely a result of adopting the shorter period of record which considered the impact of the upstream storages. The Water Technology analysis has also included the 29 missing years of data as below threshold events which further reduces the estimates.

TABLE 4-21 FFA COMPARISON – MOORABOOL RIVER AT BATESFORD

AEP	CCMA (2015) ML/d	GHD (2016) ML/d	Water Technology ML/d	Difference to CCMA % (+/-)	Difference to GHD % (+/-)
20%	10,000	13,500	8,771	- 12	- 35
10%	17,400	20,700	14,012	- 19	- 32
5%	25,200	28,800	20,071	- 20	- 30
2%	35,000	40,300	29,222	- 17	- 28
1%	41,900	49,700	36,926	- 12	- 26

4.7.5 Comparison to Regional Estimates

The Moorabool River catchment at Batesford is calculated at 1088 km^2. A number of regional estimated peak flows shown in Table 4-22 of the 1% AEP design flow indicate various peak flow estimates for comparison. It can be seen that the adopted FFA lies between the range of estimates and is very similar to the rational method estimates. The adopted 1% AEP flow is considerably lower than the RFFE tool, but the tool is known to have poor accuracy in many locations across Victoria.

TABLE 4-22 1% AEP REGIONAL ESTIMATES

Catchment Area	Rational Method (Adams Method)	Vicroads Rational Method	Hydrologic Recipes – Rural Estimate (Grayson, 1996) p107	RFFE (AR&R, 2016)	Water Technology FFA (2017)
1088km^2	36,775 ML/d	36,747 ML/d	83,700 ML/d	92,400 ML/d	**36,900 ML/d**

4.8 Barwon River at Geelong Flood Frequency Analysis

4.8.1 Approach and Assumptions

Flood frequency analysis on the Barwon River through Geelong is challenging due to limited reliable hydrological data through Geelong. The McIntyre Bridge gauge is the location of current instantaneous flow records on the Barwon River at Geelong.

Good quality gauge data is only available for nine years based on data available through the DELWP Water Information Management System website[2], whilst maximum stage levels during large flood events is available for an additional 39 years and were sourced from a range of sources as part of the 1982 and 1997 GHD flood studies.

The rating of the gauge through Geelong at its various locations has changed over the years as has the nature of the floodplain through these areas. With the limited instantaneous flood record through Geelong, some uncertainty exists regarding the estimated flows through this reach. Having regard for this, the calibration of the flood model through this area will place greater emphasis on historic flood level data. A review of the current rating curve based on the results of the hydraulic model will also be undertaken.

The following section outlines the flood frequency analysis undertaken on the available data for the Barwon River at Geelong. This analysis required the gauge record to be constructed and extended using multiple data sources as described below. An analysis of the concurrence of flows from the Moorabool and Barwon Rivers is provided further below in Section 5.

TABLE 4-23 SUMMARY OF FFA FOR THE BARWON RIVER AT GEELONG (MCINTYRE BRIDGE) GAUGE

Gauge: Barwon River at Geelong (McIntyre Bridge) (232202)	
Period of Gauge Record:	9 years from 2001-2015, 39 years from recorded water levels between McIntyre and Breakwater Bridges and documented in GHD reports (1982,1997) and further below.
Missing Data:	60 years from 19010-2015, 1917-1932, 1934-1950 and 1953-1961.
Thresholds Applied:	60 years below 126,552 ML/day was adopted (based on the scaled, largest recorded flow as this location)
Other adjustments to record:	None
Sensitivity Analysis	▪ Short Record: 1962-2015, 43 years of record ▪ Full Record: 1909-2015, 50 years of record ▪ Reduced Record: 1852-2015, 48 years of record (Adopted – impact of upstream storages deemed to be small)
Adopted Distribution	Log Pearson 3
Previous Analyses	Corangamite CMA (2015), GHD (1982/1997)

4.8.2 Rating Curve Comparison and Flow Record Analysis

A calibrated hydraulic model of the Barwon River at Geelong is now available (see hydraulic calibration report). Hydraulic models are very useful tools for investigating rating curves at streamflow gauges. Rating curves are most reliable over the range of flows for which accurate discharge measurements are available. This is typically over the lower flow range than for high flows due to the limited occurrence of high flow events that are able to be measured. Subsequently, the higher flow ranges of rating curves are often extrapolated and the uncertainty in the extrapolated section of the curve is considerable. A hydraulic model, which has been calibrated to large flood events, can be used to improve the accuracy of the rating curve for high flows. The hydraulic model is able to explicitly represent the relationship between flow and the complex floodplain geometry that typically exists for large, out-of-bank flows.

The rating curve for the Barwon River at Geelong gauge has been updated on numerous occasions over the years. Several of these rating curves have been plotted below in Figure 4-16, which demonstrates the variability in the stage vs flow relationship across the various rating curves. Also plotted on this figure is the stage-discharge results from the calibrated hydraulic model developed in this project (see hydraulics report). The stage discharge relationship from the modelled 1995 calibration event, which is the largest of the modelled events, is included in the plot for both the rising and falling limbs. The current rating curve for Geelong (V5.0) as determined by Ventia, is also plotted. It should be noted that above 70,800 ML/d (4.8 m AHD) the rating table for the gauging station uses extrapolated values and uncertainty in that section of the curve increases accordingly.

Comparing the current rating curve (V5.0) and the modelled 1995 event curve, the following observations can be made:

- for water levels below 3 m AHD, the model results indicate a higher flow capacity with greater discharge values for the same levels. At lower flow rates rating curves typically perform well, with numerous gaugings to develop the relationship. Given the hydraulic model has been calibrated to larger flow events, it is possible the hydraulic model is less accurate than the rating curve for in-bank flows.
- for levels between 3 and 5 m AHD the existing rating curve and model rating curve correlate very closely. The model results indicate marginally higher flow capacity than the rating curve at these levels. It is noted that through this section of the curve, both the existing rating curve and hydraulic model curves are lower than the older GHD curves i.e. predict a lower flow rate for the same water levels.
- for levels above 5 m AHD the rating curve indicates higher flow rates than the model results. The curves begin to diverge beyond 5 m, however both curves don’t extend far above 5 m. It is noted that the current rating curve is extrapolated beyond 4.8 m and uncertainty is greater for that section of the curve.

Based on the analysis above it was concluded that the current rating curve performs well across a wide range of flows and is appropriate for continued adoption. There appears no need for the curve to be modified unless additional information becomes available, such as observed stage-height information from large flood events in the future.

Based on the analysis above, and the conclusion that the current rating curve is suitable for adoption, the stage height information collected at Geelong was re-processed with the current rating (V5.0). Previously peak discharges for historical events were based on the GHD (1982 and 1997) rating curves. This has generally meant that the revised flow estimates for historical flood events are lower than previously estimated. The refitted peaks compared to the previous estimates are shown in Table 4-24. The lower annual series estimates resulted in lower

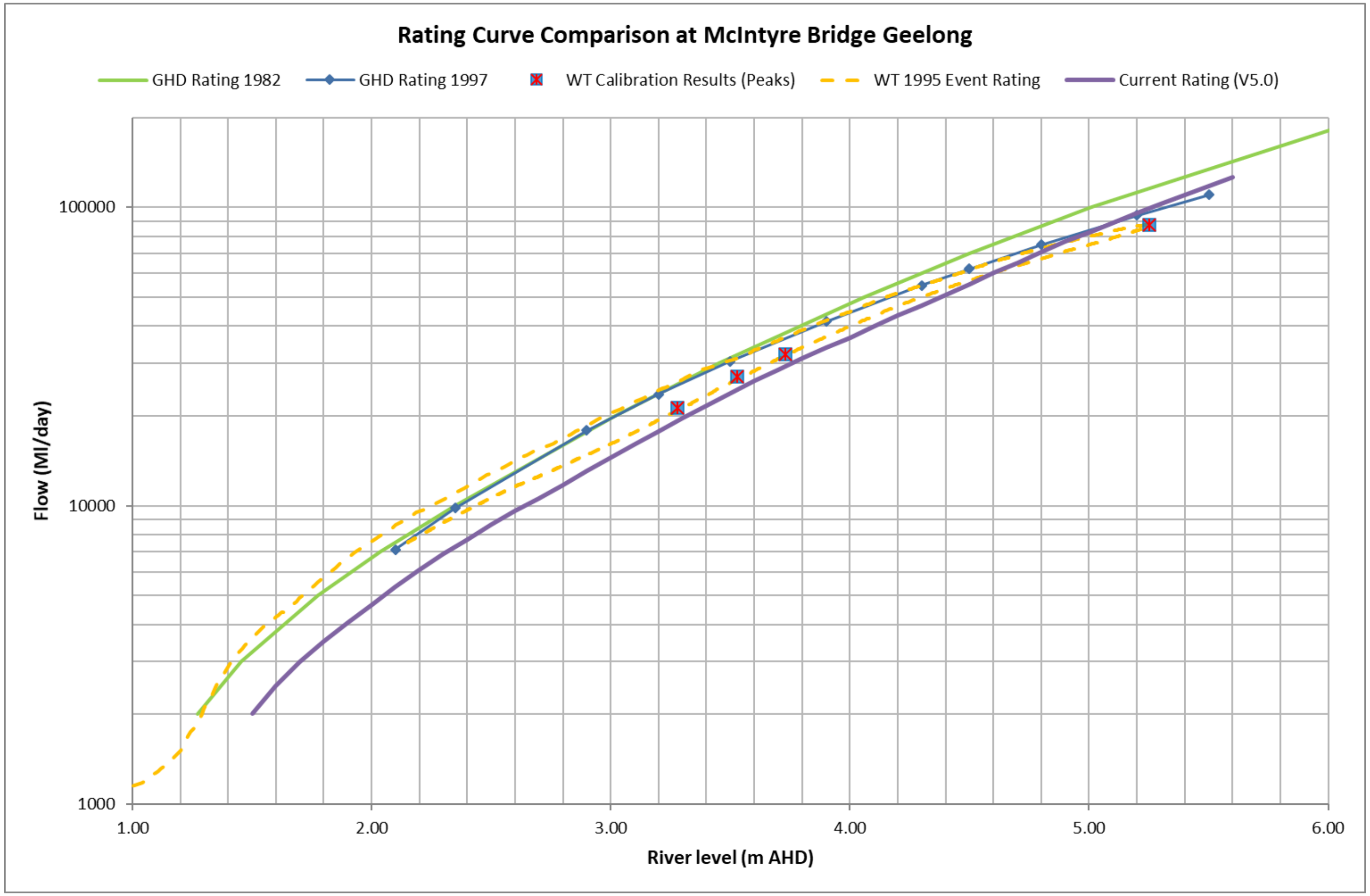


FIGURE 4-16 RATING CURVE COMPARISON AT BARWON RIVER AT GEELONG (MCINTYRE BRIDGE) GAUGE

TABLE 4-24 STAGE HEIGHT FLOW COMPARISON

Year	Stage Height (m)	GHD 1997 Flow Estimate (ML/d)	Refitted Flow Estimate (ML/d)
1909	4.60	77,760	60,200
1916	3.99	53,586	36,300
1933	3.68	34,387	28,100
1951	5.17	105,408	93,800
1952	5.47	126,552	116,000
1963	2.89	16,416	12,900
1964	3.20	22,291	17,700
1965	3.07	19,613	15,600
1966	2.14	7,949	5,650
1967	1.02	346	286
1968	2.07	7,344	5,150
1969	1.52	3,197	2,100
1970	3.71	35,251	28,800
1971	3.04	19,094	15,200
1972	4.26	55,123	45,500
1973	2.62	12,269	9,800
1974	3.5	29,376	23,900
1975	3.10	20,218	16,100
1976	3.93	42,422	34,600
1977	3.47	28,598	23,200
1978	4.48	65,059	54,400
1979	2.24	8,726	6,410
1980	2.20	8,381	6,100
1981	2.56	13,046	9,200
1982	0.97	322	178
1983	3.80	40,867	31,100
1984	3.09	22,464	15,900
1985	2.35	10,195	7,290
1986	2.9	18,662	13,100
1987	2.53	12,614	8,910
1988	2.13	7,690	5,580
1989	2.54	12,787	9,010
1990	3.00	20,736	14,500
1991	2.89	18,576	12,900
1992	3.11	22,896	16,300
1993	3.14	23,587	16,700
1994	1.50	2,938	2,010
1995	5.23	95,990	97,900

4.8.3 Adopted Annual Series

The adopted annual series for the Barwon River at Geelong FFA is provided below. Table 4-25 presents the peak flow and source of the adopted flow. 48 years of record are available for use, with 9 years sourced from the DELWP[2] gauge record (233217).

The annual peaks for the remaining years were extracted from the Geelong Flood Mitigation Strategy (1997) and Floodplain Management Study (1982) with flows based on the rating curve developed in the 1982 study and described in the previous section.

TABLE 4-25 ADOPTED ANNUAL SERIES FOR THE BARWON RIVER AT GEELONG

Year	Peak Flow (ML/d)	Year	Peak Flow (ML/d)	Year	Peak Flow (ML/d)
1909	60,200 *	1974	23,900 *	1990	14,500 *
1916	36,300 *	1975	16,100*	1991	12,900 *
1933	28,100 *	1976	34,600 *	1992	16,300 *
1951	93,800 *	1977	23,200 *	1993	16,700 *
1952	116,000 *	1978	54,400 *	1994	2,010 *
1963	12,900 *	1979	6,410 *	1995	97,900 *
1964	17,700 *	1980	6,100 *	2001	26,200 ^
1965	15,600 *	1981	9,200 *	2007	6,700 ^
1966	5,650 *	1982	178 *	2010	7,667 ^
1967	286 *	1983	31,100 *	2011	28,100 ^
1968	5,150 *	1984	15,900 *	2012	8,616 ^
1969	2,100 *	1985	7,290 *	2013	4,158 ^
1970	28,800 *	1986	13,100 *	2014	1,416 ^
1971	15,200 *	1987	8,910 *	2015	491 ^
1972	45,500 *	1988	5,580 *	2016	19,451 ^
1973	9,800 *	1989	9,010 *	2017	4,113 ^

* Sourced from GHD report (1996) with flows determined from manually measured flood levels (various sources) recorded between McIntyres Bridge and Breakwater Bridge and applied to current rating curve
^ Sourced from DELWP - Barwon River at McIntyre Bridge (433200) gauge record

4.8.4 Adopted Flood Frequency Results

The adopted results of the FFA is provided in Table 4-26 below and is based on the annual series presented in the section above. The results show a 1% AEP peak flow of 171,198 ML/d with 5-95% confidence limits of 78,961 ML/d to 198,573 ML/d. These confidence limits are considered reasonable based on experience with other FLIKE analyses and were some of the lowest confidence intervals in comparison to the range of distributions tested.

TABLE 4-26 ADOPTED FFA PEAK FLOWS FOR BARWON RIVER AT GEELONG GAUGE

Design Event (AEP)	Full Record Log Pearson III with Low Flow Censoring (ML/d)		
	Peak Flow (ML/d)	Lower Confidence Limit (ML/d)	Upper Confidence Limit (ML/d)
50%	9,999	7,667	13,245
20%	25,983	19,913	34,275
10%	41,559	31,524	55,028
5%	60,343	44,890	83,246
2%	90,367	64,006	136,961
1%	117,198	78,691	198,573
0.5%	147,736	92,808	281,232
0.2%	194,022	109,926	438,929
0.01%	395,615		

Water Technology determined that the censored LP3 distribution of the full available record was the preferred option based on the following:

- The full record provided a much longer period of record for assessment.
- The full records enable the inclusion of a number of significant historical floods including 1909, 1916, 1951, 1952.
- The LP3 distribution with censoring provides the best fit across AEPs with confidences limits within a reasonable range.
- A flow threshold was included for the 60 years of missing data from 19010-2015, 1917-1932, 1934-1950 and 1953-1961 for the full record FFA, a threshold of 126,552 ML/day was adopted based on the largest recorded flow as this location.

4.8.5 Comparison to Previous Studies

The results of the adopted FFA were compared against previous analyses completed by GHD (1982) and Corangamite CMA (2015) and are shown in below.

The results of the adopted FFA are similar to that determined by CCMA in 2015 with differences generally less than 10%. The adopted FFA flows are significantly lower than the GHD (1982) which is primarily a result of the additional 35 years of data that is now available, including a significant drought period.

It is of note that the Corangamite CMA 2015 analysis adopted an annual series from of 1972 to 2015, so as to include only the years after construction of upstream storages which were constructed in 1971/1972. The concern with this approach is that a number of very significant historic events occurred prior to 1972 and have been excluded from the record, including the largest on record which occurred in 1952.

Whilst it is acknowledged that the construction of upstream storages has some impact on peak flows in Geelong, it was deemed of greater importance to include these large historic events within the FFA annual series. The upstream storages are generally located in the upland areas of the catchment, with a relatively small proportion of the total catchment area upstream of them. The adopted approach is more conservative and deemed appropriate with the inclusion of the pre-1972 events.

TABLE 4-27 FFA COMPARISON – BARWON RIVER AT GEELONG (MCINTYRE BRIDGE)

AEP	CCMA (2015) ML/d	GHD (1982) ML/d	Water Technology ML/d	Difference to CCMA % (+/-)	Difference to GHD % (+/-)
20%	28,800	42,300	25,983	- 10	- 39
10%	44,000	58,900	41,559	- 6	- 29
5%	62,100	77,800	60,343	- 3	- 22
2%	87,300	N/A	90,367	+ 4	N/A
1%	107,100	137,400	117,198	+ 9	- 15

4.8.6 Comparison to Regional Estimates

To provide some comparison of alternative catchment based peak flow estimation methods the following comparison peak flow assessment are provided. Each of the following methods is accepted by industry for the determination of peak flows for various applications. These regional estimates are based on the Barwon River catchment area of 3,925 km^2 are shown in Table 4-40.

It can be seen that the current FFA 1% AEP peak sits within the range of other values. The rational methods produce flows much lower than the FFA predicted peak flows for this catchment area. The prows produced by the RFFE with prior information produce peak flows within a closer range that those shown below. It should be noted that some of the alternative methods such as the rational method are known to perform poorly on catchments of this size so the comparison is of limited value as a validation tool. It does however give an indication that the magnitude of the FFA 1% AEP flow is reasonable.

TABLE 4-28 1% AEP REGIONAL ESTIMATES – BARWON RIVER AT GEELONG

Catchment Area	Rational Method	Vic Roads Method	Hydrologic Recipes – Rural Estimate **(Grayson, 1996)** p107	RFFE	**Water Technology FFA (2017)**
3925 km^2	134,059 ML/d	133,952 ML/d	222,807 ML/d	180,576 ML/d	**117,198 ML/d**

4.9 Historical Event Flood Behaviour and Timing

A significant amount of information including flood levels, gauge information and historical photographs are available for a number of flood events along the Barwon River and Moorabool River. Less information is available to validate the tributaries including Waurn Ponds Creek.

The peak height and time of peak at Batesford and Pollocksford are important information on which Water Technology based it's calibration of the hydraulic model. Further to this, the recorded maximum flood levels and time of peak on the Barwon River at Geelong were also used to validate the model at this location. The travel time of the floods of various magnitude were of particular importance to gaining a greater awareness of the dynamics of flooding through this reach and at the confluence of the Barwon and Moorabool Rivers.

Whilst a number of the historical records do not have time information recorded in relation to the maximum annual flow data, more recent records provide important information relating to the rate of rise of the river at the upper gauges and through Geelong. Additional information sources from short gauge records downstream of Geelong at the lower breakwater and within Reedy Lake was also considered.

Calibration of the model was undertaken for the 1995, 2001 and 2011 flood events.

Table 4-29 shows the peak flow and time of peak of several significant events from the Moorabool and Barwon Rivers. Based on a review of these historic events the following conclusions can be drawn:

- The Barwon River is nearly always dominant in major flood events across the Barwon catchment compared to the Moorabool River.
- The Moorabool River at Batesford generally peaks a number of hours before the Barwon River at Pollocksford, with the difference in peak timing ranging from 0 to 24 hours. As determined in the CCMA concurrent flow analysis the mean difference for the top six flood events is 9.5 hours. There are some exceptions, where the Barwon has peaked prior to the Moorabool, but this is rare.
- Travel time for the flood peak from Batesford to Geelong ranges from 5 hours to 24 hours but will be dependent on the timing of the peak in the Barwon River upstream of the confluence.
- Travel time for the flood peak from Pollocksford to Geelong ranges from 5 hours to 20 hours.

TABLE 4-29 HISTORICAL FLOOD PEAK AND TIMING

Barwon River @ Pollocksford			Moorabool River @ Batesford			Barwon River @ Geelong		
Year	Time of Peak	Discharge (ML/d)	Year	Time of Peak	Discharge (ML/d)	Year	Time of Peak	Discharge (ML/d)
1973	6/02/1973 18:55	48,722	1973	6/02/1973 16:07	18,904	1973		55,123
1976	17/10/1976 13:43	45,026	1976	16/10/1976 14:35	12,634	1976		42,422
1978	19/11/1978 21:27	45,247	1978	19/11/1978 21:52	20,578	1978	20/11/1978 17:35	65,059
1983	16/10/1983 22:37	25,002	1983	16/10/1983 22:08	16,670	1983	17/10/1983 3:24	40,867
1995	7/11/1995 19:30	79,030	1995	7/11/1995 03:21	35,401	1995	8/11/1995 04:00	95,990
2001	24/4/2001 14:00	21,923	2001	24/4/2001 01:40	11,804	2001		

Barwon River @ Pollocksford			Moorabool River @ Batesford			Barwon River @ Geelong		
2011	15/01/2011 14:30	29,460	2011	15/01/2011 22:30	7957	2011	16/01/2011 01:30	28,100

4.10 Moorabool River and Barwon River Concurrent Flow

The Moorabool and Barwon Rivers combine immediately upstream of Geelong at Fyansford. The design flood flows through Geelong can be dominated by flooding events in either the Moorabool or Barwon Rivers, although large flood events are nearly always dominated by the Barwon River. In addition, flows from the Barwon River can also be influenced by two distinctly different areas, being either the upper Barwon River off the Otway ranges catchment, or the Leigh River catchment.

The relationship between the flow at Batesford, Pollocksford and Geelong is one of the key areas of investigation of this study. Analysis of the historical events of both the Barwon and Moorabool Rivers does indicate variation in relative time of peaks of the Batesford and Pollocksford gauges in relation to the time of peak at Geelong.

Water Technology will build on an existing assessment by Corangamite CMA of joint probability and concurrence of flows from the Barwon and Moorabool Rivers within the hydraulic modelling. A discussion of the current findings is provided below.

4.10.1 Corangamite CMA Flow Concurrence Assessment

The Corangamite CMA have undertaken prior assessments of flow concurrence on the Barwon and Moorabool Rivers for the purposes of predicting peak flood levels at the confluence of the Moorabool and Barwon Rivers and though Geelong.

One assessment was based on the AR&R (1987) method "Estimating of Concurrent Tributary Flows", with Barwon River dominance assumed. This analysis fits flood peaks from known historical events between the Moorabool and Barwon to derive a correlation between flood peaks and probability at the confluence. The results of this assessment are shown below in Table 4-30. This assessment produced peak discharges but did not provide information on volumes, hydrograph shape or timing.

Note that "Design 1 in Y (ARI)" terminology is used in the tables below as opposed to AEP to be consistent with the CCMA analysis and allow the concurrent ARIs that were derived in that work to be reported.

TABLE 4-30 CCMA CONCURRENT FLOWS IN BARWON AND MOORABOOL RIVERS (AR&R ESTIMATION OF CONCURRENT TRIBUTARY FLOWS METHOD)

Barwon River at Pollocksford		Moorabool River at Barwon Confluence	
Design 1 in Y (ARI)	**Peak Flow (ML/d)**	**Design 1 in Y (ARI)**	**Peak Flow (ML/d)**
2	13,500	2	5,900
5	23,300	5	11,500
10	35,850	9	16,400
20	51,000	15	21,900
50	71,700	32	30,400
100	89,900	65	37,700

Barwon River at Pollocksford		Moorabool River at Barwon Confluence	
200	105,800	160	46,000

Corangamite CMA deemed that the alternative approach described below, based on RORB modelling, was preferred and recommended for adoption. The second approach to determining concurrent design flows for the Barwon and Moorabool River as applied by Corangamite CMA is described below:

- A calibrated RORB model using Pollocksford and Batesford 1 hour flow values for the record 1/1/1972 to 31/12/2014 was developed. The RORB model was calibrated to previous model results at Fyansford for both the Barwon and Moorabool Rivers. A statistical analysis of the annual peak flows was then undertaken using the new 2016 AR&R Flike method, resulting in peak flow estimates for design events.
- Design flood hydrographs for the Barwon and Moorabool Rivers at Fyansford were determined by scaling the November 1995 flood hydrographs up or down to match design flows at Pollocksford and Batesford respectively. These design hydrographs were input into the calibrated RORB model to route them down to Fyansford and on to McIntyre Bridge.
- Using the design flows in the Barwon River at Pollocksford, the concurrent flow on the Moorabool River was altered until the peak flow at McIntyre Bridge was matched. This was done for 8 design events ranging from a 10 year ARI to a 10,000 year Average Recurrence Interval.

By using a calibrated RORB model this method provides hydrograph volume, shape and timing as well as the peak flow, and it is considered that the method results in hydrographs that can then be utilised in the hydraulic modelling. The results of the above method are shown below in Table 4-31. The concurrent flows in the Moorabool River are not too dissimilar to those determined in the AR&R method above.

TABLE 4-31 CCMA CONCURRENT FLOWS IN BARWON AND MOORABOOL RIVERS (RORB MODEL METHOD)

Barwon River at Pollocksford		Moorabool River at Barwon Confluence	
Design 1 in Y (ARI)	**Peak Flow (ML/d)**	**Design 1 in Y (ARI)**	**Peak Flow (ML/d)**
2	13,500	2	5,400
5	23,300	5	10,200
10	35,850	9.5	16,400
20	51,000	17	22,800
50	71,700	38	31,500
100	89,900	65	37,300
200	105,800	120	43,600

4.10.2 Adopted Concurrent Flows

The above RORB model approach adopted by Corangamite CMA was deemed appropriate for adoption in this study, however the updated design flows for the Barwon River at Pollocksford and Geelong from the revised flood frequency analysis completed in this study were used. The calibrated RORB model was used to derive the concurrent flows on the Moorabool River at Batesford to give the target design flows at Geelong using the same method as described above. Design inflow hydrographs were utilised at the Barwon River at Pollocksford gauge and scaled 1995 hydrographs were used as inflows at the Moorabool River at Batesford. The scaled hydrographs were scaled up and down in an iterative process until the desired peak flow was achieved at Geelong.

The design peak flow at Batesford was timed to occur 10 hours before the peak at Pollocksford which is consistent with the findings in the CCMA analysis which determined a time difference of 9.5 hours based on the mean of the largest 6 events. The assumed timing of the peak has a direct impact on the resulting concurrent flows that are determined, and sensitivity testing has highlighted that the larger the difference in time between peaks, the larger the magnitude of event required for the concurrent flow in the Moorabool River.

The RORB concurrent flows were used as the starting point for testing in the hydraulic model, and they were then refined in the hydraulic model until the required conditions were achieved in central Geelong at McIntyres Bridge. The results of the analysis are shown in below with the full range of design, concurrent and sensitivity scenarios shown.

TABLE 4-32 DESIGN SCENARIOS - SUMMARY

Scenarios	Barwon at Pollocksford AEP	Peak flow m3/s	Moorabool at Batesford AEP	Peak flow m3/s	Barwon, McIntyre bridge - AEP	Peak flow m3/s	Waurn Ponds Creek AEP	Storm Tide AEP	Storm Tide Level (m) ADH)
50% - Concurrent	50%	106	57%	27	50%	116	50%-6h		
50% - Barwon Dominant	50%	106	Low Flow				50% - 12h		
50% - Moorabool Dominant	Low flow		50%	37			50% - 1h		
20% Concurrent	20%	279	33%	67	20%	312	20% - 6h		
20% Barwon Dominant	20%	279	50%	37			20% - 12h		
20% Moorabool Dominant	50%	106	20%	102			20% - 1h		
10% Concurrent	10%	440	20%	102	10%	493	10% - 6h		
10% Barwon Dominant	10%	440	50%	37			10% - 12h		
10% Moorabool Dominant	50%	106	10%	162			10% - 1h		
5% Concurrent	5%	627	15%	125	5%	694	5% - 12h		
5% Barwon Dominant	5%	627	50%	37			5% - 6h		
5% Moorabool Dominant	50%	106	5%	232			5% - 1h	10%	1.56
2% Concurrent	2%	911	~5%	218	2%	1045	2% - 12h		
2% Barwon Dominant	2%	911	10%	162			2% - 6h		
2% Moorabool Dominant	10%	440	2%	338			2% - 1h		
1% Concurrent	1%	1152	~2%	325	1%	1367	1% - 12h		
1% Barwon Dominant	1%	1152	10%	162			1% - 1h		
1% Moorabool Dominant	10%	440	1%	427			1% - 6h		
0.5% Concurrent	0.5%	1415	~1%	445	0.5%	1700	0.5% - 12h		
0.5% Barwon Dominant	0.5%	1415	10%	162			0.5% - 6h		
0.5% Moorabool Dominant	10%	440	0.5%	524			0.5% - 1h		
0.2% Concurrent	0.2%	1797	0.2%	660	0.2%	2265	0.2% - 12h		
0.2% Barwon Dominant	0.2%	1797	10%	162			0.2% - 6h		

0.2% Moorabool Dominant	*10%*	*440*	*0.2%*	*660*			*0.2% - 1h*		
PMF	**PMF**	**16824**	**PMF**	**9495**			**PMF - 3h**		
Sensitivity – Storm Tide	1%	1152	~2%	325	**1%**	**1367**	1% - 12h	1%	1.82
	10%	440	20%	102	**10%**	**493**	10% - 6h	1%	1.82
Climate Change – Sea level Rise only	1% Concurrent				**1%**	**1367**		1% + 0.2m	2.02
	10% Concurrent				**10%**	**493**		1% + 0.2m	2.02
	1% Concurrent				**1%**	**1367**		1% + 0.5m	2.32
	10% Concurrent				**10%**	**493**		1% + 0.5m	2.32
	1% Concurrent				**1%**	**1367**		1% + 0.8m	2.62
	10% Concurrent				**10%**	**493**		1% + 0.8m	2.62

4.11 Waurn Ponds Creek

4.11.1 Overview

A hydrologic model of the Waurn Ponds Creek catchment was developed to determine design flow hydrographs at several locations within the Waurn Ponds Creek catchment to be used as inflow boundary conditions in the hydraulic model. The rainfall-runoff program, RORB, was utilised for this study.

RORB is a non-linear rainfall runoff and streamflow routing model for calculation of flow hydrographs in drainage and stream networks. The model requires catchments to be divided into subareas, connected by a series of conceptual reaches and storage areas. Observed or design storm rainfall is input to the centroid of each subarea. Specific initial and continuing losses are then deducted, and the excess runoff is routed through the reach network.

The adopted methodology described below is based on current guidelines described in 2016 Australian Rainfall and Runoff. A Monte Carlo approach was adopted which is a probabilistic approach whereby a large, number of potential combinations of parameters and catchment conditions are run through the hydrological model to determine appropriate design flow estimates. In this instance 10,000 model runs were simulated, with varying initial losses and temporal patterns, to produce a probabilistic distribution of design flows. This allowed design peak flows for the range of design events to be determined. A Monte Carlo approach results in less uncertainty than a traditional deterministic approach as a range of input parameters are considered in the determination of design flows. The final parameters adopted for each design event was based on selecting a combination of parameters from the 10,000 simulations which produces the desired peak flow at Barwon Heads Road.

The Waurn Ponds Creek catchment is ungauged therefore the adopted design flows were validated against a range of other flow estimate methods including regional estimates and an existing RORB model developed by Corangamite CMA (2008).

4.11.2 Design Event Modelling Parameters

The following section details the inputs and parameters used for the design event modelling in RORB. This includes a section on flow verification which is important given the catchment is ungauged.

4.11.2.1 Design Rainfall Depths

Design rainfall depths were determined using the Bureau of Meteorology online IFD tool and generated for a location at the centre of the Waurn Ponds Creek Catchment (38.21S, 144.309E) and are shown in Table 4-33 below.

TABLE 4-33 IFD RAINFALL DEPTHS (AR&R 2016) – WAURN PONDS CREEK CATCHMENT

	EY	Annual Exceedance Probability (AEP)					
Duration	**1EY**	**50%**	**20%**	**10%**	**5%**	**2%**	**1%**
1 hour	10.6	12.3	17.7	21.7	25.7	31.3	35.9
2 hour	13.9	15.8	22.3	26.9	31.6	38.1	43.2
3 hour	16.4	18.6	25.7	30.8	36	43.1	48.8
6 hour	22.3	24.9	33.5	39.7	46	54.9	62
12 hour	30.2	33.5	44.6	52.4	60.6	72.6	82.3

	EY	Annual Exceedance Probability (AEP)					
24 hour	39.1	43.7	58.8	69.7	80.7	97.2	110
48 hour	47.1	53.5	74.4	89.3	104	126	143
72 hour	50.9	58.2	82.4	99.7	117	141	159
96 hour	53.4	61.2	86.9	105	124	149	168
120 hour	55.6	63.5	89.5	108	128	153	172
144 hour	57.8	65.6	91.1	110	130	154	174
168 hour	60.1	67.6	92	110	130	155	174

4.11.2.2 Areal Reduction Factors

Areal reduction factors were used to convert point rainfall to areal estimates and are used to account for the variation of rainfall intensities over a large catchment. 2016 AR&R areal reduction factors were applied to the catchment area and extracted from the AR&R data hub. The catchment lies within the Southern Temperate Zone of aerial reduction factors and these were applied for all design modelling.

4.11.2.3 Routing Parameters - Kc

Kc is the primary routing parameter in RORB. As the Waurn Ponds Creek is an ungauged catchment with no streamflow record it is not possible to calibrate the RORB model against known catchment flows and rainfall records. As such a comparison of regional Kc values has been undertaken from regional equations as well as against Kc values from other RORB models in the Geelong region. The regional parameters of six available RORB models were compared along with the available previous Waurn Ponds Creek RORB models.

The routing parameter kc varies proportionally with the stream length. In light of this the application of Equation 1 below allows the kc from another RORB model to be adjusted to represent the applicable Kc for the Waurn Ponds catchment model. This effectively scales the kc parameter based on its relationship to nearby catchments of a similar nature.

$$k_{c\ New\ WP\ Model} = \frac{k_{c\ Existing\ Model}}{D_{av\ Existing\ Model}} \times D_{av\ New\ WP\ Model}$$

Equation1

Where:

$k_{c\ New\ WP\ Model}$	kc parameter for new Waurn Ponds Creek model
$k_{c\ Existing\ Model}$	kc parameter for existing regional RORB model
$D_{av\ New\ WP\ Model}$	Average distance from centroid of subarea to model outlet (new Waurn Ponds Creek model)
$D_{av\ Catchment}$	Average distance from centroid of subarea to model outlet (existing regional RORB model)

Table 2-5 shows the values of the adjusted Kc values using the regional kc and Dav equation (Equation1). It should be noted that comparisons couldn't be made at all models as the Kc and Dav values were not available for some models. The existing Waurn Ponds Creek RORB model is noted to have an adjusted Kc of 17.2.

TABLE 4-34 REGIONAL K_C AND LOSS PARAMETERS

Location	Gauged (G) Ungauged (UG)	K_c	m	Dav	IL	CL	Adjusted Kc
Waurn Ponds Creek (Previous)	UG	17	0.8	15.77	20.0	Roc (0.6)	17.2
Thompson Creek	G	34	0.8	unknown	IL_B	4.8	N/A
Highton (Kardinia Creek)	UG	4.94	0.8	unknown		Roc (0.6)	N/A
Inverleigh (Leigh River)	G	55	0.8	63.8	NA	Roc	13.8
Armstrong Creek	UG	14	0.8	6.50	20	Roc (0.79	34.46
Spring Creek	UG	16.5	0.8	unknown	30	Roc (0.6)	N/A

The adjusted kc parameters range between 13.8 and 34.5. In addition, kc values were determined from several regional equations available within the RORB software. Table 4-35 shows a number of the kc values determined from regional equations. It can be seen they all lie within the range of 17-20 which correlates closely with the existing Waurn Ponds RORB model which has an adjusted Kc value of 17.2.

TABLE 4-35 CALCULATED KC PARAMETERS

Kc Equations	K_c
Default RORB Eqn.	17.58
Victoria data (Pearse et al, 2002)	20.00
Aust Wide Dyer (1994) (Pearce et al)	18.24

Based on the assessment of both the regional adjusted kc values and the regional equations it would appear that the majority of the kc values fit between the 17-20 range. Based on this analysis it was deemed appropriate to adopt a Kc value of 17.2 which is the adjusted Kc value of the existing Waurn Ponds Creek RORB model.

4.11.2.4 Routing Parameters - m

The RORB m value is typically set at 0.8. This value remains unchanged and is an acceptable value for the degree of non-linearity of catchment response (Australian Rainfall and Runoff, 1987). It is rare to vary the m value and there are were no reasons to vary the m value from 0.8 in this study particularly given the lack of calibration data. Temporal Patterns

4.11.2.5 Temporal Patterns

Temporal patterns from AR&R 2016 were utilised in the analysis and extracted from the AR&R data hub. As previously described a Monte Carlo approach was adopted in RORB and the full ensemble of temporal patterns were included within the Monte Carlo simulation. The range of temporal patterns have been included in Appendix F with relevant event ID numbers assigned as referred to in the RORB model output. The Southern Slopes (Vic/NSW) Zone of temporal patterns was utilised.

4.11.2.6 Design Losses

As previously described a Monte Carlo approach was adopted in RORB and design losses were based on 2016 AR&R loss values extracted from the AR&R data hub. The Monte Carlo simulation incorporated a range of initial loss values with a mean value of 16.0 mm as extracted from the data hub. A continuing loss value of 3 mm/hour was adopted which was also extracted from the AR&R data hub. Only the initial loss value varied in the Monte Carlo simulation.

Losses were also compared against design loss prediction equations developed by Hill et al (1998) and 1987 AR&R losses.

Hill et al (1998) calculate initial loss by first calculating the storm initial loss using Equation 2, then the burst initial loss (Equation 3). The burst initial loss varies with storm duration and accounts for the embedded nature of AR&R design rainfalls (Hill et al 1998). The continuing loss is estimated using Equation 4.

Storm initial loss:

$$IL_s = -25.8BFI + 33.8$$ **Equation 2**

Burst initial loss:

$$IL_b = IL_s \{1 - \frac{1}{1+142\sqrt{duration/MAR}}\}$$ **Equation 3**

Continuing loss:

$$CL = 7.97BFI + 0.00659PET - 6.00$$ **Equation 4**

A summary of the range of loss estimates is provided below.

TABLE 4-36 DESIGN LOSS PARAMETER ESTIMATES

Source	ILs (mm)	ILb (mm)	CL (mm/h)
Hill et al (1998)	23.9	8.6-8.9 (9-48 hr events)	5.4
AR&R 1987	15-35		2.5
AR&R 2016 (Data Hub)	16		3.0

Following the Monte Carlo simulation in RORB, combinations of design losses were selected from the 10,000 model runs which resulted in the design peak flow for each AEP and duration event. The adopted losses are shown below in Table 4-37. The initial loss in each case is considerably lower than the initial loss data hub value of 16 mm.

Note that the Monte Carlo Analysis provides the design flow of estimates based on the large number of combinations of parameters run however a final combination of parameters from the 10,000 models runs still needs to be selected for adoption for design conditions. A combination of parameters was selected which resulted in a peak flow very close to the Monte Carlo peak flow result. The second column in the table below is the reported design flow from the Monte Carlo Analysis while the last column represents the adopted peak flow based on the combination of parameters have been selected for design conditions.

TABLE 4-37 ADOPTED PARAMETERS AND PEAK FLOWS

Event	Monte Carlo Analysis Peak Flow at Barwon Heads Road (m^3/s)	Duration	Initial Loss (mm)	Continuing Loss Rate (mm/h)	Temporal Pattern Event ID*	Adopted Peak Flow at Barwon Heads Road (m^3/s)
0.2% AEP	57.1	1 hour	26.0	3	**5971**	**59.6**
	92.1	6 hour	20.0	3	**6135**	**93.1**
	114.5	12 hour	25.0	3	**6197**	**115.9**
0.5% AEP	48.2	1 hour	24.0	3	**5971**	**49.5**
	68.8	6 hour	18.0	3	**6135**	**70.3**
	84.7	12 hour	26.0	3	**6197**	**84.2**
1% AEP	39.8	1 hour	6.7	3	**5968 (27)**	**41.8**
	57.1	6 hour	12.0	3	**6016 (23)**	**58.2**
	62.3	12 hour	7.4	3	**6081 (23)**	**61.6**
2% AEP	33.9	1 hour	6.7	3	**5966**	**33.0**
	44.9	6 hour	12.6	3	**6130 (25)**	**44.4**
	50.4	12 hour	6.7	3	**6081 (24)**	**53.7**
5% AEP	26.6	1 hour	5.8	3	**5977 (16)**	**27.2**
	34.5	6 hour	8.2	3	**6139 (14)**	**33.5**
	36.5	12 hour	8.5	3	**6176**	**37.9**
10% AEP	21.5	1 hour	7.7	3	**5920**	**21.0**
	25.7	6 hour	8.3	3	**6139**	**25.7**
	27.2	12 hour	8.6	3	**6199**	**27.8**
20% AEP	15.3	1 hour	10.2	3	**5987**	**15.6**
	18.8	6 hour	6.4	3	**6149**	**18.9**
	18.3	12 hour	12.0	3	**6215**	**18.8**

* Refer to Appendix F for temporal patterns with Event IDs provided for referencing

4.11.2.7 Spatial Patterns

An analysis of design rainfall was made across the Waurn Ponds Creek catchment to determine if a non-uniform spatial pattern should be utilised. The 2016 AR&R guidelines recommend that for catchment areas of more than 20 km^2 non-uniform spatial patterns should be considered. Gridded rainfall data is not yet available on the BOM IFD website however a comparison was undertaken of the variation in rainfall depths between two points at the upper and lower ends of the catchment.

Table 4-38 below shows a comparison of design rainfall between the upper and lower ends of the catchment for the critical duration events in the Waurn Ponds catchment. It can be seen that the difference in rainfall is minor with differences of less than 1% in the 1 and 6 hour duration events and less than 5% in the 12 hour duration events. Based on this analysis it was deemed appropriate to adopt a uniform rainfall spatial pattern for the design modelling.

TABLE 4-38 COMPARISON OF RAINFALL DEPTHS AT UPSTREAM AND DOWNSTREAM ENDS OF WAURN PONDS CREEK CATCHMENT

Duration	10% AEP event			1% AEP event		
	Downstream (mm)	Upstream (mm)	Difference (mm)	Downstream (mm)	Upstream (mm)	Difference (mm)
1hr	21.9	21.5	-0.4	36.2	35.5	-0.7
6hr	39.3	40.2	0.9	61.6	62.7	1.1
12hr	51.4	54.3	2.9	80.8	85.2	4.4

4.11.3 Flow Validation

To ensure flow estimates are reasonable, peak flows were validated against the existing Waurn Ponds Creek RORB model (CCMA 2008) and a range of regional estimates methods including the VicRoads rational method and RFFE Tool (AR&R 2016). The RFFE Tool is part of the recent update of Australian Rainfall and Runoff (Rahman, et al, 2015). Comparisons were made at three key locations in the catchments at Barwon Heads Road, Surf Coast Highway and Pioneer Road.

The rational method calculations were based on the 1987 IFD parameters outlined in Table 4-39.

TABLE 4-39 IFD PARAMETERS (1987 AR&R)

Location	1 HR DUR 2 ARI	12 HR DUR 2 ARI	72 HR DUR 2 ARI	1 HR DUR 50 ARI	12 HR DUR 50 ARI	72 HR DUR 50 ARI	G (skewness)	F2 Geo factor 2 ARI	F50 Geo factor 50 ARI
Waurn Ponds Catchment Centroid	17.96	3.32	0.89	34.39	6.01	1.79	0.42	4.29	14.83

Latitude: -38.198, Longitude: 144.263

The Waurn Ponds Creek catchment area is calculated at 63.9 km^2. A number of regional estimates for the 1% AEP peak flow are shown in Table 4-40 as well as the existing and current RORB model estimates. It can be seen that the new RORB model correlates very closely with the existing RORB model (CCMA 2008) and the RFFE Tool (AR&R 2016). Based on the validation process the design flows are deemed appropriate for adoption.

TABLE 4-40 COMPARISON TO 1% AEP REGIONAL ESTIMATES

Location	Catchment Area	Rational Method (Adams)	Vic Roads Method	Hydrologic Recipes – Rural Estimate	RFFE Tool	Previous RORB (CCMA 2008)	RORB Model (Water Tech 2017)
Barwon Heads Road	63.9 km^2	39.4 m^3/s	39.3 m^3/s	111 m^3/s	69.6	64.0	**62.3**
Surf Coast Highway	59.3 km^2	37.3 m^3/s	37.3 m^3/s	105 m^3/s	65.4	63.0	**59.3**
Pioneer Road	55.6 km^2	35.6 m^3/s	35.5 m^3/s	100 m^3/s	61.9	51.0	**57.6**

4.11.4 Summary of RORB Design Flows

Table 4-41 below displays the adopted peak flows at key locations for the full range of design events in Waurn Ponds Creek.

TABLE 4-41 SUMMARY OF DESIGN FLOWS IN WAURN PONDS CREEK

Location	AEP Peak Flow (m^3/s)				
	20%	10%	5%	2%	1%
Barwon Heads Road	18.8	27.2	36.5	50.4	62.3
Surf Coast Highway	16.0	24.4	33.1	48.0	59.4
Pioneer Road	23.7	31.9	39.9	50.9	57.6

4.11.5 RORB Model Construction

4.11.5.1 Sub-area and Reach Delineation

Sub-area boundaries and reaches were delineated using ArcHydro and revised as necessary to allow flows to be extracted at the points of interest. The RORB model was constructed using MiRORB (MapInfo RORB tools), RORB GUI and RORBWIN V6.15.

The subareas and reaches were delineated from the provided 1m LiDAR of the area. Nodes were placed at areas of interest (to extract flow hydrographs), the centroid of each sub-area and the junction of any two reaches. Nodes were then connected by RORB reaches, each representing the length, slope and reach type. The revised RORB model has 58 sub-catchments and the sub-catchment delineation and reach network is shown in Figure 4-17.

Five different reach types are available in RORB as shown in Table 4-42. Reach types were selected based on aerial imagery and site visits. The reach types are predominately “natural” in the middle and upper catchment and “excavated and unlined” or “lined channel or pipe” in the lower catchment.

TABLE 4-42 RORB REACH TYPE SUMMARY

Reach Number	Reach Type
1	Natural
2	Excavated & Unlined
3	Lined Channel or Pipe
4	Drowned Reach
5	Dummy Reach

4.11.5.2 Fraction Impervious

Fraction Impervious (FI) values were calculated using MiRORB. Default sub-area FI values were derived based on an assessment of current Planning Scheme Zones (current January 2017) and then revise using aerial imagery. The spatial distribution of the fraction impervious data is shown in Figure 4-18. It can be seen there is a considerable difference in fraction impervious between the lower, urban areas of the catchment and the upper, agricultural areas.

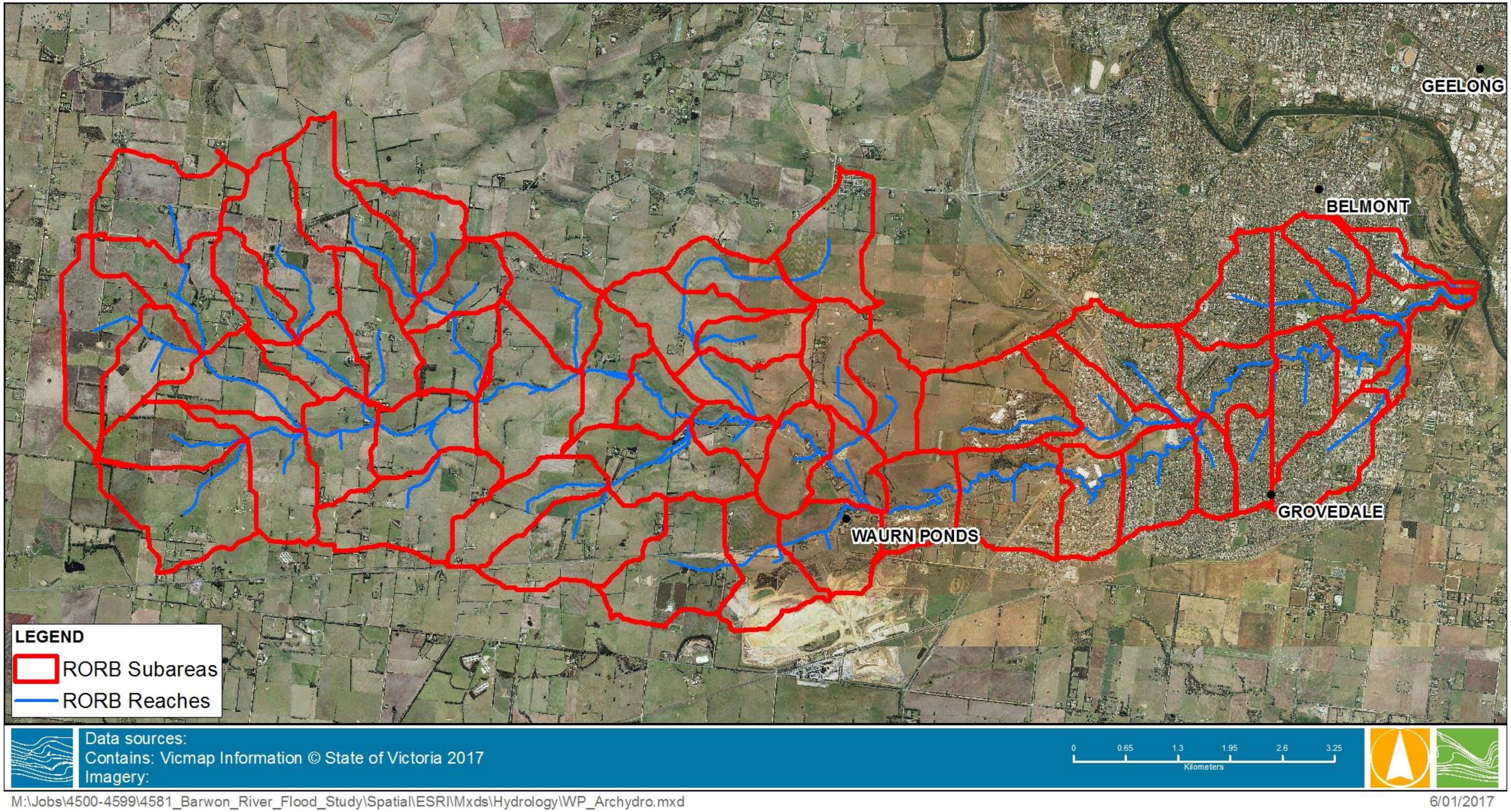


FIGURE 4-17 RORB REACHES AND SUB-CATCHMENTS

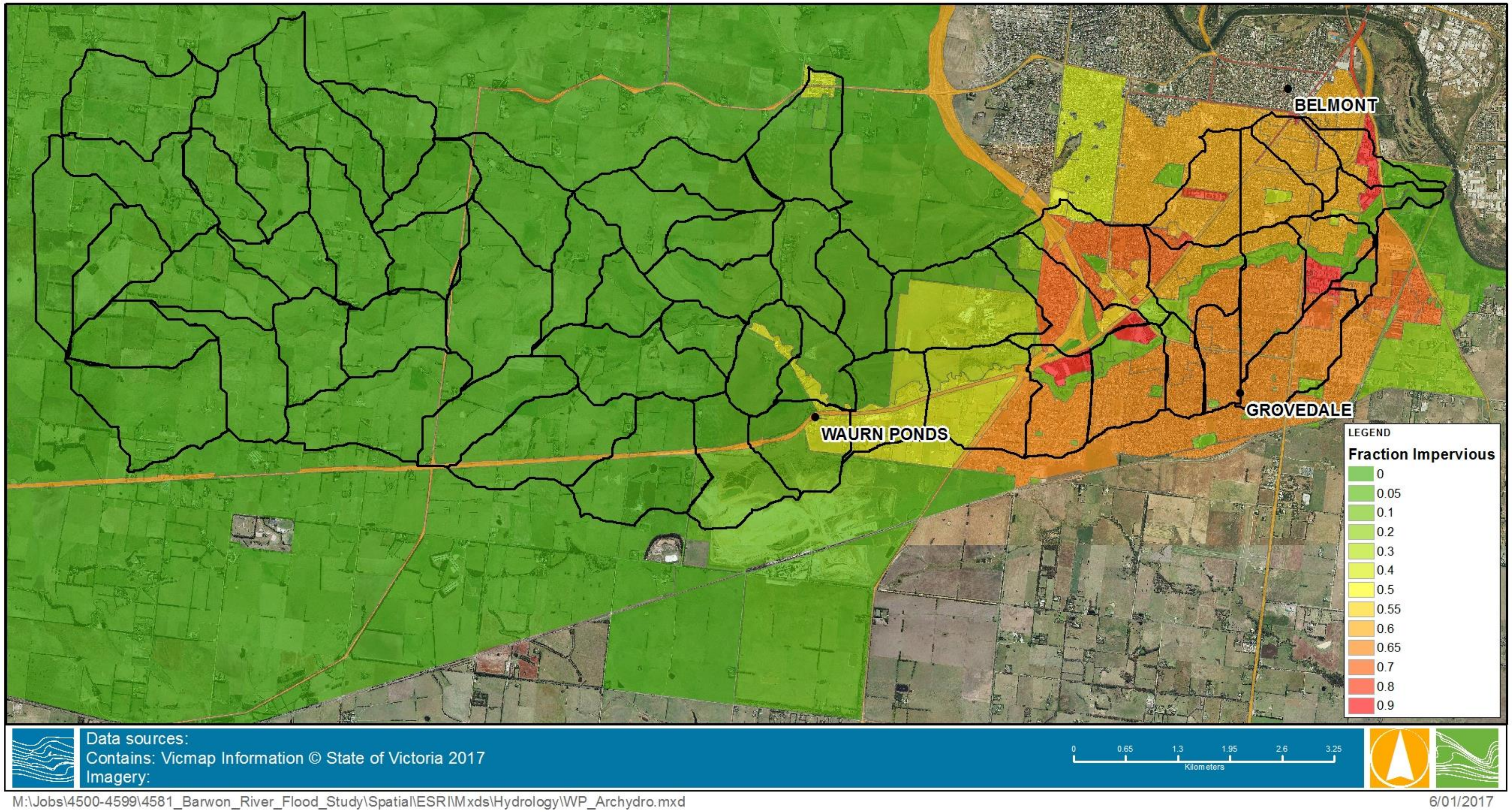


FIGURE 4-18 RORB FRACTION IMPERVIOUS

4.12 Local Tributaries

4.12.1 Introduction

A number of small, local tributaries are also to be flood mapped within this study and are shown in Figure 4-19. Many of the local tributaries have very small upstream catchment areas which means using a traditional methodology based on a rainfall runoff model has some limitations. Rainfall runoff models require a certain number of subareas to route through before being able to generate a hydrograph with appropriate routing characteristics. For this reason, a direct rainfall approach is to be adopted whereby rainfall will be applied directly to a hydraulic model across the entire catchment area of each local tributary. Direct rainfall on grid models allow the simulation of overland flow generated from rainfall applied directly onto a two-dimensional grid, representative of the site topography. Rainfall, minus some interception and infiltration losses, are applied directly to each grid cell within the model. Overland flow then moves across the grid based on the topography of the site and the runoff characteristics.

To ensure the rainfall on grid approach produces realistic flood behavior, peak flows near the outlet of the tributary was validated against the Vicroads Rational Method. This approach is widely used for urban flood modelling applications and is the most common approach for flood mapping urban areas across Greater Melbourne. Peak flow estimates in the Waurn Ponds Creek catchment were also validated against the Waurn Ponds Creek RORB model peak flows.

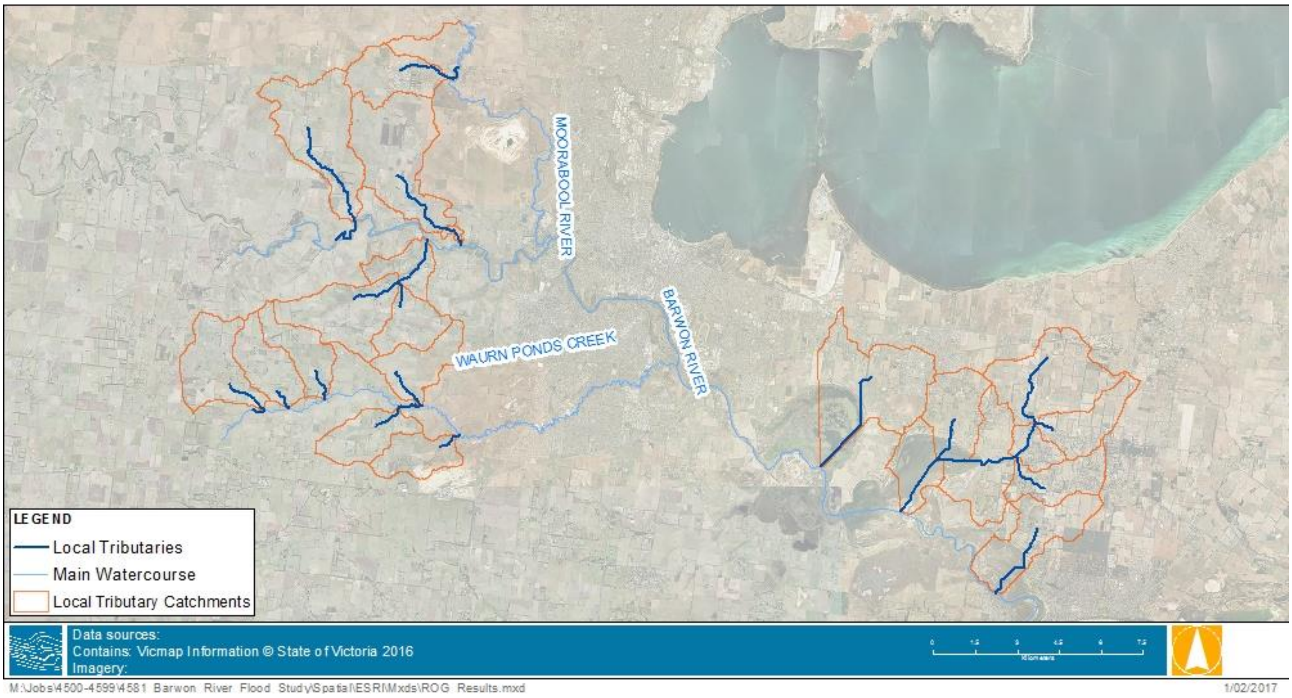


FIGURE 4-19 LOCAL TRIBUTARIES TO BE FLOOD MAPPED

The outputs from a rainfall on grid model are the same as per a traditional 2D hydraulic model with inflow boundaries from a traditional rainfall runoff hydrology model. The main difference is that because rainfall is applied to every grid cell in the model, every grid cell is shown as wet when a maximum depth map is generated. For this reason, the mapping undergoes a filtering process to remove shallow depths and small puddles. The result is a flood map, that that if the model is schematized well, and the inputs are good, should accurately represent overland flow off the catchment and flooding along the waterway.

There will be a higher level of detail in the model along the watercourse reaches to be mapped (as described in the project brief), with all bridges and key hydraulic structures accurately represented. There will be less detail of the broader catchment except where there is a significant hydraulic control, e.g. culverts under a railway line or major highway. The minor pit and pipe networks will not be incorporated into the modelling as the modelling is focused on the waterways not the catchment draining to the waterways.

The outputs from the local tributary modelling will be enveloped with the results from the main riverine hydraulic model to produce a single set of results.

The rainfall on grid modelling competed to date was based on a preliminary mosaiced DEM whilst new LiDAR of the catchment was being flown and processed. The preliminary modelling has shown that some areas of the mosaiced DEM which were based on coarse LiDAR were not suitable for this type of analysis. The direct rainfall modelling will be completed with the new LiDAR once the detailed Barwon modelling has been completed.

4.12.2 Model Build

To ensure reasonable model run times, three separate two-dimensional rain-on-grid models have been developed. The modelling will be undertaken using the package TUFLOW Classic which is widely used for flood mapping applications such as this.

The topography in the model is represented via the DEM and is developed by resampling the available high resolution LiDAR data. The proposed grid resolution is 5 m, which is sufficiently detailed to accurately represent the drainage behaviour while ensuring practical model run times.

Roughness maps, based on land use, were created for the entire study area and applied to each model. The map was developed using satellite imagery and has been refined manually based on aerial imagery. The applied Manning's values are shown in Table 4-43 and the roughness map shown in Figure 4-20.

TABLE 4-43 ROUGNESS VALUES

Land Use	Manning's n
Bare earth	0.03
Bitumen road	0.02
Dense vegetation/Trees	0.09
Dirt road	0.025
Fresh water	0.02
Light vegetation/trees	0.04
Ocean	0.02
Pasture	0.04
Urban	0.10

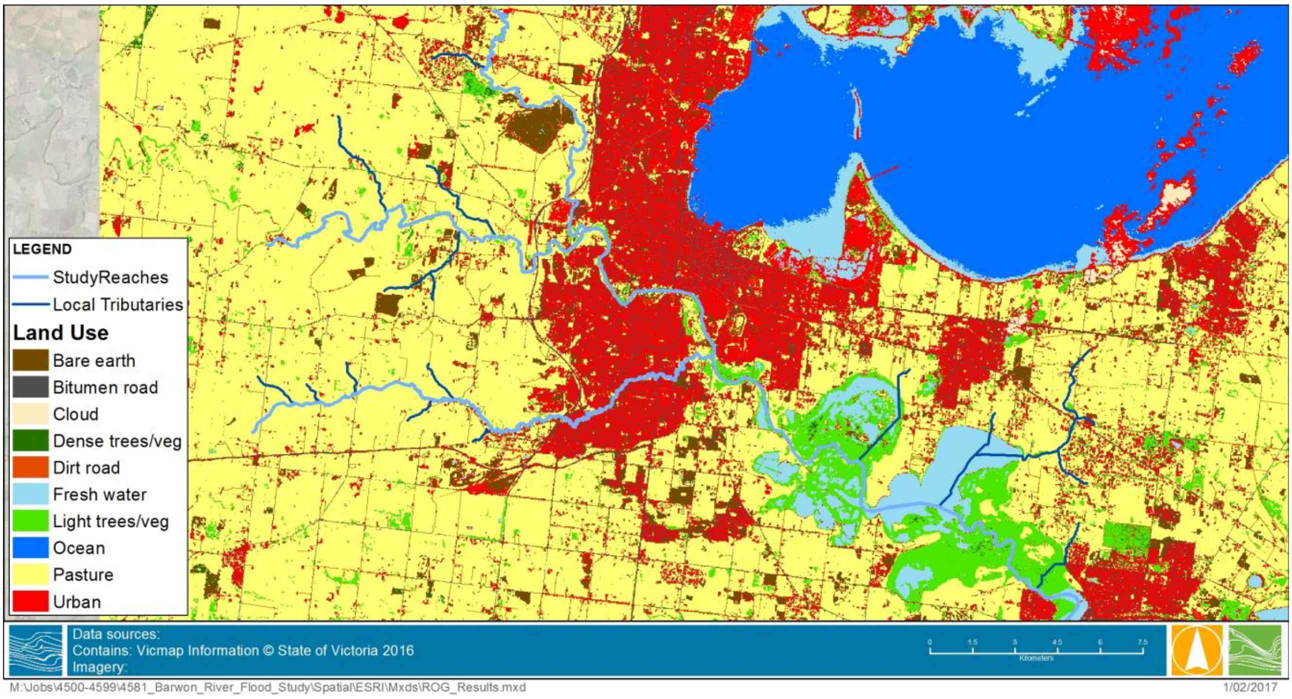


FIGURE 4-20 ROUGHNESS MAP FOR THE DIRECT RAINFALL MODELS

4.12.3 Boundaries

The key model boundaries consist of the rainfall inflow hyetographs and downstream boundaries applied near the confluence with the downstream main watercourses.

4.12.3.1 Rainfall

4.12.3.1.1 DESIGN RAINFALL DEPTHS

Design rainfall depth was determined using 1% AEP rainfall intensities which were obtained using the AR&R 2016 version of the Bureau of Meteorology's online intensity-frequency-duration (IFD) database[3]. Table 4-44 and Table 4-45 summarise the rainfall intensities and durations for the eastern and western local tributary catchments. Although only marginal, the estimated rainfall quantiles vary spatially, from west to east, within the study area with higher depths over the western catchments.

[3] BoM Online IFD Tool - http://www.bom.gov.au/water/designRainfalls/revised-ifd

TABLE 4-44 IFD RAINFALL DEPTHS (AR&R 2016) – WESTERN CATCHMENTS

	EY	Annual Exceedance Probability (AEP)					
Duration	1EY	50%	20%	10%	5%	2%	1%
1 hour	10.5	12.1	17.4	21.3	25.4	31	35.5
2 hour	13.5	15.5	21.7	26.2	30.8	37.2	42.3
3 hour	16.0	18.1	24.9	29.9	34.9	41.8	47.4
6 hour	21.6	24.2	32.4	38.4	44.4	53.1	60.0
12 hour	29.3	32.5	43.2	50.9	58.7	70.3	79.6
24 hour	38.1	42.7	57.5	68	78.7	94.5	107.3
48 hour	46.1	52.5	73.2	87.6	102.3	122.9	139.5
72 hour	49.7	57.1	81.1	97.9	115	137.9	156.1
96 hour	52.0	59.8	85.3	103.5	122	146.1	164.8
120 hour	53.8	61.7	87.4	106.3	125.6	150.3	168.9
144 hour	55.5	63.2	88.4	107.6	127.2	152.2	170.5
168 hour	57.4	64.7	88.7	107.8	127.5	152.6	170.5

TABLE 4-45 IFD RAINFALL DEPTHS (AR&R 2016) – EASTERN CATCHMENTS

	EY	Annual Exceedance Probability (AEP)					
Duration	1EY	50%	20%	10%	5%	2%	1%
1 hour	11.4	13.1	18.6	22.5	26.6	32.1	36.5
2 hour	14.8	16.8	23.3	28	32.7	39.2	44.3
3 hour	17.4	19.6	26.9	32	37.2	44.4	50.1
6 hour	23.3	25.9	34.7	41	47.4	56.6	64
12 hour	30.8	34.3	45.5	53.6	62	74.5	84.6
24 hour	39.3	44	59.2	70.3	81.8	98.8	112.5
48 hour	47.2	53.4	74.1	89.2	104.6	126.3	143.6
72 hour	51.1	58.2	81.8	99.2	116.8	140.5	159.1
96 hour	53.8	61.3	86.3	104.6	123.6	148.1	167.2
120 hour	56.2	63.8	89	107.5	127.1	152.1	171.3
144 hour	58.5	66	90.8	108.8	128.6	153.9	173.1
168 hour	60.9	68.1	91.9	109	128.9	154.3	173.6

4.12.3.1.2 RAINFALL LOSSES

To account for rainfall losses an initial/continuing loss model was applied to the rainfall depths. The initial loss represents rainfall which falls prior to the commencement of runoff and the continuing loss the ongoing infiltration losses which occur throughout a storm.

Losses were adopted from the Waurn Ponds Creek RORB model given it is located in close vicinity to most of the local tributaries, however the initial loss was halved. Results from previous direct rainfall modelling in similar studies has identified that considerably lower initial losses in direct rainfall modelling is required to achieved similar flood behaviour as traditional rainfall-runoff models such as RORB. This is predominately due to storage losses from the large number of small depressions across the catchment which aren't explicitly included within traditional lumped. rainfall-runoff models.

The adopted losses are shown in Table 4-46.

TABLE 4-46 ADOPTED LOSS RATES FOR DIRECT RAINFALL MODELLING

Initial Loss	Continuing Loss
5 mm	3 mm/hr

4.12.3.1.3 TEMPORAL PATTERNS

AR&R 2016 temporal patterns will be applied to the rainfall, with the same temporal patterns from the Monte Carlo RORB analysis for each applicable design event used in the Waurn Ponds Creek model. The full range of temporal patterns are provided in Appendix F.

4.12.3.1.4 SPATIAL PATTERNS

A uniform spatial pattern will be used given all catchments are either less than, or very close to, 20 km^2. AR&R 2016 recommends using a uniform pattern for catchment areas of less than 20 km^2.

4.12.3.2 Downstream Boundaries

To avoid water backing up at the model limits, rating curves are applied at the downstream boundaries of the three models. These boundaries are located on the main rivers and at a sufficient distance after the confluence with the tributary to not impact the results in the areas of interest. A H-Q boundary type was used in TUFLOW which determines a water level based on the discharge and local topography.

4.12.4 Validation

The local tributaries are all ungauged and so as a form of validation peak flows were compared against a range of estimation methods. The Vicroads rational method has recently been used for validation in other studies in the Geelong region and is deemed the most appropriate for validation in this study where there is a lack of gauged, historic data. It should be noted that in some locations significant differences are to be expected due to local hydraulics such as an upstream roadway or dam reducing peak flows.

The rational method validation points were located at the lower end of a number of the local tributaries. IFD parameters from the ARR 1987 were used as the rational method is designed to be used with the ARR 1987 values. The catchments were classed as either western or eastern catchments to determine appropriate IFD parameters. The eastern catchments consist of those running into the lower Barwon River near Lake Connewarre while the western catchment consist of tributaries of Waurn Ponds Creek, Moorabool River and the mid Barwon River.

Validation against the rational method was undertaken on six of the western catchments and three of the eastern catchments using the IFD parameters shown in Table 4-48. Three validation points were located in

Waurn Ponds Creek and were also validated against the Waurn Ponds Creek RORB model. The locations of the validation checks are shown in Figure 4-21 below. Validating flows to the Waurn Ponds Creek RORB further reduces uncertainty in the estimates. The results show that there is generally a reasonable correlations between the TUFLOW results and the rational method and/or RORB results. Greater differences are seen in the Lower Barwon tributaries which is a result of very significant storage losses in those catchments from dams and other hydraulic features such as roadways. Gradients are also very low in the lower portions of those catchments which further reduces peak discharges.

TABLE 4-47 RATIONAL METHOD IFD PARAMETERS (1987 AR&R)

Location	1 HR DUR 2 ARI	12 HR DUR 2 ARI	72 HR DUR 2 ARI	1 HR DUR 50 ARI	12 HR DUR 50 ARI	72 HR DUR 50 ARI	G (skewness)	F2 Geo factor 2 ARI	F50 Geo factor 50 ARI
West	17.3	3.17	0.86	37.9	6.55	1.94	0.42	4.29	14.84
East	17.4	3.37	0.88	37.1	6.73	1.97	0.42	4.28	14.85

West - Latitude: -38.136, Longitude: 144.273 East – Latitude: -38.202, Longitude: 144.446

TABLE 4-48 COMPARISON OF TUFLOW PEAK FLOW ESTIMATES TO REGIONAL AND RORB ESTIMATES

Catchment	Catch ID	Area (km^2)	East/West Catchment	1% AEP Flow Estimates (m^3/s)				
				Rational Adams	Rational VicRoads	RFFE	RORB	**TUFLOW RoG**
Mid Barwon	5	10.4	West	12.0	19.09	17.9	N/A*	11.3
	16	14.0	West	14.9	22.88	21.8	N/A*	7.8
	11	11.3	West	12.7	20.00	17.7	N/A*	16.8
Waurn Ponds Creek	96	4.60	West	6.56	12.26	8.23	7.39	10.8
	115	4.40	West	6.38	11.98	7.93	11.30**	7.2
	122	3.70	West	5.64	10.79	6.87	10.97**	5.6
	100	6.81	West	8.77	15.42	11.6	13.92	18.8
Lower Barwon	119	4.87	East	6.71	12.44	14.1	N/A*	4.5
	131	9.75	East	11.2	18.04	22.2	N/A*	6.6
	125	24.0	East	21.7	30.17	47.9	N/A*	21.6

* RORB results only available for Waurn Ponds Creek catchment
** Only 3 upstream subareas available – less accurate

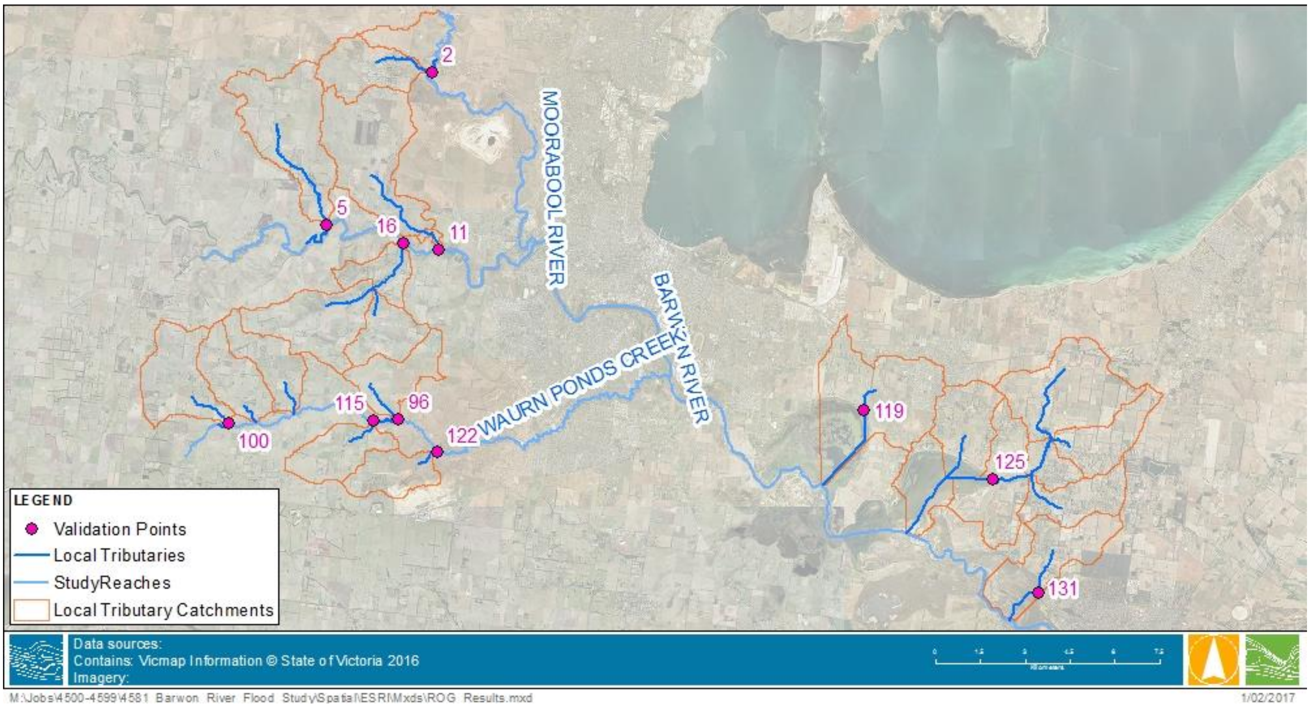


FIGURE 4-21 LOCAL TRIBUTARY HYDROLOGY VALIDATION POINTS

4.12.5 Summary

This section has detailed the direct rainfall methodology that was adopted for the hydrological and hydraulic analysis of the local tributaries to be flood mapped. A direct rainfall approach was adopted due to the limited upstream catchment areas of the watercourses to be mapped, which makes a traditional hydrology approach challenging. Flow estimates were compared against a range of regional estimation techniques including the Vicroads rational method, to ensure the approach is producing realistic peak flows.

A full range of mapping outputs has been provided for the local tributaries including maps of peak depths, water levels, velocities and hazard. These are described further in the study report.

5 CLIMATE CHANGE ANALYSIS

It is now generally accepted that changes in weather patterns and ocean levels are observed and predicted as a result of climate change. In considering how the nature of climate change may influence design flood hydrology a number of factors which influence these assessments must be considered.

The following factors are likely to be influenced by the effect of climate change and will directly impact on climate change related flood modelling.

- Rainfall Intensity and distribution
- Antecedent conditions and baseflows
- Storm surge and coastal water levels

Having considered the most up to date science at the time of development the new ARR (2016 provides guidance on how these factors should be considered.

There are a range of scenarios that have been predicted as part of forecasting by the CSIRO. The climate change projections undertaken by the CRISO are broken down into Natural Resource (NRM) Clusters (Figure 5-1). The Barwon River catchment falls into the Southern Slopes Mainland NRM Cluster.

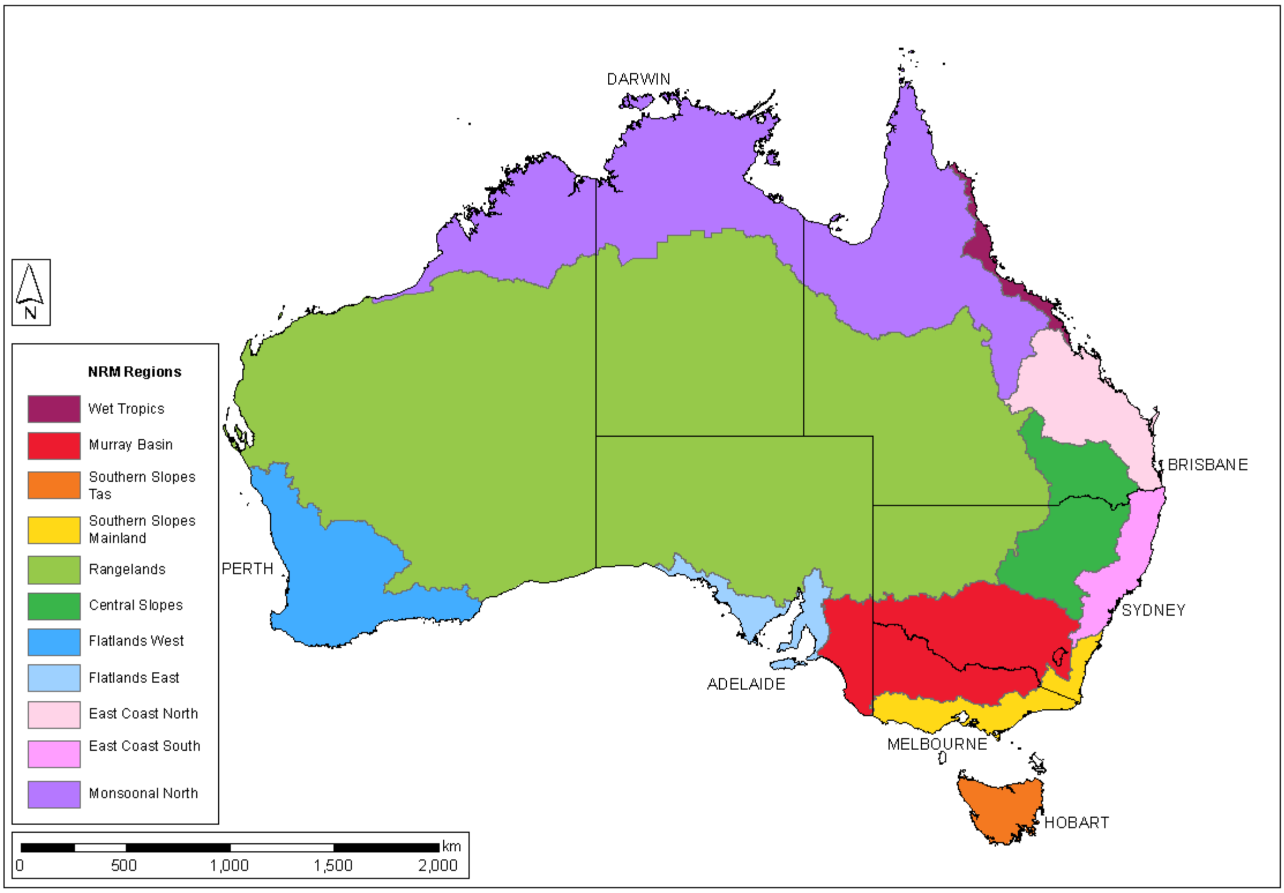


FIGURE 5-1 NATURAL RESOURCE MANAGEMENT CLUSTER LOCATIONS

The Representative Concentration Pathways (RCP) for greenhouse gas and aerosol concentrations that are used to drive the global climate models. The Climate futures websites enables interrogation of the various climate model results across a range of factors. For the purposes of this assessment consideration is being given to the likely changes in rainfall intensity of various time periods and varying degrees of sea level rise.

The ARR datahub tool allows for the extraction of catchment-based data relevant to the NRM cluster region and predicted temperature increases and corresponding increases in rainfall intensity.

The RCPs provided in ARR are for 4.5,6 and 8.5 which represent low, moderate and high concentrations, respectively. The following table therefore shows the range of possible rainfall intensity increases for the Southern Slopes Mainland NRM Cluster.

TABLE 5-1 INTERIM CLIMATE CHANGE FACTORS

	RCP 4.5	RCP 6	RCP 8.5
2030	0.719 (3.6%)	0.739 (3.7%)	0.822 (4.1%)
2040	0.925 (4.6%)	0.915 (4.6%)	1.119 (5.6%)
2050	1.123 (5.6%)	1.085 (5.4%)	1.449 (7.2%)
2060	1.271 (6.4%)	1.294 (6.5%)	1.865 (9.3%)
2070	1.394 (7.0%)	1.526 (7.6%)	2.333 (11.7%)
2080	1.477 (7.4%)	1.778 (8.9%)	2.776 (13.9%)
2090	1.527 (7.6%)	2.009 (10.0%)	3.21 (16.1%)

In assessing the likely changes in rainfall intensity as part of the climate sensitivity assessment will include consideration of rainfall intensity increases of 5,10 and 15 % in line with RCP 8.5 for 2040, 2060 and 2090 respectively. These also align closely with the brief specified coastal sea level rise scenarios of +0.2, +0.5 and +0.8 metres. The results of the climate change analysis are discussed in the study report.

6 SUMMARY

This report is the second technical report of the Lower Barwon River and Lower Moorabool River Flood Study. The report details the recommended adopted hydrological inputs for the hydraulic modelling phase of the project. This includes recommend design flows for the Barwon River at Pollocksford and Geelong and the Moorabool River at Batesford based on Flood Frequency Analysis and extensive sensitivity analysis.

The report also documents the modelled RORB outflows from Waurn Ponds Creek as well as the Rainfall-on-Grid approach proposed for the local tributaries which have been mapped as part of this study.

7 REFERENCES

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APPENDIX A
AVAILABLE DATA

Available Data

Streamflow

There are a number of streamflow gauges within the study area and greater catchment. Streamflow gauges play a vital role in the development and calibration of hydrology and hydraulic model components to flood studies. Of specific importance to this study are the following gauges which will provide the basis of model inflows for the main reaches within the hydraulic model:

- Barwon River @ Pollocksford (Section 4.2)
- Moorabool River @ Batesford (Section 4.3)
- Barwon River @ McIntyre Bridge (Section 4.4)

The location of these gauges is shown in Figure A-1 and are summarised in Table A-1 . Given the size of both the Moorabool River and Barwon River catchments there are many gauges which record stream flow data on these rivers and their tributaries within the catchment.

TABLE A-1 STREAMFLOW GAUGES

Station No:	Station Name	Catchment Area (km^2)	Period of Record
233217	Barwon River @ Geelong	3925	Irregular Record 1850s -2016
233200	Barwon River @ Pollocksford	2713	1906-2016
232202	Moorabool River @Batesford	1088	1908-2016
233215	Leigh River @ Mt Mercer	593	1956 - 2016
233213	Leigh River @ Shelford	839	1954 - 1962 2011 - 2016
233224	Barwon River @ Inverleigh	593	1961 - 2016
233218	Barwon River @ Rickets Marsh	1,269	1971 - 2016
233201	Barwon River @ Winchelsea	1,052	1922 - 2016
232204	Moorabool River @ Morrisons	575	1945 - 2016
233223	Warrambine Creek @ Warrambine	839	1970 - 2016

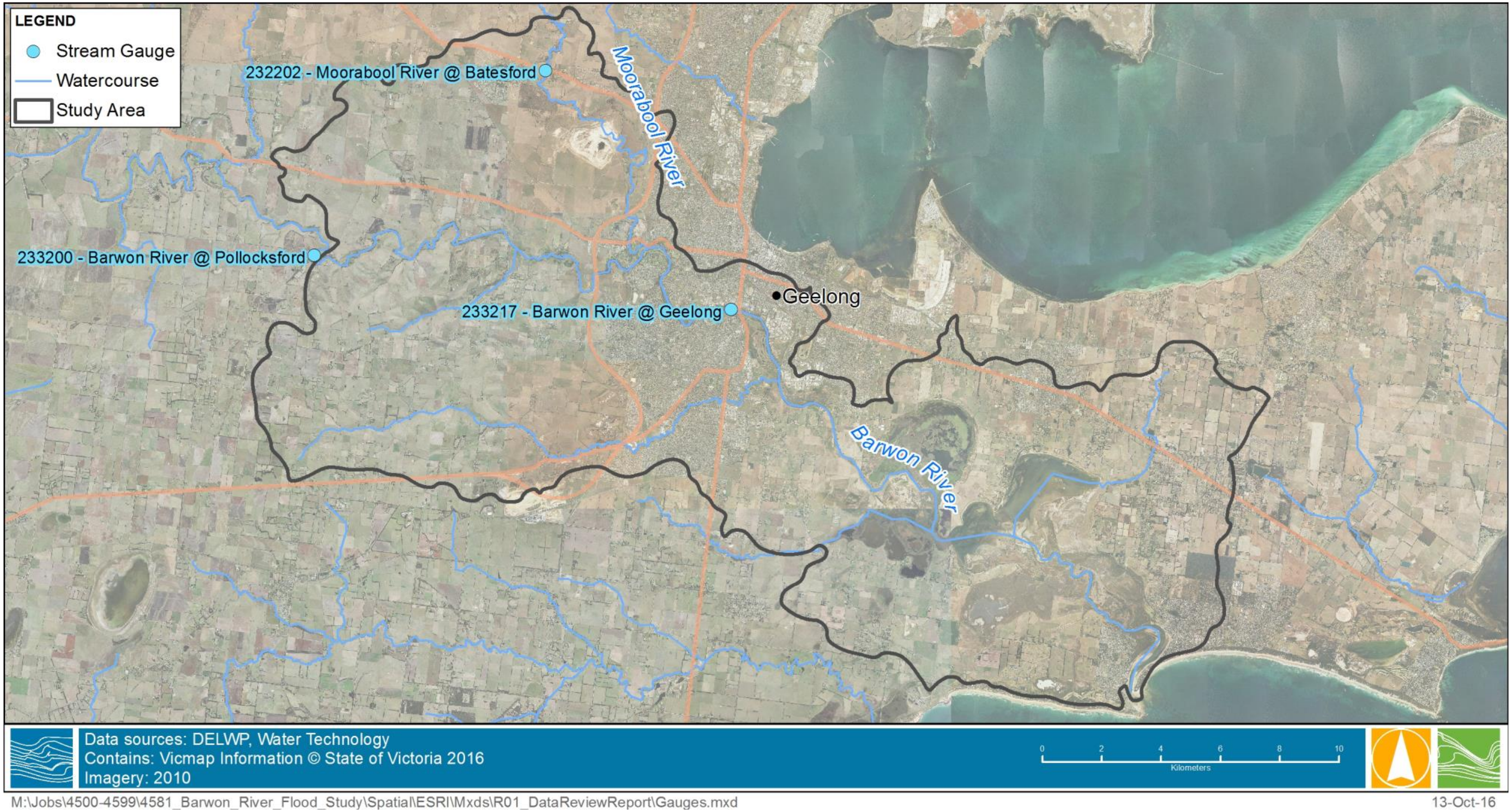

FIGURE A-1 STREAMFLOW GAUGE LOCATIONS

Barwon River at Pollocksford Gauge

The Barwon River gauge at Pollocksford (site No. 233200) is located within a relatively narrow confined section of the Barwon River. At this location the size of the upstream catchment is estimated to be approximately 2,713 km². Gauging at this location commenced in 1906, with the gauge itself having moved several times since records began. Table A-2 summarises the various locations of the gauge over the period of record. Table A-3 identifies the variation in the gauge zero datum at the various sites.

TABLE A-2 BARWON RIVER AT POLLOCKSFORD GAUGE DESCRIPTION

Record Period	Location	Control Structure	Recorder
1906 - 1922	Site A	Gravel and Clay	Manual Daily Readings
1922 - 1969	No Record	No Record	No Record
1969 - 1972	Site B	Rock and Boulders	Recorder
1972 - Current	Site B	Concrete Hump	Recorder

TABLE A-3 BARWON RIVER AT POLLOCKSFORD GAUGE ELEVATION AT ZERO HEIGHT

Record Period	Gauge Height at Zero
May 1969 to July 1986	24.074 Meters AHD
July 1986 to October 1986	24.156 Meters AHD
October 1986 to Current	24.074 Meters AHD

While the gauge record at this location extends from 1906 to current day, there is a significant period of 'no record' from 1922 to 1969. This is observed in the continuous height and flow data as displayed on the DELWP Water Information Monitoring System[2] and is clearly shown in Figure A-2 .

The current rating table at this location was last updated in October 2012 (Figure A-3). A significant portion of the rating table is extrapolated. The reliability of the rating table based on the stage height is shown in Table A-4 . The maximum gauged event for construction of the rating curve was measured at 8.998 m which occurred on 7/11/1995. Larger stage heights have been recorded over the gauges history, with the 1909 and 1995 events recording levels 9.601 and 9.054 m respectively. Figure A-4 shows all historic gauging measurements completed. The scatter in the gauging points for lower flows most likely represents the difference in the river heights gauged at the Site A and B locations over the gauges history.

Given that there was a gauging measurement completed during a high flow event in 1995, with a stage height of 8.998 m, the rating curve is likely more accurate than the description provided in Table A-4 . The rating curve quality codes state that the rating curve is extrapolated beyond a stage height of 5.50 m. It is likely that this extrapolation is reasonably accurate given the high flow gauging that has been used to extrapolate the curve through.

TABLE A-4 POLLOCKSFORD GAUGE RATING TABLE RELIABILITY

Gauge Stage Range (m)	Reliability Description
0.2 – 3.21	Reliable
3.21 – 3.59	Rating Extrapolated within x1.5 max flow
3.59 – 5.50	Rating based on measurements > 20 years old
5.50 – 9.1	Rating table extrapolated

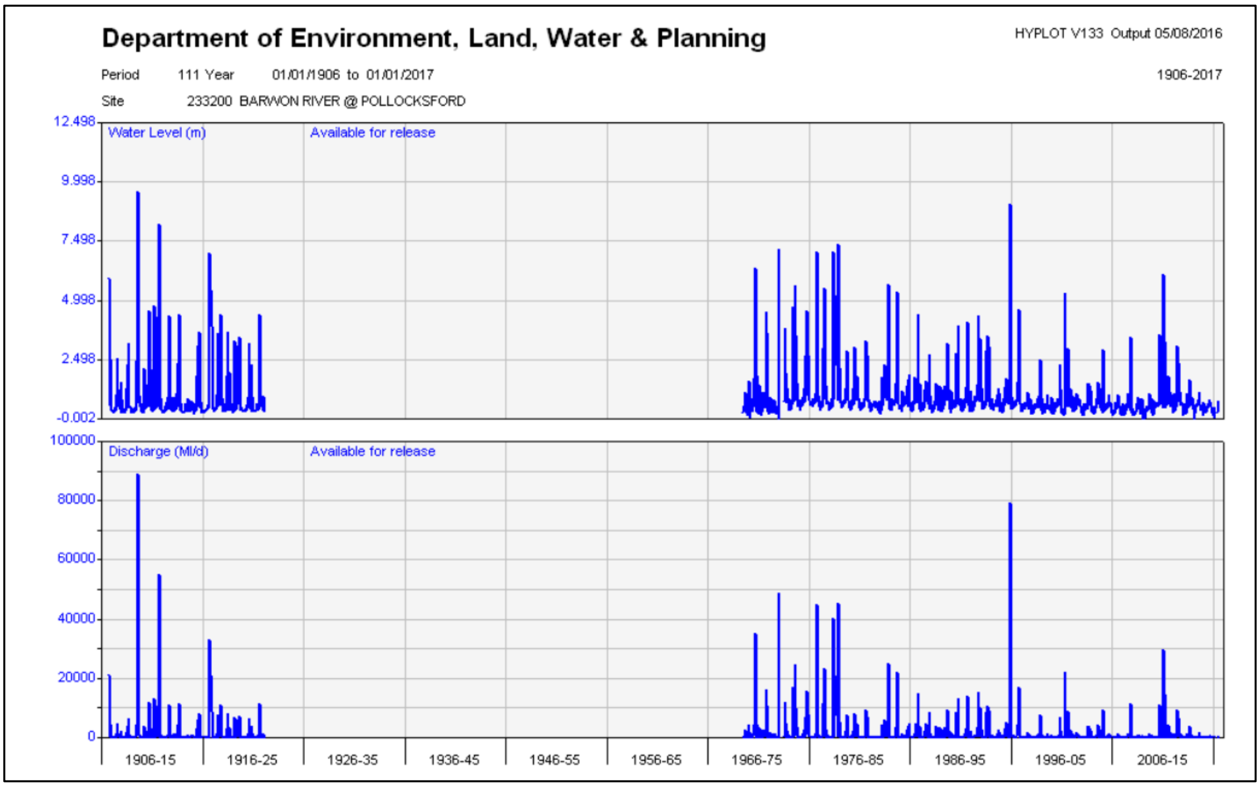

FIGURE A-2 BARWON RIVER @ POLLOCKSFORD GAUGE RECORD

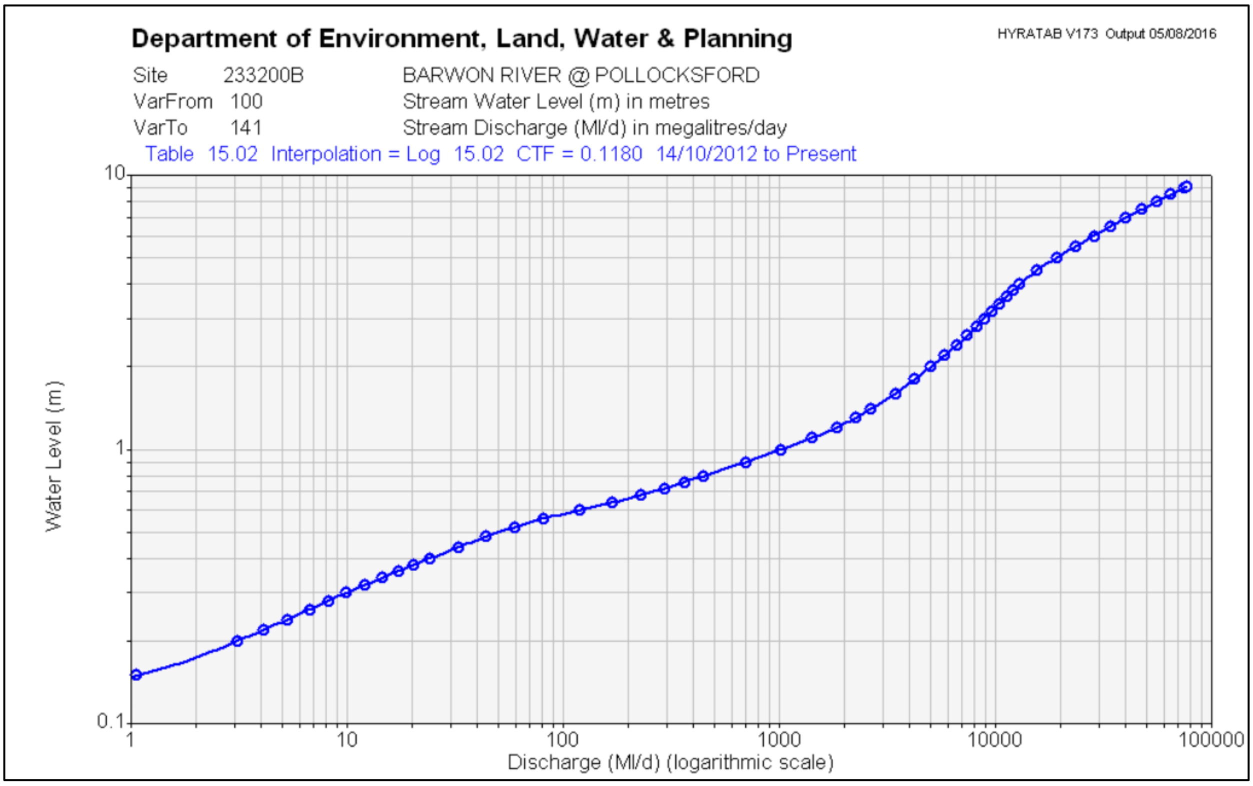

FIGURE A-3 BARWON RIVER @ POLLOCKSFORD GAUGE RATING CURVE

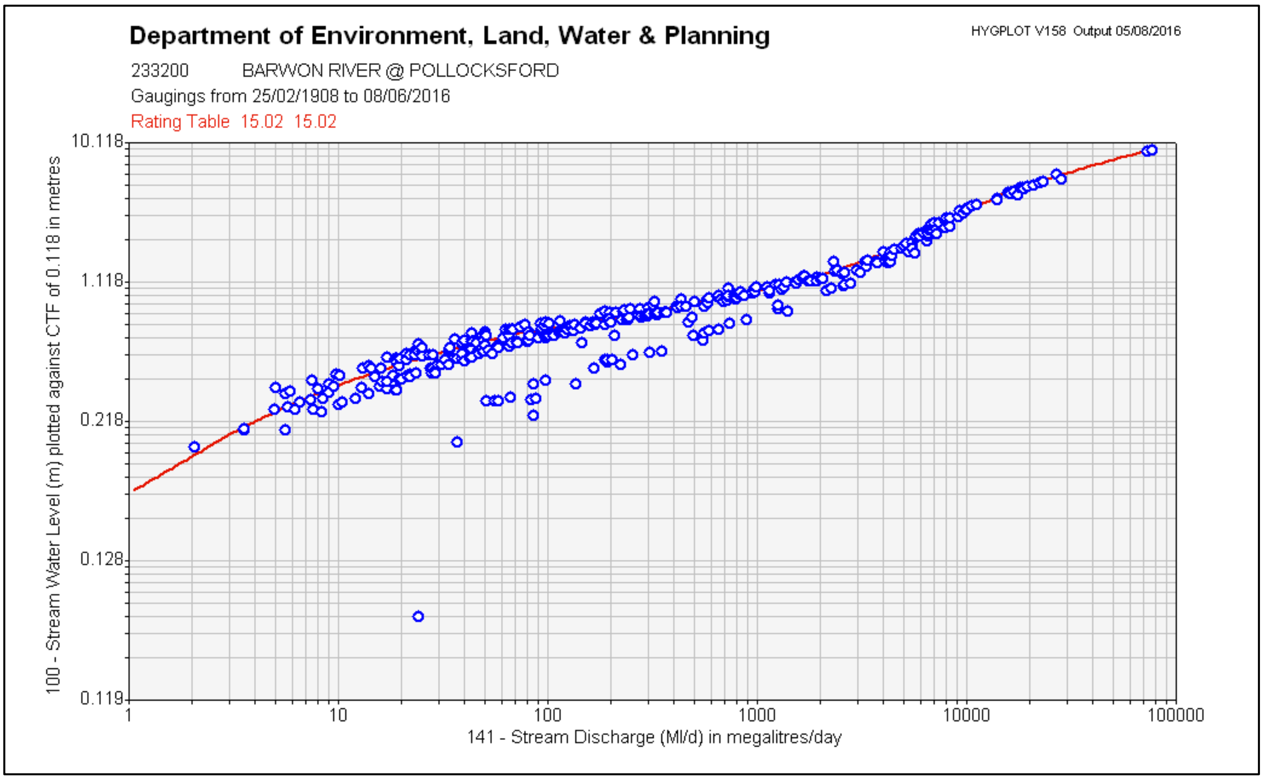

FIGURE A-4 BARWON RIVER @ POLLOCKSFORD GAUGE ALL HISTORICAL GAUGINGS

Moorabool River at Batesford Gauge

The Moorabool River gauge (site No. 232202) is located at the Midland Hwy in Batesford. The highway bridge is a dual carriageway. The upstream catchment at the gauge location is approximately 1,088 km².

The location of the gauge at Batesford has moved several times over the period of record and this is summarised in Table A-5 . Site A is the original location immediately downstream of the Midland Highway bridge, with the gauge moving to Site B, 2.5 km downstream (referred to as "Lynnburn"), and then moving back to Site A.

TABLE A-5 MOORABOOL RIVER @ BATESFORD GAUGE DESCRIPTION

Record Period	Location	Control	Recorder
1908 - 1921	Site A	Gravel	Manual Daily Readings
1922-1944	No Record	No Record	No Record
1945-1953	Site A	Gravel	Manual Daily Readings
1953-1957	Site B	Concrete Weir	Manual Daily Readings
1959 – 1967	Site A	Concrete Weir	Recorder
1967- Current	Site A	Concrete Weir	Recorder

Table A-6 shows the gauge zero for Site A, applicable since 1959.

TABLE A-6 MOORABOOL RIVER @ BATESFORD GAUGE ELEVATION AT ZERO HEIGHT

Record Period	Gauge Height at Zero
1959 to Current	17.11 Meters AHD

The gauge record extends from 1908 to present, however a large amount of data from 1921 to 1945 and 1953 to 1959 is absent from the record. This is observed in the continuous height and flow data as displayed on the DELWP Water Information Management System and is shown in Figure A-5 .

The current gauge rating curve is shown in Figure A-6 . The upper portion of the rating table is extrapolated. The reliability of the rating table based on the stage height is shown in Table A-7 . The maximum gauging was measured at 4.247 m on 20/11/1978. Since 1959 7 events larger than the maximum gauged flow have been recorded, with the 1995 event the largest at 5.440 m. A stage height of 6.096 m was recorded in 1952 at Site A, however this was prior to the concrete weir being installed at the gauging location, so there is some uncertainty regarding how this height corresponds to the current day heights.

All historical gaugings can be observed along with the current rating curve in Figure A-7 . The gaugings showing some scatter at the lower end, however this does not impact on the flood flow record.

The rating curve does not appear to extend out to cover some of the largest events recorded, with the rating curve stopping at 4.80 m. It is likely that the extrapolated rating curve is of reasonable quality as it has the gauged event at 4.247 m to extrapolate through. The reliability of the flow estimates for the 1995 and 1952 events are uncertain as they exceed the rating curve and were most likely based on estimates using an unofficial extrapolation of the existing rating curve at the time or from hand calculations.

TABLE A-7 BATESFORD GAUGE RATING TABLE RELIABILITY

Gauge Stage Range	Reliability Description
0.40 – 1.60	Reliable
1.61 – 2.39	Rating extrapolated within 1.5 x max flow
2.40 – 4.80	Rating table based on measurement greater than 20 years old

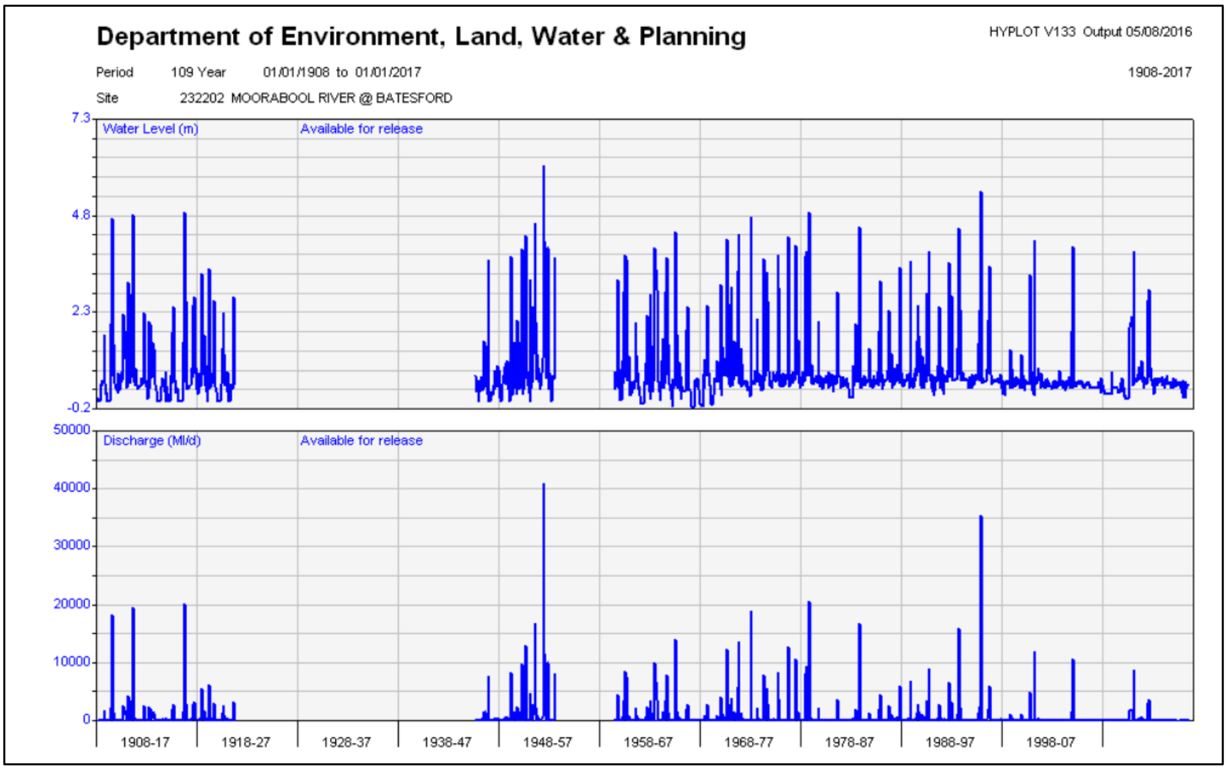

FIGURE A-5 MOORABOOL RIVER @ BATESFORD GAUGE RECORD

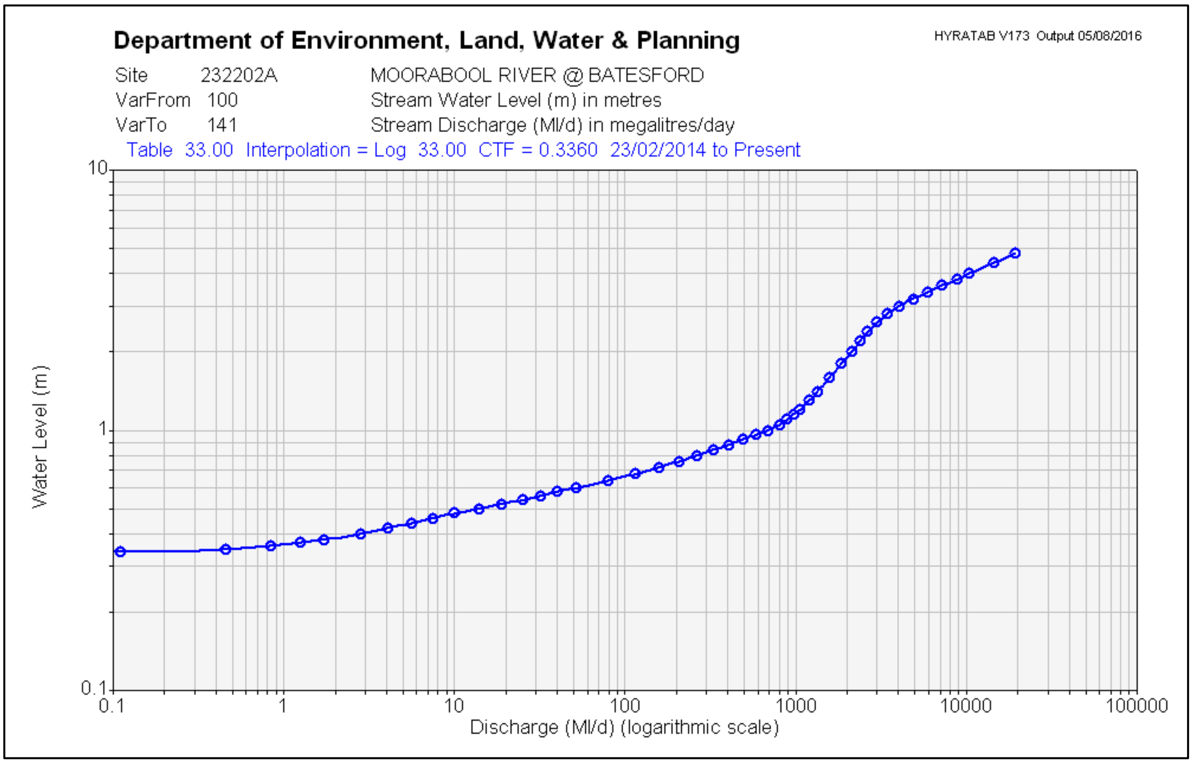

FIGURE A-6 MOORABOOL RIVER @ BATESFORD GAUGE RATING CURVE

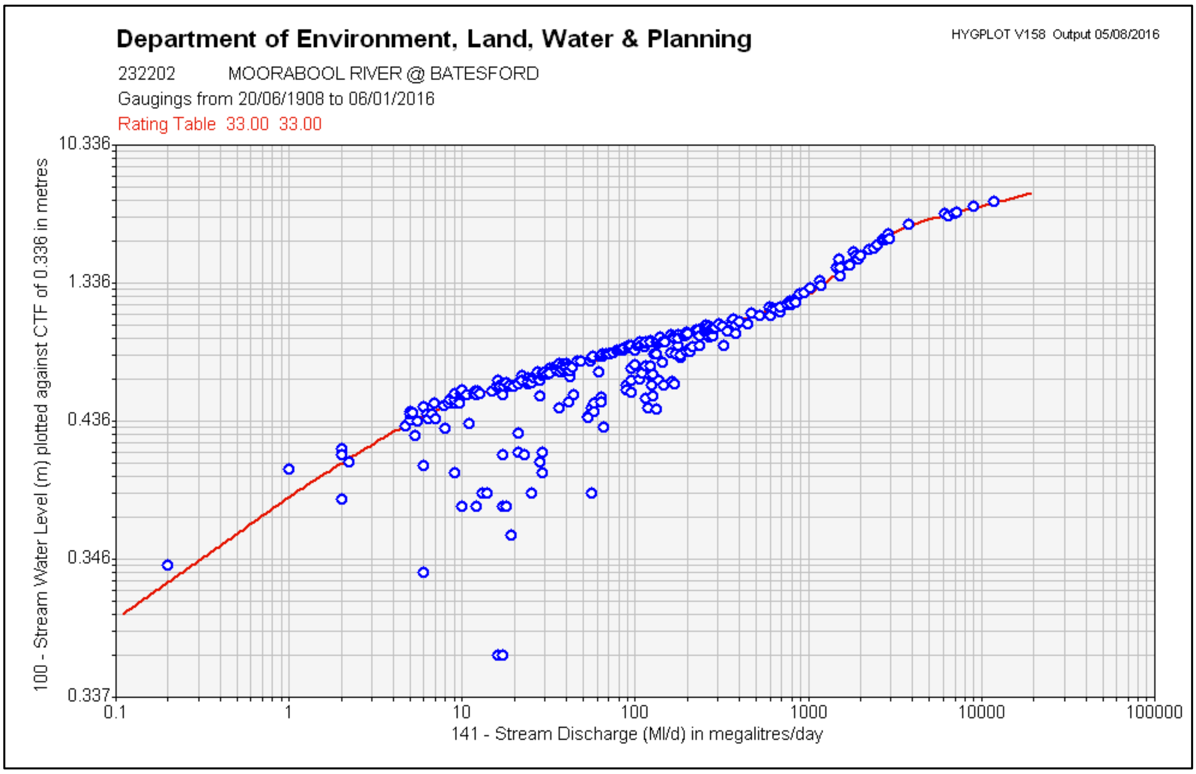

FIGURE A-7 MOORABOOL RIVER @ BATESFORD GAUGE ALL HISTORICAL GAUGINGS

Barwon River at Geelong (McIntyre Bridge)

The Barwon River gauge at Geelong, colloquially referred to as the McIntyre Bridge gauge (Site No. 233217) is located within the main rowing mile of the Barwon River through Geelong. The upstream catchment at this point is estimated to be 3,925 km².

Gauging of the Barwon River through Geelong has occurred at a number of locations throughout this reach of the river. Records indicate at least four different sites have been used to record river height and flow data over the past 55 years. This data is shown in Figure A-8 . The four known sites are described in Table A-8 .

The current site is located at McIntyres Bridge in Newtown, on a section of the river where it becomes less confined, with a small floodplain on the southern bank.

TABLE A-8 GAUGE PERIOD AND LOCATION

Record Period	Location	Control	Recorder
1960-1985	Site A - At the Princess Highway Bridge	Natural	Manual Readings – Flood Only
1961-1969	Site B - Ford at the Railway Bridge, Tucker Street Breakwater	Concrete Ford	Manual Readings – Daily
1978-1985	Site C - Downstream of Queens park Bridge (400meters)	Natural - Gravel	Recorder
1977-current	Site D - McIntyre Bridge (Current location)	Natural	Recorder

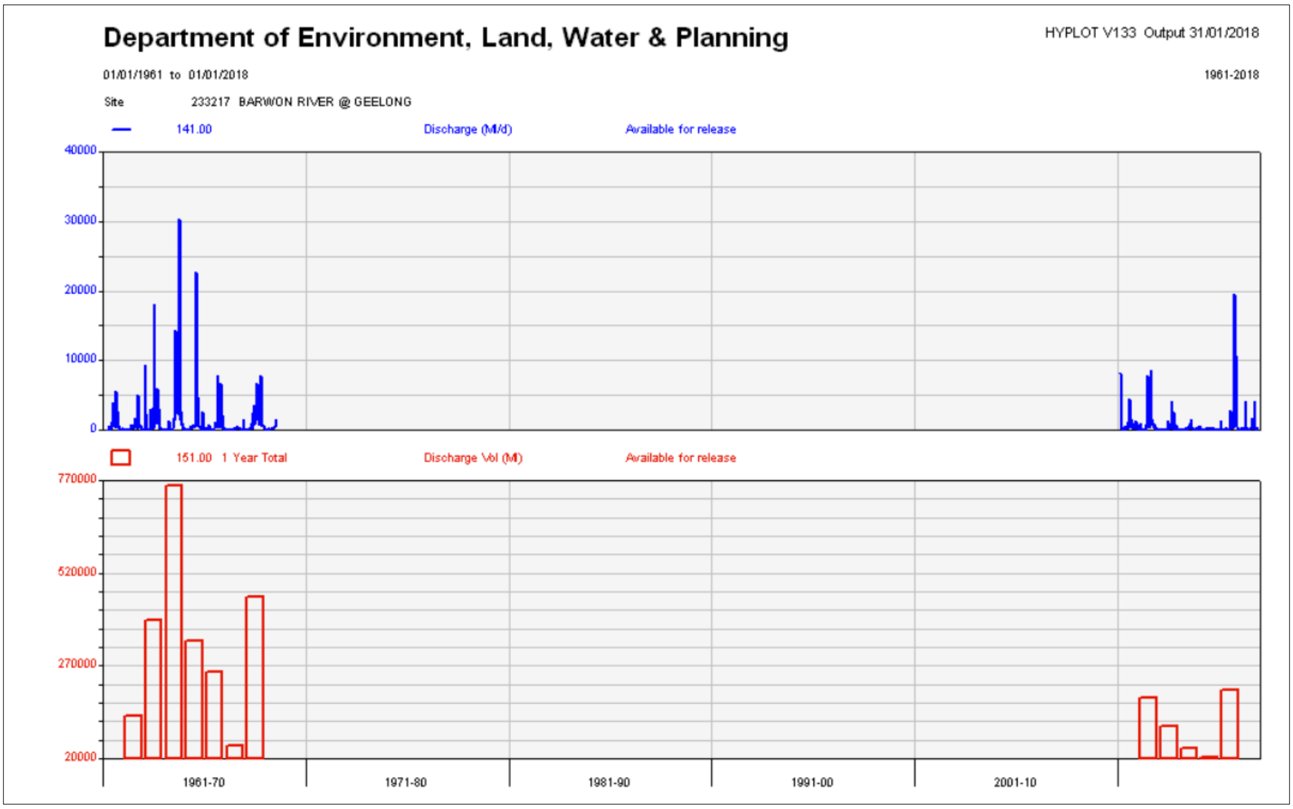

FIGURE A-8 BARWON RIVER @ GEELONG GAUGE RECORD

The rating table for the Barwon River gauge at Geelong is based on relatively few gauging events spread across multiple site locations. For this reason, it is considered that the rating curve may be somewhat unreliable. The current rating curve is shown in Figure A-9 , with the rating curve and all historic gauging events shown in Figure A-10 . The upper portion of the rating table is extrapolated. The reliability of the rating table based on the stage height is shown in Table A-9 . The maximum gauged measurement at this location was taken at a stage height of 4.054 m which occurred on 7/2/1973.

Given the lack of gauging, the rating curve at this location is uncertain at high flood flows. Having regard for this further investigation of the rating curve in relation to recorded stage height levels will be undertaken as part of the hydraulic modelling component of this study.

TABLE A-9 BARWON RIVER AT GEELONG GAUGE RATING TABLE RELIABILITY

Gauge Stage Range	Reliability Description
1 – 2.4	Reliable
2.4 – 3.19	Rating Extrapolating within x 1.5 max flow
3.2– 4.8	Rating based on measurements > 20 years old
4.8 – 5.6	Rating table extrapolated

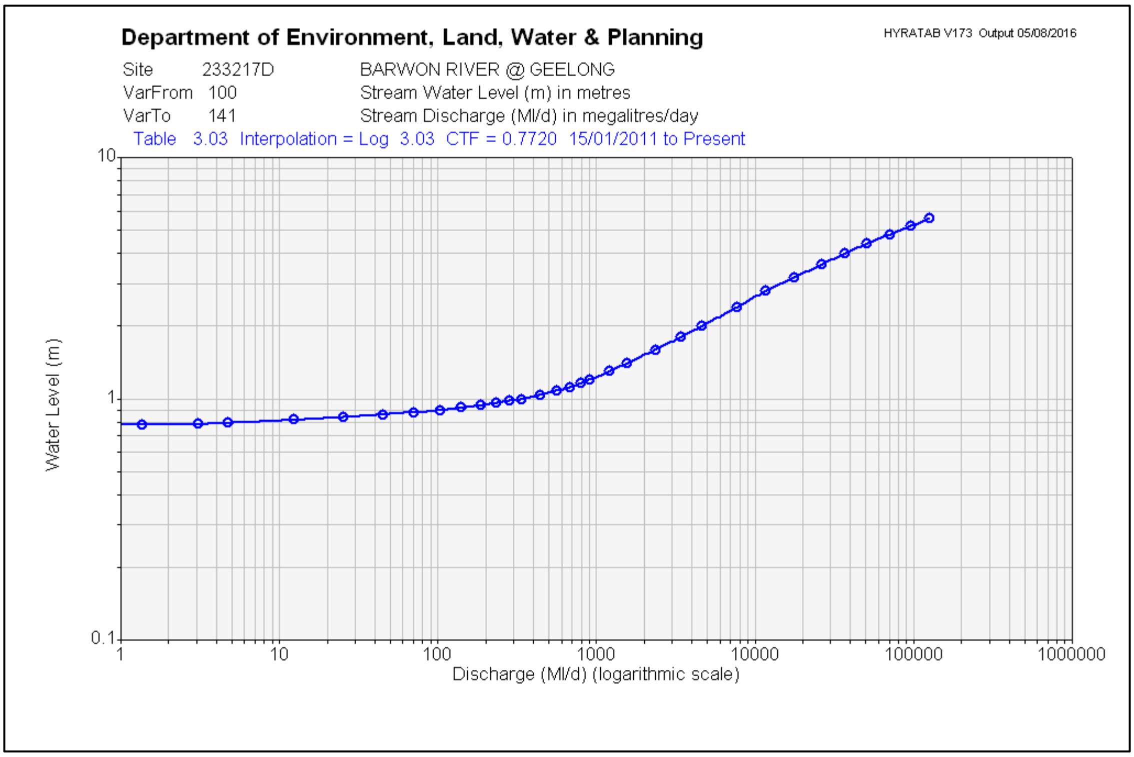

FIGURE A-9 BARWON RIVER @ GEELONG GAUGE RATING CURVE

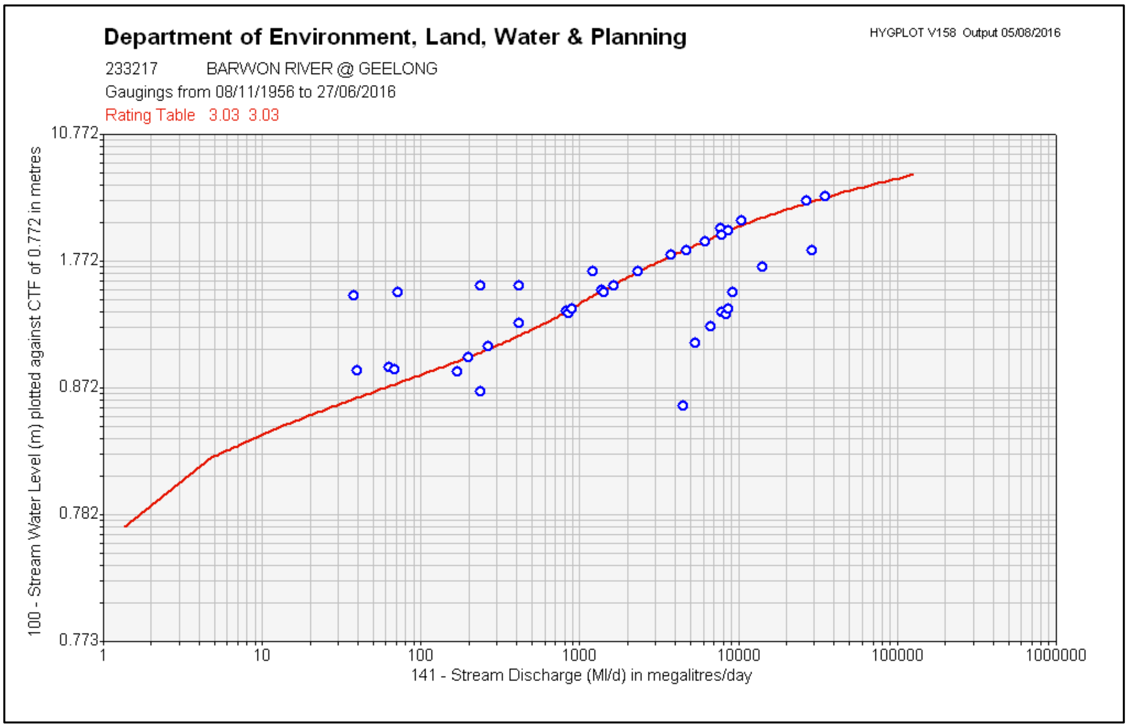

FIGURE A-10 BARWON RIVER @ GEELONG GAUGE ALL HISTORIC GAUGINGS

APPENDIX B
FLOOD FREQUENCY ANALYSIS
BARWON RIVER AT POLLOCKSFORD

Flows Analysis – Barwon River @ Pollocksford

Whilst the gauge at Pollocksford has a long reliable record, prior to 1969 no sub daily flow record exists. Available flow records in most cases are based on mean daily flow record or event-based records. The issue with this is that if only a mean daily flow is available, it often underestimates the instantaneous peak flow, as a flood may rise and fall within a day. A regression analysis of the available sub-daily discharge data was undertaken, and the mean daily/max daily flow relationship developed.

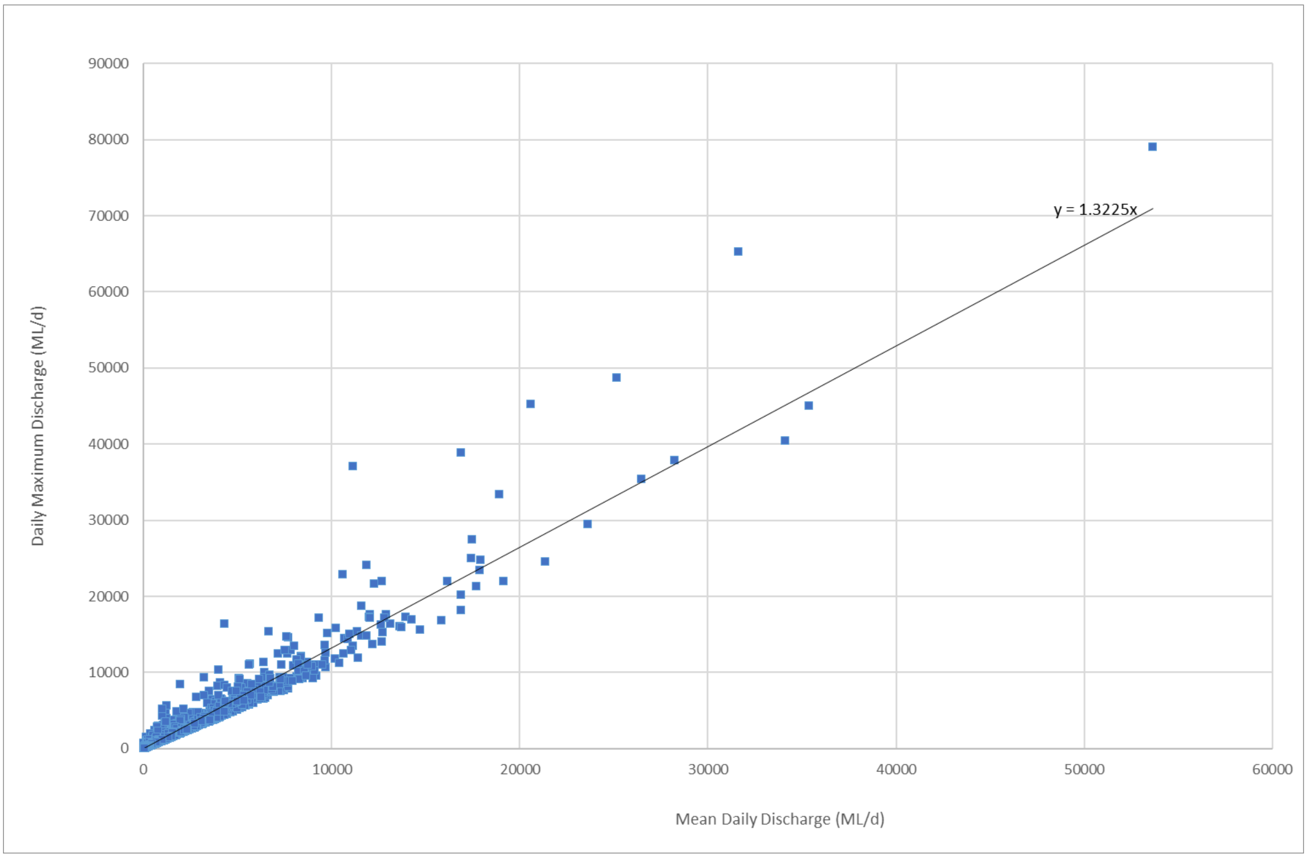

FIGURE B-11 POLLOCKSFORD GAUGE REGRESSION ANALYSIS

For the period of record where mean daily data was only available the record has been scaled in accordance with the regression equation Y=1.3225X, with Y being the daily maximum instantaneous and X being the mean daily discharge.

The available mean daily flows were scaled to provide an estimated maximum daily flow and an annual series developed for these results. A comparison of the scaled annual series, the annual maximum flows provided by the DELWP Water Measurement Information System and the Victorian Surface Water Information to 1987 – Volume 2 (Rural Water Commission of Victoria) annual instantaneous maximum flow record is provided in the table below .

The comparison indicates a reasonable fit between the scaled mean daily flows and those recorded from both the DELWP database and Rural Water Commission historic record.

TABLE B-10 COMPARISON OF AVAILABLE ANNUAL SERIES DATA (1909-1922)

Year	Mean Daily Scaled Flow (ML/d) Y= 1.3225x	Annual Maximum Flow (ML/d) (DELWP)	Rural Water Commission Max Instantaneous (ML/d)
1906	23,906	21,245	21,200
1907	5,573	4,562	5,220
1908	7,098	6,321	-
1909	84,909	89,083	89,600
1910	12,407	11,965	11,900
1911	45,911	54,990	55,200
1912	13,758	11,070	11,000
1913	12,474	11,325	-
1914	1,089	889	-
1915	8,484	7,898	7,890
1916	38,573	33,248	36,500
1917	9,105	11,202	-
1918	10,028	7,898	-
1919	9,387	7,138	-
1920	7,793	6,321	-
1921	10,956	11,325	11,200
1922	1,242	1,174	-

Upon further discussion with Corangamite CMA it was decided not to use the scaled flow record in the adopted FFA analysis. The Corangamite CMA were confident that the values recorded in the rural water commission are representative of the highest flood level that occurred, particularly in the larger flood events. It was deemed more accurate to use the Rural water Commission values.

Flood Frequency Analysis

The Flood Frequency Analysis for the Pollocksford streamflow record was completed using two periods of record (entire record and post construction of the East Barwon Dam). Low flow censoring and pre-record historic event threshold censoring was also used. Each of the relevant analysis is discussed below.

Post Dam Construction Flood Frequency Analysis

The gauge record post construction of storages in the upper catchment from 1973-2015 was used to complete a flood frequency analysis on the peak flow annual series in FLIKE.

The analysis was completed on a raw annual peak flow series and a modified annual series with low flow censoring to remove years of low flow using the Multiple Grubbs Beck test. This determined a low flow threshold of 2,615 ML/d, removing 9 years from the 43-year record. The top 5 ranked (highest to lowest) flow events are shown in below.

TABLE B-11 POLLOCKSFORD RANKED PEAK HISTORICAL FLOW EVENTS

Year	Peak Flow (m^3/s)	Peak Flow (ML/d)
1995	915	79,030
1973	564	48,722
1978	524	45,247
1976	521	45,026
2011	468	29,460

The Log Normal (LN), Log Pearson Type 3 (LP3), Generalised Extreme Value (GEV), Generalised Pareto (GP) and Gumbel distributions were tested. Of these distributions, the LP3 and GP matched well for both the raw and censored annual series, while GEV matched better using the censored annual series. A comparison of the FFA results for all distributions for the raw and censored annual series are shown below in Table B-12. The 1% AEP flow estimate and associated confidence limits are compared below for the range of FFA distributions tested and shown in Figure B-16. The plot shows the GEV Raw and low flow censored data have the narrowest confidence limits, followed by the LP3 censored distribution. The FFA plots for the LP3 raw, LP3 censored, GP censored and GEV censored provide the best fit. The available gauge record and the resulting distributions are shown in Figure B-12, Figure B-13, Figure B-14 and Figure B-15 respectively.

TABLE B-12 FLOOD FREQUENCY ANALYSIS DISTRIBUTION COMPARISON

Design Event	Log Normal		LP3		Gumble		GEV		GP	
AEP	Raw (ML/d)	Censored (ML/d)	Raw (ML/d)	Censored (ML/d)	Raw (ML/d)	Censored (ML/d)	Raw (ML/d)	Censored (ML/d)	Raw (ML/d)	Censored (ML/d)
50%	7,227	7,768	8,185	8,179	11,136	10,346	8,214	9,126	9,271	9,233
20%	22,106	21,337	22,750	22,737	21,439	23,014	21,285	22,282	23,762	23,419
10%	39,657	36,185	36,070	36,415	28,261	31,401	36,739	34,241	36,905	36,675
5%	64,258	55,970	50,912	52,068	34,804	39,446	60,245	48,970	52,280	52,590
2%	110,622	91,446	72,298	75,363	43,274	49,860	111,652	74,262	76,686	78,633
1%	158,897	126,854	89,446	94,657	49,621	57,664	175,526	99,226	98,821	102,969

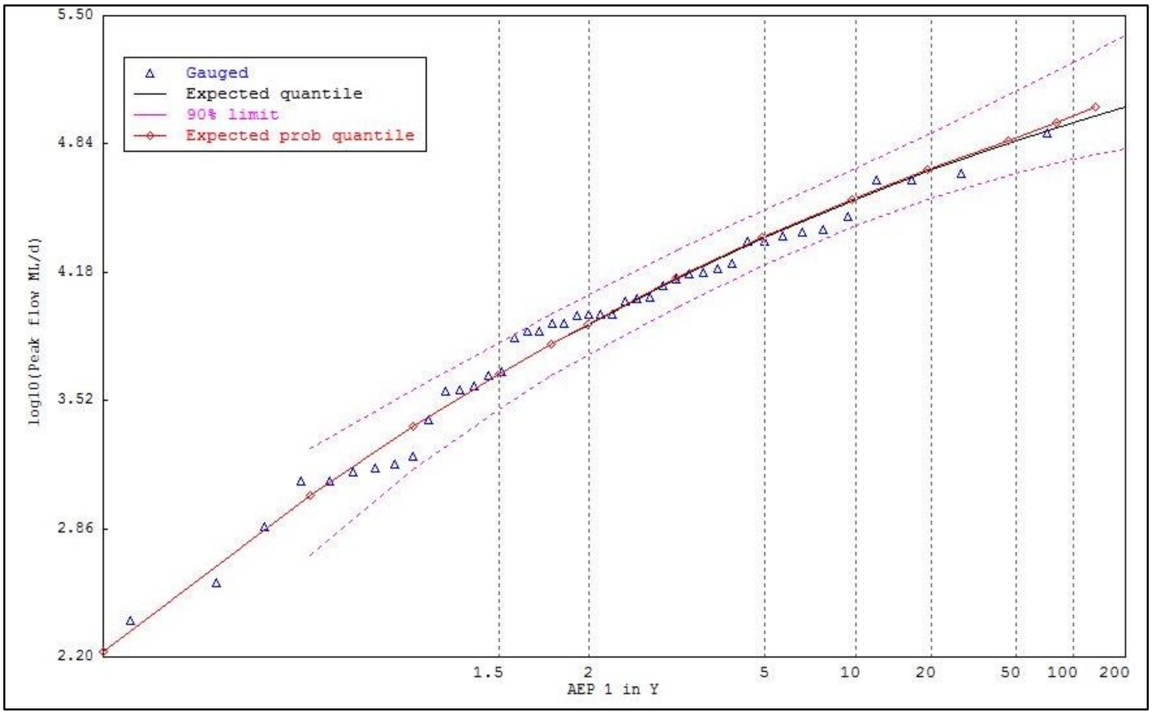

FIGURE B-12 POLLOCKSFORD (PARTIAL RECORD) -LOG PEARSON 3 (RAW) DISTRIBUTION PLOT

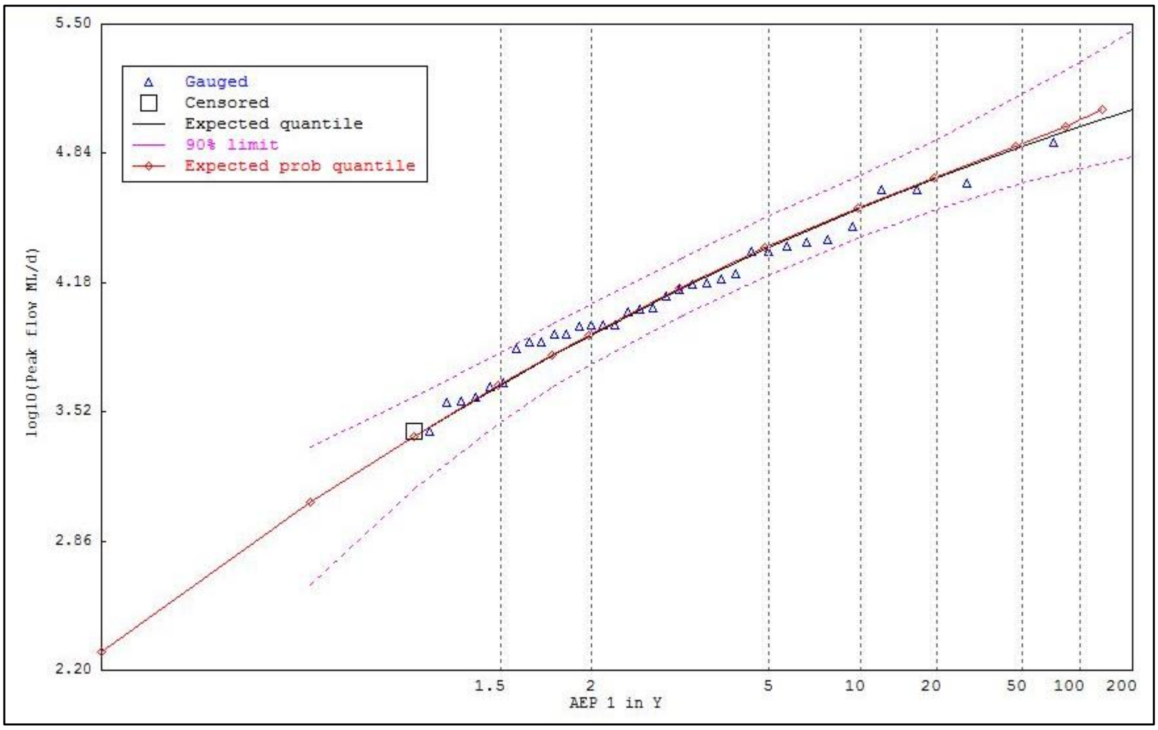

FIGURE B-13 POLLOCKSFORD (PARTIAL RECORD) LOG PEARSON 3 (CENSORED) DISTRIBUTION PLOT

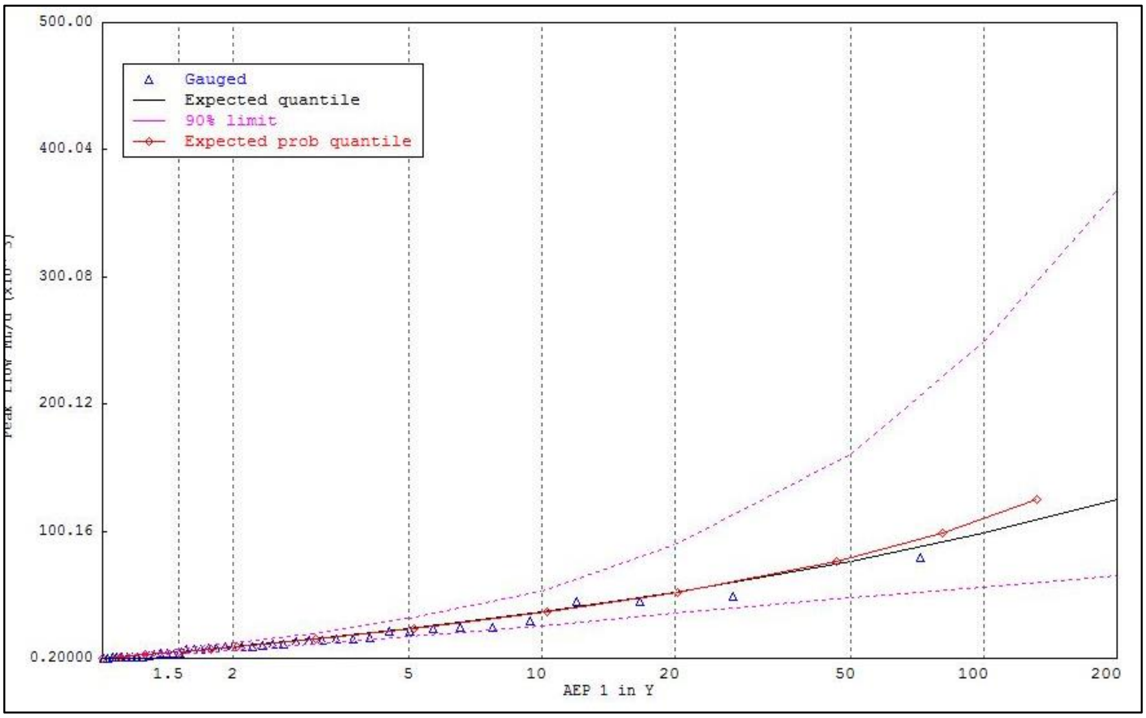

FIGURE B-14 POLLOCKSFORD (PARTIAL RECORD) GENERALISED PARETO (RAW) DISTRIBUTION PLOT

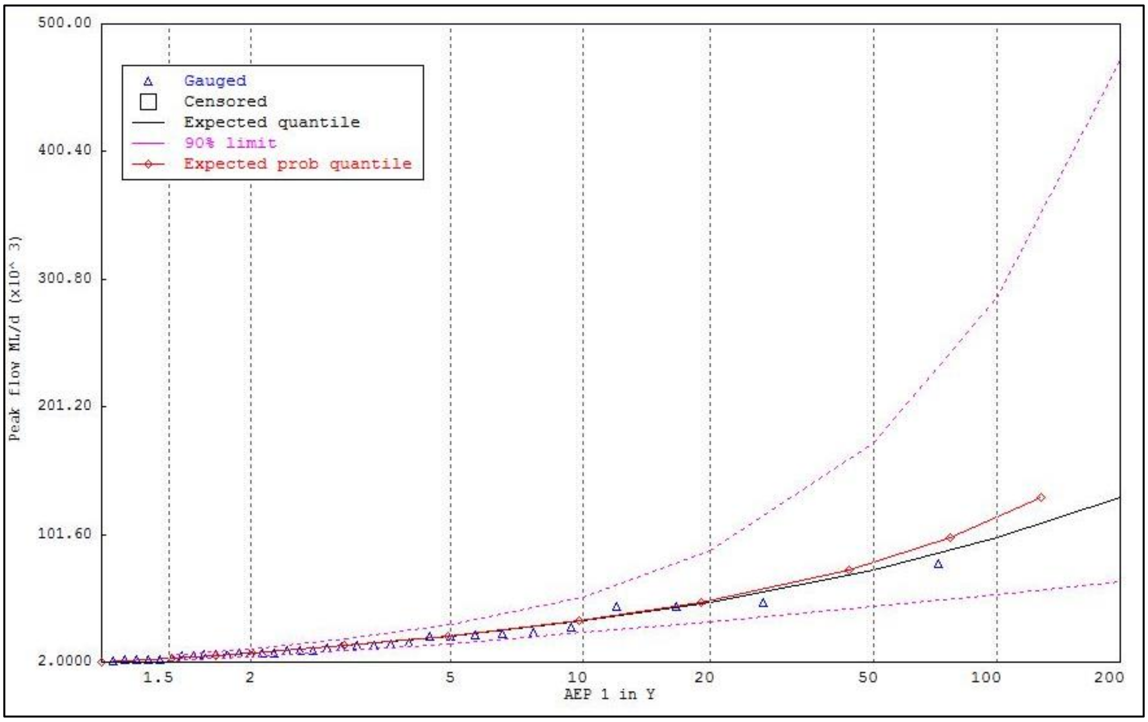

FIGURE B-15 POLLOCKSFORD (PARTIAL RECORD) GEV (CENSORED) DISTRIBUTION PLOT

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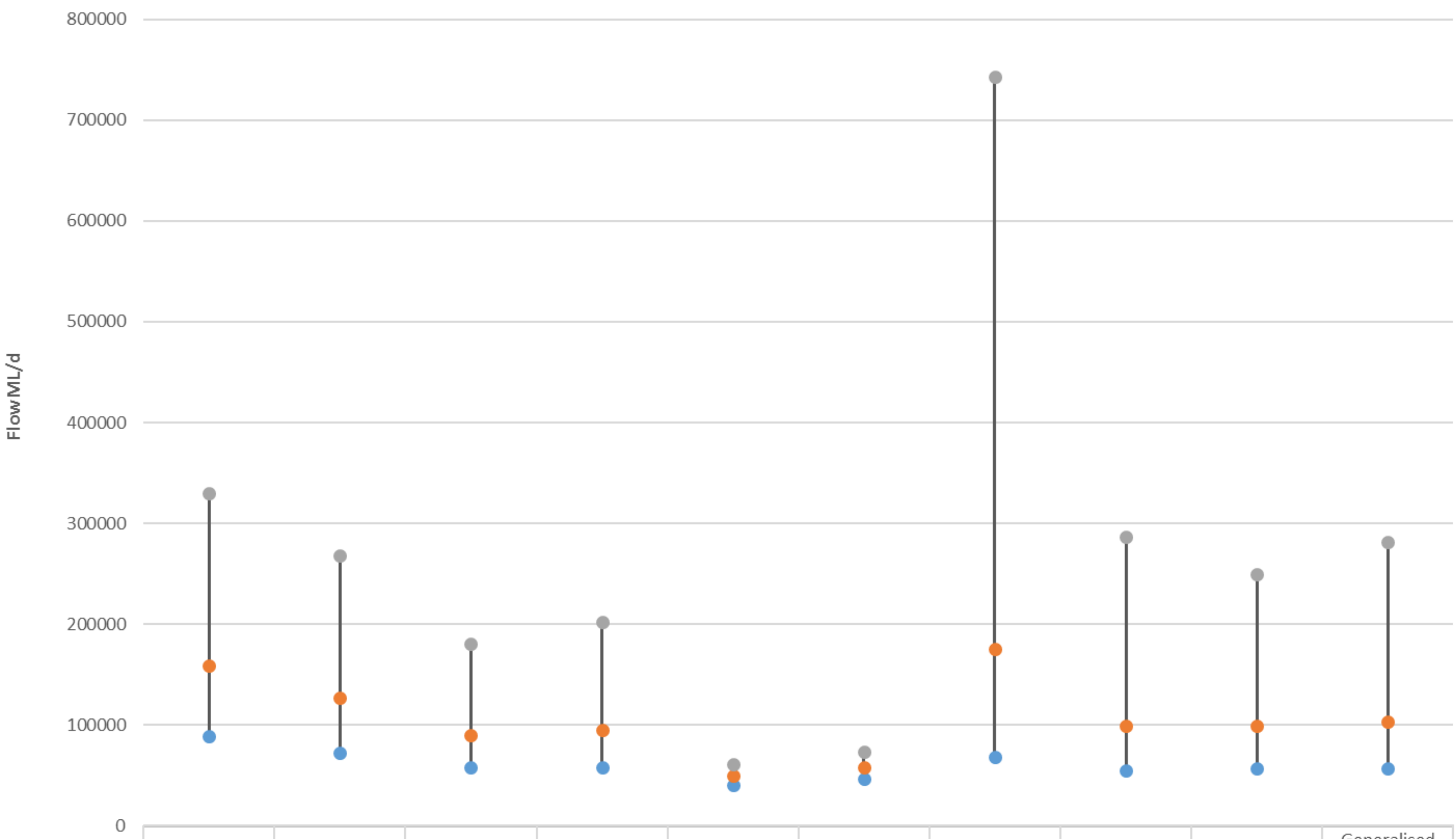


	Log Normal Raw	Log Normal Censored	Log Pearson 3 Raw	Log Pearson 3 Censored	Gumbel Raw	Gumbel Censored	GEV Raw	GEV Censored	Generalised Pareto Raw	Generalised Pareto Censored
Lower Confidence Limit	88433	71997	57973	57928	40726	46061	67990	54857	56539	56649
Mean	158897	126854	89446	94657	49621	57664	175526	99226	98821	102969
Upper Confidence Limit	329708	268214	180553	202103	61018	73399	743133	286600	249402	281095

FIGURE B-16 SHORT RECORD 1% AEP FLOOD FREQUENCY ANALYSIS DISTRIBUTION

Full Record Flood Frequency Analysis

The full gauge record from 1906-2015 was used to complete a flood frequency analysis on the peak flow annual series in FLIKE.

The analysis was completed on a raw annual peak flow series and a modified annual series with low flow censoring to remove years of low flow using the Multiple Grubbs Beck test. This determined a low flow threshold of 3,682 ML/d, removing 14 years from the 64-year record. Between 1922 and 1969 there is a large period of missing data. The 1952 event is known to have been a very significant flood in the study area, the largest on record. Based on an assessment of the annual series of the three relevant gauges within the study area, it was assumed that the 1952 event would have a peak flow higher than the 1909 flood. The FFA was completed assuming a single event with peak flow greater than 84,909 ML/d with 45 years below that threshold. The top 5 ranked (highest to lowest) gauged flow events are shown in Table B-13 below.

TABLE B-13 POLLOCKSFORD RANKED PEAK HISTORICAL FLOW EVENTS

Year	Peak Flow (m^3/s)	Peak Flow (ML/d)
1909	983	84,909
1995	915	79,030
1973	564	48,722
1911	531	45,911
1978	524	45,247

The Log Normal (LN), Log Pearson Type 3 (LP3), Generalised Extreme Value (GEV), Generalised Pareto (GP) and Gumbel distributions were tested. Of these distributions, the LP3 and GP matched well for both the raw and censored annual series, while GEV matched better using the censored annual series. A comparison of the FFA results for all distributions for the raw and censored annual series are shown in Table B-14. The 1% AEP flow estimate and associated confidence limits are compared below for the range of FFA distributions tested. The plot shows the Gumble Raw and low flow censored data have the narrowest confidence limits, followed by the LP3 censored distribution. The FFA plots for the LP3 raw, LP3 censored, GP censored and GEV censored provide the best fit. The available gauge record and the resulting distributions are shown in Figure B-17, Figure B-18, Figure B-19 and Figure B-20 respectively.

TABLE B-14 FLOOD FREQUENCY ANALYSIS DISTRIBUTION COMPARISON

Design Event	Log Normal		LP3		Gumble		GEV		GP	
AEP	Raw (ML/d)	Censored (ML/d))	Raw (ML/d))	Censored (ML/d)	Raw (ML/d)	Censored (ML/d)	Raw (ML/d)	Censored (ML/d)	Raw (ML/d)	Censored (ML/d)
50%	7,982	8,955	8,942	9,182	11,922	11,804	8,837	9,661	9,640	9,803
20%	23,229	22,329	23,918	24,063	22,753	26,234	22,091	22,795	24,497	24,436
10%	40,601	35,999	37,511	38,004	29,924	35,788	37,274	35,543	37,788	38,262
5%	64,388	53,404	52,699	54,149	36,802	44,953	59,785	52,084	53,152	55,021
2%	108,193	83,245	74,762	78,702	45,705	56,816	107,585	82,232	77,202	82,754
1%	152,920	111,913	92,648	99,568	52,377	65,705	165,351	113,739	98,715	108,956

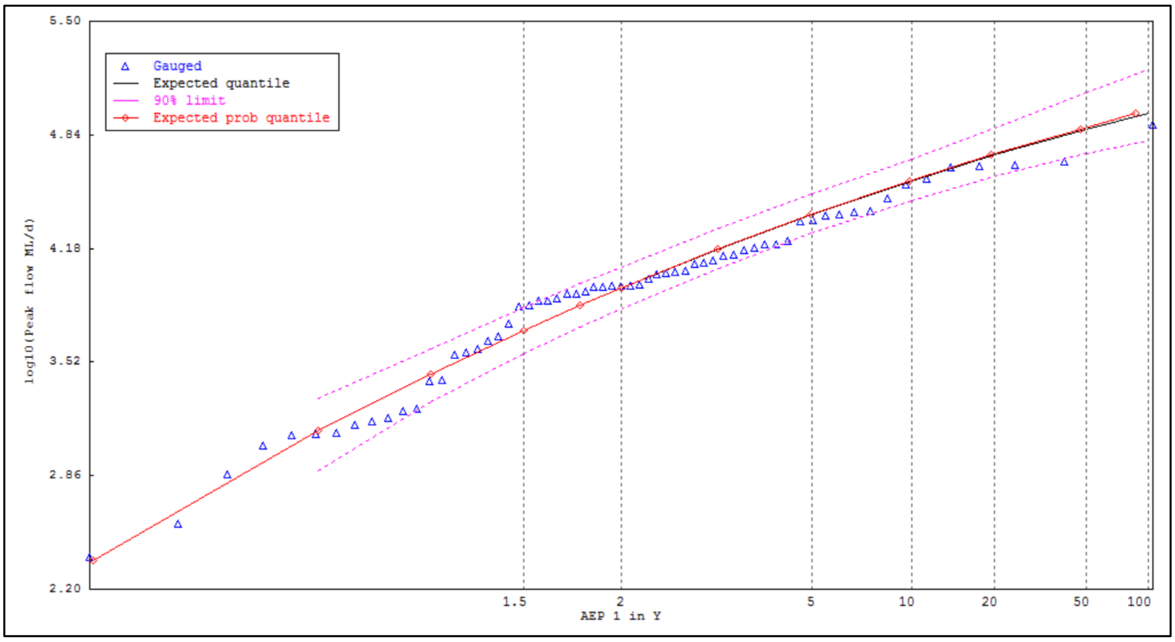


FIGURE B-17 POLLOCKSFORD (FULL RECORD) LOG PEARSON III (RAW) DISTRIBUTION PLOT

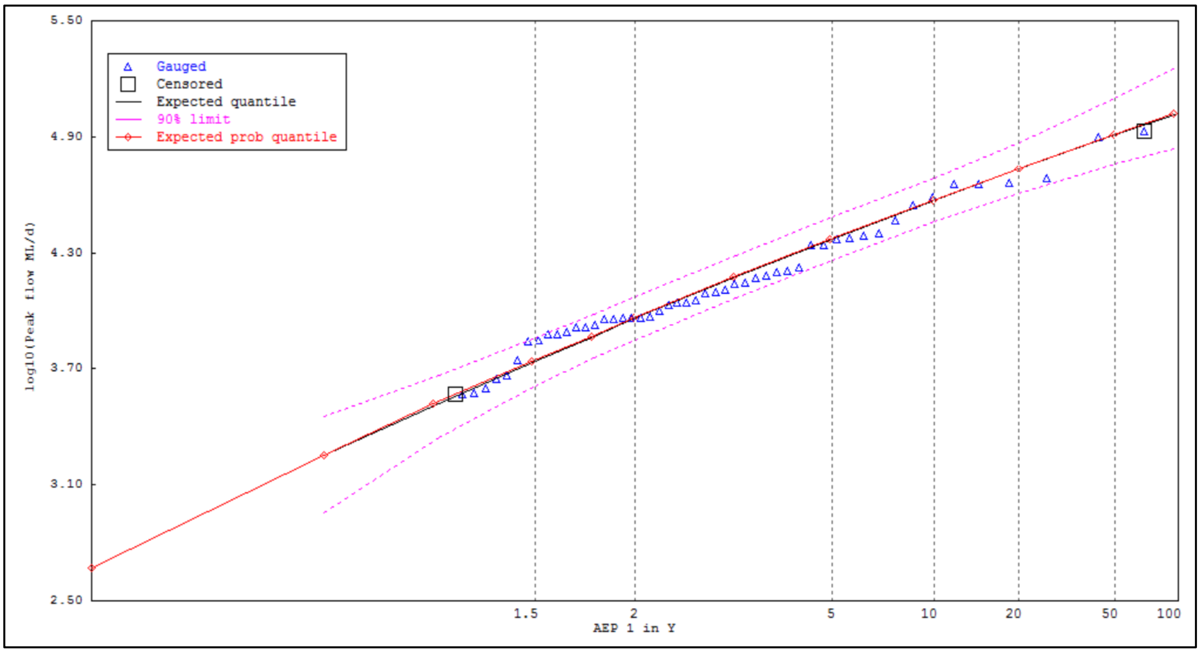


FIGURE B-18 POLLOCKSFORD (FULL RECORD) LOG PEARSON III (CENSORED) DISTRIBUTION PLOT

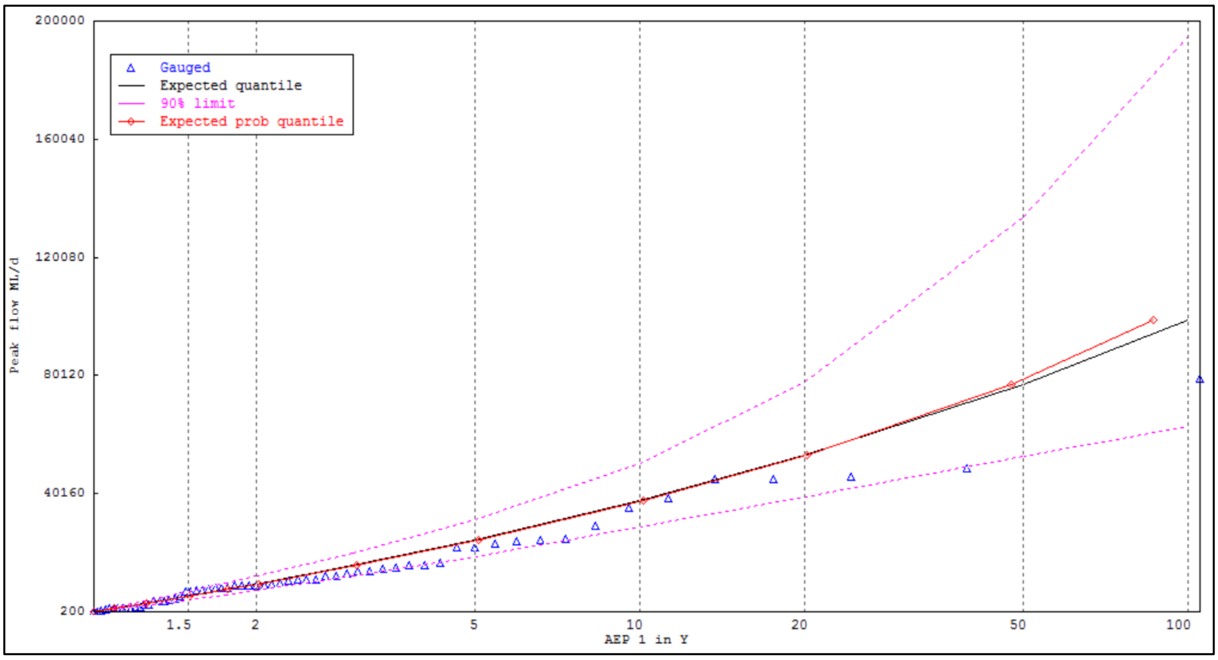


FIGURE B-19 POLLOCKSFORD (FULL RECORD) GENERALISED PARETO (RAW) DISTRIBUTION PLOT

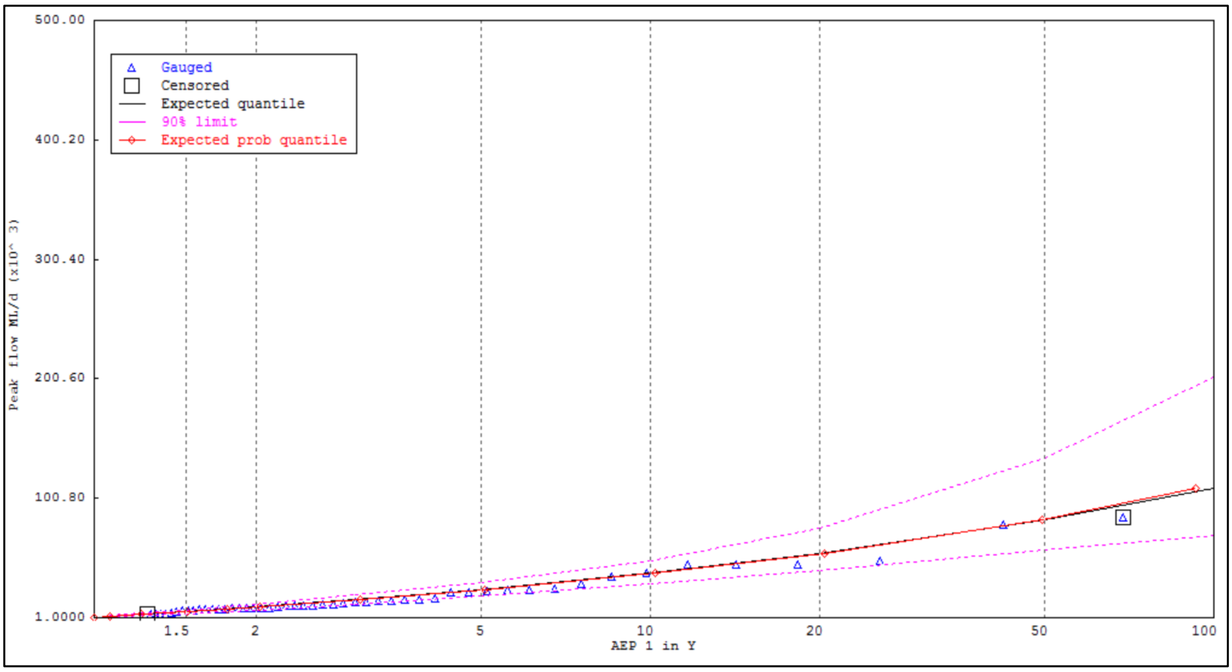
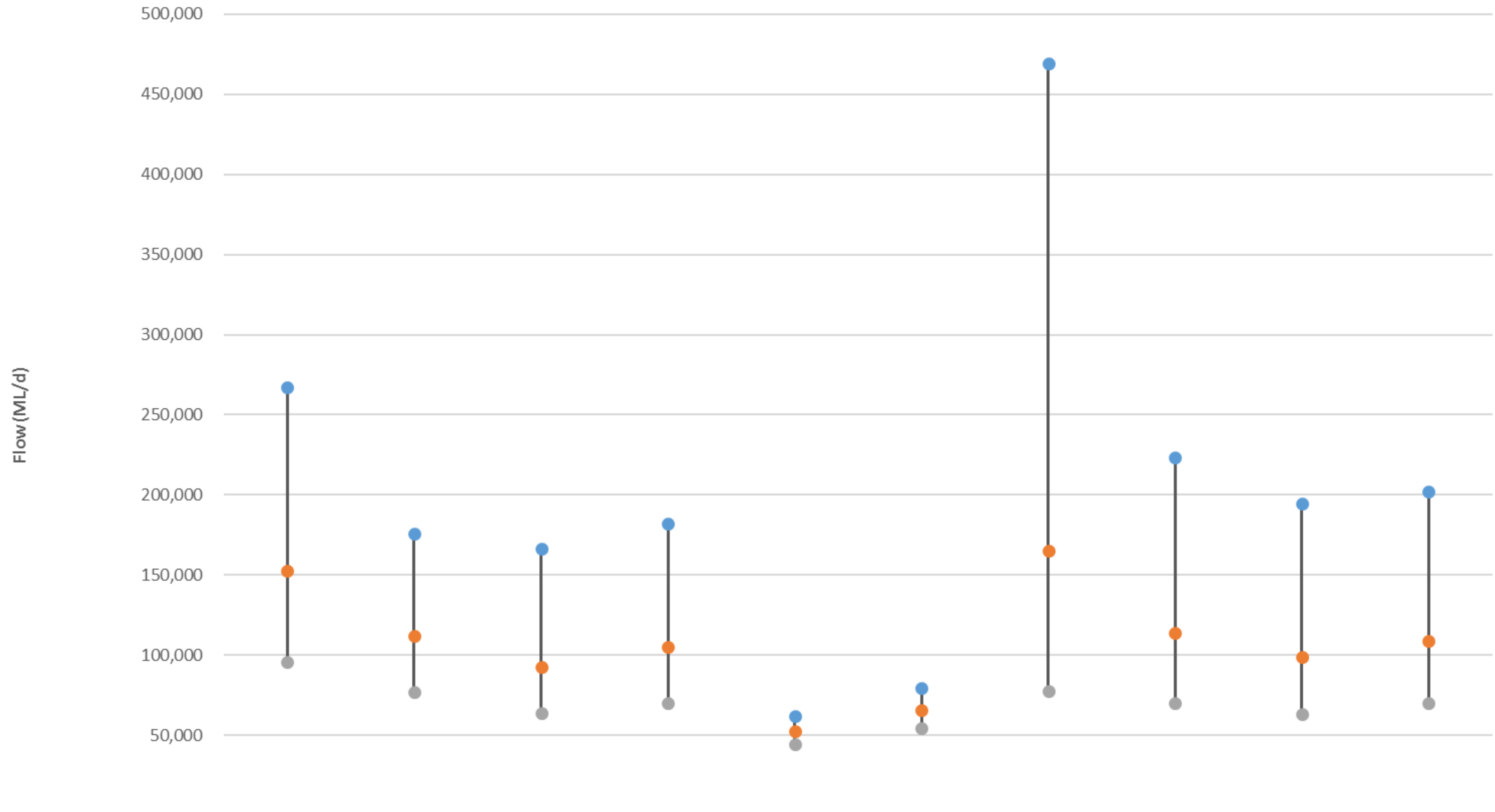


FIGURE B-20 POLLOCKSFORD (FULL RECORD) GENERALISED PARETO (CENSORED) DISTRIBUTION PLOT



	Log Normal Raw	Log Normal Censored	Log Pearson 3 Raw	Log Pearson 3 Censored	Gumbel Raw	Gumbel Censored	GEV Raw	GEV Censored	Generalised Pareto Raw	Generalised Pareto Censored
Upper Confidence Limit	267,240	176,057	166,241	182,154	62,028	79,607	469,260	223,650	194902	201,990
Mean	152,920	111,913	92,648	105,429	52,377	65,705	165,351	113,739	98715	108,956
Lower Confidence Limit	95,943	76,923	63,752	70,285	44,512	54,742	77,814	70,252	63090	70,021

FIGURE B-21 FULL RECORD 1% AEP FLOOD FREQUENCY DISTRIBUTION

Comparison of Full and Short Record Flood Frequency Analysis

A comparison of the FFA using the full record and post storage construction in the upper catchment record for the Barwon River at Pollocksford gauge based on the LPIII censored results as discussed in the previous section is shown below in Table B-15 .

The results from the FFA using the full record show slightly higher estimated peak flows than those with the post construction of dams period of record. One of the reasons for this is the exclusion of the 1909 and 1911 events from the analysis with the shorter record. Both events are very significant, ranking as the largest and third largest events in the full gauge record. It is also important to note that the Pollocksford gauge record did not capture the largest flood of the past 100 years through Geelong, that being the 1952 event. But the FFA for the period of full record included the 1952 event using the peak above threshold method, assuming the flow was greater than the next largest on record, the 1909 event. Sensitivity testing of including this event as an above threshold flow significantly increase the estimated 1% AEP flow across the range of distributions. Whilst no reliable record of the extent or height of this event exists for Pollocksford, based on the assumption that the event is likely to be the largest within the period of record it was considered reasonable to include this in the analysis as a single above threshold flow.

TABLE B-15 ADOPTED PEAK FLOWS – BARWON RIVER AT POLLOCKSFORD

Design Event (AEP)	Post Construction of Dams Record Log Pearson III with Low Flow Censoring (ML/d)			Full Record Log Pearson III with Low Flow Censoring (ML/d)		
	Peak Flow	Lower Confidence Limit	Upper Confidence Limit	Peak Flow	Lower Confidence Limit	Upper Confidence Limit
50%	8,179	5,784	11,711	9,132	7,092	11,873
20%	22,737	16,506	33,014	23,444	18,249	30,446
10%	36,415	25,943	53,894	37,378	28,784	48,856
5%	52,068	36,052	80,992	54,209	40,746	73,724
2%	75,363	49,018	138,601	81,203	57,649	125,246
1%	94,657	57,928	202,103	105,429	70,285	182,154
0.5%	115,156	66,141	290,755	133,117	82,196	262,587
0.2%	143,772	75,101	456,993	175,304	96,547	411,500
0.01%	166,338	80,556	639,233	211,643	106,193	575,656

Flood Frequency using Regional Parameters

The skewness results from the FFA for the Log Pearson 3 low flow censored with full period of record are shown in Table B-16 below.

TABLE B-16 POSTERIOR SKEWNESS

Posterior Mean of Skewness	Posterior Standard Deviation
-0.24732	0.041648

Whilst these confidence limits are not considered to be overly wide, an additional assessment of this distribution using 'prior information' was undertaken with the ARR 2016 Regional Flood Frequency Estimation (RFFE) tool. The parameters derived for the Barwon River at Pollocksford using the RFFE tool are shown in .

TABLE B-17 RFFE PARAMETERS

Parameters	Mean	Std dev	Correlation		
Mean of log Q	6.275	0.520	1.000		
Std dev of log Q	0.722	0.235	-0.330	1.000	
Skew of log Q	0.136	0.030	0.170	-0.280	1.000

Using the RFFE parameters the LP3 censored flood frequency analysis was refitted. Table B-18 below shows the resulting LP3 posterior moments with and without the use of the regional parameters, referred to here as prior information. It should be noted that the RFFE tool is not recommended where the catchment area exceeds 1,000 m^2.

below shows the fitted flow distribution using the regional parameters. Many of the plotted flows are shown to be outside the confidence limits of this distribution plot, which would indicate a poor fit with many of the plotted flows sitting above the upper confidence limit. Further censoring of low events was undertaken to check if a better fit of confidence limits could be achieved with the prior information. However, a significant number of event were still observed to sit outside the confidence limits of the distribution plot.

TABLE B-18 COMPARISON OF LP3 PARAMETERS

LP3 parameters	No prior information		With Prior Information	
	Mean	Std Deviation	Mean	Std Deviation
Mean	9.07157	0.15763	8.90637	0.13834
Loge	0.15168	0.1333	0.00172	0.09559
Skew	-0.24732	0.41648	0.12216	0.02805

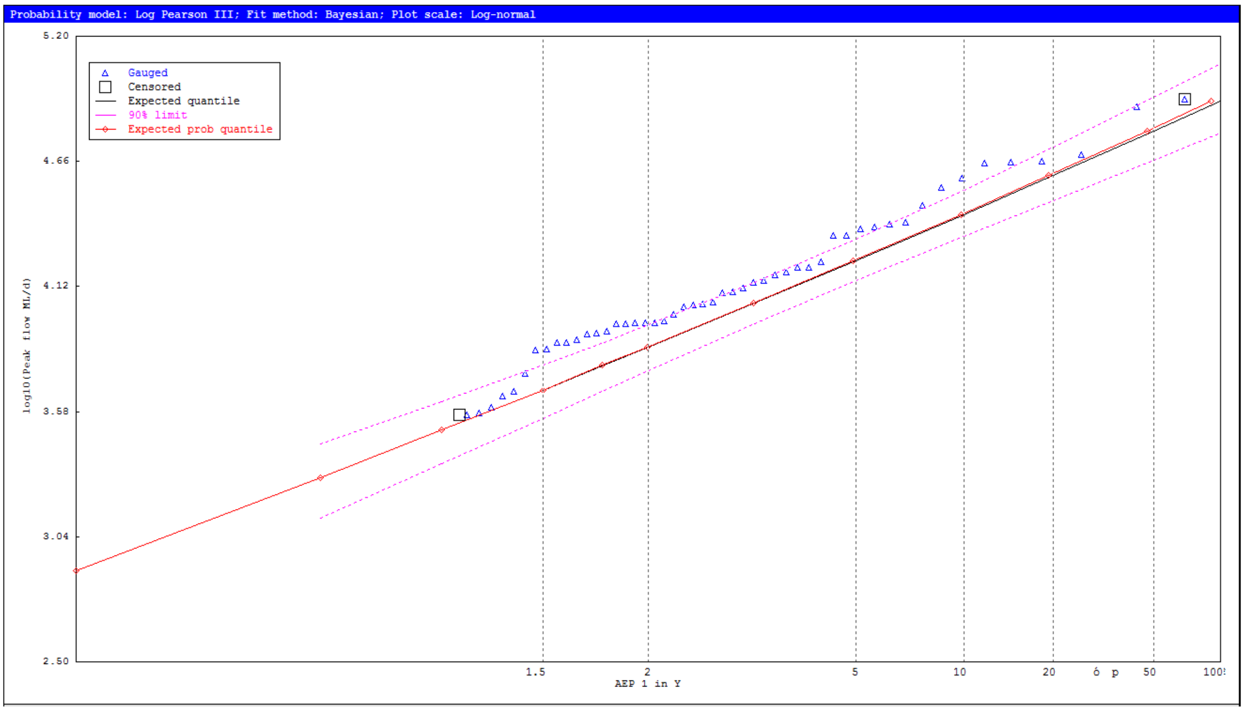


FIGURE B-22 LP3 CENSORED FLOOD FREQUENCY DISTRIBUTION USING REGIONAL PARAMETERS AS PRIOR INFORMATION

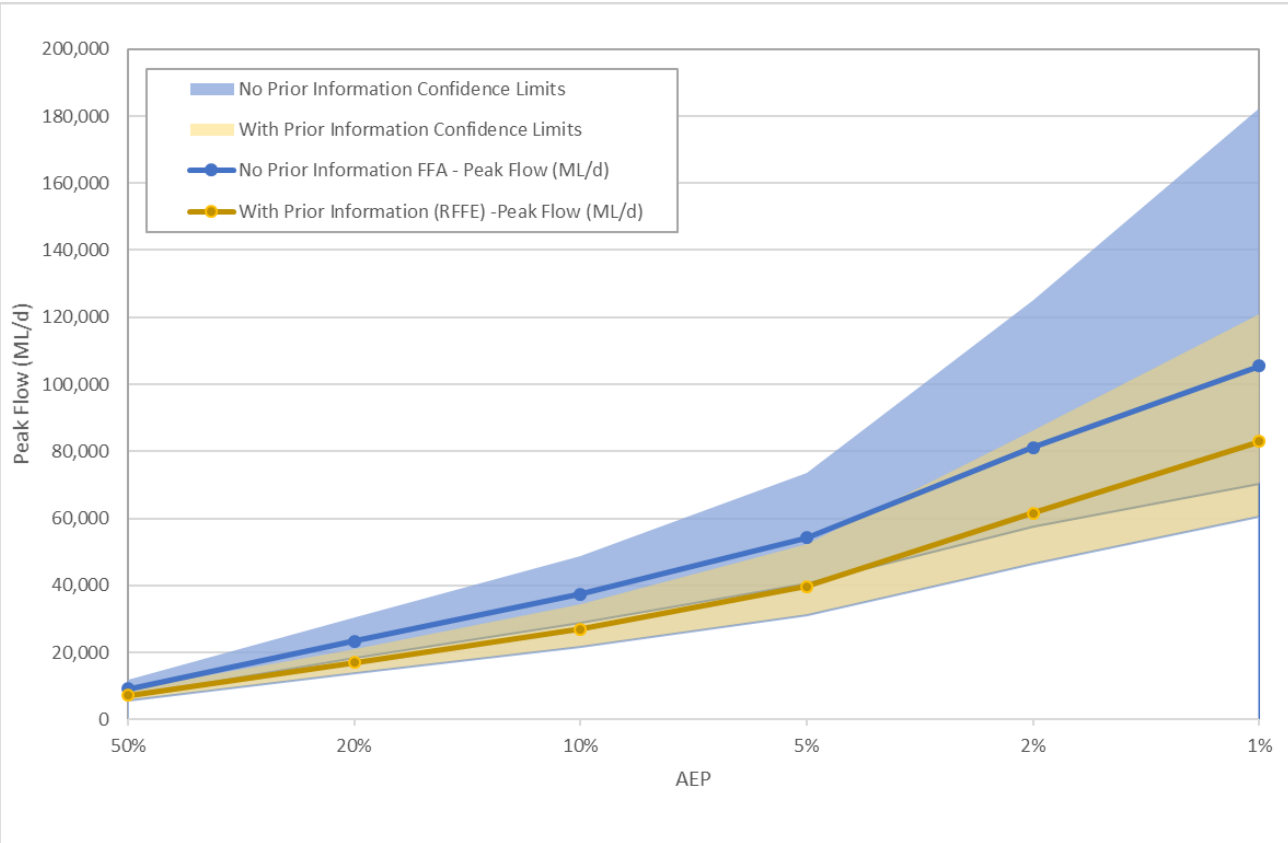


FIGURE B-23 LP3 REGIONAL COMPARISON

Based on the comparison of FFA results with and without the prior information from the RFFE tool, the prior information was not used for the final adopted FFA. Whilst the prior information reduces the confidence limits, the distribution plot shows the design flows are likely to be underestimated, particular in the lower order events where the majority of the flows sit above the confidence limits.

TABLE B-19 COMPARISON OF LP3 ESTIMATED PEAK FLOWS AND CONFIDENCE LIMITS

AEP (%)	No prior information			With prior Information (RFFE)		
	Peak Flow (ML/d)	Lower Confidence Limit (ML/d)	Upper Confidence Limit (ML/d)	Peak Flow (ML/d)	Lower Confidence Limit (ML/d)	Upper Confidence Limit (ML/d)
50%	9,132	7,092	11,873	7,230	5,703	8,985
20%	23,444	18,249	30,446	17,033	13,954	21,078
10%	37,378	28,784	48,856	26,969	21,736	34,358
5%	54,209	40,746	73,724	39,659	31,039	52,471
2%	81,203	57,649	125,246	61,621	46,310	86,189
1%	105,429	70,285	182,154	82,990	60,420	121,060

Adopted Flood Frequency Results

The adopted results of the FFA is provided in Table 4-15 below and is based on the annual series for the full period of record. The results show a 1% AEP peak flow of 99,568 ML/d with 5-95% confidence limits of 69,670 ML/d to 167,815 ML/d. These confidence limits are considered reasonable based on experience with other FFA analyses.

TABLE 7-20 ADOPTED PEAK FLOWS – BARWON RIVER AT POLLOCKSFORD

Design Event (AEP)	Full Record Log Pearson III with Low Flow Censoring		
	Peak Flow (ML/d)	Lower Confidence Limit (ML/d)	Upper Confidence Limit (ML/d)
50%	9,182	7,010	12,053
20%	24,063	18,777	31,009
10%	38,004	29,665	48,963
5%	54,149	41,542	73,354
2%	78,702	57,828	119,120
1%	99,568	69,670	167,815
0.5%	122,294	80,366	231,120
0.2%	155,267	92,686	344,555
PMF	1,453,594		

Water Technology determined that the censored LP3 distribution of the full available record was the preferred option based on the following:

- The full record provided a much longer period of record for assessment which reduces the uncertainty and confidence limits of the analysis.
- The full records enable the inclusion of a number of significant historical floods including 1909, 1911, 1973, 1978, 1976, 1995, with the addition of the missing 1952 event as a peak above threshold.
- The Log Pearson 3 distribution with censoring provides the best fit across all AEPs with confidence limits within a reasonable range.
- The flows produced by this assessment are similar to previous FFA assessments undertaken by Corangamite CMA (2015) and GHD (2016) for the more frequent event and are 9-12% higher for the 1% AEP event.

Barwon River at Pollocksford Hydrographs

Similar to the analysis of peak flows, an analysis on volume was undertaken to inform the choice of hydrograph shape for design flows at the Barwon River (at Pollocksford) streamflow gauge. In order to do this, the ratio of historic event peak flows to volumes was compared to the ratio of design peak flows to volumes determined by FFA.

The six largest events recorded at the Barwon River at Pollocksford gauge (August 1909, September 1911, February 1973, October 1976, November 1978 and November 1995) are shown overlayed in Figure B-24 . In all events the flood occurred over a two to five-day period. The 1995, 1973, 1909 and 1911 events all have a similar shape, whilst the 1978 event record contained multiple peaks. Based on this analysis it was determined a four-day volume FFA would be appropriate. Further to this, based on the similar shape of the 1909, 1995, 1978 and 1976 events it was determined that a hydrograph shape similar to those events would likely be adopted.

The four-day volume FFA was completed using a variety of distributions including low flow and peak below threshold censoring, with the LP3 distribution the best fit of the recorded data. The four-day volume FFA results and comparisons for the design events are shown in Table B-21 , with the historical events shown in Table B-22 . The 1% AEP 4-day volume distribution with confidence limits is shown in Figure B-25 .The LP3 (Figure B-26) and GP (Figure B-27) distributions provided the best fit for the 4 day volume data, with the LP3 being used for the adopted volume.

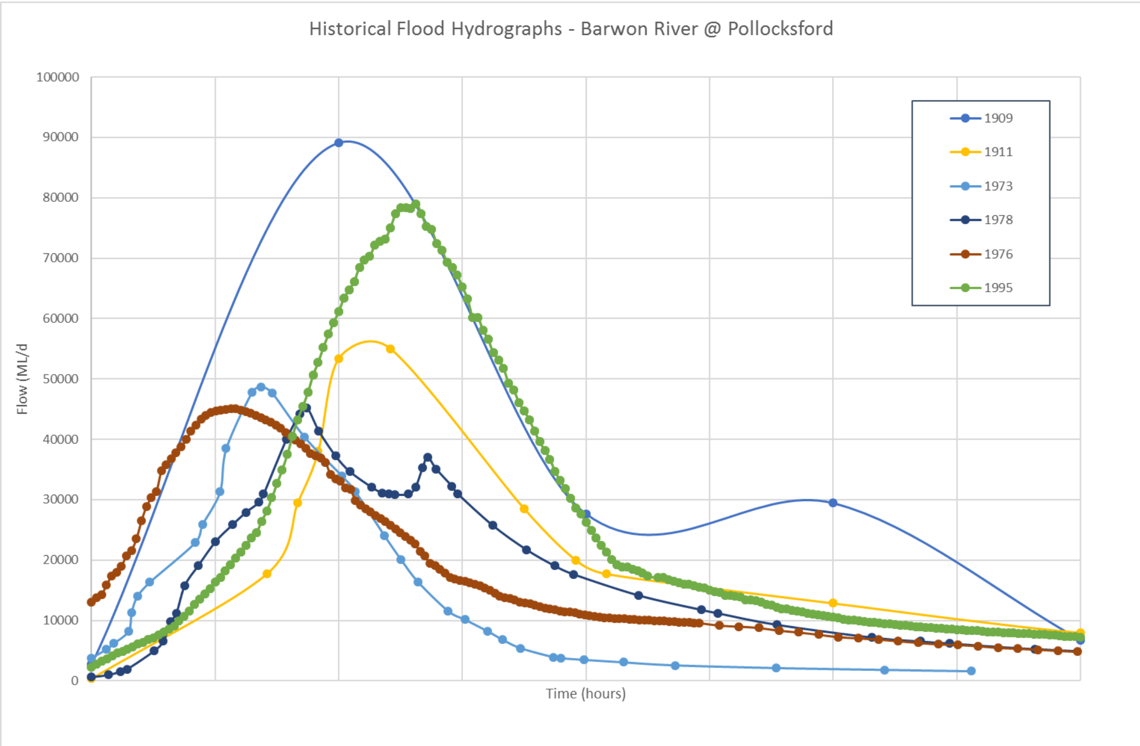


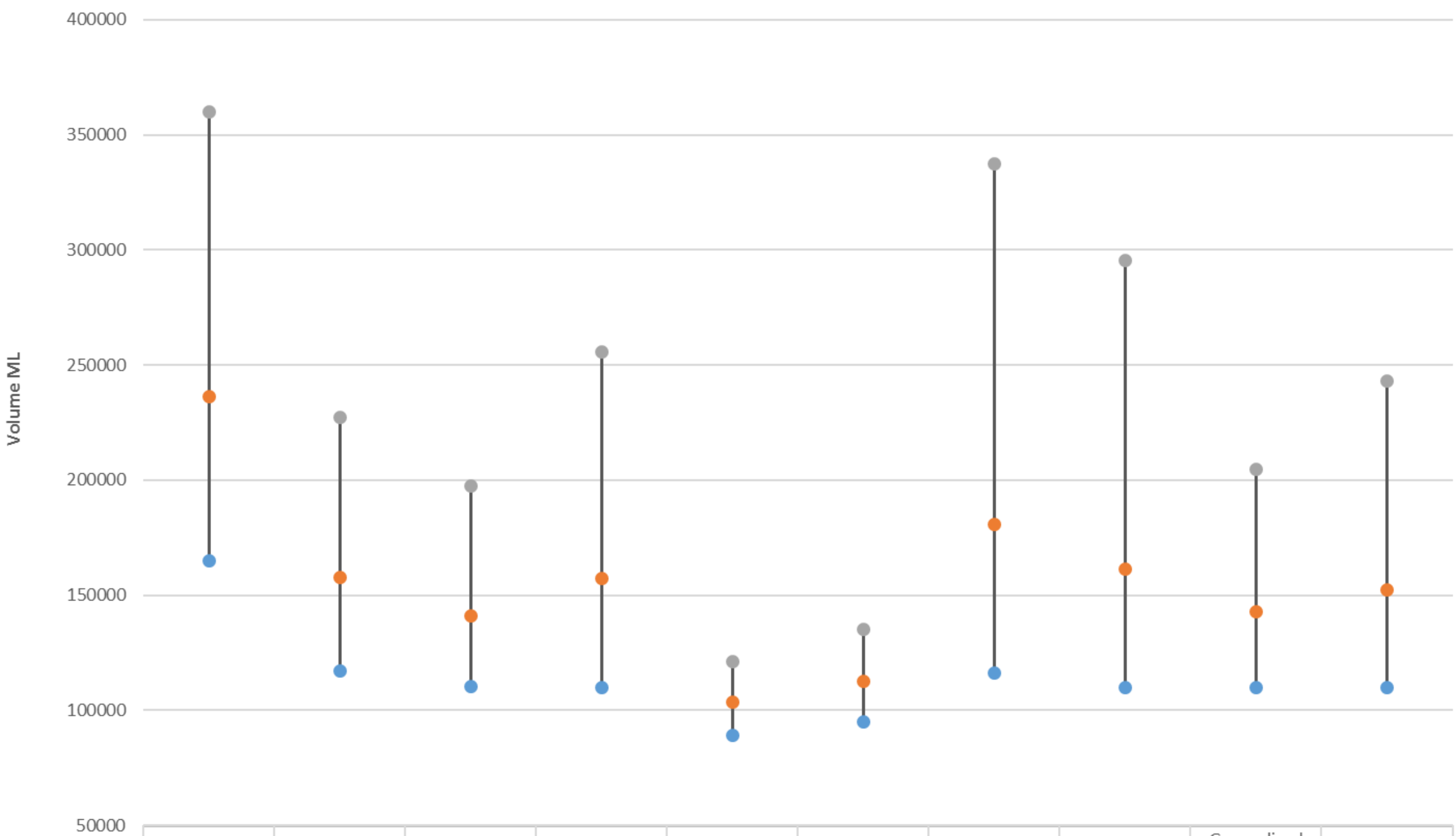
FIGURE B-24 HISTORICAL FLOOD HYDROGRAPHS

The volume to peak flow ratio of the 1976 historic event matches the average ratio of the range of design events considerably better than some of the other historic event. The 1995 event provides an almost perfect fit to the 1% AEP ratio. Given the 1995 hydrograph has a slightly lower ratio and is a better fit to the 1% AEP design ratio it was chosen as the donor hydrograph shape for design purposes. This is also consistent with the approach recommended by Corangamite CMA in the project brief.

Four Day Volume Assessment

TABLE B-21 FLOOD FREQUENCY DISTRIBUTION

	Log Normal		LP3		Gumble		GEV		GP	
AEP	Raw (ML)	Censored (ML)	Raw (ML)	Censored (ML)	Raw (ML)	Censored (ML)	Raw (ML)	Censored (ML)	Raw (ML)	Censored (ML)
50%	17,433	21,334	20,726	21,485	25,425	24,714	21,081	22,180	21,869	22,477
20%	44,793	44,018	48,480	45,338	46,364	48,321	44,189	44,818	50,302	48,164
10%	73,355	64,277	70,247	66,189	60,228	63,950	65,299	64,396	71,802	69,358
5%	110,241	87,870	92,098	89,913	73,527	78,942	91,399	87,568	93,295	92,200
2%	174,363	124,929	120,488	126,098	90,741	98,348	136,419	125,604	121,697	125,147
1%	236,699	157,960	141,262	157,386	103,640	112,890	181,045	161,546	143,173	152,330



	Log Normal Raw	Log Normal Censored	Log Pearson 3 Raw	Log Pearson 3 Censored	Gumbel Raw	Gumbel Censored	GEV Censored	Generalised Pareto Raw	Generalised Pareto Censored	
Lower Confidence Limit	165348	117118	110744	110217	89209	95062	116498	109894	110250	110219
Mean	236699	157960	141262	157386	103640	112890	181045	161546	143173	152330
Upper Confidence Limit	360215	227370	197771	256118	121228	135482	337398	295682	205031	243132

FIGURE B-25 1% AEP 4 DAY VOLUME FLOOD FREQUENCY DISTRIBUTION

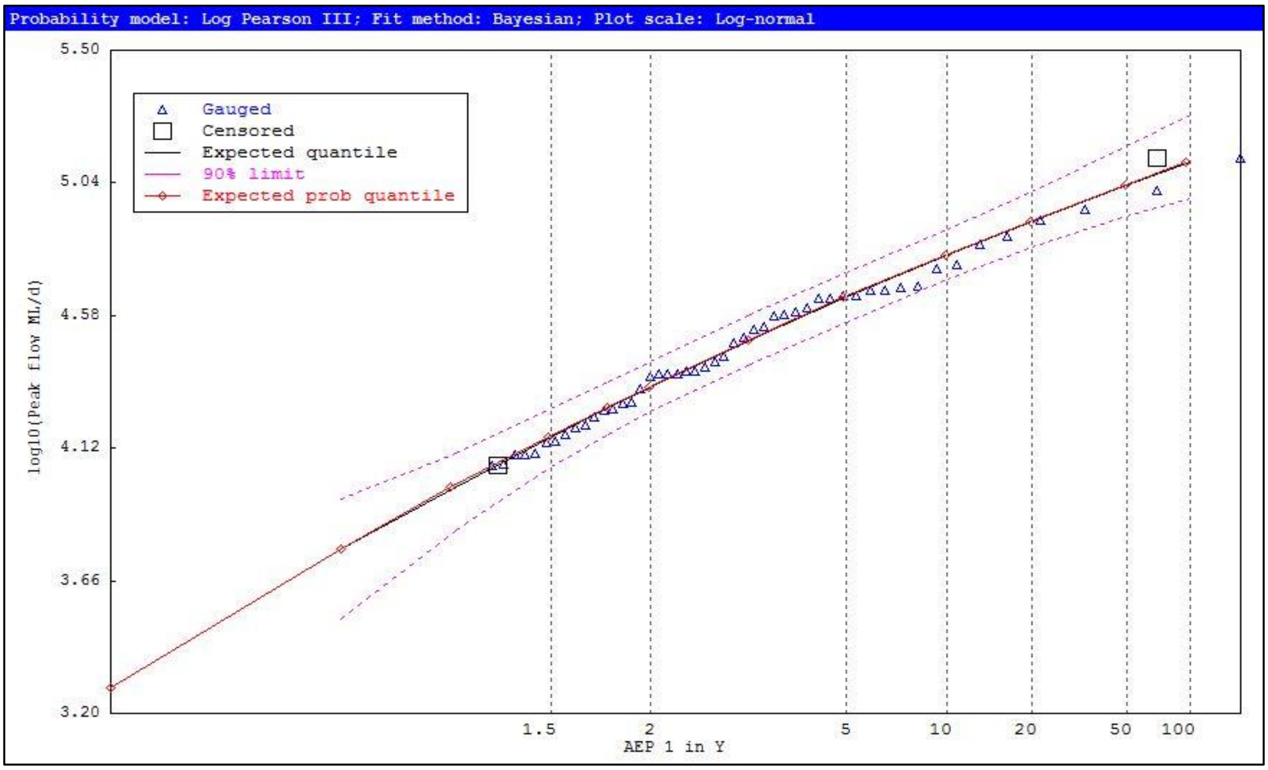


FIGURE B-26 LOG PEARSON III (CENSORED) – FLOOD FREQUENCY DISTRIBUTION PLOT

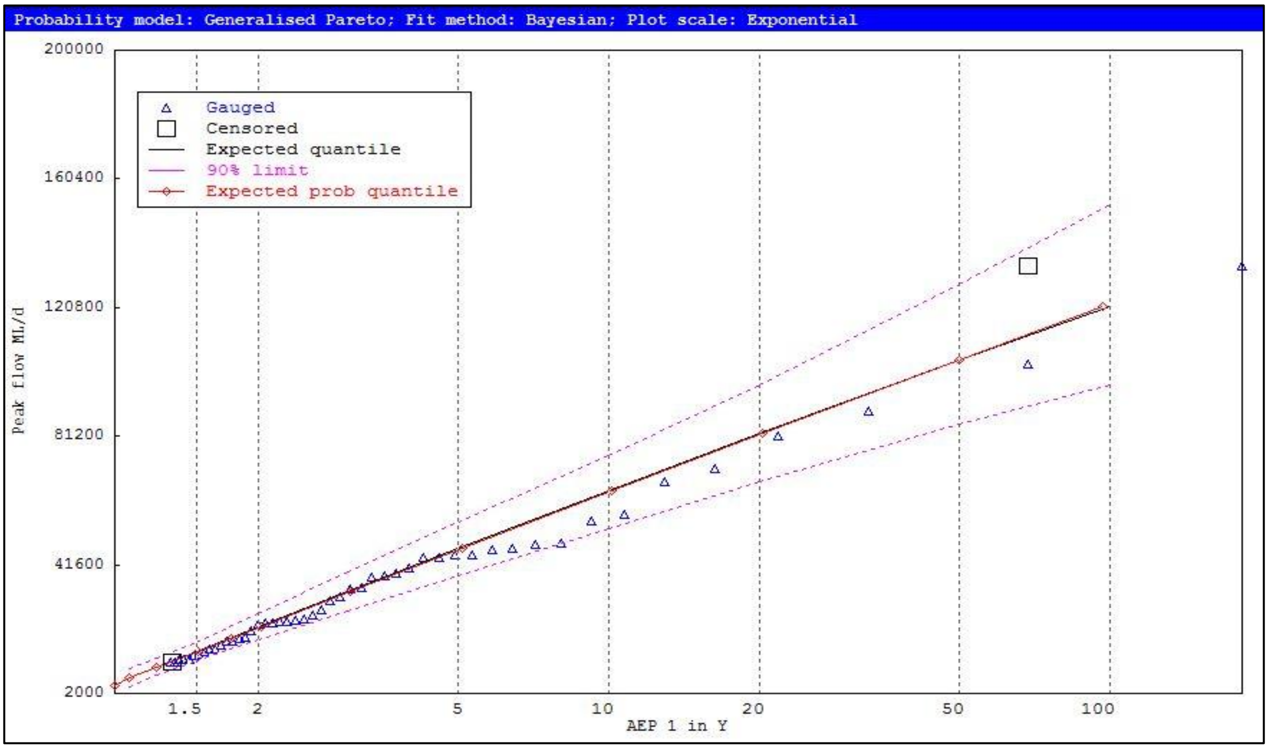


FIGURE B-27 GP (CENSORED) - FLOOD FREQUENCY DISTRIBUTION PLOT

The November 1995 hydrograph shape was scaled for each design event to match the peak flow and the volume of the design hydrograph from the FFA. Figure B-28 presents the final design flood hydrographs.

TABLE B-22 HISTORIC PEAK FLOW TO VOLUME RATIO

Year	Peak Flow (ML/day)	4 Day Volume (ML)	Ratio
August 1909	84909	133739	1.57
November 1995	79,030	103523	1.31
September 1911	45911	81401	1.77
February 1973	48,722	46480	0.95
November 1978	45,246	67120	1.48
October 1976	45,026	71409	1.59
		Average	1.39

TABLE B-23 ADOPTED VOLUME TO PEAK FLOW

AEP	4 Day Volume (ML)	Peak Flow (ML/day)	Ratio
50%	21485	9182	2.35
20%	45338	24063	1.93
10%	66189	38004	1.77
5%	89913	54149	1.65
2%	126098	78702	1.55
1%	157386	99568	1.49

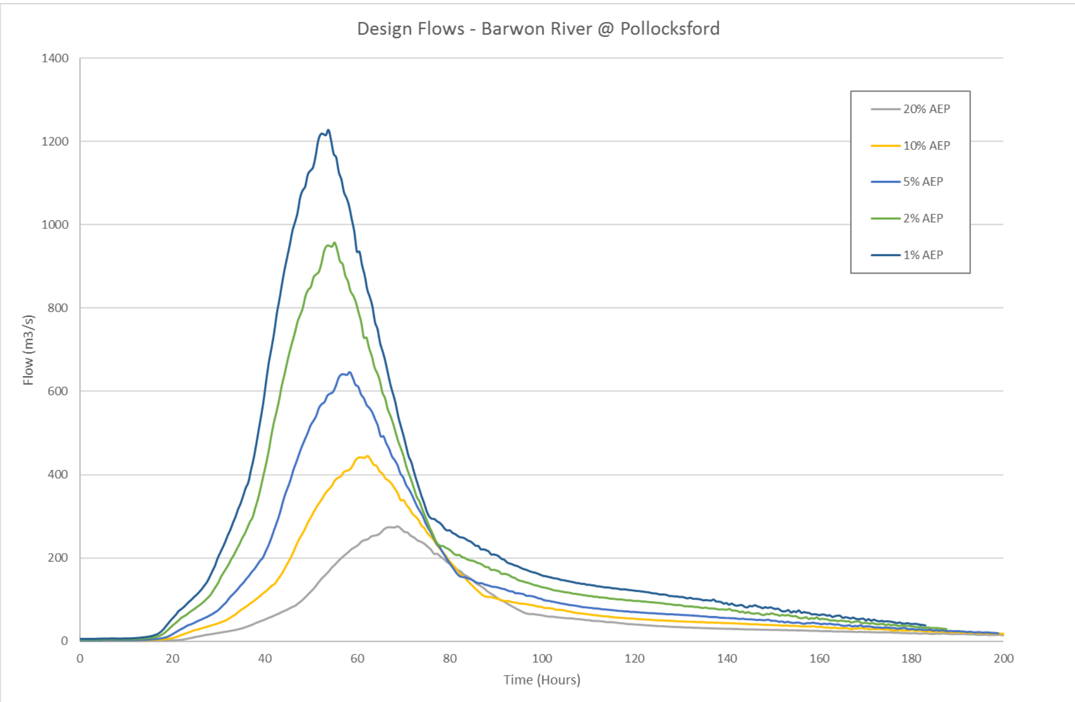


FIGURE B-28 DESIGN HYDROGRAPHS – BARWON RIVER AT POLLOCKSFORD

APPENDIX C
FLOOD FREQUENCY ANALYSIS
MOORABOOL RIVER @ BATESFORD

Flows Analysis – Moorabool River @ Batesford

Whilst the gauge at Batesford has a long reliable record prior to 1960 no sub daily flow record exists. Available flow records in most cases are based on mean daily flow record or event-based records.

A regression analysis of the available sub-daily discharge data was undertaken, and the mean daily/max daily flow relationship developed.

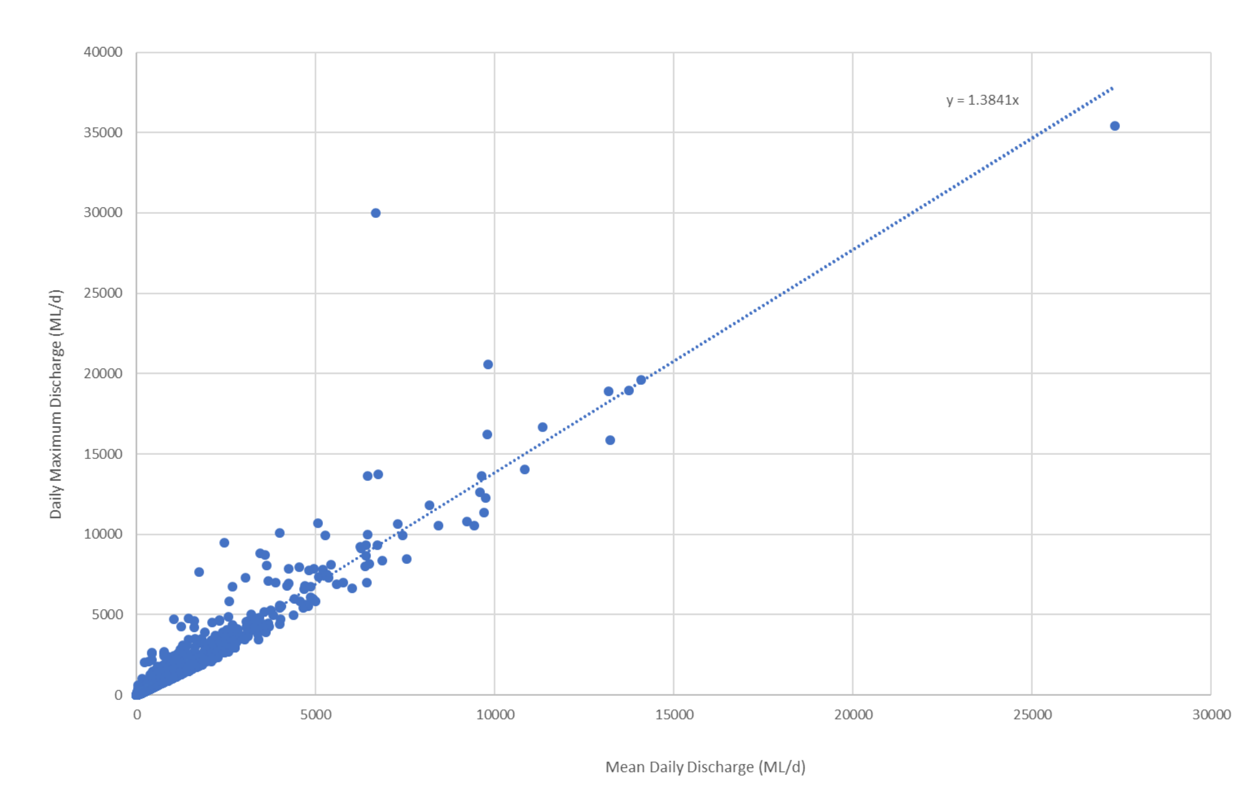


FIGURE C-29 BATESFORD GAUGE REGRESSION ANALYSIS

For the period of record where mean daily data was only available the record has been scaled in accordance with the regression equation Y=1.3841X, with Y being the maximum and X being the mean daily discharge.

The available mean daily flows were scaled to provide an estimated maximum daily flow and an annual series developed for these results. A comparison of the scaled annual series, the annual maximum flows provided by the Victorian Water Date Warehouse and the scaled (mean daily) annual series provided below.

The comparison indicates a reasonable fit between the scaled mean daily flows and the recorded from both the date warehouse and Rural Water Commission.

TABLE C-24 SCALED ANNUAL SERIES

Year	Mean Daily Scaled Flow (ML/d) Y= 1.3841x	Annual Maximum Flow (ML/d) Vic Water Date Warehouse
1908	2,459	1,777
1909	25,231	18,229
1910	3,456	2,497
1911	27,045	19,540
1912	3,503	2,531
1913	3,088	2,231
1914	467	338
1915	3,792	2,740
1916	27,985	20,219
1917	4,382	3,166
1918	7,480	5,404
1919	8,464	6,115
1920	3,503	2,531
1921	4,382	3,166
1945	307	222
1946	10,495	7,583
1947	677	489
1948	929	671
1949	11,431	8,259
1950	17,888	12,924
1951	23,189	16,754
1952	56,538	40,848
1953	11,160	8,063

Flows censoring - 5 at or above 20,000 ML/d

Flood Frequency Analysis

The Flood Frequency Analysis for the Moorabool River at Batesford streamflow record includes assessment of 2 periods of record for this gauge and considered low flow censoring and threshold censoring of the record. Each of the relevant analysis is discussed below.

7.1.1.1 Post Construction of Dams Record Annual Series Analysis

An annual series FFA was completed at the Moorabool River at Batesford gauge to determine design flow estimates for comparison. A partial gauge record from 1973-2015 was used for this assessment which represented the period following the construction of a number of upstream storages in the catchment.

This period of gauge record was used to complete an annual series FFA in Flike. The analysis was completed on a raw annual peak flow series and a modified annual series with low flow censoring to remove years of low flow using the Multiple Grubbs Beck test. This determined a low flow threshold of 957 ML/d, removing 13 years from the 43-year record during the censored assessments. The top 5 ranked (highest to lowest) flow events are shown in below Table C-25.

TABLE C-25 BATESFORD RANKED PEAK HISTORICAL FLOW EVENTS

Year	Peak Flow (m^3/s)	Peak Flow (ML/d)
1995	410	35,401
1978	238	20,578
1973	219	18,904
1983	193	16,670
1993	183	15,851

The Log Normal (LN), Log Pearson Type 3 (LP3), Generalised Extreme Value (GEV), Generalised Pareto GP) and Gumbel distributions were tested. Of these distributions, the LP3 and GP matched well for both the raw and censored annual series, while GEV matched better using the censored annual series. A comparison of the FFA results for all distributions for the raw and censored annual series are shown in Table C-26. The 1% AEP flow estimate and associated confidence limits are compared in Figure C-34 for the range of FFA distributions tested. The plot shows the GEV Raw and low flow censored data have the narrowest confidence limits, followed by the LP3 censored distribution. The FFA plots for the LP3 raw, LP3 censored, GP censored and GEV censored provide the best fit. The available gauge record and the resulting distributions are shown in Figure C-30, Figure C-31, Figure C-32 and Figure C-33 respectively.

TABLE C-26 FLOOD FREQUENCY COMPARISON

Design Event	Log Normal		LP3		Gumble		GEV	GP	
AEP	Raw (ML/d)	Censored (ML/d)	Raw (ML/d)	Censored (ML/d)	Raw (ML/d)	Censored (ML/d)	Censored (ML/d)	Raw (ML/d)	Censored (ML/d)
20%	9,744	9,055	9,999	9,822	9,415	10,404	10,149	10,221	9,748
10%	25,670	18,032	17,520	16,704	12,695	14,863	16,013	22,136	17,242
5%	57,125	31,848	25,312	24,039	15,842	19,140	22,899	44,841	28,114
2%	140,550	60,413	34,988	33,663	19,915	24,676	34,102	109,105	50,345
1%	256,156	92,577	41,441	40,529	22,967	28,825	44,596	210,559	76,134

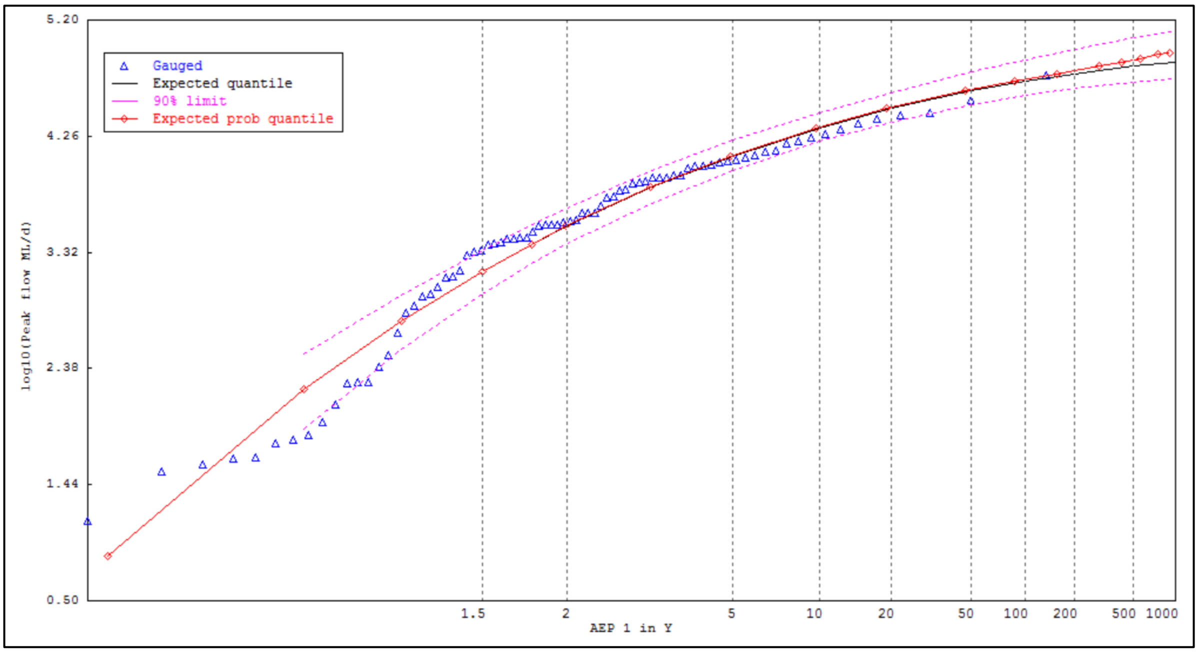


FIGURE C-30 LOG PEARSON III (RAW) FLOOD FREQUENCY DISTRIBUTION PLOT

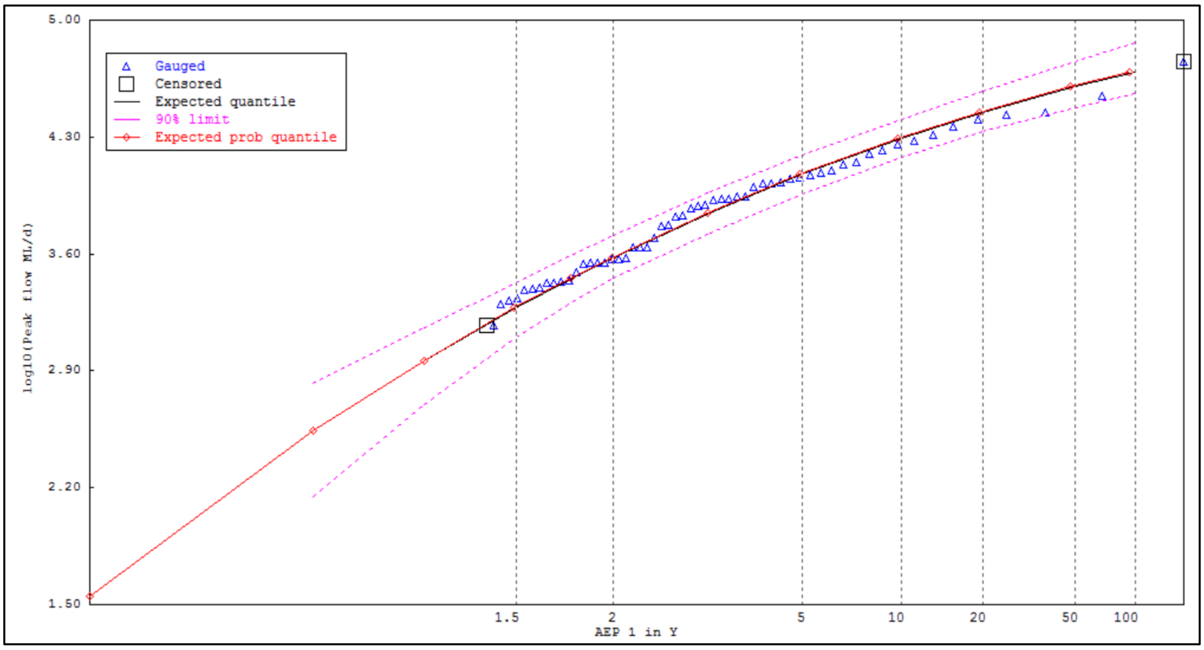


FIGURE C-31 LOG PEARSON III (CENSORED) FLOOD FREQUENCY DISTRIBUTION PLOT

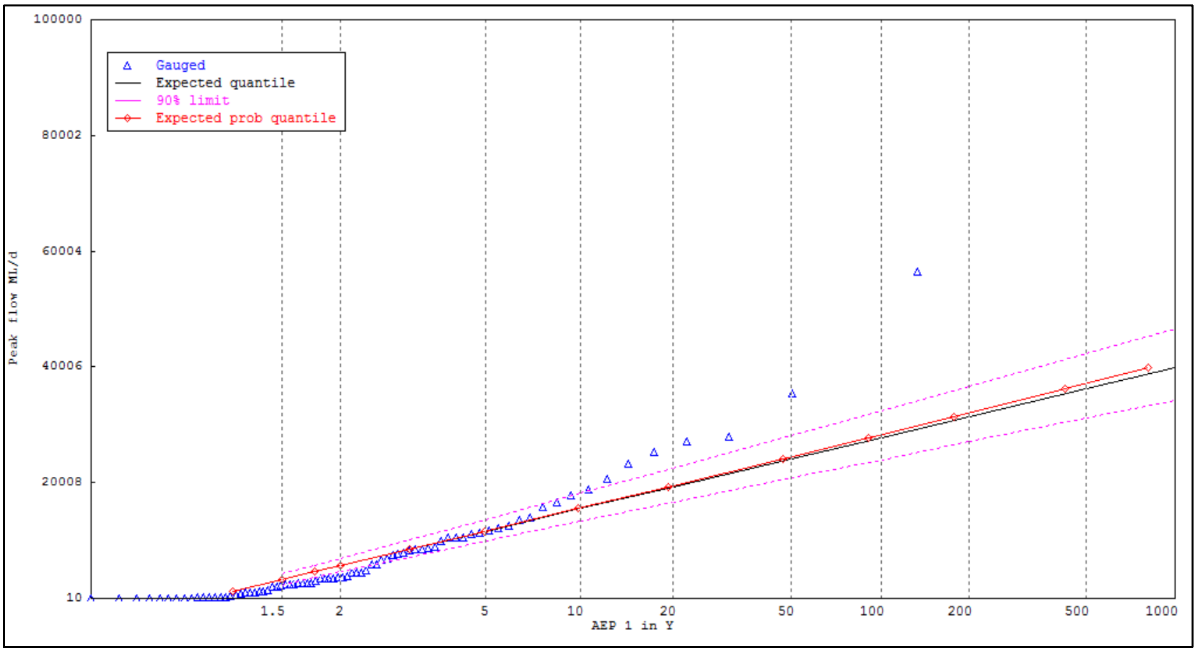


FIGURE C-32 GUMBLE (CENSORED) FLOOD FREQUENCY DISTRIBUTION PLOT

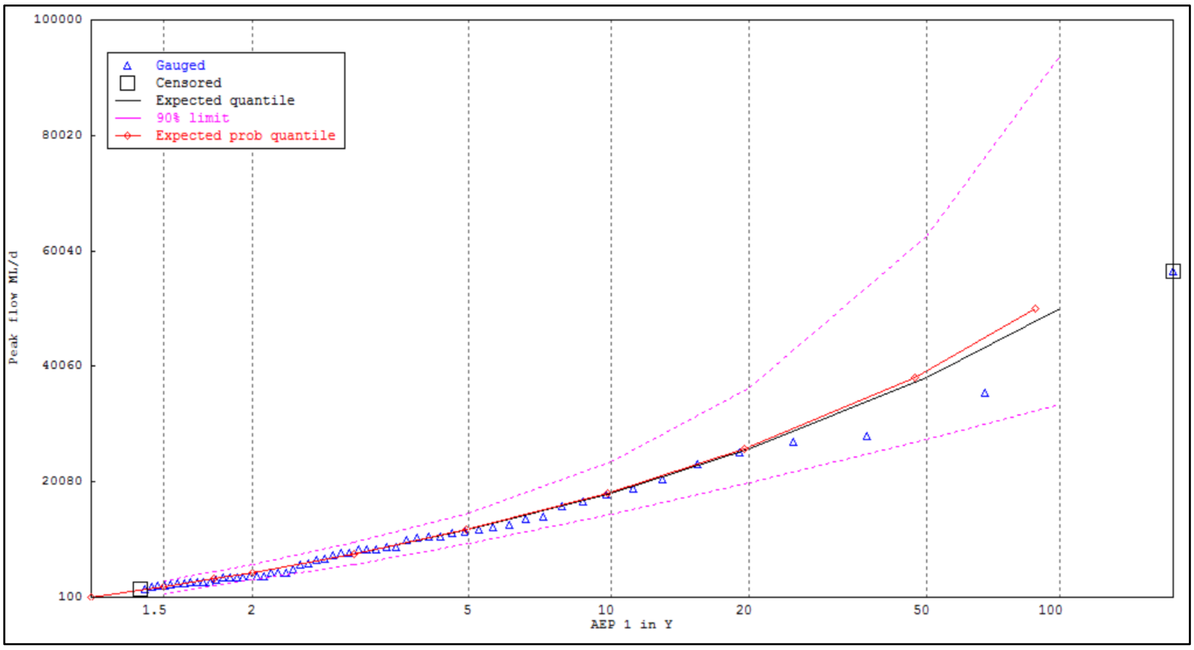
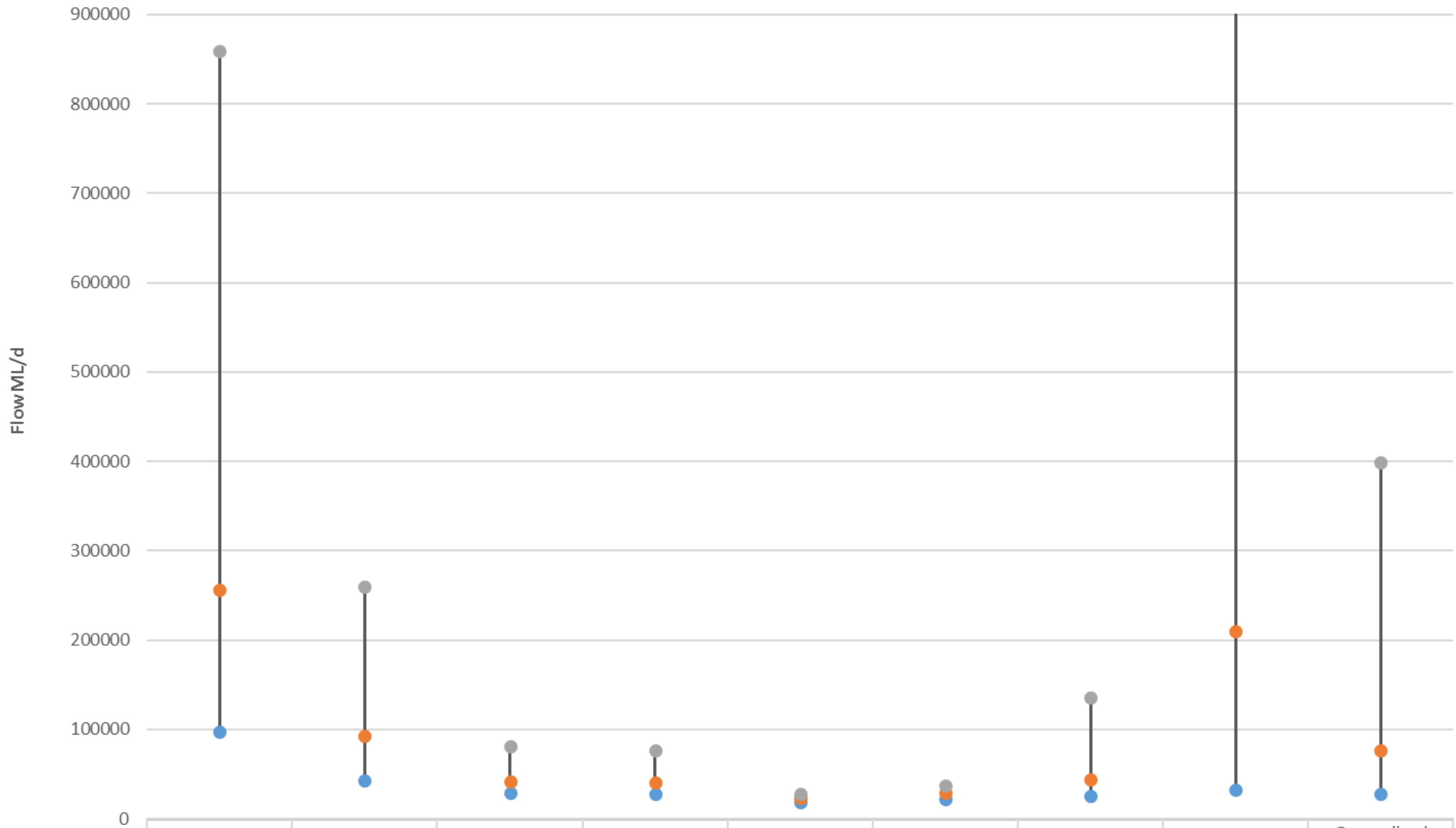


FIGURE C-33 GEV (CENSORED) FLOOD FREQUENCY DISTRIBUTION PLOT



	Log Normal Raw	Log Normal Censored	Log Pearson 3 Raw	Log Pearson 3 Censored	Gumbel Raw	Gumbel Censored	GEV Censored	Generalised Pareto Raw	Generalised Pareto Censored
Lower Confidence Limit	96982	43285	28976	27771	18687	22495	25274	33022	27919
Mean	256156	92577	41441	40529	22967	28825	44596	210559	76134
Upper Confidence Limit	858888	259877	80969	76760	28528	37777	136205	4932455	398662

FIGURE C-34 PARTIAL RECORD 1% AEP FLOOD FREQUENCY DISTRIBUTION

Full Record Annual Series Analysis

An annual series FFA was completed at the Moorabool River at Batesford gauge to determine design flow estimates for comparison. The full period of record at this gauge from 1906-2015 was used for this assessment.

This period of gauge record was used to complete an annual series FFA in Flike. The analysis was completed on a raw annual peak flow series and a modified annual series with low flow censoring to remove years of low flow using the Multiple Grubbs Beck test. This determined a low flow threshold of 1495 ML/d, removing 39 years from the 80-year record during the censored assessments. Peak below threshold censoring was considered and included as 28 Years Flow < 56538 ML/Day. The top 5 ranked (highest to lowest) flow events are shown in below Table C-27.

TABLE C-27 RANKED PEAK FLOWS

Year	Peak Flow (m^3/s)	Peak Flow (ml/d)
1952	654	56538
1995	410	35401
1978	324	27985
1916	313	27045
1911	292	25231

The Log Normal (LN), Log Pearson Type 3 (LP3), Generalised Extreme Value (GEV), Generalised Pareto GP) and Gumbel distributions were tested. Of these distributions, the LP3 and GP matched well for both the raw and censored annual series, while GEV matched better using the censored annual series. A comparison of the FFA results for all distributions for the raw and censored annual series are shown in Table 4-38. The 1% AEP flow estimate and associated confidence limits are compared in for the range of FFA distributions tested. The plot shows the GEV Raw and low flow censored data have the narrowest confidence limits, followed by the LP3 censored distribution. The FFA plots for the LP3 raw, LP3 censored, GP censored and GEV censored provide the best fit. The available gauge record and the resulting distributions are shown in Figure C-35, Figure C-36 , Figure C-37 and Figure C-38 respectively.

TABLE C-28 FLOOD FREQUENCY COMPARISON

	Log Normal		LP3		Gumble		GEV	GP	
AEP	Raw (ML/d)	Censored (ML/d)	Raw (ML/d)	Censored (ML/d)	Raw (ML/d)	Censored (ML/d)	Censored (ML/d)	Raw (ML/d)	Censored (ML/d)
50%	2,499	3,521	3,403	3,791	5,714	4,926	3,255	4,315	4,016
20%	12,872	10,654	12,614	11,896	11,634	12,752	11,560	11,728	11,458
10%	30,323	19,004	21,266	19,521	15,553	17,933	24,770	18,140	19,321
5%	61,528	30,648	30,366	27,972	19,313	22,903	50,380	25,730	29,831
2%	136,439	52,482	42,135	39,880	24,180	29,336	124,570	38,190	49,339
1%	232,014	75,118	50,417	49,135	27,827	34,157	244,346	49,965	69,953

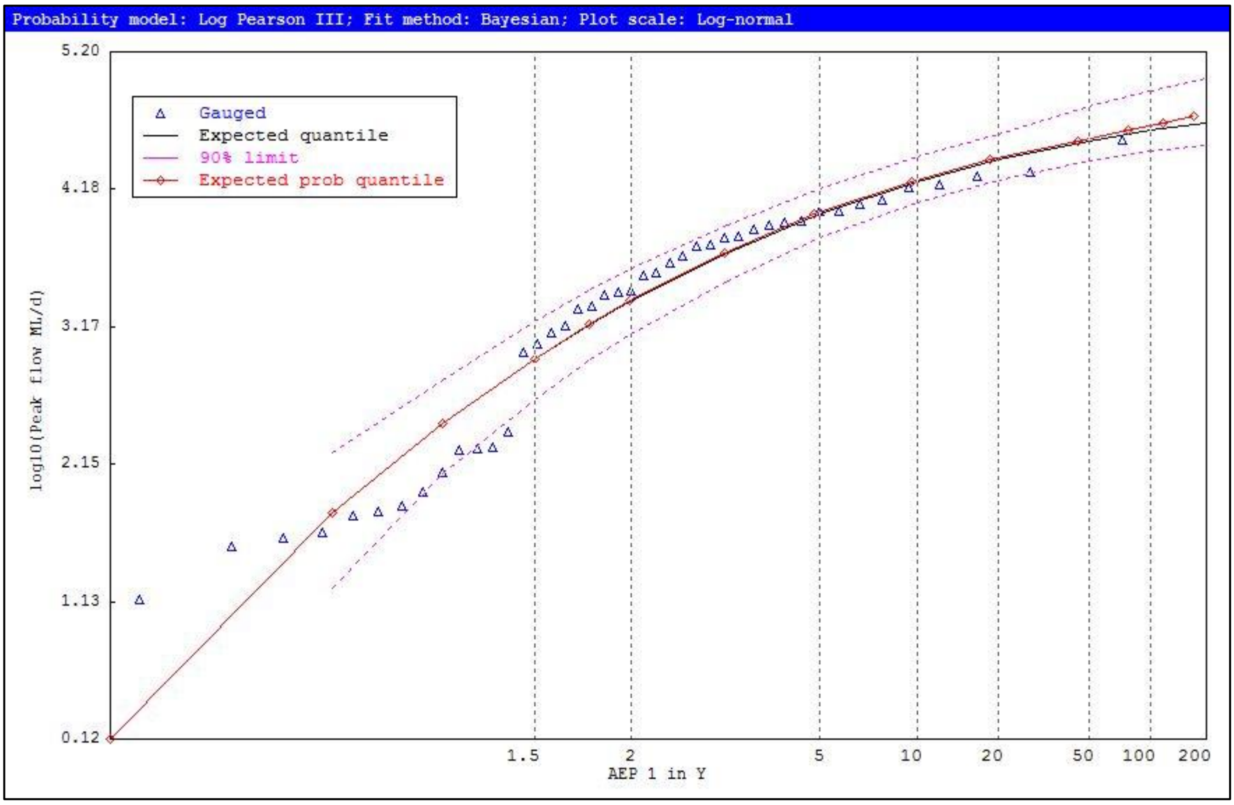


FIGURE C-35 PARTIAL RECORD LOG PEARSON III (RAW) FLOOD FREQUENCY DISTRIBUTION PLOT

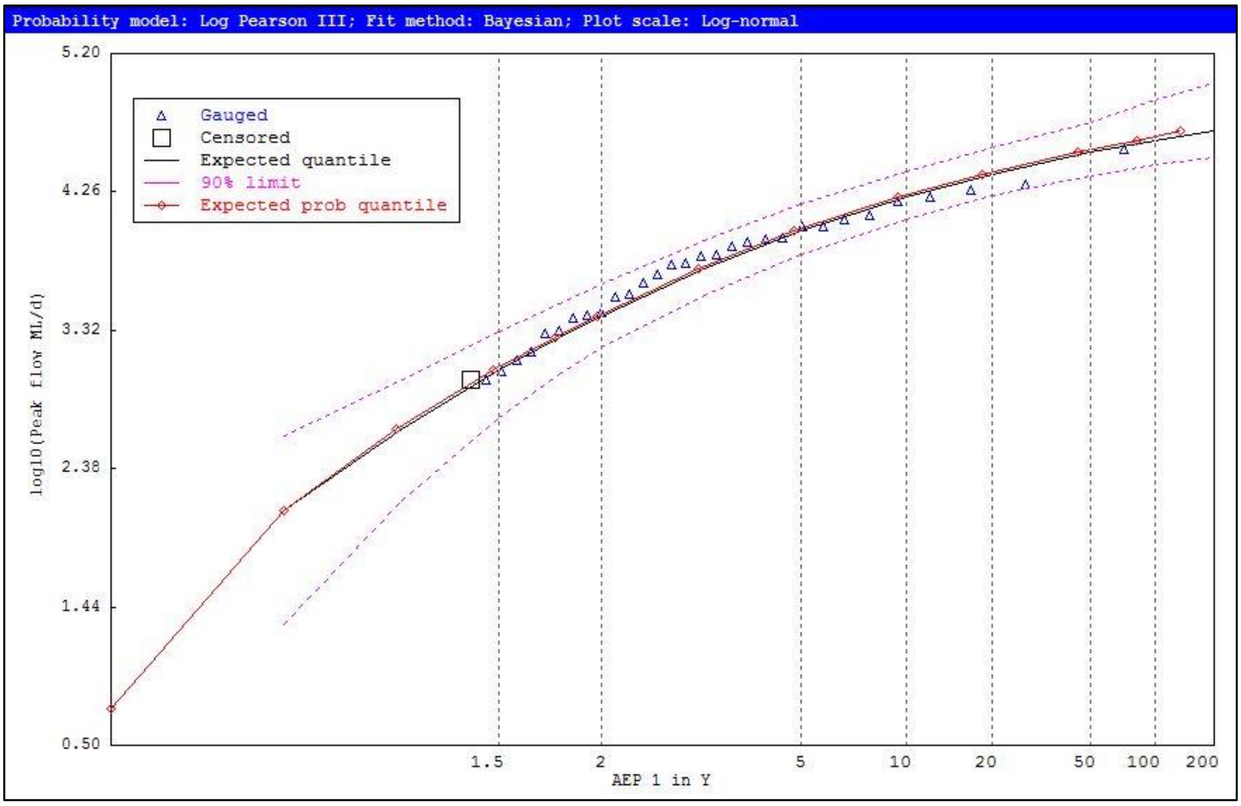


FIGURE C-36 PARTIAL RECORD LOG PEARSON III (CENSORED) FLOOD FREQUENCY DISTRIBUTION PLOT

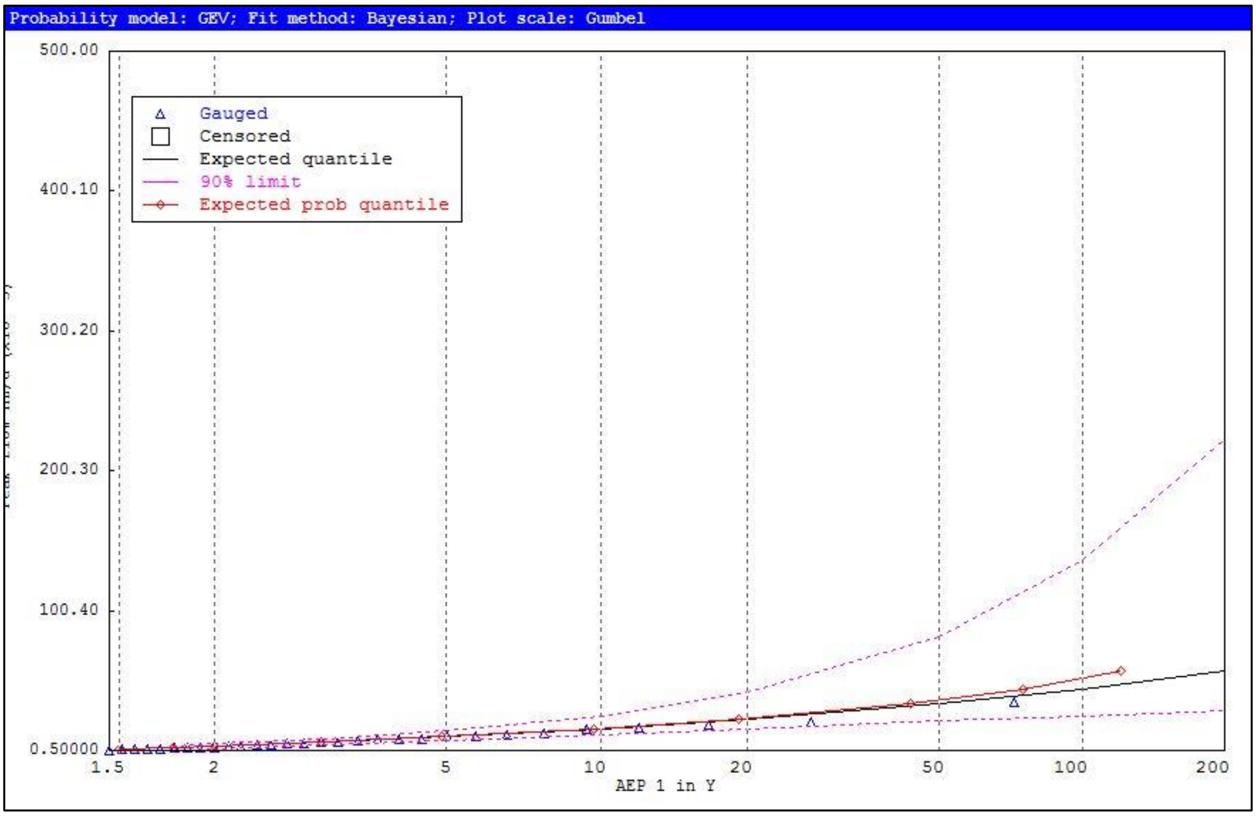


FIGURE C-37 PARTIAL RECORD GEV (CENSORED) FLOOD FREQUENCY DISTRIBUTION PLOT

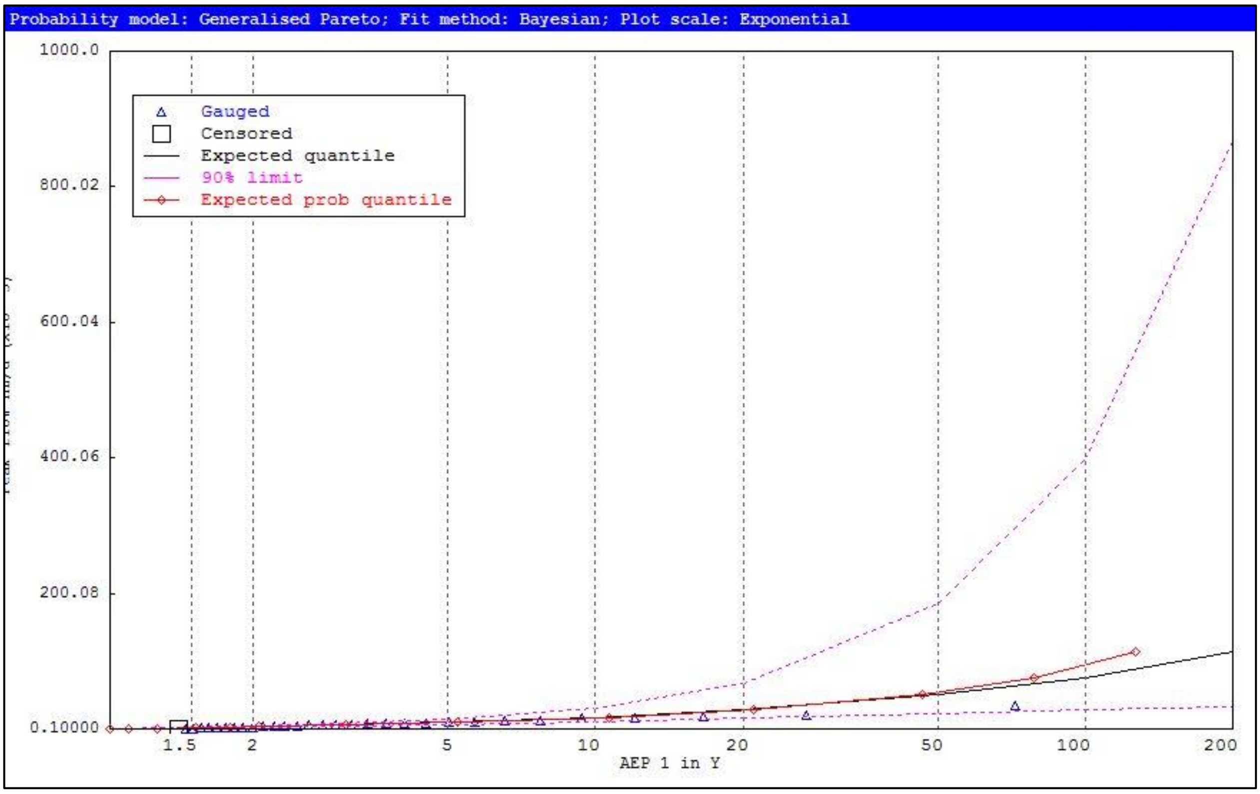
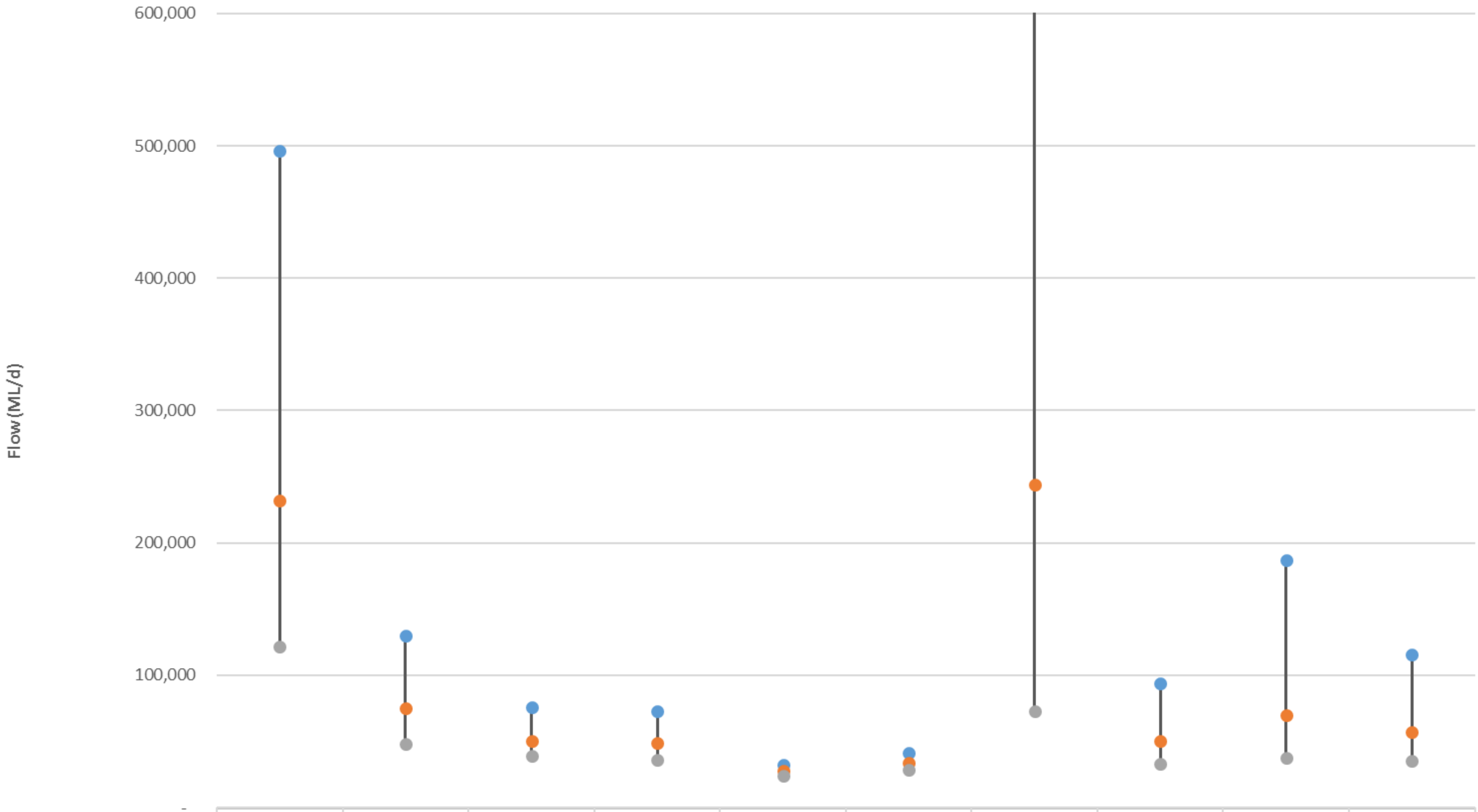


FIGURE C-38 PARTIAL RECORD GP (CENSORED) FLOOD FREQUENCY DISTRIBUTION PLOT



	Log Normal Raw	Log Normal Censored	Log Pearson 3 Raw	Log Pearson 3 Censored	Gumbel Raw	Gumbel Censored	GEV Raw	GEV Censored	Generalised Pareto Raw	Generalised Pareto Censored
Upper Confidence Limit	496,581	129,954	75,635	73,104	32,453	41,197	1,306,893	93,644	186732	115,617
Mean	232,014	75,118	50,417	49,135	27,827	34,157	244,346	49,965	69953	56,980
Lower Confidence Limit	121,803	47,968	38,724	36,103	23,973	28,566	73,021	33,402	37840	34,954

FIGURE C-39 FULL RECORD 1% AEP FLOOD FREQUENCY DISTRIBUTION

Flow Comparison

A comparison of the full and partial record for this gauge based on the LPIII censored results is shown below in Table C-29.

The results from the full records analysis show slightly higher estimated peak flows than those with the reduced record. Given the results show remarkably similar results, in line with the current best practice and given the additional benefit of the longer record the full record FFA results will be adopted for use as the design peak flows for the Moorabool River at Batesford.

TABLE C-29 ADOPTED PEAK FLOWS – MOORABOOL RIVER AT BATESFORD

Design Event (AEP)	Partial Record (ML/d)			Full Record (ML/d)		
	Peak Flow	Lower Confidence Limit	Upper Confidence Limit	Peak Flow	Lower Confidence Limit	Upper Confidence Limit
50%	2,615	1,580	4,297	3,791	2,837	5,164
20%	9,822	6,839	15,082	11,896	9,117	15,594
10%	16,704	11,819	25,001	19,521	14,972	25,525
5%	24,039	17,072	36,110	27,972	21,651	37,339
2%	33,663	23,533	54,237	39,880	29,997	56,219
1%	40,529	27,771	76,760	49,135	36,103	73,104
0.5%	46,864	31,249	100,457	58,394	41,619	92,010
0.2%	54,314	34,831	140,449	70,406	47,934	119,128
0.01%	59,235	36,727	174,469	79,188	51,714	151,388

Flood Frequency using Regional Parameters

The skewness results from the FFA for the Log Pearson 3 low flow censored with full period of record are shown in Table C-30 below.

TABLE C-30 POSTERIOR SKEWNESS

Posterior Mean of Skewness	Posterior Standard Deviation
-0.75761	0.28336

Whilst these confidence limits would not be considered to be significant an additional assessment of this distribution using the recently available ARR 2016 regional information within the FLIKE assessment will be undertaken as a sensitivity test in this circumstance. The regional paraments are sourced from the ARR Regional Flood Frequency Estimation (RFFE) method for LP3 distribution comparison. The parameters derived for the Moorabool River @ Batesford using the RFFE tool are shown in Table C-31.

TABLE C-31 RFFE PARAMETERS

Parameters	Mean	Std dev	Correlation		
Mean of log Q	5.312	0.654	1.000		
Std dev of log Q	0.664	0.217	-0.330	1.000	
Skew of log Q	0.141	0.030	0.170	-0.280	1.000

Using the RFFE parameters the LP3 censored flood frequency analysis was refitted. Table C-32 below shows the resulting LP3 posterior moments with and without the use of the regional parameters, referred to here as prior information. It should be noted that the RFFE tool is not recommended where the catchment area exceeds 1000m2.

Figure C-40 below shows the fitted flows distribution using the regional parameters. Many of the plotted flows are shown to be outside the confidence limits of this distribution plot, which would indicate a poor date fit with many of the plotted flows sitting above the upper confidence limit.

TABLE C-32 COMPARISON OF LP3 PARAMETERS

LP3 parameters	No prior information		With Prior Information	
	Mean	Std Deviation	Mean	Std Deviation
Mean	8.4482	0.20306	8.00534	0.14925
Loge	0.44686	0.13748	0.17269	0.09065
Skew	-75761	0.28336	0.10759	0.10759

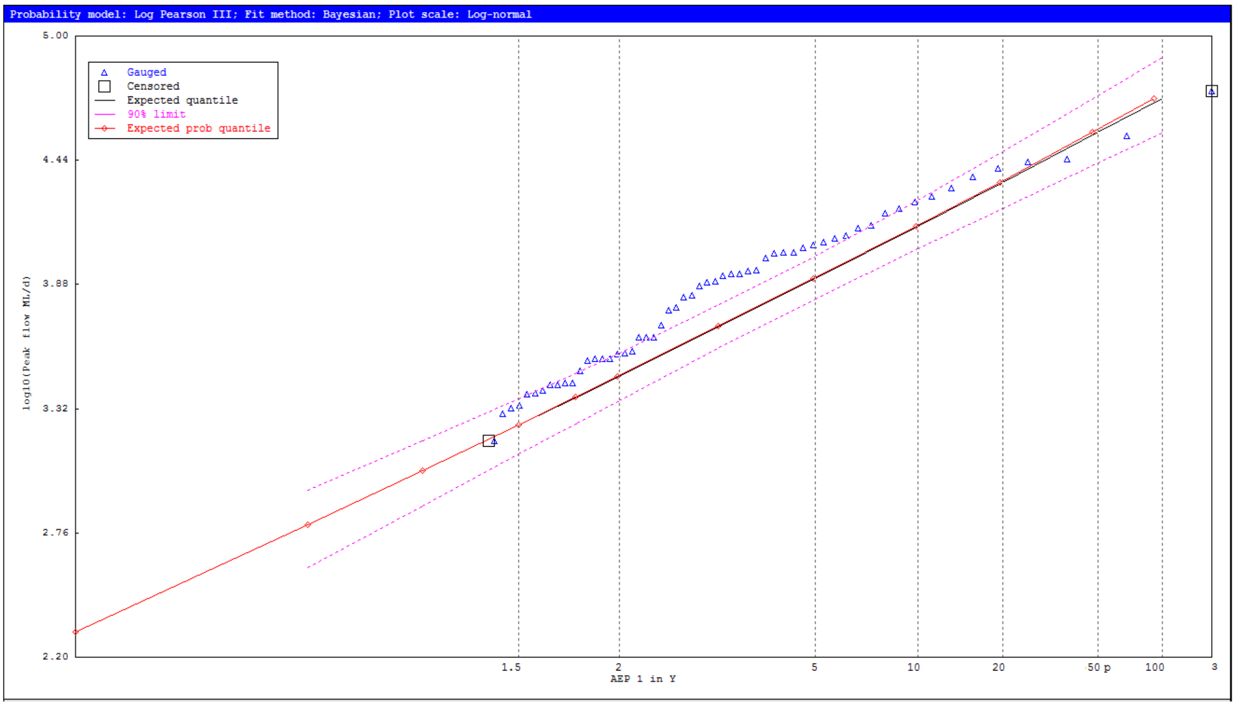


FIGURE C-40 LP3 CENSORED FLOOD FREQUENCY DISTRIBUTION USING REGIONAL PARAMETERS

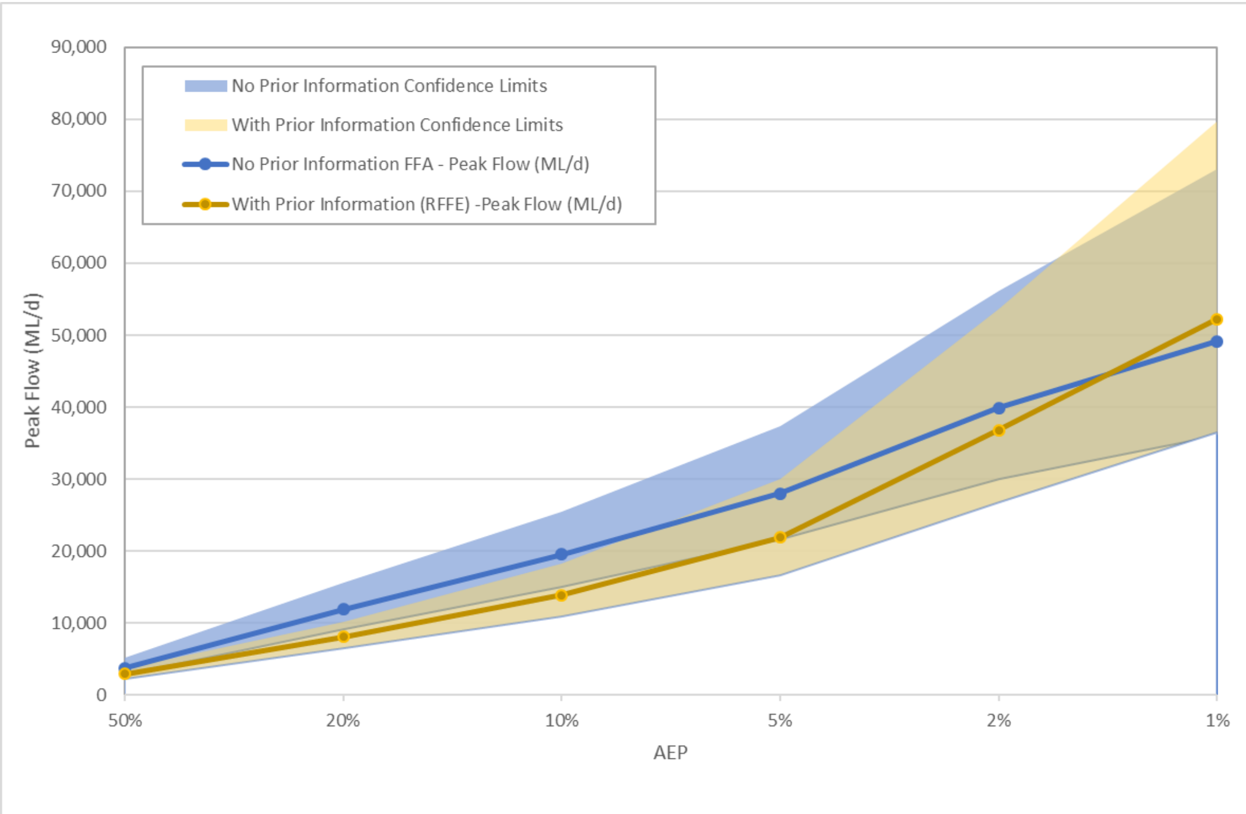


FIGURE C-41 LP3 REGIONAL COMPARISON

Based on the results of this assessment and a comparison of both the plotted data with and without the regional parameters as shown in Figure C-42 and Table C-32. These derived peak flows will not be utilised as the recommended design peak flows in this instance. Whilst the confidence limits of this assessment are narrower based on the distribution plot it would appear that in this instance flow are likely to be underestimated particular in the lower order events where the majority of the flows sit above the confidence limits.

TABLE C-33 COMPARISON OF LP3 ESTIMATED PEAK FLOWS AND CONFIDENCE LIMITS

AEP (%)	No prior information (ML/d)			With prior Information (RFFE) (ML/d)		
	Peak Flow	Lower Confidence	Upper Confidence	Peak Flow	Lower Confidence	Upper Confidence
50%	3,791	2,837	5,164	2,934	2,270	3,709
20%	11,896	9,117	15,594	8,094	6,494	10,201
10%	19,521	14,972	25,525	13,925	10,957	18,258
5%	27,972	21,651	37,339	21,936	16,701	30,075
2%	39,880	29,997	56,219	36,839	26,735	53,728
1%	49,135	36,103	73,104	52,262	36,545	79,691

Adopted Flood Frequency Results

The adopted results of the FFA is provided in Table 4-20 below and is based on the partial annual series as shown in Table 4-19 to account for the impact of upstream storages. The results show a 1% AEP peak flow of 36,927 ML/d with 5-95% confidence limits of 26,266 ML/d to 57,776 ML/d. These confidence limits are considered reasonable based on experience with other FFA analyses.

Note that years prior to 1960 were not adopted in the final analysis due to the impact of upstream storages constructed in the early 1970s, as previously discussed. Missing years were included as below threshold years.

TABLE 7-34 ADOPTED PEAK FLOWS – MOORABOOL RIVER AT BATESFORD

Design Event (AEP)	Partial Record Log Pearson III with Low Flow Censoring (m^3/s)		
	Peak Flow (ML/d)	Lower Confidence Limit (ML/d)	Upper Confidence Limit (ML/d)
50%	3,221	2,204	4,553
20%	8,771	6,923	11,699
10%	14,012	10,981	18,524
5%	20,071	15,387	26,594
2%	29,222	21,660	41,023
1%	36,927	26,266	57,776
0.5%	45,237	30,612	80,127
0.2%	45,236	35,689	117,936
PMF	1,453,594		

Water Technology determined that the censored LP3 distribution of the partial record was the preferred option based on the following:

- CCMA analysis indicates the upstream storages reduce peak flows at Batesford by approximately 20% in large flood events.
- The LP3 distribution with censoring provides the best fit across AEPs with confidences limits within a reasonable range.
- The flows produced by this assessment are lower than previous catchment analysis and former flood frequency analysis undertaken by the Corangamite CMA (2015), and approximately 20% lower than estimates by GHD (2016).

Moorabool River at Batesford Hydrographs

Similar to the analysis of peak flows, an analysis on volume was undertaken to inform the choice of hydrograph shape for design flows at the Moorabool River at Batesford streamflow gauge. To determine the design hydrograph the ratio of historic event peak flows to volumes was compared to the ratio of design peak flows to volumes determined by FFA.

The six largest events recorded at the Moorabool River at Batesford gauge (June 1952, November 1995, November 1978, September 1916 and November 1911) are shown overlayed in Figure C-42 . In all events the flood occurred over a three to five-day period. The 1995, 1952, and 1973 events all have a similar shape. The 1995, 1973 and 1978 hydrograph shapes all show a very steep rising arm to the hydrograph, although the 73 and 78 events show an initial peak before the maximum peak. Both the 1995 and 1911 event show a singular peak with a rapid initial rise and a more gradual falling tail to the hydrograph. Based on the lengths of the hydrographs it was determined a four-day volume FFA would be completed to determine appropriate peak flow/peak volume ratios. Furthermore, based on the similar shape of the 1995, 1973 and 1911 events it was determined that a hydrograph shape similar to these events would be adopted.

The four-day volume FFA was completed using a variety of distributions including low flow and peak under threshold censoring, with the LP3 distribution providing the best fit of the recorded data. The four-day volume FFA results and comparisons for the design events are Table C-36 , Figure C-42 with the historical events shown in Table C-35 .

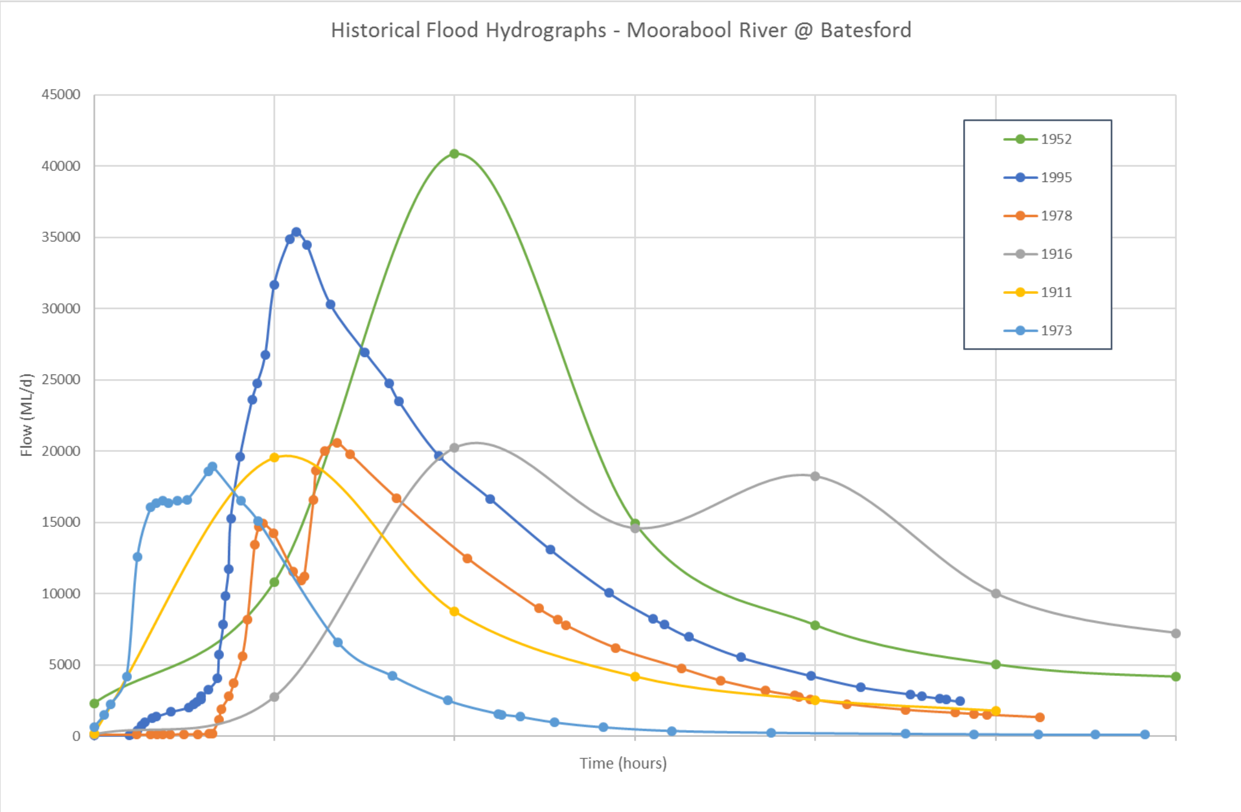


FIGURE C-42 HISTORICAL FLOOD HYDROGRAPHS

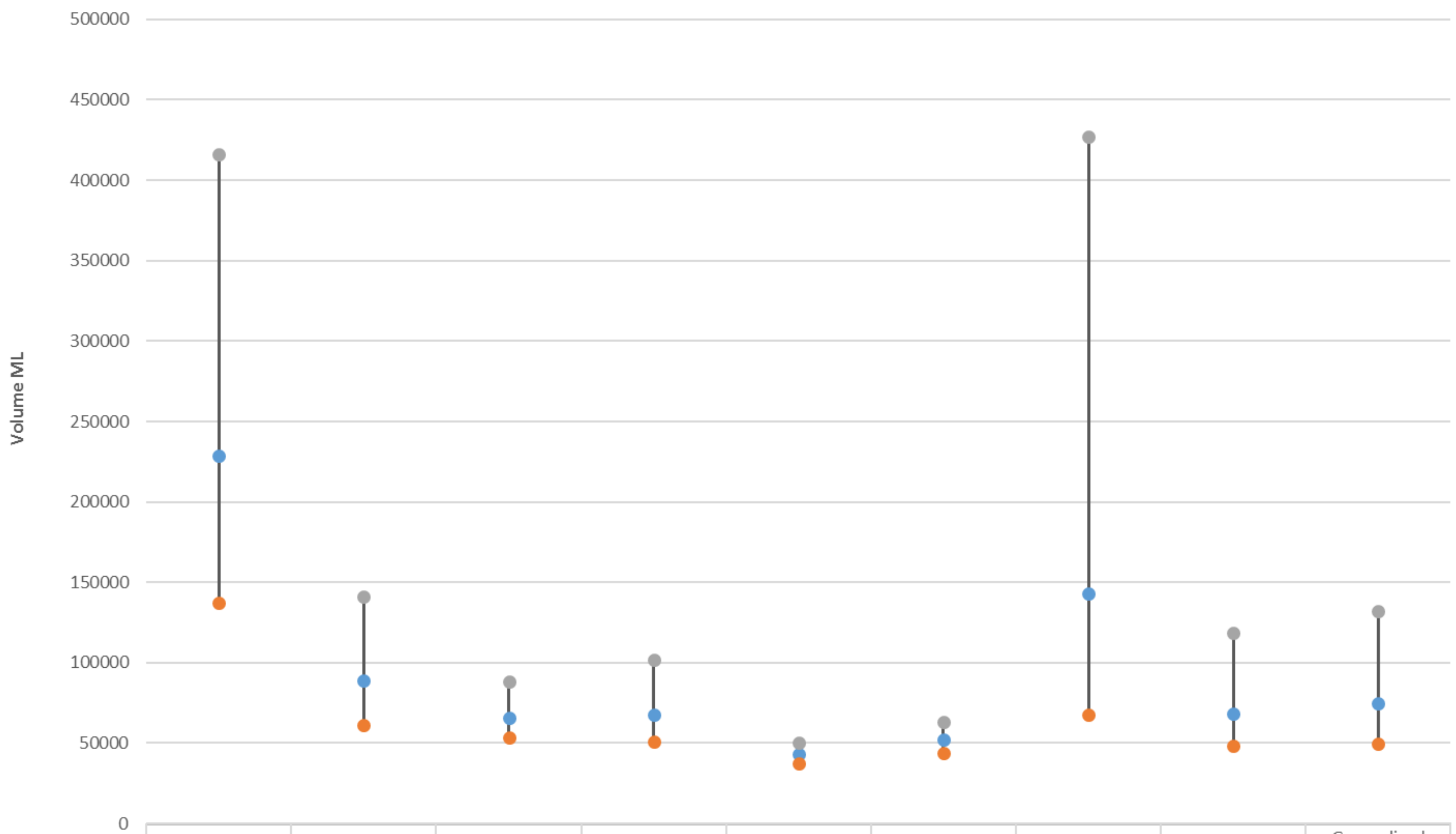
The volume to peak flow ratio of the 1978 historic events match the average ratio of the range of design events considerably better than some of the other historic event. The 1995, 1993, 1983 and 1978 event provides a good fit to the 1% AEP ratio. However, given that the smooth shape of the 1995 hydrograph it was chosen as the donor hydrograph shape for design purposes. The November 1995 hydrograph shape was scaled for each design event to match the peak and the volume of the design hydrograph from the FFA. Figure C-46 presents the final design flood hydrographs.

TABLE C-35 MOORABOOL RIVER AT BATESFORD – FLOW TO VOLUME RATIO

Year	Peak Flow (ML/day)	4 Day Volume (ML)	Ratio
June 1952	40,848	69,923	1.71
November 1995	35,401	53,997	1.53
November 1978	20,578	32,937	1.60
September 1916	20,219	59,044	2.92
September 1911	19,540	29,439	1.51
February 1973	18,904	21,088	1.12
		Average	1.73

TABLE C-36 4 DAY VOLUME FLOOD FREQUENCY DISTRIBUTION

	Log Normal		LP3		Gumble		GEV	GP	
AEP	Raw (ML)	Censored (ML)	Raw (ML)	Censored (ML)	Raw (ML)	Censored (ML)	Raw (ML)	Censored (ML)	Raw (ML)
20%	4,367	6,880	6,256	7,119	9,337	8,268	6,311	7,713	7,252
50%	18,292	17,363	20,056	18,991	18,471	20,040	17,148	18,949	18,536
10%	38,677	28,171	31,603	29,330	24,518	27,834	29,899	28,063	28,610
5%	71,778	42,010	42,875	40,427	30,319	35,310	49,217	38,319	40,233
2%	143,958	65,870	56,460	55,792	37,827	44,987	91,271	54,212	58,386
1%	228,947	88,902	65,457	67,664	43,454	52,238	143,301	68,417	74,591



	Log Normal Raw	Log Normal Censored	Log Pearson 3 Raw	Log Pearson 3 Censored	Gumbel Raw	Gumbel Censored	GEV Censored	Generalised Pareto Raw	Generalised Pareto Censored
Lower Confidence Limit	228947	88902	65457	67664	43454	52238	143301	68417	74591
Mean	137251	61328	53452	50858	37564	43837	67568	48438	49930
Upper Confidence Limit	416000	140974	88303	101814	50491	62972	427112	118613	132017

FIGURE C-43 1% AEP FLOOD FREQUENCY 4 DAY VOLUME DISTRIBUTION

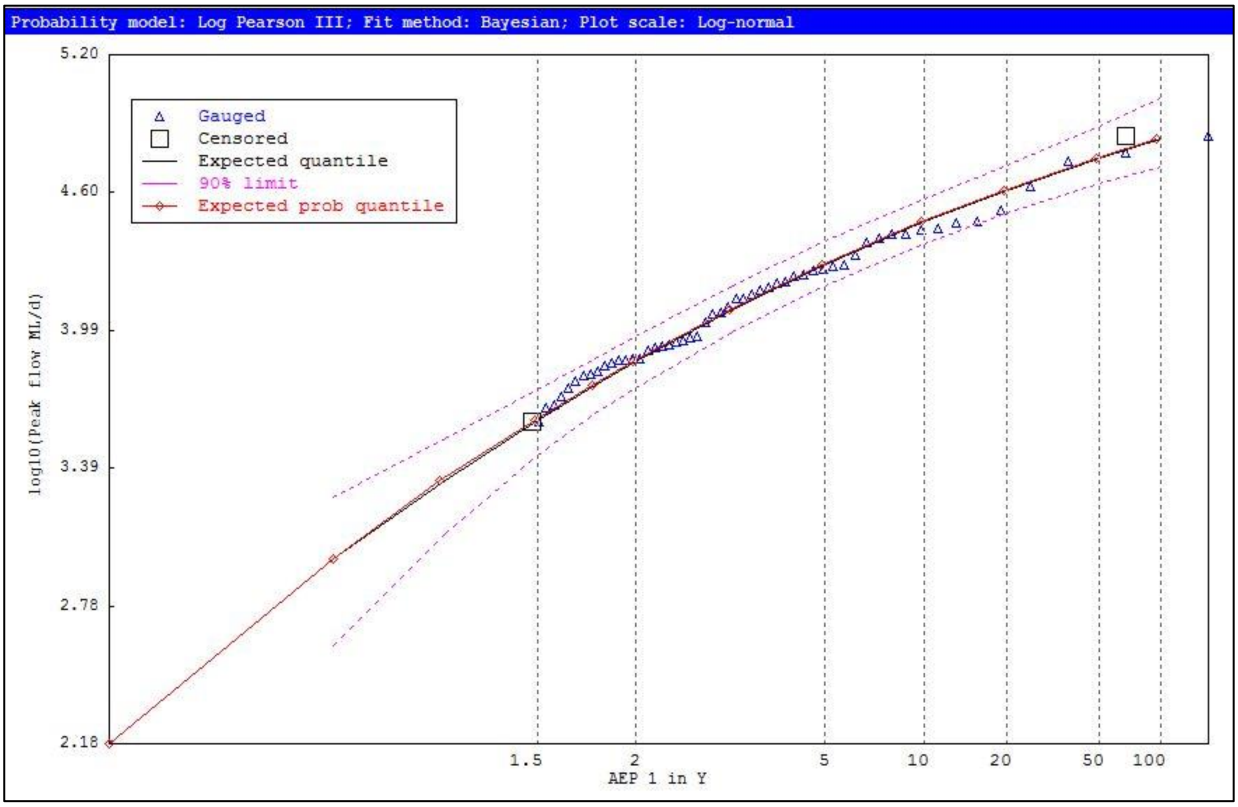


FIGURE C-44 LOG PEARSON (CENSORED) – 4 DAY VOLUME

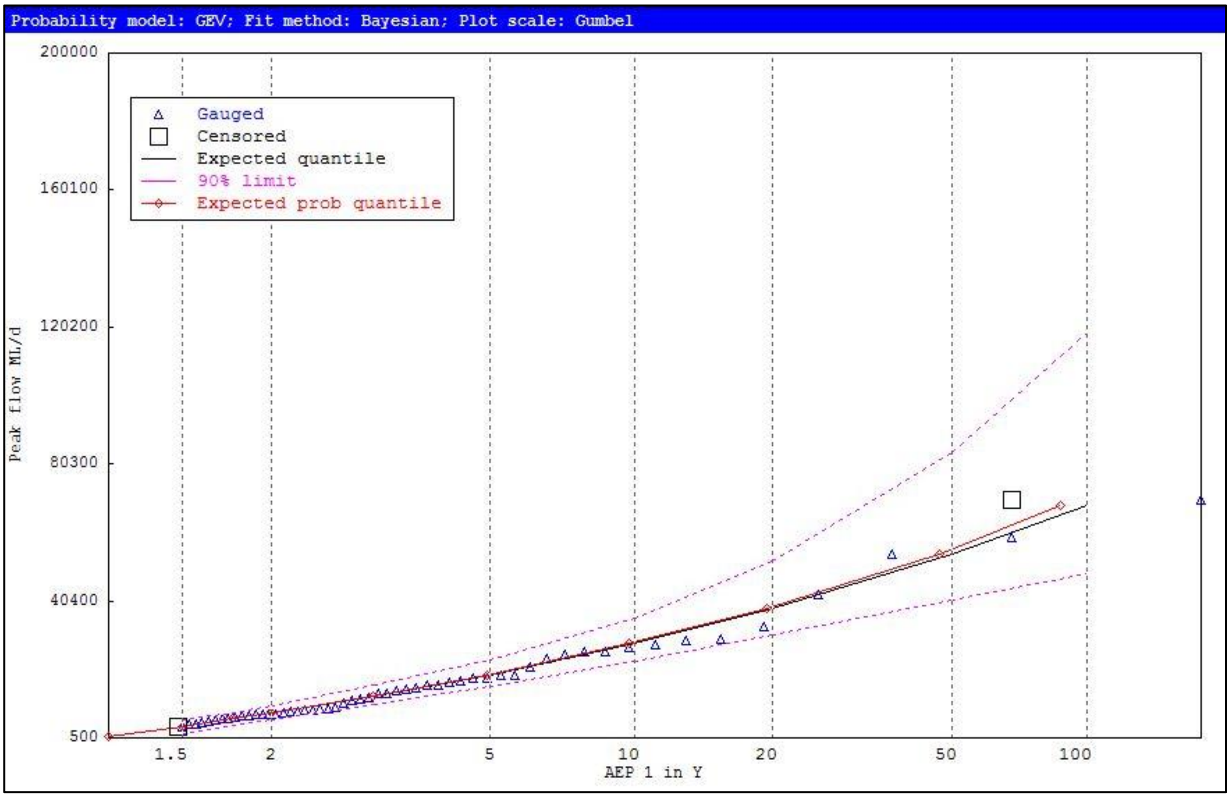


FIGURE C-45 GEV (CENSORED) – 4 DAY VOLUME

TABLE C-37 DESIGN FLOW TO VOLUME RATIO

AEP	4 Day Volume (ML)	Peak Flow (ML/day)	Ratio
50%	7119	3221	2.16
20%	18991	8771	1.83
10%	29330	14012	1.76
5%	40427	20071	1.74
2%	55792	29222	1.76
1%	67664	36927	1.79

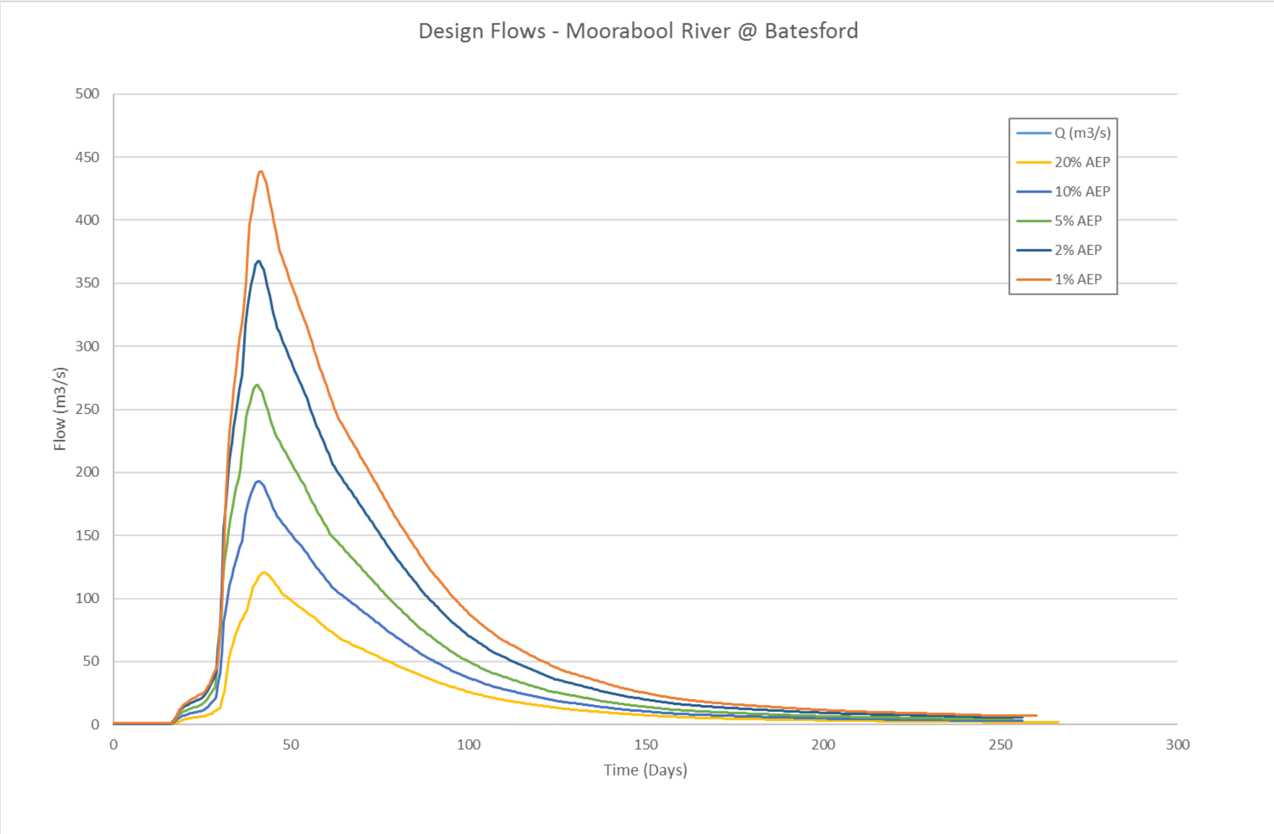


FIGURE C-46 MOORABOOL RIVER AT BATESFORD – DESIGN HYDROGRAPHS

APPENDIX D
FLOOD FREQUENCY ANALYSIS
BARWON RIVER @ GEELONG

Annual Series Flood Frequency Assessment

An annual series FFA was completed at the Barwon River at Geelong gauge to determine design flow estimates for comparison.

The available period of record at this gauge is varied as the location of the gauge has shifted several times in the past 130 years of intermittently recorded height data. Instantaneous flow records are sparse with the continuous record to current day only extending back to 2012. Whilst a number of data gaps exist relating to flow records at this gauge the majority of the significant floods through Geelong have recorded height data at McIntyre Bridge. As part of the previous flooding assessment on the Barwon River as undertaken by GHD in 1997, this height data was converted to estimated flows at McIntyre Bridge in order to fill the numerous data gaps. Further to this assessment Water Technology have utilised the GHD extended record with the available recent data between 1997-2016 to provide an updated annual series for the purposes of a full record flood frequency assessment.

The historical record provided in the previous assessment also included a number of events which occurred in the 1800's. Given the accuracy of record for these events is uncertain a number of varied versions of the annual series have been provided for comparison. The analysis was completed on a raw annual peak flow series and a modified annual series with low flow censoring to remove years of low flow using the Multiple Grubbs Beck test. The numerous periods of records analysed, the years of record, low flow censoring thresholds and peak below threshold censoring for absent data are shown below in Table D-38. The top 10 ranked (highest to lowest) flow events are shown in Table D-39 below.

TABLE D-38 BARWON RIVER AT GEELONG – FLOOD FREQUENCY RECORDS ANALYSIS

Period of Record	Years of Record	Flow Censoring Threshold (ML/day)	No. Flows Censored
Reduced Record -1900's to current Threshold Censoring 60 Years Flow < 126,552 ML/Day	47	4158	6
Short Record - 1962 to current	43	6700	8

TABLE D-39 RANKED PEAK FLOWS

Year	Peak Flow (m^3/s)	Peak Flow (ML/d)
1952	1465	126,552
1852	1430	123,552
1880	1230	106,272
1951	1220	105,408
1995	1111	95,990
1909	900	77,760
1978	753	65,059
1972	638	55,123
1916	620	53,586
1976	491	42,422

Partial Annual Series Flood Frequency Analysis

An annual series FFA was completed at the Barwon River at Geelong gauge to determine design flow estimates for comparison. The short period of record at this gauge used for this assessment and includes 43 years of available record.

This period of gauge record was used to complete an annual series FFA in Flike. The analysis was completed on a raw annual peak flow series and a modified annual series with low flow censoring to remove years of low flow using the Multiple Grubbs Beck test. This determined a low flow threshold of 6700 ML/d, removing 8 years from the 43-year record during the censored assessments.

The Log Normal (LN), Log Pearson Type 3 (LP3), Generalised Extreme Value (GEV), Generalised Pareto GP) and Gumbel distributions were tested. Of these distributions, the LP3 matched well for both the raw and censored annual series, while a number of the alternative distributions appeared to over or underestimate the flows best on the best fit. Further to this the confidence limits of many of the distributions were large with many flows sitting outside these limits.

A comparison of the FFA results for all distributions for the raw and censored annual series are shown in Table D-40 . The FFA plots for the Log Normal (censored), LP3 raw, LP3 censored and GP fit and are shown in Section 8.1.9. The resulting 1% AEP flows and confidence limits of the various distributions is shown in Figure D-51 .

TABLE D-40 SHORT RECORD - FLOOD FREQUENCY COMPARISON

Design Event	Log Normal (ML/d)		LP3 (ML/d)		Gumble (ML/d)		GEV (ML/d)		GP (ML/d)	
AEP	Raw	Censored	Raw	Censored	Raw	Censored	Raw	Censored	Raw	Censored
20%	11,464	14,247	13,410	14,298	16,283	16,334	14,315	14,868	14,434	15,152
10%	19,920	20,721	21849	21,152	22,519	23,262	20,966	21,493	22,938	22,857
5%	33,743	29,620	32,919	30,587	29,464	30,978	29,886	30,303	33,831	33,178
2%	59,328	43,424	48,224	45,170	38191	40,673	43,872	43,981	48,937	48,354
1%	94,545	59,558	63,391	62,080	46,563	49,973	60,934	60,486	64,427	64,999

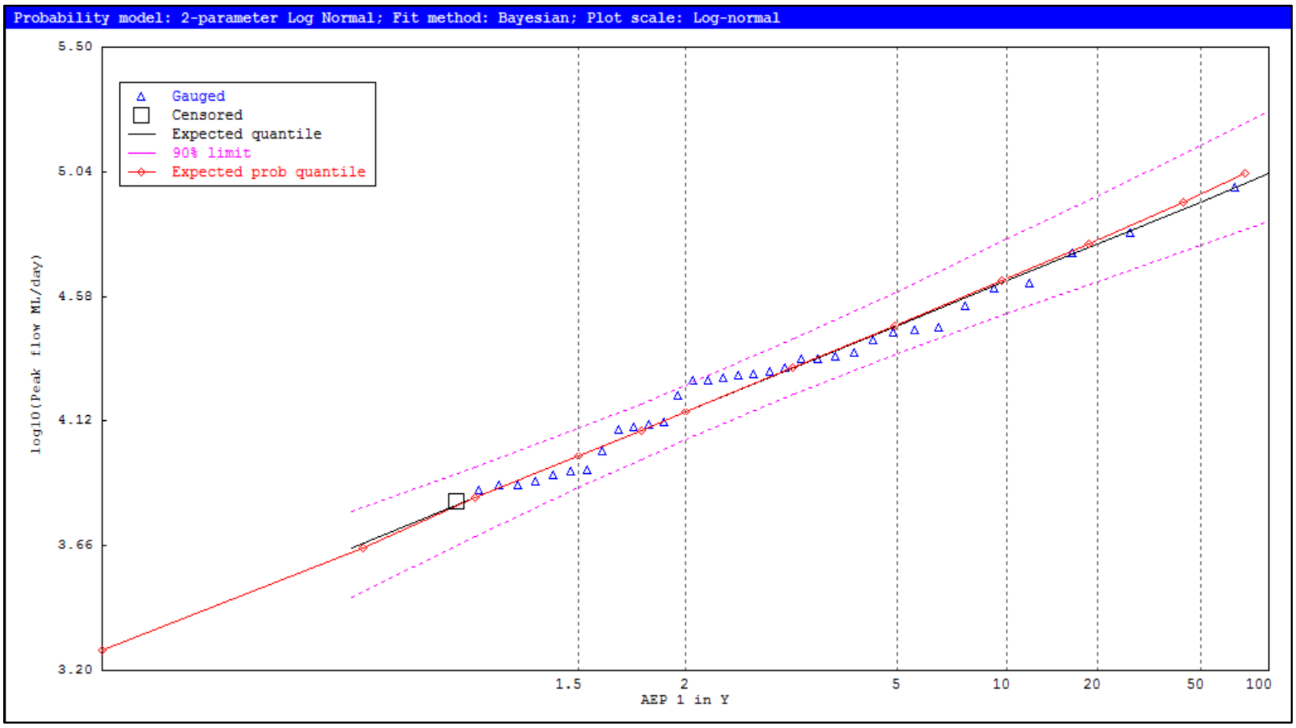


FIGURE D-47 PARTIAL RECORD LOG NORMAL (CENSORED) FLOOD FREQUENCY DISTRIBUTION PLOT

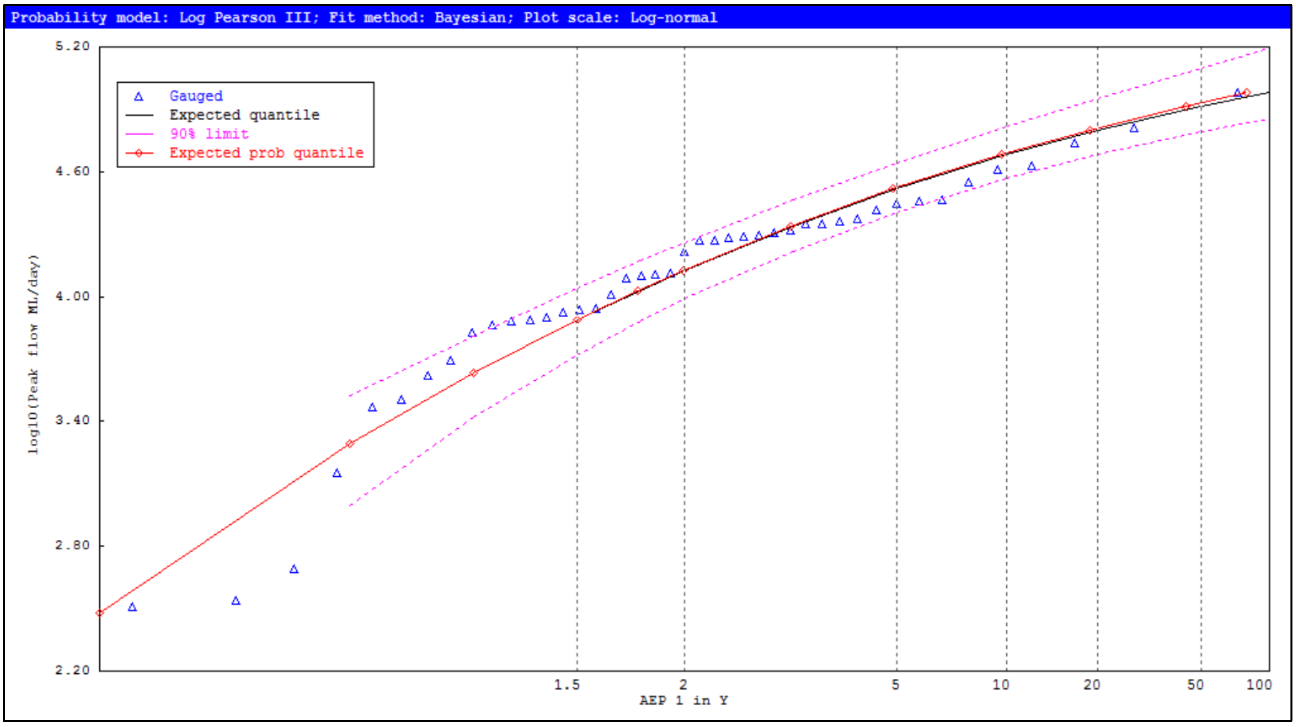


FIGURE D-48 PARTIAL RECORD LOG PEARSON III (RAW) FLOOD FREQUENCY DISTRIBUTION PLOT

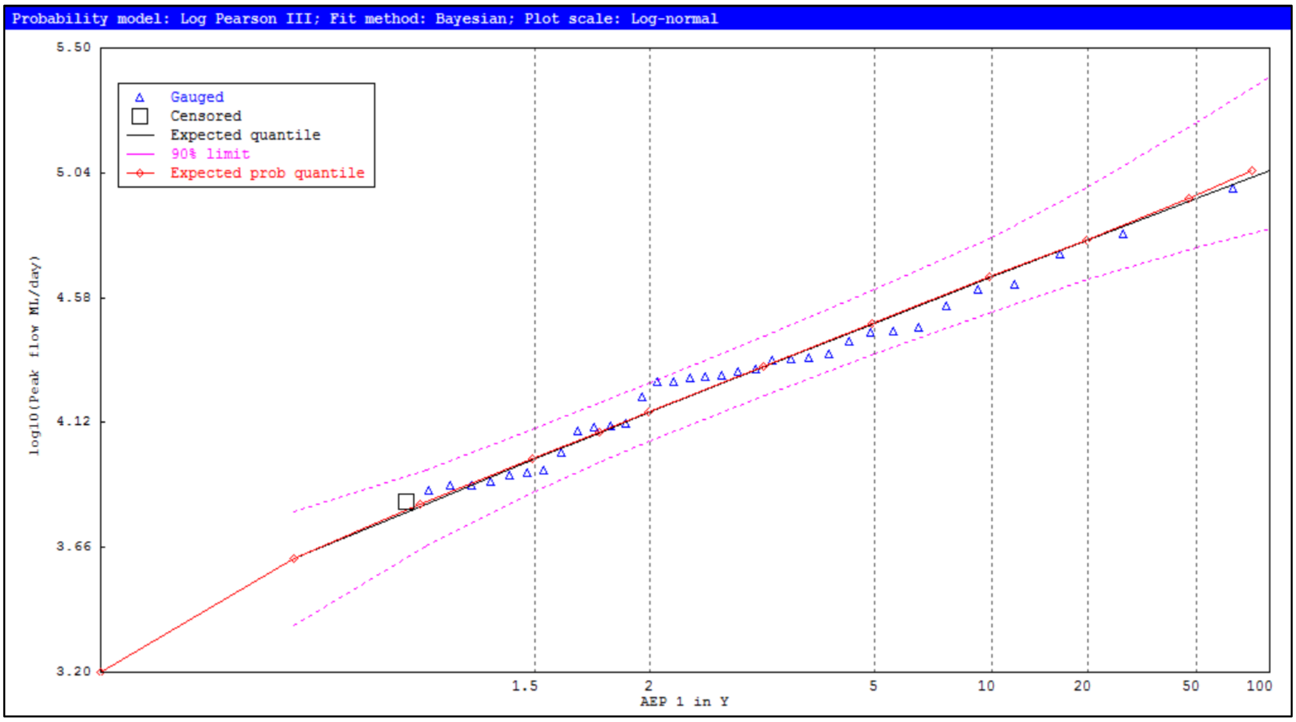


FIGURE D-49 PARTIAL RECORD LOG PEARSON III (CENSORED) FLOOD FREQUENCY DISTRIBUTION PLOT

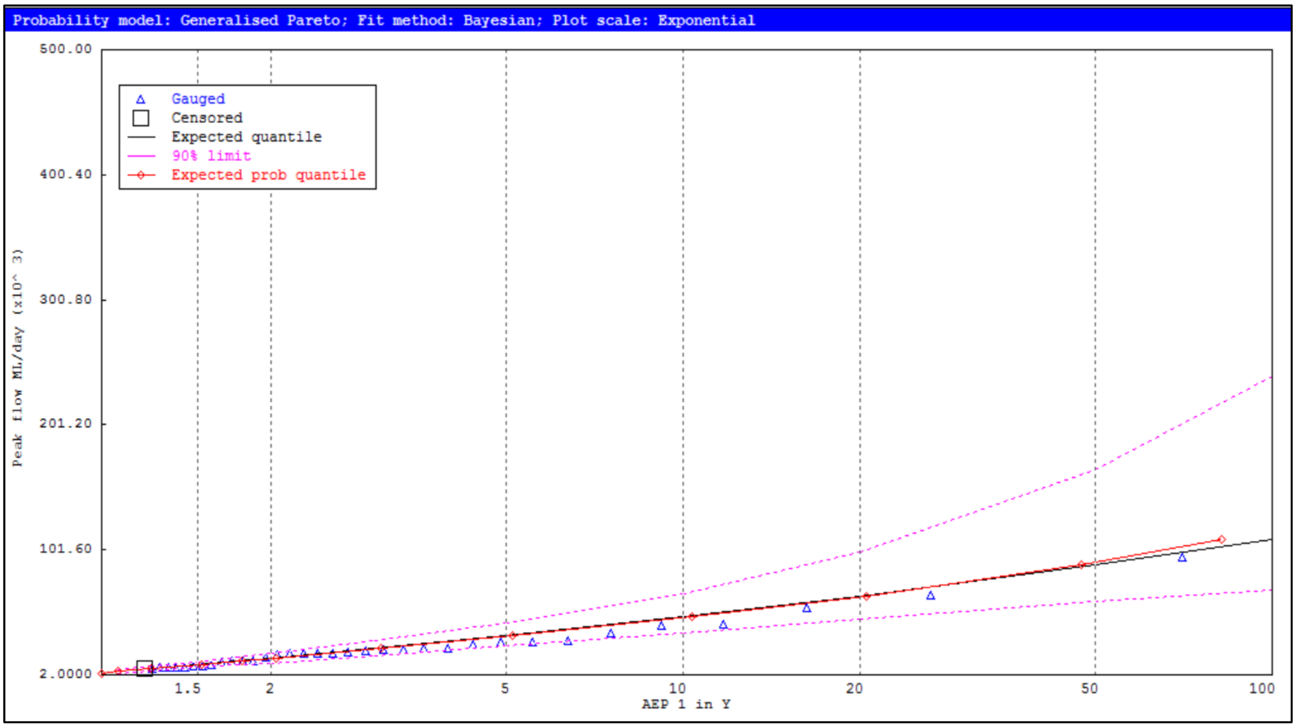
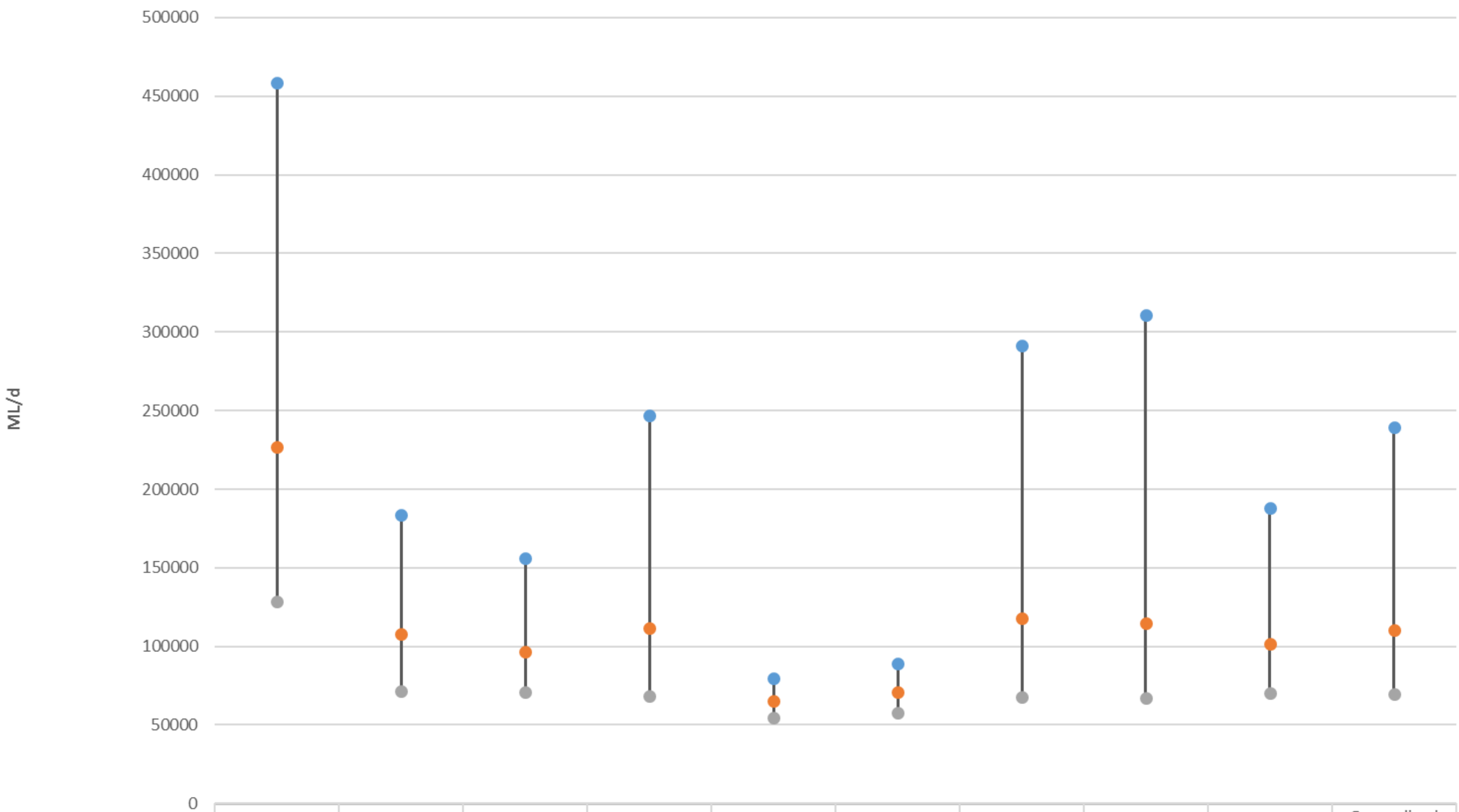


FIGURE D-50 PARTIAL RECORD GENERALISED PARETO (CENSORED) FLOOD FREQUENCY DISTRIBUTION PLOT



	Log Normal Raw	Log Normal Censored	Log Pearson 3 Raw	Log Pearson 3 Censored	Gumbel Raw	Gumbel Censored	GEV Raw	GEV Censored	Generalised Pareto Raw	Generalised Pareto Censored
Upper Confidence Limit	458525	183561	156329	246707	79623	89095	291307	311036	188168	239512
Mean	226607	107727	96438	111654	65518	71031	118228	114916	101925	110132
Lower Confidence Limit	128690	71679	71073	68378	54461	57652	67785	66955	70063	69593

FIGURE D-51SHORT RECORD 1% AEP FLOOD FREQUENCY DISTRIBUTION

Full Record Extended Annual Series Flood Frequency Analysis (1900s – current)

An annual series FFA was completed at the Barwon River at Geelong gauge to determine design flow estimates for comparison. The full extended available period of record at this gauge used for this assessment and includes 48 years of available record. This analysis has excluded the two events from the full records which occurred in 1852 and 1880.

This period of gauge record was used to complete an annual series FFA in Flike. The analysis was completed on a raw annual peak flow series and a modified annual series with low flow censoring to remove years of low flow using the Multiple Grubbs Beck test. This determined a low flow threshold of 4,158 ML/d, removing 6 years from the 47-year record during the censored assessments.

The Log Normal (LN), Log Pearson Type 3 (LP3), Generalised Extreme Value (GEV), Generalised Pareto GP) and Gumbel distributions were tested. Of these distributions, the LP3 matched well for both the raw and censored annual series, while a number of the alternative distributions appeared to over or underestimate the flows best on the best fit. Further to this the confidence limits of many of the distributions were large with many flows sitting outside these limits.

A comparison of the FFA results for all distributions for the raw and censored annual series are shown in . The FFA plots for the LP3 raw, LP3 censored, fit and are shown in Figure D-52 and Figure D-53. The resulting 1% AEP flows and confidence limits of the various distributions is shown in Figure D-54.

Peak below threshold censoring was considered and included as 60 Years Flow < 126,552 ML/Day. Again, this was based on the assumption that the peak flow event in each of the missing data years would have been lower than the largest event on record otherwise there would have been some recording of it – either measured or anecdotal.

TABLE D-41 FULL RECORD - FLOOD FREQUENCY COMPARISON

Design Event	Log Normal (ML/d)		LP3 (ML/d)		Gumble (ML/d)		GEV (ML/d)		GP (ML/d)	
AEP	Raw	Censored	Raw	Censored	Raw	Censored	Raw	Censored	Raw	Censored
20%	13,064	12,650	13,159	12,893	17,333	16,839	13,425	13,288	14,157	13,967
50%	31,250	29,032	39,111	30,403	33,014	34,044	32,025	28,974	36,309	32,845
10%	49,301	44,818	60,362	46,781	43,396	45,435	52,014	44,079	56,119	49,512
5%	71,841	64,148	81,136	66,187	53,356	56,362	80,161	63,556	79,015	68,560
2%	109,750	96,041	106,474	96,886	66,247	70,505	136,495	98,800	114,843	97,980
1%	145,578	125,692	123,555	124,218	75,907	81,104	200,864	135,382	146,884	123,952

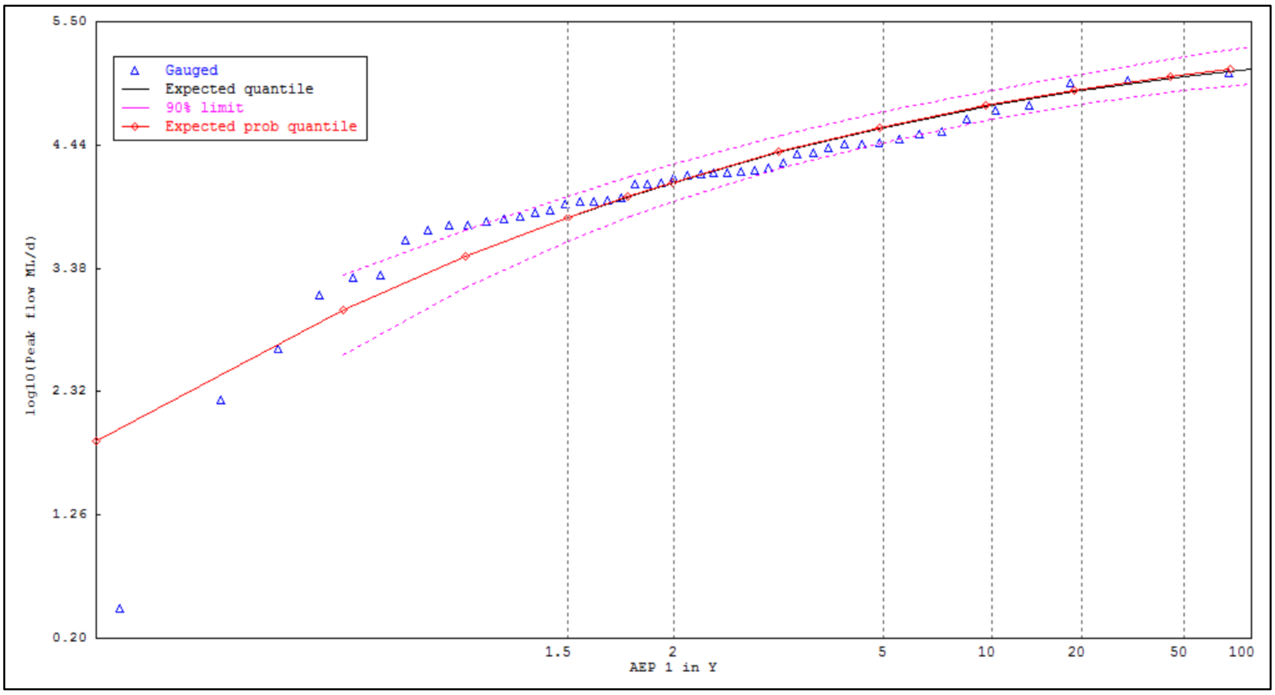


FIGURE D-52 FULL RECORD LOG PEARSON III (RAW) FLOOD FREQUENCY DISTRIBUTION PLOT

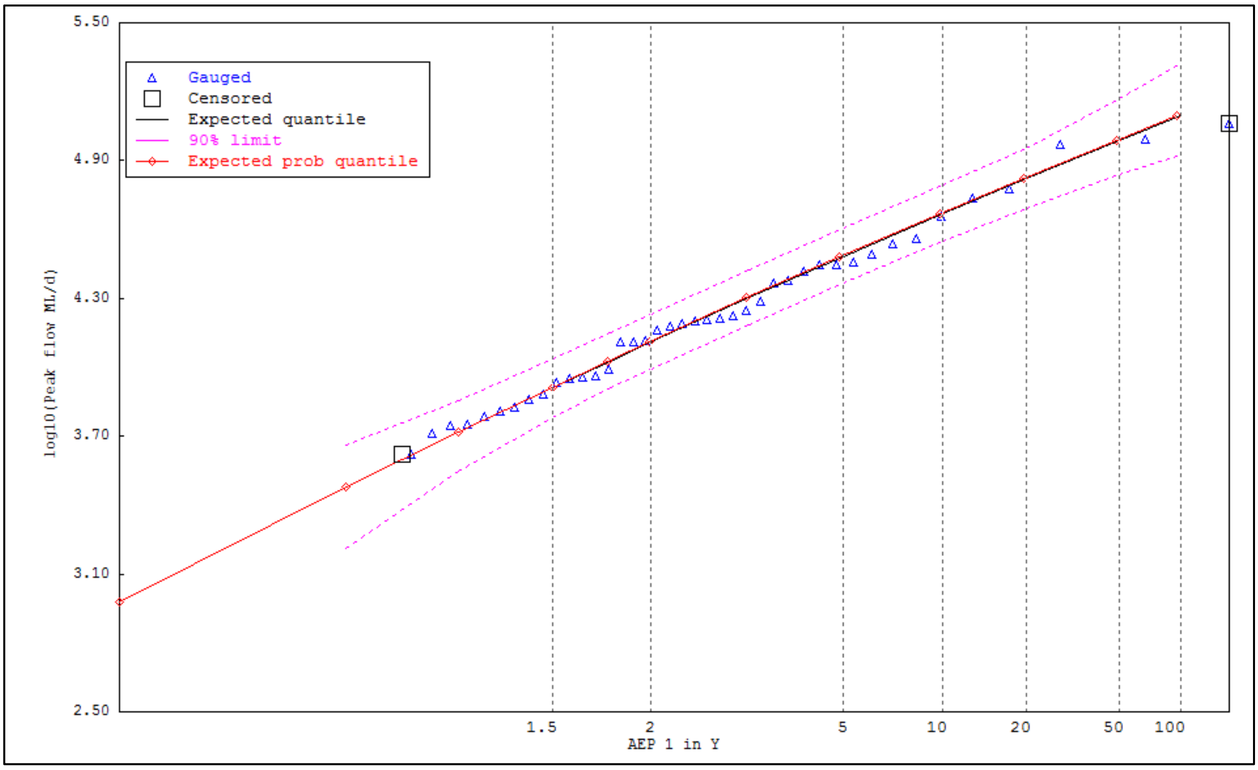
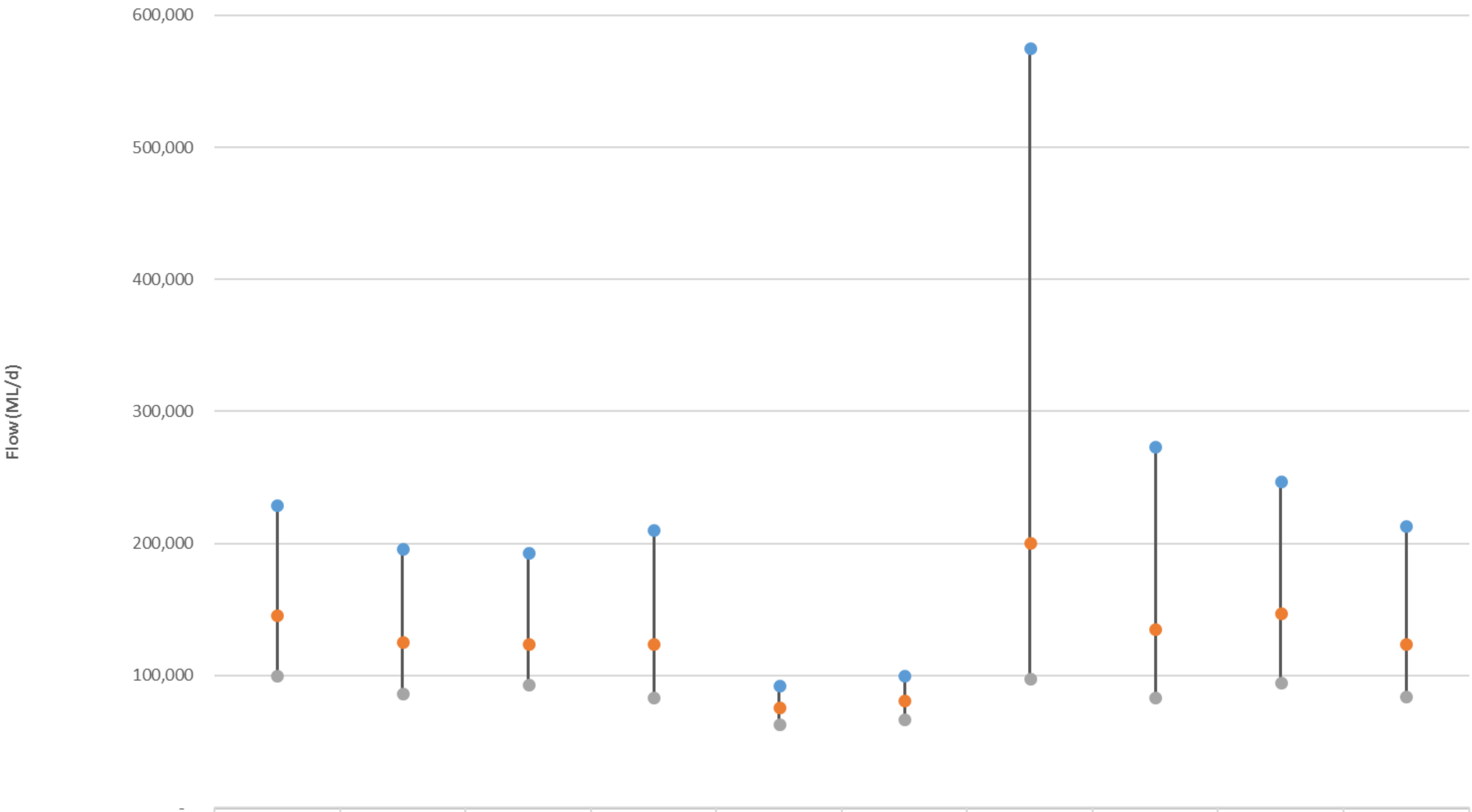


FIGURE D-53 FULL RECORD LOG PEARSON III (CENSORED) FLOOD FREQUENCY DISTRIBUTION PLOT



	Log Normal Raw	Log Normal Censored	Log Pearson 3 Raw	Log Pearson 3 Censored	Gumbel Raw	Gumbel Censored	GEV Raw	GEV Censored	Generalised Pareto Raw	Generalised Pareto Censored
Upper Confidence Limit	229,382	195,920	193,026	210,056	92,570	99,891	575,277	273,408	246706	213,028
Mean	145,578	125,692	123,555	124,218	75,907	81,104	200,864	135,382	146884	123,952
Lower Confidence Limit	99,784	86,727	93,002	83,701	62,786	66,534	97,884	83,567	94271	83,777

FIGURE D-54 FULL RECORD 1% AEP FLOOD FREQUENCY DISTRIBUTION

Flood Frequency Comparison and Discussion

A comparison of the full and short flow record data for the LP3 censored distributions is shown below in Table D-43. The comparison shows the highly variable nature of the distribution using the three periods of flow records. Based on the reliability of the flows from the 1800s being largely unknown and the largest flood in living memory (1952) being absent from the short records the use of the modified full record for consideration of design flows through Geelong was adopted.

TABLE D-42 FFA PEAK FLOWS BASED ON VARIED FLOOD RECORD

Design Event (AEP)	Modified Full Record (ML/d)	Short Record (ML/d)
50%	12,893	14,298
20%	30,403	21,152
10%	46,781	30,587
5%	66,187	45,170
2%	96,886	62,080
1%	124,218	88,420

The results of the Barwon River at Geelong FFA are slightly lower than those adopted by GHD as part of the 1982 and 1997 analysis (Table D-43). Whilst GHD extended the flood record to include the 1995 flood event as part of the 1997 investigation this version of the FFA was never adopted as it showed higher flows than those previously considered. An additional assessment was undertaken by CCMA to fill a number of data gaps between the Pollocksford, Batesford and McIntyres gauges to determine peak flows through Geelong and consider flow concurrence between the Moorabool River and Barwon River. The CCMA estimated attenuation of flood flows from the Pollocksford and Batesford data in RORB and based on this synthetic stream records at Geelong for the period of record from 1977-2014.

It is of note that the current FFA was based on a similar flood record to that used by GHD for this period however the CCMA assessment does not include several significant events at Geelong including most importantly the 1952 event, the largest on record. The concern with only using the post-storage record is that a number of very significant historic events occurred prior to 1972 and have therefore been excluded from the analysis, including the largest on record which occurred in 1954. These pre-1972 events a have a significant impact on the resulting FFA.

Whilst it is acknowledged that the construction of upstream storages has some impact on peak flows in Geelong it was deemed of greater importance to include the historic events within the FFA annual series. The upstream storages are generally located in the upland areas of the catchment, with a relatively small proportion of the total catchment area upstream by them. The adopted approach is more conservative and deemed more appropriate with the inclusion of the pre-1972 events.

TABLE D-43 FFA COMPARISON – BARWON RIVER AT GEELONG (MCINTYRE BRIDGE)

AEP	CCMA (2015) ML/d	GHD (1982) ML/d	Water Technology ML/d	Difference to CCMA % (+/-)	Difference to GHD % (+/-)
20%	28,800	42,600	30,403	+ 5	- 28
10%	44,000	58,000	46,781	+ 6	- 19
5%	62,100	78,000	66,187	+ 6	- 15
2%	87,300	N/A	96,886	+ 10	N/A
1%	107,100	137,500	124,218	+ 15	- 9

Adopted Flood Frequency Results

The adopted results of the FFA is provided in Table 4-26 below and is based on the annual series presented in the section above. The results show a 1% AEP peak flow of 171,198 ML/d with 5-95% confidence limits of 78,961 ML/d to 198,573 ML/d. These confidence limits are considered reasonable based on experience with other FLIKE analyses and were some of the lowest confidence intervals in comparison to the range of distributions tested.

TABLE 7-44 ADOPTED FFA PEAK FLOWS FOR BARWON RIVER AT GEELONG GAUGE

Design Event (AEP)	Full Record Log Pearson III with Low Flow Censoring (ML/d)		
	Peak Flow (ML/d)	Lower Confidence Limit (ML/d)	Upper Confidence Limit (ML/d)
50%	9,999	7,667	13,245
20%	25,983	19,913	34,275
10%	41,559	31,524	55,028
5%	60,343	44,890	83,246
2%	90,367	64,006	136,961
1%	117,198	78,691	198,573
0.5%	147,736	92,808	281,232
0.2%	194,022	109,926	438,929
0.01%	395,615		

Water Technology determined that the censored LP3 distribution of the full available record was the preferred option based on the following:

- The full record provided a much longer period of record for assessment.
- The full records enable the inclusion of a number of significant historical floods including 1909, 1916, 1951, 1952.
- The LP3 distribution with censoring provides the best fit across AEPs with confidences limits within a reasonable range.

- A flow threshold was included for the 60 years of missing data from 19010-2015, 1917-1932, 1934-1950 and 1953-1961 for the full record FFA, a threshold of 126,552 ML/day was adopted based on the largest recorded flow as this location.

APPENDIX E REGIONAL FLOOD FREQUENCY ESTIMATION TOOL – (AR&R, 2016)

Barwon River @ Pollocksford - RFFE

The Regional Flood Frequency Estimation (RFFE) technique has been developed as part of the 2016 release of Australian Rainfall and Runoff. The online tool uses the catchment centroid, catchment outlet and size to estimate peak flow outputs for a range of flood magnitudes. The tool was developed utilising data based on gauged catchments to form region-based flood relationships.

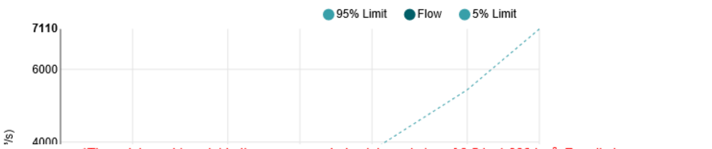
The RFFE tool has several limitations to its application and should be avoided where:

- The catchment includes greater than 10% urban,
- Catchment storage significantly altered the natural rainfall runoff behaviour,
- Catchment where large scale clearing has taken place,
- Catchments which are greatly affected by irrigation activity and or drainage.

The reliability of the tool is also considered less accurate for catchments less than 0.5 km^2 and or greater than 1,000 km^2 or where a catchment exhibits atypical characteristics.

Whilst several of the catchment characteristics, including the size of the total catchment (greater than 1000 km^2) and significant catchment storage of the Barwon River suggest that the method is not suitable as a means as providing a comparison to the FFA for the Pollocksford gauge the results of the tool output are provided below in Figure E-55. The results yielded from this assessment show estimated peak flows significantly higher than those produced by the gauge FFA.

Results | Regional Flood Frequency Estimation Model



*The catchment is outside the recommended catchment size of 0.5 to 1,000 km^2. Results have lower accuracy and may not be directly applicable in practice.

*The catchment has unusual shape. Results have lower accuracy and may not be directly applicable in practice.

AEP (%)	Discharge (m^3/s)	Lower Confidence Limit (5%) (m^3/s)	Upper Confidence Limit (95%) (m^3/s)
50	421	161	1110
20	774	312	1950
10	1070	425	2760
5	1420	541	3770
2	1940	694	5440
1	2400	818	7110

Statistics

Variable	Value	Standard Dev
Mean	6.275	0.520
Standard Dev	0.722	0.235
Skew	0.136	0.030

Note: These statistics come from the nearest gauged catchment. Details.

Correlation		
1.000		
-0.330	1.000	
0.170	-0.280	1.000

Note: These statistics are common to each region. Details.

Input Data	
Date/Time	2017-02-27 14:32
Catchment Name	Barwon River @ Pollocksford
Latitude (Outlet)	-38.1434
Longitude (Outlet)	144.187111
Latitude (Centroid)	-38.0563
Longitude (Centroid)	143.9375
Catchment Area (km^2)	2713.0*
Distance to Nearest Gauged Catchment (km)	34.98
50% AEP 6 Hour Rainfall Intensity (mm/h)	4.15822
2% AEP 6 Hour Rainfall Intensity (mm/h)	8.948412
Rainfall Intensity Source (User/Auto)	Auto
Region	East Coast
Region Version	RFFE Model 2016 v1
Region Source (User/Auto)	Auto
Shape Factor	0.46*
Interpolation Method	Natural Neighbour
Bias Correction Value	0.539

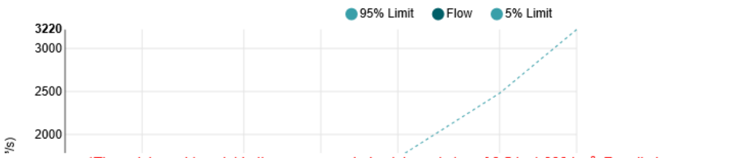
FIGURE E-55 BARWON RIVER AT POLLOCKSFORD – REGIONAL FLOOD FREQUENCY ESTIMATE

Moorabool River at Batesford - RFFE

The Regional Flood Frequency Estimation (RFFE) as discussed in Section 5.2.3.2 was also applied to the Moorabool River catchment at Batesford.

Whilst a number of the catchment characteristics of the Moorabool River suggest that the method is not suitable as a means as providing a comparison to the FFA for the Batesford gauge, most significantly the number of significant storages, the results of the tool output are provided below in Figure E-56 .

Results | Regional Flood Frequency Estimation Model



*The catchment is outside the recommended catchment size of 0.5 to 1,000 km². Results have lower accuracy and may not be directly applicable in practice.

AEP (%)	Discharge (m^3/s)	Lower Confidence Limit (5%) (m^3/s)	Upper Confidence Limit (95%) (m^3/s)
50	193	71.1	526
20	351	137	908
10	484	186	1280
5	635	237	1730
2	867	304	2480
1	1070	358	3220

Statistics

Variable	Value	Standard Dev
Mean	5.279	0.654
Standard Dev	0.664	0.217
Skew	0.141	0.030

Note: These statistics come from the nearest gauged catchment. Details.

Correlation		
1.000		
-0.330	1.000	
0.170	-0.280	1.000

Note: These statistics are common to each region. Details.

Input Data	
Date/Time	2017-02-07 11:58
Catchment Name	Moorabool River
Latitude (Outlet)	-38.0893
Longitude (Outlet)	144.2782
Latitude (Centroid)	-37.831
Longitude (Centroid)	144.182
Catchment Area (km^2)	1088.0*
Distance to Nearest Gauged Catchment (km)	33.12
50% AEP 6 Hour Rainfall Intensity (mm/h)	4.348198
2% AEP 6 Hour Rainfall Intensity (mm/h)	10.162375
Rainfall Intensity Source (User/Auto)	Auto
Region	East Coast
Region Version	RFFE Model 2016 v1
Region Source (User/Auto)	Auto
Shape Factor	0.91
Interpolation Method	Natural Neighbour
Bias Correction Value	0.496

FIGURE E-56 MOORABOOL RIVER - RFFE

APPENDIX F WAURN PONDS CREEK - RORB TEMPORAL PATTERNS

Temporal Patterns - Waurn Ponds RORB Model

EventID	Duration	TimeStep	Region	AEP	Inc 1	Inc 2	Inc 3	Inc 4	Inc 5	Inc 6	Inc 7	Inc 8	Inc 9	Inc 10	Inc 11	Inc 12	Inc 13	Inc 14	Inc 15	Inc 16	Inc 17	Inc 18	Inc 19	Inc 20	Inc 21	Inc 22	Inc 23	Inc 24
5982	60	5	Southern Slopes (mainland)	frequent	6.6	14.05	16.53	9.92	16.53	4.96	3.31	3.31	7.44	8.26	4.13	4.96												
5983	60	5	Southern Slopes (mainland)	frequent	4.67	17.89	16.84	12.62	10.26	7.22	2.19	2.27	6.57	12.17	4.87	2.43												
5984	60	5	Southern Slopes (mainland)	frequent	6.36	9.31	16.45	10.25	14.68	8.33	5.87	3.81	6.36	6.19	7.88	4.51												
5985	60	5	Southern Slopes (mainland)	frequent	5.71	6.86	4	7.43	6.86	12	12.57	16.57	10.29	6.86	5.14	5.71												
5986	60	5	Southern Slopes (mainland)	frequent	6.59	9.58	9.02	8.4	5.31	7.24	8.79	8.79	10.34	8.4	9.41	8.13												
5987	60	5	Southern Slopes (mainland)	frequent	6.41	12.2	5.82	1.3	10.27	9.97	11.61	15.28	13.79	6.04	4.08	3.23												
5988	60	5	Southern Slopes (mainland)	frequent	3.79	5.72	7.27	7.1	3.72	5.93	15.91	15.74	12.19	10.15	6.05	6.43												
5990	60	5	Southern Slopes (mainland)	frequent	8.47	6.49	9.44	7.6	5.29	12.72	11.25	11.67	6.55	7.26	4.28	8.98												
5992	60	5	Southern Slopes (mainland)	frequent	5.18	1.02	7.3	12.17	10.18	2.21	3.67	0.75	4.42	4.42	8.1	40.58												
5993	60	5	Southern Slopes (mainland)	frequent	14.65	0.69	15.44	3.1	0	0	0.81	4.03	8.06	19.35	19.76	14.11												
5920	60	5	Southern Slopes (mainland)	intermediate	11.03	4.2	3.64	8.77	9.78	9.88	10.15	10.55	16.62	3.36	7.88	4.14												
5972	60	5	Southern Slopes (mainland)	intermediate	10.75	18.81	9.95	5.11	8.46	7.37	6.73	6.73	6.32	7.13	7.93	4.71												
5974	60	5	Southern Slopes (mainland)	intermediate	8.64	14.39	13.86	8.46	6.43	13.69	13.36	7.62	2.81	1.78	3.84	5.12												
5975	60	5	Southern Slopes (mainland)	intermediate	24.4	12.2	7.13	16.39	10.79	5.72	1.14	5.72	7.51	3.93	1.91	3.16												
5976	60	5	Southern Slopes (mainland)	intermediate	5.79	7.25	2.9	11.59	7.97	15.22	11.59	7.25	7.25	8.7	9.42	5.07												
5977	60	5	Southern Slopes (mainland)	intermediate	6.07	6.35	4.47	5.73	14.84	15.76	9.57	10.03	8.03	4.52	6.73	7.9												
5978	60	5	Southern Slopes (mainland)	intermediate	4.35	1.09	5.43	22.83	9.78	15.76	10.87	10.87	7.61	4.89	3.26	3.26												
5979	60	5	Southern Slopes (mainland)	intermediate	6.8	5.28	8.24	4.63	4.15	20.65	10	8.68	10.27	6.74	8.8	5.76												
5980	60	5	Southern Slopes (mainland)	intermediate	7.5	12.75	11.36	4.39	1.87	3.37	3.75	10.5	18.49	10.01	10.01	6												
5981	60	5	Southern Slopes (mainland)	intermediate	18.26	5.11	0.73	0.99	4.12	10.95	1.82	9.6	15.58	17.04	12.77	3.03												
5891	60	5	Southern Slopes (mainland)	rare	3.45	5.86	3.02	2.5	9.31	11.72	5.17	10	16.55	18.97	10.69	2.76												
5909	60	5	Southern Slopes (mainland)	rare	11.95	15.65	15.1	11.99	8.38	6.83	7.79	6.04	4.43	4.43	4.97	2.44												
5914	60	5	Southern Slopes (mainland)	rare	8.5	9.5	7.5	5	9.5	8.5	12.5	13	14.5	4.5	2	5												
5940	60	5	Southern Slopes (mainland)	rare	12.21	11.14	16.13	8.18	2.31	1.46	7.56	13.53	7.58	8.44	6.96	4.5												
5966	60	5	Southern Slopes (mainland)	rare	22.4	15.23	6.83	2.51	4.04	3.46	2.33	3.17	7.49	16.96	7.06	8.52												
5967	60	5	Southern Slopes (mainland)	rare	13.95	22.09	12.21	2.91	3.49	2.91	3.49	0	3.49	5.81	16.28	13.37												
5968	60	5	Southern Slopes (mainland)	rare	4.65	11.2	5.7	11.52	13.11	10.78	6.41	13.98	10.61	4.54	3.86	3.64												
5969	60	5	Southern Slopes (mainland)	rare	2.51	10.07	12.15	8.89	1.97	11.07	13.33	8.18	6.64	13.04	10.37	1.78												
5970	60	5	Southern Slopes (mainland)	rare	7.72	6.37	7.06	7.91	8.06	9.03	7.95	12.24	7.47	6.22	10.46	9.51												
5971	60	5	Southern Slopes (mainland)	rare	1.11	3.33	3.9	1.49	3.01	13.25	15.06	10.24	16.27	18.67	9.04	4.63												
6122	360	15	Southern Slopes (mainland)	frequent	9.49	6.09	1.18	0.77	4.28	13.12	11.84	2.91	0.69	2.73	3.77	5.13	8.34	3.93	4.28	5.8	2.83	3.18	2	2.06	1.58	0.72	2.08	1.2
6147	360	15	Southern Slopes (mainland)	frequent	8.33	7.57	7.08	9.66	10.55	4.56	6.37	1	1.22	1.17	2.55	0.84	0.92	2.41	1.95	1.76	1.6	2.87	1.44	1.79	3.69	8.11	5.13	7.43
6148	360	15	Southern Slopes (mainland)	frequent	5.78	7.49	5.16	5.11	4.51	4.39	5.71	4.85	4.77	4.87	3.78	2.76	2.67	2.65	2.71	3.24	3.48	3.89	3.26	3.31	3.92	3.48	3.89	4.32
6149	360	15	Southern Slopes (mainland)	frequent	3.7	7.2	6.77	1.75	1.75	4.8	5.24	1.96	2.4	10.04	6.55	5.67	3.08	4.58	7.64	1.11	1.53	2.18	3.06	2.4	6.77	3.06	4.8	1.96
6150	360	15	Southern Slopes (mainland)	frequent	2.61	4.57	2.77	3.22	3.99	2.77	3.28	7.87	6.89	4.8	4.05	5.6	3.13	5.73	4.38	2.25	4.48	3.95	4.87	4.68	3.3	1.27	5.49	4.05
6151	360	15	Southern Slopes (mainland)	frequent	2.78	3.53	3.16	3.53	4.28	2.79	2.79	3.9	2.42	3.9	6.32	8.18	3.9	4.65	4.83	6.69	3.9	5.76	4.28	4.65	3.53	3.16	3.72	3.35
6152	360	15	Southern Slopes (mainland)	frequent	3.16	2.71	2.71	4.06	4.51	4.96	5.42	4.05	4.05	4.05	3.15	3.6	4.05	4.95	5.86	6.31	4.05	2.7	4.05	4.95	4.95	3.6	3.15	4.95
6153	360	15	Southern Slopes (mainland)	frequent	1.51	2.03	2.54	2.54	4.06	8.12	3.05	2.54	2.03	2.03	3.55	6.09	8.63	1.52	3.55	12.69	10.15	5.08	0.51	1.02	2.03	7.11	4.57	3.05
6154	360	15	Southern Slopes (mainland)	frequent	1.46	1.88	2.63	2.54	3.44	3.58	3.73	3.36	4.54	5.33	4.04	2.35	2.19	1.45	3.23	5.13	5.55	2.7	4.61	7.33	6.3	7.09	13.54	2
6155	360	15	Southern Slopes (mainland)	frequent	2.59	2.57	2.5	2.95	3.97	2.65	3.32	3.58	5.02	3.17	2.5	4.68	2.8	3.51	2.16	0	0.43	6.04	7.98	6.25	3.73	2.74	16.39	8.47
6136	360	15	Southern Slopes (mainland)	intermediate	2.31	12.88	7.94	6.25	12.55	2.23	0.96	2.31	3.01	2.19	1.56	2.1	0.51	0.36	1.37	3.73	4.3	5.24	1.64	6.02	11.92	5.41	1.79	1.42
6137	360	15	Southern Slopes (mainland)	intermediate	33.3	10.91	5.35	1.8	1.14	0.56	0.33	0	0	0	0.44	0.75	0.88	1.41	2.83	13.91	2.88	1.05	2.22	0.72	2.24	4.19	2.89	10.2
6138	360	15	Southern Slopes (mainland)	intermediate	0.97	0.32	6.81	11.03	8.13	4.54	12.67	4.87	1.61	0.97	10.38	13.97	3.41	0.16	0.16	2.11	2.11	1.78	0.83	1.8	2.77	1.46	5.68	1.46
6139	360	15	Southern Slopes (mainland)	intermediate	4.95	3.84	4.24	3.67	3.74	4.13	5.86	6.58	5.86	6.97	5.1	5.59	4.08	4.02	3.95	4.72	0.25	1.83	5.29	4.3	3.68	2.4	2.07	2.88
6140	360	15	Southern Slopes (mainland)	intermediate	5.25	1.15	1.46	1.8	2.11	2.62	2.62	2.45	4.09	5.07	4.75	3.76	5.73	6.07	8.04	5.74	6.37	5.55	5.56	6.22	5.91	3.76	2.45	1.47
6141	360	15	Southern Slopes (mainland)	intermediate	2.59	2.95	2.78	4.17	5.38	1.89	1.89	1.91	6.08	0.87	12.84	3.82	6.08	4.69	4.69	4.34	2.26	4.36	3.99	6.77	4.7	3.3	3.99	3.66
6142	360	15	Southern Slopes (mainland)	intermediate	2.46	2.94	2.88	2.91	2.78	3.6	3.58	4	3.55	4.82	5.43	8.68	7.01	5.57	6.23	7.4	3.38	1.87	2.3	4.11	4.43	4.23	2.98	2.86
6143	360	15	Southern Slopes (mainland)	intermediate	3.34	3.9	5.31	4.69	5.42	5.39	5.06	5.81	5.24	5.65	3.98	3.78	3.57	4.35	4.02	3.62	3.7	3.87	2.71	3.08	2.89	2.95	3.57	4.1
6145	360	15	Southern Slopes (mainland)	intermediate	2.61	0.97	1.95	1.3	0.65	4.55	8.12	13.96	7.14	0.32	0	0	0.65	4.22	1.95	4.87	5.52	11.36	10.71	9.42	1.62	1.62	3.57	2.92
6146	360	15	Southern Slopes (mainland)	intermediate	3.7	5.08	2.15	1.95	2.54	2.15	2.34	2.15	5.86	4.49	6.64	4.3	2.15	2.34	3.71	8.01	6.84	4.49	6.45	6.25	7.23	2.34	4.3	2.54
5826	360	15	Southern Slopes (mainland)	rare	7.42	6.07	2.01	3.45	2.87	2.49	1.72	0.96	3.35	0.49	0.19	2.11	4.4	0.1	0	1.54	2.49	15.99	12.99	16.15	5.79	6.08	1.01	0.33
6010	360	15	Southern Slopes (mainland)	rare	4.33	3.77	1.55	4.01	1.26	4.54	9.07	7.35	4.95	2.2	12.07	8.4	4.26	2.66	2.03	1.21	2.06	7.06	1.51	1	5.42	2.18	1.43	5.68
6016	360	15	Southern Slopes (mainland)	rare	4.48	5.35	3.06	2.62	3.83	3.17	6.47	5.36	2.74	2.95	2.85	5.46	3.94	3.5	2.74	2.08	1.42	2.08	4.05	4.71	5.25	0	18.06	3.83
6032	360	15	Southern Slopes (mainland)	rare	2.36	16.82	11.35	5.32	3.38	12.19	2.64	2.16	0.45	3.15	2.44	1.23	3.82	6.28	0.8	1.58	3.5	8.49	4.77	3.3	1.7	0.49	0.77	1.01
6130	360	15	Southern Slopes (mainland)	rare	5.58	5.02	13.54	6.58	2.09	9.92	4.47	9.22	4.61	1.83	0.56	1.96	1.26	0.7	0.84	5.59	0.84	0	0	0.56	12.7	2.37	2.37	7.39
6131	360	15	Southern Slopes (mainland)	rare	23.69	0.59	0	24.86	3.22	0	0.88	0.88	0.29	2.63	2.63	1.46	2.92	1.75	0	0.58	0	0	0	0	0.58	16.08	13.45	3.51
6132	360	15	Southern Slopes (mainland)	rare	2.87	3.39	7.57	8.62	3.13	3.92	3.13	3.66	3.66	3.13	4.18	4.18	3.39	4.7	5.74	5.48	4.18	3.92	4.96	3.92	4.18	3.13	2.87	2.09
6133	360	15	Southern Slopes (mainland)	rare	4.19	4.38	4.29	3.41	2.91	4.39	5.19	6.04	5.81	8.72	4.44	7.07	6.36	2.31	3.21	5.74	2.18	1.24	1.46	1.56	2.46	4.35	4.43	3.86
6134	360	15	Southern Slopes (mainland)	rare	4.3	3.63	4.76	1.68	5.3	6.5	3.22	5.76	6.04	5.76	4.62	5.43	4.7	3.08	3.48	2.41	5.96	3.82	2.07	2.21	1.94	5.56	4.69	3.08
6135	360	15	Southern Slopes (mainland)	rare	2.01	1.89	1.3	2.39	2.24	2.86	2.56	3.23	2.65	2.87	3.5	3.79	3.43	4.23	8.86	7.93	8.2	8.45	4.88	7	3.93	5.01	4.64	2.15
6208	720	30	Southern Slopes (mainland)	frequent	5.88	13.78	4.48	2.77	2.43	7.59	5.15	2.43	4.13	9.28	5.51	3.81	4.82	1.39	1.38	1.03	1.72	1.74	2.41	5.15	3.1	2.43	2.77	4.82
6209	720	30	Southern Slopes (mainland)	frequent	1.69	4.39	4.26	4.27	3.09	3.88	5.41	5.33	14.27	8.73	5.49	3.96	3.15	2.79	4.48	4.45	4.51	1.88	2.05	1.69	3.01	0.65	2.22	4.35
6210	720	30	Southern Slopes (mainland)	frequent	4.77	8.47	9.23	7.6	4.06	3.57	4.83	7.14	1.66	1.71	2.71	3.39	2.63	3.34	3.77	3.82	2.95	1.63	1.86	2.48	2.58	3.52	5.82	6.46
6211	720	30	Southern Slopes (mainland)	frequent	2.07	3.57	3.4	3.65	3.96	5.13	5	4.02	3.33	3.83	3.26	2.9	3.56	5.44	6.87	6.85	7.5	3.6	2.32	4.28	3.16	5.22	3.56	3.52
6212	720	30	Southern Slopes (mainland)	frequent	5.43	5.94	2.52	2.73	1.85	1.32	3.43	1.34	6.01	9.52	6.12	4.43	9.38	7.08	5.74	6.77	3.41	2.55	3.19	2	1.11	3.23	2.55	2.35
6213	720	30	Southern Slopes (mainland)	frequent	5.61	5.67	4.01	3.09	2.83	3.02	4.48	4.13	6.11	4.07	5.12	4.23	3.69	3.96	4.89	4.02	4.48	4.08	4.34	2.86	4.33	4.31	3.26	3.41
6214	720	30	Southern Slopes (mainland)	frequent	2.44	2.45	4.2	3.39	5.26	2.24	7.11	5.02	6.64	5.02	4.42	7.32	9.79	4.67	6.07	5.82	5.12	3.02	0.93	2.45	3.37	2.2	0	1.05
6215	720	30	Southern Slopes (mainland)	frequent	3.81	3.46	0.35	1.73	1.04	4.84	2.08	3.11	2.77	3.46	3.46	3.81	3.81	4.84	1.38	3.11	3.46	3.81	6.92	6.57	12.46	5.88	6.57	7.27
6216	720	30	Southern Slopes (mainland)	frequent	5.94	22.42	4.29	0.12	0.12	0.12	0.12	5.46	4.47	0.76	0.58	0.1	0	0	0	0	0	0	4.53	7.38	7.64	10.65	9.02	16.28
6217	720	30	Southern Slopes (mainland)	frequent	2.28	3.27	2.95	0	3.61	1.97	1.66	1.31	7.21	4.92	4.59	4.59	2.95	2.29	4.59	5.24	1.97	6.23	4.26	1.97	3.28	6.23	4.28	18.35
6176	720	30	Southern Slopes (mainland)	intermediate	2.02	3.78	4.13	2.84	5.94	4.86	5.9	4.21	3.84	5.19	5.53	7.29	6.47	5.05	4.44	5.26	2.91	5.99	2.03	1.84	2.26	2.25	3.69	2.28
6191	720	30	Southern Slopes (mainland)	intermediate	3.79	2.05	1.59	1.89	1.89	4.41	4.09	1.57	2.99	2.22	1.9	2.06	0.96	3.15	3.92	4.56	8.19	5.19	10.86	10.39	10.23	6.61	2.99	2.5
6198	720	30	Southern Slopes (mainland)	intermediate	1.21	0.59	2.26	13.26	20.66	9.22	1.84	0.62	0	0.67	0	0	0	2.07	5.44	6.36	4.11	0.83	2.53	4.68	5.39	7.17	1.22	9.87
6199	720	30	Southern Slopes (mainland)	intermediate	3.89	8.06	2.55	2.39	0.51	1.82	3.1	9	14.08	7.61	3.8	4.55	3.53	2.12	3.25	5.41	4.92	3.06	1.04	4.14	4.74	2.63	1.88	1.92
6200	720	30	Southern Slopes (mainland)	intermediate	2.63	4.87	4.73	4.21	10.04	8.86	8.22	5.38	3.08	2.05	1.15	2.15	3.62	3.31	4.75	4.58	4.57	4.85	2.74	3.38	3.45	2.32	2.35	2.71
6201	720	30	Southern Slopes (mainland)	intermediate	4.66	1.36	5.04	1.06	3.64	9.51	5.62	5.96	6.24	3.85	3.98	4.95	2.72	3.53	4.44	3.29	4.22	3.57	4.72	5.16	4.45	4.93	1.27	1.83
6202	720	30	Southern Slopes (mainland)	intermediate	3.51	6.06	3.89	3.01	5.86	3.42	3.38	2.23	0.4	0.15	4.13	3.74	3.99	6.11	4.82	5.31	4.72	4.31	3.97	2.97	6.64	6.21	4.87	6.3
6203	720	30	Southern Slopes (mainland)	intermediate	5.82	4.91	4.55	4.82	3.96	3.51	3.27	2.75	3.84	3.44	4	3.63	3.69	1.61	1.32	2.4	2.19	4.65	5.87	11.12	5.56	2.9	5.24	4.95
6204	720	30	Southern Slopes (mainland)	intermediate	6.48	4.36	3.5	4.11	4.33	4.8	4.28	3.65	3.3	1.19	2.28	1.19	0.21	0.38	1.09	1.03	3.14	9.77	9.75	8.07	5.17	4.3	7.4	6.22
6205	720	30	Southern Slopes (mainland)	intermediate	1.04	6.16	9.76	5.48	0.68	1.71	1.37	3.08	2.91	5.99	3.42	0.86	1.54	0.34	6.34	4.62	3.94	3.77	8.9	2.57	3.77	6.85	9.08	5.82
5991	720	30	Southern Slopes (mainland)	rare	4.91	1.54	1.78	7.94	6.16	4.87	8.09	1.69	0.18	0.67	1.48	1	0.85	0.76	0.67	1.07	1.64	3.45	5.43	8.54	10.1	13.05	8.39	5.74
6017	720	30	Southern Slopes (mainland)	rare	5.25	5.2	4.89	7.59	5.11	4.37	6.79	4.16	2.37	5.11	6.11	14.54	3.48	3.53	2.78	3	2.37	1.64	0.91	0.58	1.37	2.21	3.95	2.69
6081	720	30	Southern Slopes (mainland)	rare	3.48	9.18	8.17	7.67	6.43	5.69	4.95	4.43	3.97	3.45	4.45	5.19	4.95	3.46	2.23	3.79	0.76	0.24	0.49	4.16	2.98	3.58	3.83	2.47
6157	720	30	Southern Slopes (mainland)	rare	3.2	5.17	6.47	8.3	7.03	9.9	5.65	5.44	7.41	4.12	2.87	2.09	3.12	2.6	3.61	3.95	1.99	2.03	1.15	2.04	1.45	3.13	4.21	3.07
6171	720	30	Southern Slopes (mainland)	rare	1.98	3.15	1.97	1.57	1.38	1.57	2.76	4.53	5.91	0.79	0.59	1.18	2.36	6.3	2.95	0.98	2.56	2.56	7.09	7.48	0.98	4.13	19.88	15.35
6180	720	30	Southern Slopes (mainland)	rare	0.98	1.33	2.13	3.41	3.55	2.88	3.98	3.05	6.01	4.21	6.39	4.81	5.61	6.16	3.7	6.61	5.96	5.24	3.24	2.18	4.26	3.18	5.23	5.9
6194	720	30	Southern Slopes (mainland)	rare	3.82	4.76	4.99	5.49	5.93	6.48	8.1	8.21	7.8	4.03	1.14	3.09	1.69	0.71	0.17	0.09	0.08	1.41	3.95	6.74	7.16	4.61	4.74	4.81
6195	720	30	Southern Slopes (mainland)	rare	0.33	0.33	1.17	3.66	2.96	2.71	5.66	2.82	2.05	1.87	1.61	2.96	15.99	12.08	11.37	6.62	5.11	3.37	3.08	4.24	1.54	0.19	4.56	3.72
6196	720	30	Southern Slopes (mainland)	rare	2.59	1.98	2.6	3.42	3.81	4.58	4.37	4.38	5	6.08	5.49	7.37	6.45	5.28	4.74	6.08	5.79	2.66	3.45	4.27	2.49	2.83	2.68	1.61
6197	720	30	Southern Slopes (mainland)	rare	1.8	2.07	1.45	1.3	1.87	1.43	1.76	1.69	6.35	7.7	13.57	5.87	1.89	0.31	2.24	4.52	2.61	10.63	1.86	2.25	5.23	6.32	11.59	3.69

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