Goulburn Constraints Business Case Hydrology Analysis

Goulburn Broken Catchment Management Authority

Flood Event Characterisation

Final 1

6 October 2015

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Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to review and collate historical stream gauging data for the Goulburn River and its tributaries to characterise the hydrological properties of flow events in accordance with the scope of services set out in the contract between Jacobs and the Client. That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client (if any) and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

This study is a purely desktop assessment of existing information, relevant to the characterisation of flow events in the Goulburn River and its tributaries.

This report has been prepared on behalf of, and for the exclusive use of, Jacobs's Client, and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and the Client. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party

1. Introduction

1.1 Background

The Murray Darling Basin Plan Constraints Strategy (MDBA, 2013) has identified the Goulburn River as one of seven key focus areas. The ability to deliver flows between 25,000 ML/day and 40,000 ML/day to the Lower Goulburn River is constrained under current operational management in order to minimise flooding impacts, particularly in the mid-Goulburn River. MDBA (2014) “Goulburn River reach report: Constraints Management Strategy” describes the constraints strategy and the work undertaken relating the Goulburn River, which has included community consultation on existing constraints.

The Department of Environment, Land, Water and Planning (DELWP) has requested that the Goulburn Broken Catchment Management Authority (GBCMA) develop a business case for the easing of constraints on delivering higher environmental flows in the Goulburn River.

1.2 Previous Studies

Department of Sustainability and Environment report “Overbank flow recommendations for the lower Goulburn River” (February 2011) identified target flows of 25,000 ML/day to 40,000 ML/day for 4 to 5 days to water wetlands and the floodplain within the lower Goulburn levee system.

Water Technology (2011) examined issues with generating out-of-bank environmental flows which concluded that flows of 40,000 ML/day could not be provided directly from Lake Eildon due to the severity of the flooding in the reaches immediately downstream of the storage. These flows targets could however be met by making smaller releases of up to 20,000 ML/day together with reducing diversions to Waranga Basin.

Water Technology (2009) report “Hydrologic analysis - Streamflow data assessment and Tributary inflow analysis” described the behaviour of the Goulburn River and its tributaries. Typical flow events were analysed to understand the Goulburn River and tributary behaviour, including contributions from gauged tributaries, flow timing, and change in flows as they move downstream. The large contribution to flow made by tributaries upstream of Trawool indicate that these have the greatest potential for contributing to environmental flow events. Inflows from the more flashy downstream tributaries are more likely to pose a threat to providing targeted flows.

An initial scoping of the potential to add environmental releases from Lake Eildon to tributary flows was undertaken by Sinclair Knight Merz (2012) using the daily timestep Source model of the Goulburn River. The development of the Source model is documented in “Development of a Source Model of the Goulburn River to Simulate Winter and Spring High Flows – Modelling Report” (GBCMA, 2012) and in the draft extract from “Trialling eWater Models in River Management – Application in the Goulburn and Ovens Catchment” (GBCMA , 2012).

1.3 Project Objectives

The objectives of this project are to use historical flow data to:

- Assess whether environmental releases from Lake Eildon can be added to tributary flows to create desirable environmental events in the range of 25,000 ML/day to 40,000 ML/day in the lower Goulburn River.
- Assess what the corresponding flow rates are in the Goulburn River in various reaches (particularly in the mid-Goulburn River)
- Assess methods to limit the occurrence of undesirable outcomes such as the target flow rate not being achieved or the maximum target rate being exceeded.

This report describes the method and results of the flood characterisation component of the project. This task was undertaken to characterise the hydrologic behaviour of the river system using historical gauged flow data to support the later tasks of the project to achieve the project objectives listed above.

2. Historical Time Series Analysis

2.1 Collation of historical daily flow time series

Daily flow time series at a number of key locations on the Goulburn and Broken rivers and their tributaries were collated. On the Goulburn and Broken rivers this included:

- Goulburn River at Shepparton (405204)
- Goulburn River upstream of Goulburn Weir (405200 + 405700 + 405702 + 405704 + Change in storage of Goulburn Weir pool)
- Goulburn River at Seymour (405202)
- Goulburn River at Trawool (405201)
- Goulburn River at Eildon (405203)
- Broken River at Orrvale (404222)
- Broken River at Casey's Weir (404216)

Each of these flow time series was downloaded from the Victorian data warehouse including daily data quality codes.

In addition, flow data for diversions from Goulburn Weir and the Goulburn Weir storage volume was requested from GMW which was supplied by GMW and included in the analysis.

A second time series of "adjusted" flow in the Goulburn River at Shepparton was created by adding the flow that was historically diverted to Waranga Basin to the historical flow at Shepparton after allowing for routing effects and assuming no loss. This includes all of Cattanach Canal and Stuart Murray Canal flow. The adjusted flow time series was created to approximate the flow at Shepparton if no harvesting to Waranga Basin was taking place. This is to minimise the amount of additional water required to be released from Lake Eildon to meet the environmental flow targets at Shepparton.

It is noted that some flow in the Stuart Murray Canal is used to supply irrigation demand offtakes from the canal. These may still need to be supplied even if all diversions to Waranga Basin were ceased to assist delivery of environmental flows. However, as part of the assessment undertaken to date, the separation of this flow has not been estimated. This limitation may need to be reviewed as these diversions may be significant. This could be done by regressing historical data with the East Goulburn Main Channel (405704).

The flow diverted to Lake Mokoan from the Broken River data set was only available from 1987 onwards and has not been included in the adjusted flow calculation.

Data for the following tributaries of the Goulburn River downstream of Eildon were also collated:

- 405241 - Rubicon River@ Rubicon: 1922-current (gap for 1928-1949)
- 405209 - Acheron River @ Taggerty: 1945-current
- 405261 - Spring Creek @ Fawcett: 1973-1987
- 405274 - Home Creek @ Yarck: 1977-current

- 405205 - Murrindindi River @ Murrindindi above Colwells: 1939-current
- 405217 - Yea River @ Devlins Bridge: 1954-current
- 405231 - King Parrot Creek @ Flowerdale: 1961-current
- 405212 - Sunday Creek @ Tallarook: 1945-current (gaps for 1949-1954, 1956-1961)
- 405240 - Sugarloaf Creek @ Ash Bridge: 1972-current
- 405291 - Whiteheads Creek @ Whiteheads: 1988-current
- 405228 - Hughes Creek @ Tarcombe Road: 1958-2014
- 405248 - Major Creek @ Graytown: 1971-current
- 405293 - Gardiner Creek @ Puckapunyal: 1989-2012
- 405226 - Pranjip Creek @ Moorilim: 1957-current
- 405246 - Castle Creek @ Arcadia: 1970-current (gap for 1988-1990)
- 405269 - Seven Creeks @ Kialla West: 1977-current (gaps for 1985-1991)

The historical flow and quality code time series were downloaded from the Victorian data warehouse. The data sets were collated in a Microsoft Excel application which is suitable for testing release strategies and triggers later in the project.

Table 2.1 below presents the list of sites with available period of record and percentage of the available record which is considered good quality (Quality Code <= 100) or acceptable (quality code <=150).

Table 2.1 : Stream Gauge data period of record and quality

Site	Description	Start Date	End Date	% Good	% Acceptable
405232	Goulburn River at McCoys Bridge	25/08/1965	19/03/2015	97%	100%
405204	Goulburn River at Shepparton	6/09/1921	30/03/2015	97%	99%
405200	Goulburn River at Murchison	14/06/1881	28/03/2015	96%	96%
405700	Stuart Murray Canal	1/02/1892	27/02/2015	95%	95%
405702	Cattanach Canal	1/02/1957	19/03/2015	99%	100%
405704	East Goulburn Main Canal	7/02/1958	25/02/2015	96%	96%
405202	Goulburn River at Seymour	21/12/1957	19/03/2015	99%	100%
405201	Goulburn River at Trawool	1/01/1908	19/03/2015	72%	73%
405203	Goulburn River at Eildon	1/02/1916	21/03/2015	98%	99%
404222	Broken River at Orrvale	23/06/1977	4/03/2015	68%	69%
404216	Broken River at Casey's Weir	2/08/1888	3/07/2015	76%	77%
405241	Rubicon River@ Rubicon	5/02/1922	20/03/2015	98%	100%
405209	Acheron River @ Taggerty	13/12/1945	23/03/2015	99%	100%
405261	Spring Creek @ Fawcett	18/05/1973	24/05/1987	94%	97%
405274	Home Creek @ Yarck	6/09/1977	23/03/2015	97%	98%
405205	Murrindindi River @ Murrindindi above Colwells	17/06/1939	28/03/2015	99%	100%
405217	Yea River @ Devlins Bridge	27/03/1954	28/03/2015	99%	100%
405231	King Parrot Creek @ Flowerdale	27/05/1961	28/03/2015	99%	100%
405212	Sunday Creek @ Tallarook	21/11/1945	14/03/2015	96%	96%
405240	Sugarloaf Creek @ Ash Bridge	12/08/1972	17/03/2015	93%	96%
405291	Whiteheads Creek @ Whiteheads	15/09/1988	17/03/2015	100%	100%
405228	Hughes Creek @ Tarcombe Road	17/09/1958	29/03/2015	95%	98%
405248	Major Creek @ Graytown	19/04/1971	25/03/2015	99%	100%
405293	Gardiner Creek @ Puckapunyal	6/11/1989	26/07/2012	95%	95%
405226	Pranjip Creek @ Moorilim	12/11/1957	3/06/2015	99%	100%
405246	Castle Creek @ Arcadia	5/07/1970	27/02/2015	92%	92%
405269	Seven Creeks @ Kialla West	21/06/1977	23/02/2015	70%	71%

2.2 Flow Routing

In order to characterise flood events in the Goulburn River at Shepparton and attribute which catchments contributed to the hydrograph, each of the inflows collated was routed to the next relevant gauging station on the Goulburn River and (where relevant) the Broken River.

Muskingum routing (linear storage routing) was applied. This requires two parameters K (travel time) and X (weighting coefficient) to be fitted for each inflow to be routed.

The key sites which were used were:

- Goulburn River at Eildon (405203)

- Goulburn River at Trawool (405201) (infilled with data from Goulburn River at Seymour (405202) - Sunday Creek (405212) and Sugarloaf Creek (405240))
- Goulburn Weir (using data for downstream flow of Goulburn River at Murchison (405200), Stuart Murray Canal, Cattanach Canal and East Goulburn Main Channel
- Broken River at Orrvale (404222) infilled by Broken River at Casey's Weir (404216).
- Goulburn River at Shepparton (405204)

The purpose of this routing is to be able to enable the flow hydrograph at Shepparton to be split based on the estimated inflow from each of the contributing upstream inflows.

Importantly, no losses have been explicitly included in the analysis, rather they are implicitly included in the ungauged area contributions in each of the Goulburn River reaches.

2.2.1 Eildon to Trawool

This reach included the following inflows:

- 405203 - Goulburn River at Eildon
- 405241 - Rubicon River@ Rubicon
- 405209 - Acheron River @ Taggerty
- 405261 - Spring Creek @ Fawcett
- 405274 - Home Creek @ Yarck
- 405205 - Murrindindi River @ Murrindindi above Colwells
- 405217 - Yea River @ Devlins Bridge
- 405231 - King Parrot Creek @ Flowerdale

The outflow was Goulburn River at Trawool (405201) (infilled with data from Goulburn River at Seymour (405202) minus Sunday Creek (405212) and Sugarloaf Creek (405240))

The inflows were grouped into those at a similar river distance from the outflow location (which in this reach is Trawool) so that the same routing parameters would be applied to each inflow in that group.

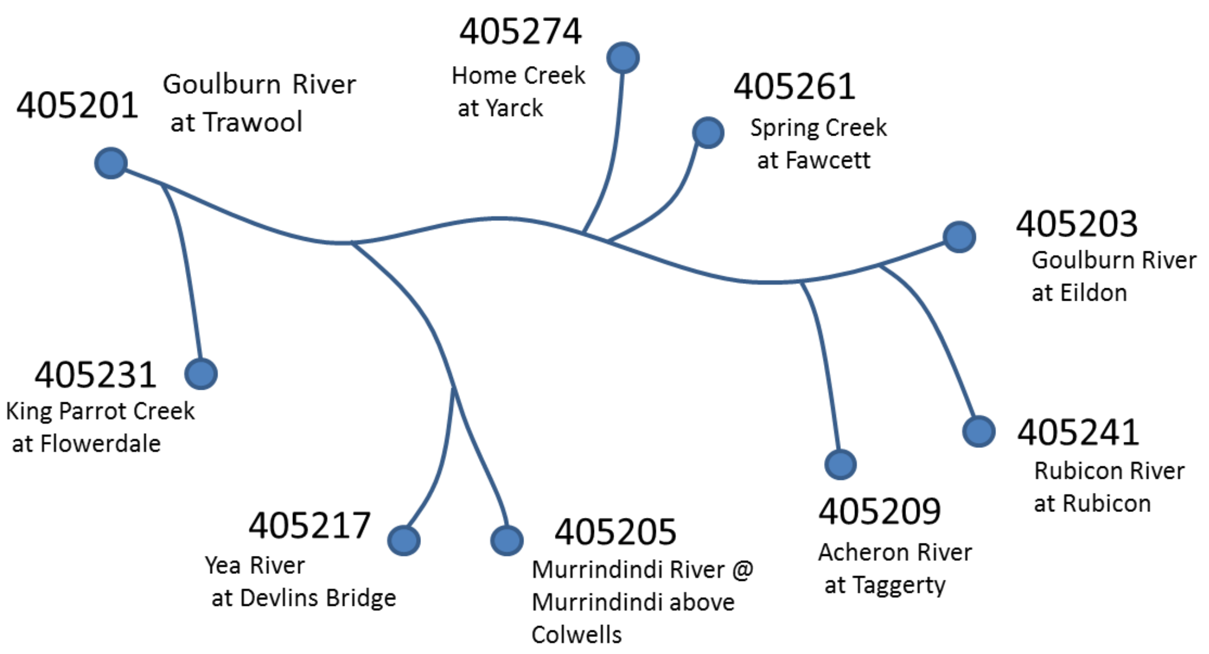
The routing groups in this reach were:

- Group 1
  - 405203 - Goulburn River at Eildon
  - 405241 - Rubicon River@ Rubicon
  - 405209 - Acheron River @ Taggerty
- Group 2
  - 405205 - Murrindindi River @ Murrindindi above Colwells
  - 405217 - Yea River @ Devlins Bridge

  - 405261 – Spring Creek @ Fawcett
  - 405274 - Home Creek @ Yarck
- Group 3
  - 405231 - King Parrot Creek @ Flowerdale

A schematic of the tributaries and gauges in this reach is shown below in Figure 2.1.

Figure 2.1 : Eildon to Trawool Reach Schematic



The routing parameters were then calibrated using a number of different events to calculate the routed flow at Trawool and the difference between the routed Eildon flow and the Trawool flow. An event in 2011 in which there was a combination in varying flow releases from Lake Eildon and tributary inflow upstream of Trawool was used as one of the events to calibrate the routing parameters. The routing parameters which provided the most realistic estimate of the total catchment inflow between Eildon and Trawool were accepted to apply to the reach. This was undertaken based on the form of the calculated hydrograph for the difference between routed Eildon flow and Trawool flow. In particular, the falling limb of the hydrograph was compared to the falling limb of gauged catchment inflow hydrographs in the reach.

The routing parameters applied are presented in Table 2.2 below.

Table 2.2 : Routing Parameters for Eildon to Trawool Reach of the Goulburn River

Group	K (days)	X
1 : Eildon, Rubicon, Acheron	1.55	0.5
2 : Murrindindi, Yea, Spring, Home	0.8	0.5
3 : King Parrot Creek	0	0.5

To ensure numerical stability of this approach using Muskingum routing, K, x and Δt must meet the following criteria:

$2Kx < \Delta t < 2K(1-x)$

As the above parameters do not meet the numerical stability criteria, simple lag routing of 1.55 days was applied to group 1 and 0.8 days for group 2. This provides a similar solution with a lag of the same time but is numerically stable.

The November 2011 event is shown below in Figure 2.2. The lines on the plot show:

- Historical Eildon gauged release (Labelled “Site 405203”)
- The historical Eildon release routed to Trawool using the routing parameters of group 1 in Table 2.2 (Labelled “Routed Site 405203”)
- Historical Trawool gauged flow (Labelled “Site 405201”)
- The difference between the gauged flow at Trawool and the routed Eildon release. This is the calculation of total net inflow in this reach (Labelled “Eildon-Trawool Differential”). This difference is significantly affected by the chosen routing parameters for Group 1.
- “Routed Trawool Tributaries” which the gauged tributary flow routed according to the parameters of group 1, 2 and 3 in Table 2.2. This is included for comparison with the Eildon to Trawool differential. It is expected that for most events the contribution to the gauged flow at Trawool from the entire catchment between Eildon and Trawool and the gauged tributaries in this reach would have similar hydrographs.

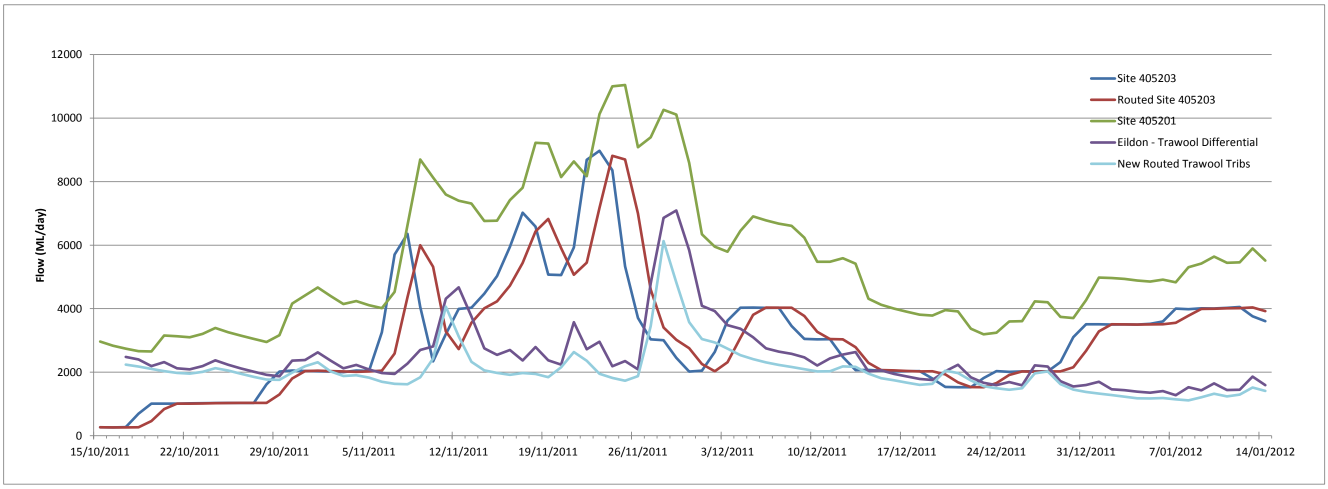


Figure 2.2 : Hydrographs for the Eildon - Trawool reach in November 2011

2.2.2 Trawool to Goulburn Weir

This reach included the following inflows:

- 405201 - Goulburn River at Trawool
- 405212 - Sunday Creek @ Tallarook
- 405240 - Sugarloaf Creek @ Ash Bridge
- 405291 - Whiteheads Creek @ Whiteheads
- 405228 - Hughes Creek @ Tarcombe Road
- 405248 - Major Creek @ Graytown

- 405293 - Gardiner Creek @ Puckapunyal

The outflow of the reach was inflow to Goulburn Weir. As there is no stream gauge available for the inflow to Goulburn Weir, this was estimated using the outflow from Goulburn Weir and the change in storage of Goulburn Weir Pool. The outflow was estimated using Goulburn River at Murchison (405200) + Stuart Murray Canal (405700) + Cattanach Canal (405702) + East Goulburn Main Channel (405704).

The inflows were grouped into those at a similar river distance from the outflow location (which in this reach is inflow to Goulburn Weir) so that the same routing parameters would be applied to each inflow in that group.

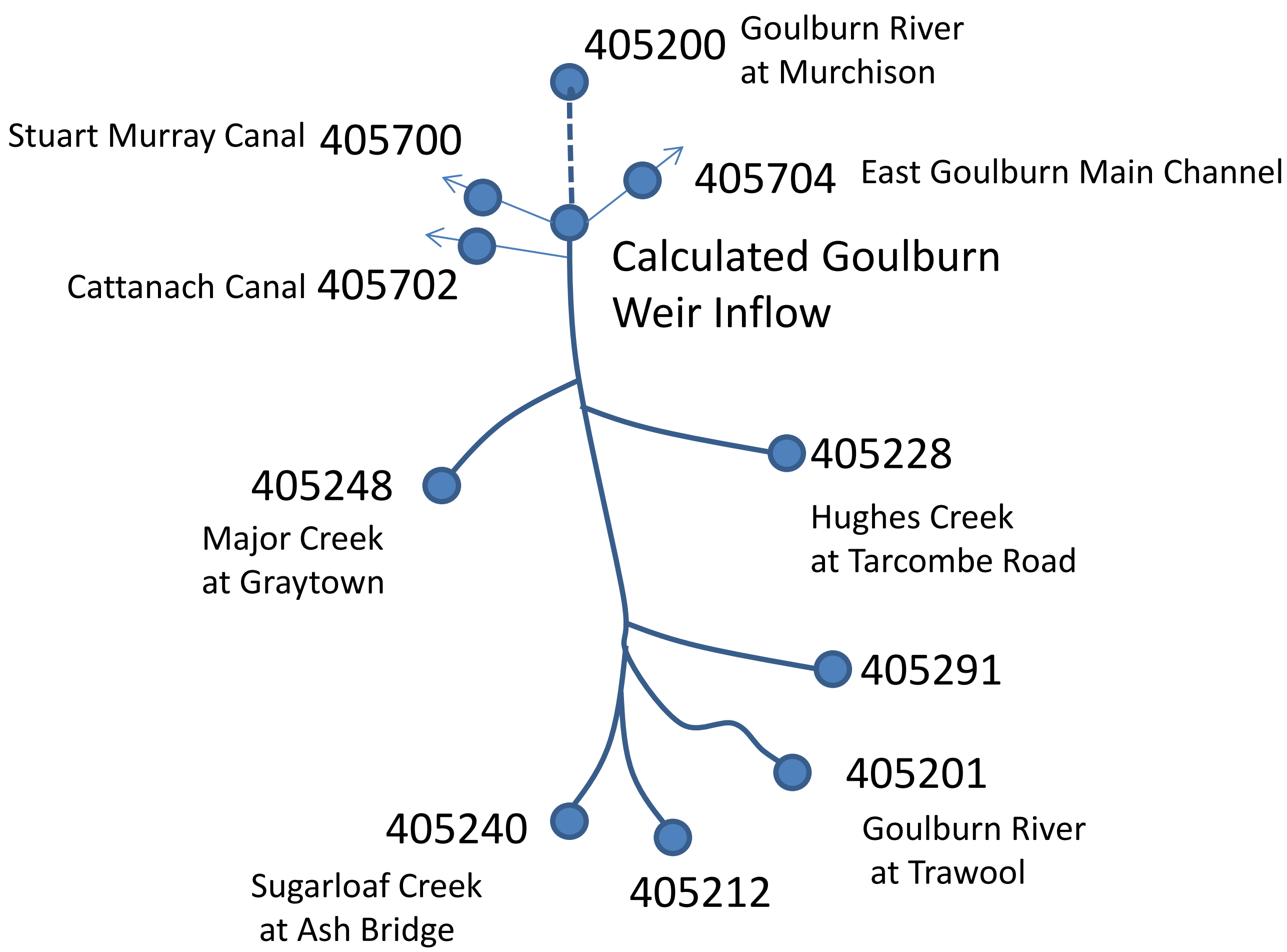
The routing groups in this reach were:

- Group 1
  - 405201 - Goulburn River at Trawool
  - 405212 - Sunday Creek @ Tallarook
  - 405240 - Sugarloaf Creek @ Ash Bridge
  - 405291 - Whiteheads Creek @ Whiteheads
- Group 2
  - 405228 - Hughes Creek @ Tarcombe Road
  - 405248 - Major Creek @ Graytown

Due to the limited data record for Gardiner Creek it was included in the Goulburn Weir inflow calculation.

A schematic of the tributaries and gauges in this reach is shown below in Figure 2.1.

Figure 2.3 : Trawool to Goulburn Weir Reach Schematic



The routing parameters were then calibrated using the same techniques as described for the Eildon to Trawool reach to calculate a realistic total inflow between Trawool and Goulburn Weir. The uncertainty in this reach is greater due to the requirement to add together a number of different gauging stations to estimate the total outflow from the reach.

The routing parameters applied are presented in Table 2.2 below.

Table 2.3 : Routing Parameters for Trawool to Goulburn Weir Reach of the Goulburn River

Group	K (days)	X
1 : Trawool, Sunday, Sugarloaf, Whiteheads	0.79	0.5
2 : Hughes, Major	0	0.5

To ensure numerical stability of this approach using Muskingum routing, K, x and Δt must meet the following criteria:

$2Kx < \Delta t < 2K(1-x)$

As the above routing parameters do not meet this criteria, simple lag routing was applied. For group 1, a lag of 0.79 days was applied and no lag was applied to group 2.

An event in 2012 is shown below in Figure 2.2. The lines on the plot show:

- Historical Trawool gauged flow (Labelled “Site 405201”)
- The historical Trawool flow routed to Goulburn Weir using the routing parameters of group 1 in Table 2.3(Labelled “Routed Site 405201”)
- Historical calculated inflow to Goulburn Weir (Labelled “Calc G Weir Inflow”)
- The difference between the calculated inflow to Goulburn Weir and the routed Trawool flow. This is the calculation of total net inflow in this reach (Labelled “Trawool-GW Differential”).
- “Routed GW Tributaries” which the gauged tributary flow routed according to the parameters of group 1 and 2 in Table 2.3.

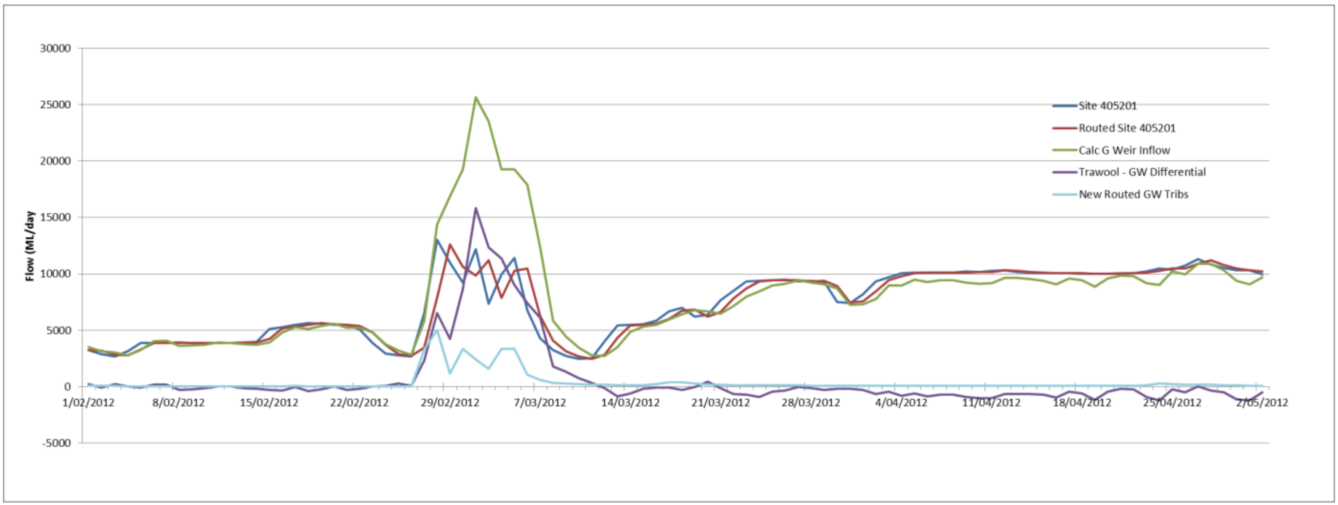


Figure 2.4 : Hydrographs for the Trawool – Goulburn Weir reach in March 2012

The ungauged catchment inflow between Trawool and Goulburn Weir was then able to be calculated as the difference between the Trawool-Goulburn Weir difference and the gauged tributary inflow. As can be seen in the chart above this could be negative at times due to losses in the reach and potentially inaccuracies in the gauged flow record. As for the Eildon to Trawool reach, no losses have been explicitly included in the analysis, rather they are implicitly included in the ungauged area contributions in each of the Goulburn River reaches (which can be negative to represent loss).

2.2.3 Goulburn Weir to Shepparton

This reach included the following inflows:

- 405200 – Goulburn River at Murchison
- 404222 - Broken River at Orrvale, infilled and extended using Broken River at Casey’s Weir (404216)
- 405226 - Pranjip Creek @ Moorilim
- 405246 - Castle Creek @ Arcadia

- 405269 - Seven Creeks @ Kialla West

The outflow was Goulburn River at Shepparton (405202).

The inflows were grouped into those in similar river distance from the outflow location (which in this reach is Trawool) so that the same routing parameters would be applied to each inflow in that group.

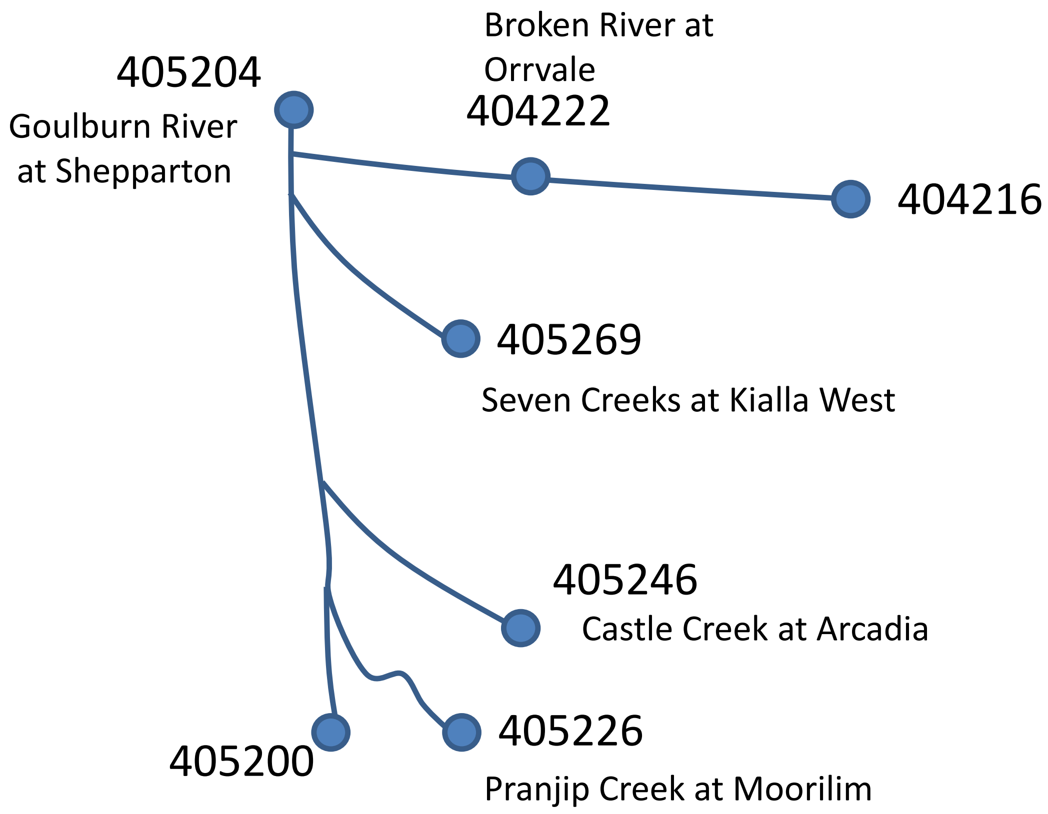
The routing groups in this reach were:

- Group 1
  - 405200 – Goulburn River at Murchison
  - 405226 - Pranjip Creek @ Moorilim
  - 405246 - Castle Creek @ Arcadia
- Group 2
  - 404222 - Broken River at Orrvale
  - 405269 - Seven Creeks @ Kialla West

The routing parameters were then calibrated using the same techniques as described for the Eildon to Trawool reach to calculate a realistic total inflow between Trawool and Goulburn Weir. The uncertainty in this reach is greater due to the requirement to add together a number of different gauging stations to estimate the total outflow from the reach.

A schematic of the tributaries and gauges in this reach is shown below in Figure 2.1.

Figure 2.5 : Goulburn Weir to Shepparton Reach Schematic



The routing parameters applied are presented in Table 2.2 below.

Table 2.4 : Routing Parameters for Goulburn Weir to Shepparton Reach of the Goulburn River

Group	K (days)	X
1 : Murchison, Pranjip, Castle	1.63	0.27
2 : Broken, Sevens	0.67	0

In this reach, the record of the Broken River at Orrvale was limited as it began in 1977. Therefore, the record was extended by using the Broken River at Casey's Weir flow record. Firstly routing parameters were calibrated for the reach of the Broken River from Casey's Weir to Orrvale. Then a daily regression of the routed Casey's Weir flow and the flow at Orrvale was calculated. The regression was:

$y = -1E\text{-}05x^2 + 1.1572x$ ($R^2 = 0.94$)

where y is Orrvale daily flow and x is the routed Casey's Weir flow.

The routing parameters for the Broken River from Casey's Weir to Orrvale are presented in Table 2.5 below.

Table 2.5 : Routing Parameters for Casey's Weir - Orrvale reach of the Broken River

Reach	K (days)	X
Casey's - Orrvale	1.24	0.40

An event in 2013 was used as one of the events to calibrate the routing parameters for the Casey's Weir - Orrvale reach. This event is shown below in Figure 2.6. The lines on the plots show:

- Gauged flow at Casey's Weir labelled "Site 404216"
- Gauged flow at Orrvale labelled "Site 404222"
- The routed flow at Casey's Weir using the parameters in Table 2.5, labelled "Routed Site 404216"

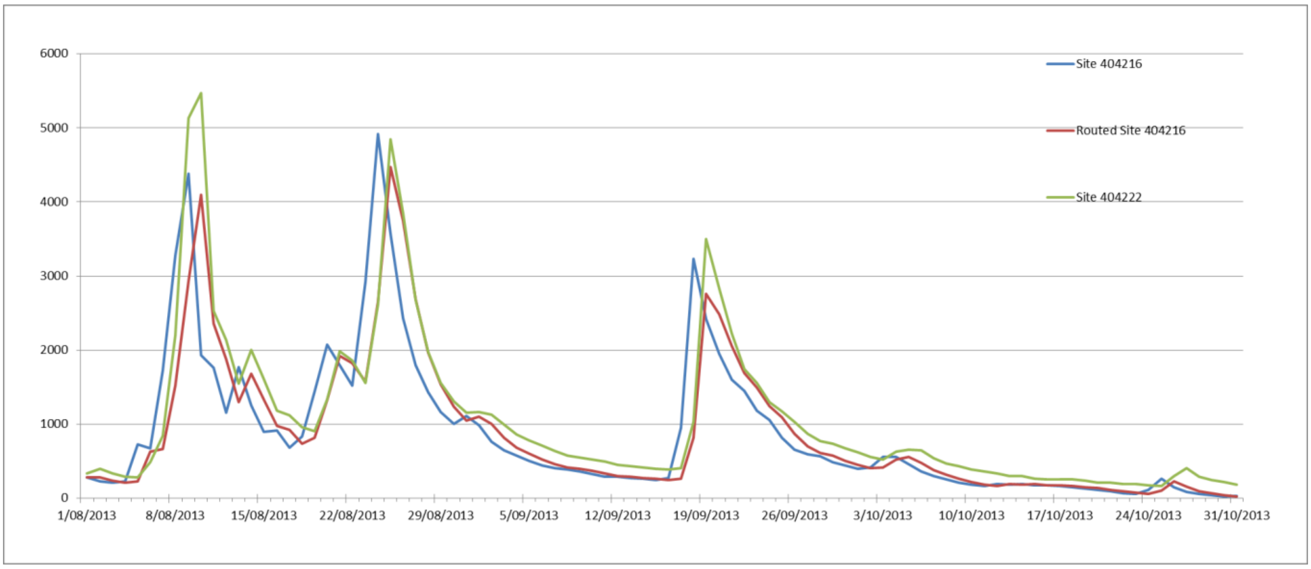


Figure 2.6 : Hydrographs for the Casey's Weir - Orrvale reach in Spring 2013

The same event in 2013 was used as one of the events to calibrate the routing parameters for the Murchison to Shepparton reach. This event is shown below in Figure 2.2. The lines on the plot show:

- Historical Murchison gauged flow (Labelled "Site 405200")
- The historical Murchison gauged flow routed to Shepparton using the routing parameters of group 1 in Table 2.4 (Labelled "Routed Site 405200")
- Historical Shepparton gauged flow (Labelled "Site 405204")
- The difference between the gauged flow at Shepparton and the routed Murchison flow. This is the calculation of total net inflow in this reach (Labelled "Murchison-Shepparton Differential"). This difference is significantly affected by the chosen routing parameters for Group 1.
- "Routed Lower Goulb Tributaries" which the gauged tributary flow routed according to the parameters of group 1, 2 and 3 in Table 2.4.

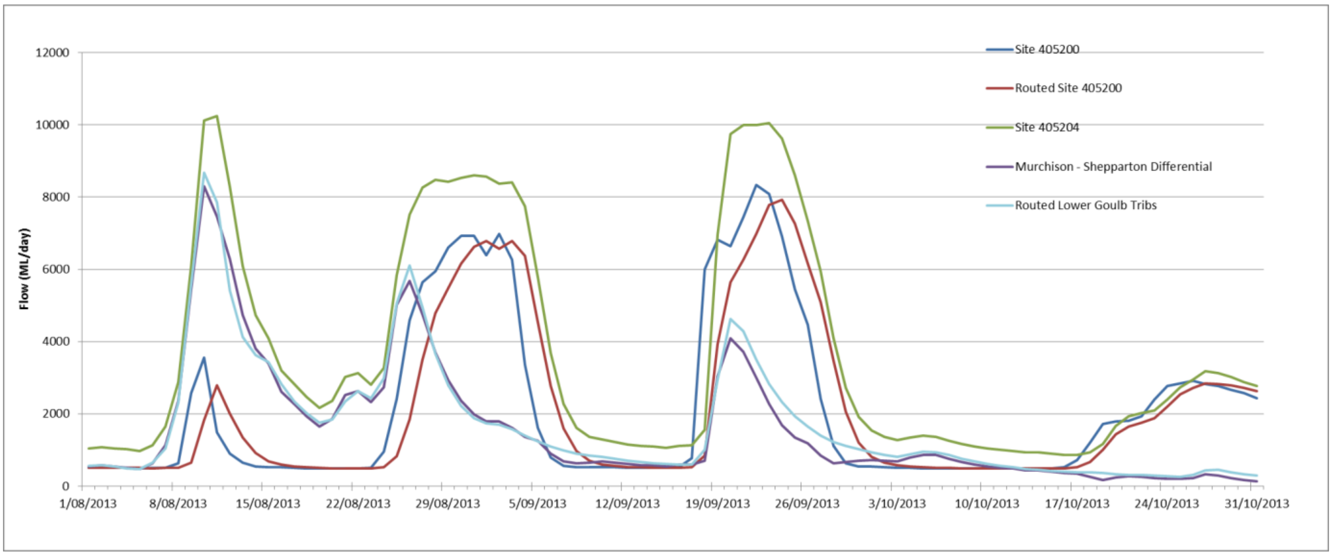


Figure 2.7 : Hydrographs for the Murchison - Shepparton reach in Spring 2013

The ungauged catchment inflow between Murchison and Trawool was then able to be calculated as the difference between the Shepparton – Murchison difference and the gauged tributary inflow.

Based on the fitted routing parameters (K), the total travel time for flows from Eildon to Shepparton is approximately four days. Eildon to Trawool is 1.55 days, Trawool to Murchison is 0.79 days, Murchison to Shepparton 1.63 days for a total of 3.97 days.

3. Flood Event Characterisation

The data assembled as described in Section 2 was used to characterise historical flood events. All events at Shepparton between 15,000 ML/day since 1960 have been identified. Each of these events was examined to identify which tributaries contributed to the hydrograph and the time of year in which they occurred.

Also calculated was the rate of environmental release that would be required from Lake Eildon if perfect foresight of future inflows were possible and assuming no diversions to Waranga Basin. The outcome of this analysis cannot be used directly as perfect knowledge of the future inflows cannot be known, however the results provide some quantification of flow rates required in various reaches of the Goulburn River downstream of Eildon, and also provide an additional source of information to help formulate appropriate delivery strategies as part of Task 3. Also the release rate is calculated simply as a four day lag flow and does not allow for attenuation of flows or operational constraints on rate of rise or fall of Eildon releases.

The rate of environmental flow required at Shepparton was based on MDBA (2012) in which the following two flow events are described:

- 25,000 ML/day for 5 days from June to November
- 40,000 ML/day for 4 days from June to November

It has assumed rate of rise of 0.8m/day from the peak of the historical event and a rate of fall of 0.72m/day. This rate of Rise and Fall is specified in Cottingham et al (2003).

The time series of the contribution of each inflow to the Shepparton flow is shown in Figure 3.1 below. The Shepparton flow has been adjusted by the routed impact of diversions at Goulburn Weir to Waranga Basin (Assumed to be the total Stuart Murray and Cattanach Canal flows) plus the change in Goulburn Weir storage.

The time series of an example event and the pie chart representing the percentage contribution to the peak flow is shown in Figure 3.1 below. Sites with missing data in the period analysed for the event is denoted with a "*". The lower panel in the chart shows the time series of adjusted flow at Shepparton over ten years within the time of the selected event.

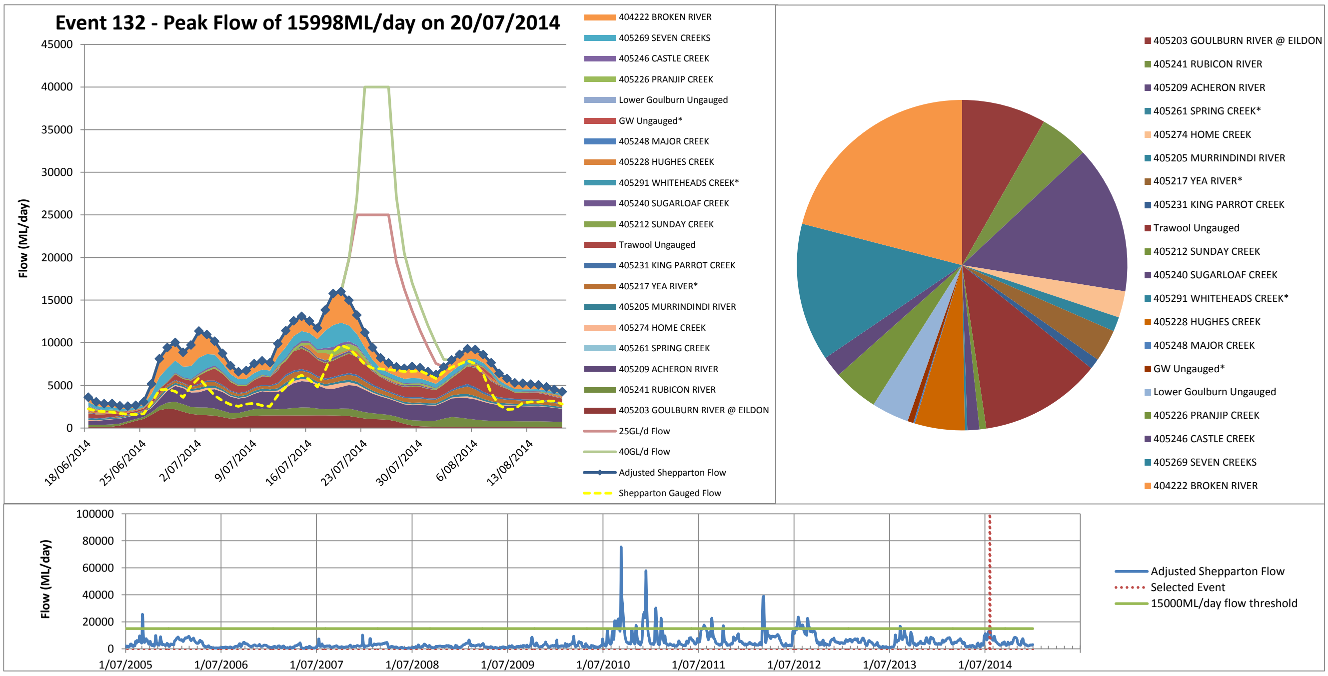


Figure 3.1 : Adjusted Shepparton flow and inflow contributions to the hydrograph

This information is summarised by events in Table 3.1 and Table 3.2below. The tables includes:

- Event
  - Year
  - Event No
  - Peak Flow (ML/day)
- Timing
  - Month of Peak Flow (Month Number)
  - Years Since Last event > 15GL/day
- Duration
  - Greater than 15000 (Days greater than 15,000ML/day)
  - Days within 5% of peak (Number of days flow is within 5% of the peak flow and greater than 15,000ML/day)
  - Days within 10% of peak (Number of days flow is within 10% of the peak flow and greater than 15,000ML/day)
  - Days within 20% of peak (Number of days flow is within 20% of the peak flow and greater than 15,000ML/day)

- Recession (Recession over the days following the day of peak flow (ML/day/day))
  - 2 Day Average Recession
  - 4 Day Average Recession
  - 7 Day Average Recession
- Water Source (ML/day) The columns below represent the relevant contribution to the day of peak flow from the various reaches. Note that these figures may in some instances be negative. A major reason for this is missing data at key gauge locations. Causes of negative inflows in specific events could be investigated further in future by reviewing all relevant streamflow records and their quality to identify the causes of negative inflows.
  - Eildon
  - Rubicon/Acheron
  - Trawool Remainder (Eildon to Trawool inflows – excluding Rubicon and Acheron)
  - GW (Trawool to Goulburn Weir Inflows)
  - Lower Goulb (Murchison – Shepparton inflows)
- 25 GL/d event
  - Peak Additional Eildon (GL/day) – Maximum additional flow rate from Eildon required to be released from Eildon to achieve the event flow target of 25,000ML/day at Shepparton
  - Peak Total Eildon (GL/day) – Maximum total flow rate from Eildon required to be released from Eildon to achieve the event flow target of 25,000ML/day at Shepparton
  - Total Additional volume (GL) – Total additional flow volume required to be released from Eildon to achieve the event flow target of 25,000ML/day at Shepparton
- 40 GL/d event
  - Peak Additional Eildon (GL/day) – Maximum additional flow rate from Eildon required to be released from Eildon to achieve the event flow target of 40,000ML/day at Shepparton
  - Peak Total Eildon (GL/day) – Maximum total flow rate from Eildon required to be released from Eildon to achieve the event flow target of 40,000ML/day at Shepparton
  - Total Additional volume (GL) – Total additional flow volume required to be released from Eildon to achieve the event flow target of 40,000ML/day at Shepparton
- Season
  - Exclude if event outside July – Nov (1 – is in July – Nov, 0 – not in this period)

A number of columns have been formatted using a Green – Red colour scale to emphasise different aspects of each event.

The formatting has been applied to the following columns:

- Peak Flow : Greater flow (Green) – Less Flow (Red)
- Days within % of peak flow columns : Greater number of days (Green) – Less Days (Red)
- Average Recession columns (Lower Recession rate (Green) – Greater Recession rate (Red)
- Water Source - Eildon : Lower Release Rate (green) – Higher Release rate (red)
- 25GL/d event and 40GL/day event columns : Less Eildon rate/volume required (green) – Greater Eildon rate/volume required (Red)

Table 3.1 : Event Summary Table 1960 - 1985

Event			Timing		Duration						Recession			Water Source					25 GL/d event			40 GL/d event			Season
Year	Event No	Peak Flow	Month of Peak Flow	Years Since Last event > 15000 ML/day	Greater than 15000 ML/day	Days above 25000 ML/day	Days above 40000 ML/day	Days within 5% of peak	Days within 10% of peak	Days within 20% of peak	2 Day Average Recession	4 Day Average Recession	7 Day Average Recession	Eildon	Rubicon/ Acheron	Trawool Remainder	GW	Lower Goulb	Peak Additional Eildon (GL/day)	Peak Total Eildon (GL/day)	Total Additional volume (GL)	Peak Additional Eildon (GL/day)	Peak Total Eildon (GL/day)	Total Additional volume (GL)	Exclude if event outside July - Nov
1960	1	21293	7	0.0	4	0	0	1	1	3	2569	2506	1192	286	3122	4701	4841	8341	15	18	67	30	31	146	1
	2	75117	9	0.2	87	20	10	1	2	2	10043	7910	5928	8890	3941	24500	-7615	45447	0	18	0	0	18	0	1
	3	18658	11	0.1	6	0	0	3	5	6	899	1332	1091	12470	4970	6669	-4896	-151	14	21	96	29	36	198	1
1961	4	23810	8	0.8	4	0	0	1	1	3	4100	3671	1980	908	2123	11989	1156	7726	17	17	91	32	32	187	1
1962	5	22910	7	0.9	5	0	0	1	2	2	2726	2749	1750	78	1297	5634	10500	5401	16	17	68	31	32	155	1
1963	6	21854	6	0.9	4	0	0	2	2	3	2050	2448	2085	43	572	5124	10875	5240	14	14	92	29	29	183	0
	7	23026	7	0.1	11	0	0	1	1	3	3612	3359	1043	96	1993	12634	2133	6170	16	16	66	31	31	148	1
	8	20380	8	0.1	3	0	0	1	2	2	2255	2266	1983	131	2900	4517	2504	10327	15	18	92	30	33	176	1
	9	18462	8	0.1	2	0	0	2	2	2	2128	1812	1533	56	2006	3210	2482	10708	16	20	112	31	35	208	1
	10	23743	10	0.1	4	0	0	1	1	3	4087	3501	2713	329	2248	6909	4588	9683	18	18	115	33	33	215	1
1964	11	66023	10	1.0	110	36	12	3	3	5	5159	5001	3121	19072	4809	13344	7488	21325	0	22	0	0	22	0	1
1965	12	15712	7	0.8	1	0	0	1	1	1	1741	2237	1469	47	2880	9263	1980	1541	19	19	119	34	34	200	1
	13	30047	8	0.1	8	3	0	1	2	3	3042	3562	2206	68	3870	13765	3029	9330	6	7	12	24	25	95	1
	14	36432	9	0.1	9	6	0	1	5	6	1039	1623	3161	466	3142	10635	5164	17042	0	8	0	10	10	43	1
1966	15	23588	8	1.0	14	0	0	2	2	6	2299	1401	1247	1016	3076	5793	4114	9590	8	9	35	23	24	130	1
	16	24566	9	0.1	5	0	0	2	2	3	4179	3133	1793	497	4533	10641	1350	7562	13	14	66	28	29	159	1
	17	20963	10	0.0	3	0	0	1	2	3	1653	2116	1989	1153	2742	4844	979	11302	14	16	92	29	31	185	1
	18	17640	12	0.2	2	0	0	1	2	2	4359	3483	838	2534	1701	3899	205	9390	22	23	115	37	38	191	0
	19	36333	12	0.0	8	4	0	1	1	2	5257	4156	3051	3408	1641	3037	91	28249	3	15	3	20	34	79	0
1967																									
1968	20	59677	6	1.5	16	9	4	2	2	3	9781	9129	6931	912	5776	23036	7849	22104	0	1	0	1	2	2	0
	21	21882	7	0.1	4	0	0	2	2	3	1919	2600	2042	56	2223	11116	2632	5855	15	15	84	30	30	175	1
	22	41990	8	0.1	20	7	1	1	3	3	5011	5286	4397	86	4433	16283	8159	13029	0	6	0	14	14	42	1
	23	17289	8	0.0	2	0	0	1	2	2	1553	1508	1128	67	2758	6954	2225	5284	15	15	103	30	30	195	1
	24	16566	10	0.1	2	0	0	2	2	2	1004	1561	1498	1198	4333	5156	-152	6340	18	18	126	33	33	218	1
1969	25	19417	7	0.8	4	0	0	1	2	4	1471	1657	1569	58	1375	5937	3215	8832	14	14	82	29	29	164	1
	26	15833	9	0.2	2	0	0	2	2	2	905	1360	1258	8190	2110	3593	302	1792	17	22	115	32	37	201	1
1970	27	15097	5	0.6	1	0	0	1	1	1	2779	2395	840	1853	2351	6837	1685	2375	20	20	128	35	35	227	0
	28	16105	7	0.2	2	0	0	2	2	2	1300	876	421	2540	3307	5561	-1236	5934	12	36	75	27	36	155	1
	29	16309	7	0.0	7	0	0	5	7	7	195	352	373	8750	3013	3084	-37	1499	11	36	63	26	36	141	1
	30	17497	8	0.0	8	0	0	4	6	8	301	337	691	8749	2381	2747	1261	2362	11	36	64	26	36	149	1
	31	51903	9	0.1	34	19	7	2	4	6	1593	2613	2995	34052	4410	4444	1884	7141	0	36	0	0	36	0	1
1971	32	15340	6	0.8	1	0	0	1	1	1	1226	1775	1368	530	5134	6714	1070	1893	19	19	161	34	34	263	0
	33	15006	9	0.2	1	0	0	1	1	1	1946	1771	1443	37	1953	4796	2988	5356	20	40	162	35	40	262	1
	34	42561	10	0.1	21	10	2	2	3	5	1661	3247	3274	25476	4060	7170	7108	475	0	40	0	6	40	6	1
	35	42125	11	0.1	16	11	2	2	2	6	2421	2407	2340	15127	5104	12450	7609	1915	0	32	0	8	32	11	1
1972	36	18884	2	0.3	3	0	0	1	2	3	4116	3383	2102	7849	705	1726	7720	1195	20	23	137	35	38	259	0
1973	37	16708	2	1.0	2	0	0	2	2	2	4248	2990	2011	4769	1306	4742	5306	741	22	25	155	37	40	240	0
	38	33296	2	0.0	7	4	0	2	4	4	5606	5764	4135	2044	3170	17546	7080	3504	8	9	39	30	30	166	0
	39	22336	5	0.2	3	0	0	1	1	3	4074	4110	2609	365	1720	3081	2060	15109	21	21	131	36	36	226	0
	40	24030	6	0.1	11	0	0	4	5	6	1060	2148	1185	4748	2564	7647	7136	1936	10	14	35	25	29	132	0
	41	29602	7	0.1	11	2	0	1	2	4	2739	1465	2356	980	1907	5830	12027	8859	4	13	7	19	19	82	1
	42	43277	8	0.1	20	8	2	2	2	4	3476	4560	2703	363	4461	14262	8819	15373	0	13	0	10	13	15	1
	43	54461	9	0.1	35	25	10	1	3	6	3094	5366	3394	177	3951	13874	13962	22497	0	22	0	0	22	0	1
	44	22207	10	0.1	4	0	0	1	1	2	3127	2845	2181	1248	2150	5210	6807	6988	16	22	79	31	33	161	1
	45	49634	10	0.0	18	15	9	2	4	9	1819	1704	1117	14514	4571	11642	7280	11643	0	22	0	0	22	0	1
1974	46	174863	5	0.6	28	16	6	2	2	2	44739	33937	22073	3311	5371	49767	46790	69624	0	8	0	0	8	0	0
	47	83806	10	0.4	124	64	18	1	1	1	13096	8201	5626	14568	4809	21897	10503	32049	0	26	0	0	26	0	1
1975	48	15655	8	0.8	2	0	0	2	2	2	1438	2296	316	3862	1916	5077	1758	3042	20	44	95	35	44	176	1
	49	16872	8	0.0	2	0	0	1	2	2	2349	2121	1750	150	1979	7625	3904	3214	19	44	121	34	44	201	1
	50	97449	9	0.1	90	59	36	2	3	4	12552	8461	7192	24489	5453	13854	13850	39805	0	44	0	0	44	0	1
1976																									
1977	51	23126	6	1.8	4	0	0	1	1	3	3526	3696	2338	142	4041	13885	-9601	14660	18	18	91	33	33	178	0
	52	22221	7	0.0	4	0	0	2	2	3	3161	3438	2223	123	4978	15366	-5890	7645	18	18	103	33	33	197	1
1978	53	27415	7	1.1	7	2	0	2	2	4	1997	2804	2677	117	1880	7728	9288	8402	9	9	42	24	24	128	1
	54	32717	8	0.0	12	8	0	1	4	7	1509	1263	1972	119	2777	10527	13839	5456	0	3	0	12	13	45	1
	55	28723	9	0.1	6	4	0	2	4	4	1245	3048	2997	132	3546	12839	7024	5262	4	4	24	23	24	130	1
1979	56	16802	8	0.9	2	0	0	2	2	2	1396	2114	1592	491	1382	6087	6951	2065	20	20	104	35	35	190	1
	57	15187	8	0.0	1	0	0	1	1	1	2105	2443	698	116	1409	4895	6617	2152	20	20	124	35	35	216	1
	58	25711	9	0.0	6	1	0	3	3	5	2115	3098	2618	147	4503	8524	7073	5649	12	12	59	27	27	146	1
	59	44378	10	0.0	22	17	2	2	2	5	3971	5276	1423	110	4063	12638	13389	14180	0	3	0	11	11	18	1
1980	60	16727	7	0.8	5	0	0	3	4	5	2500	1937	1412	706	3793	6783	4100	1346	17	17	131	32	32	222	1
	61	19218	7	0.1	2	0	0	1	2	2	2995	2702	1403	119	2789	7189	2623	6497	17	17	91	32	32	170	1
1981	62	41222	6	0.9	15	7	1	1	2	3	5071	5445	2903	1750	1499	10145	11696	16133	0	5	0	15	15	43	0
	63	92685	7	0.1	52	45	23	2	2	4	15368	11641	7768	133	5407	21077	22656	43412	0	8	0	0	8	0	1
1982																									
1983	64	57263	8	2.0	10	8	3	1	1	3	9097	8011	6514	140	2514	16703	19314	18591	0	1	0	1	1	2	1
	65	58948	9	0.1	32	10	4	1	2	2	7342	7123	5690	125	3720	14553	22980	17604	0	1	0	0	1	0	1
1984	66	28169	8	1.0	9	2	0	2	2	3	1601	2590	1867	122	3250	9734	-6356	21447	7	7	16	22	22	87	1
	67	19180	9	0.1	5	0	0	2	3	5	1539	1781	1476	494	3676	10662	-12398	16746	14	14	81	30	30	194	1
	68	31978	10	0.0	6	3	0	1	2	3	2649	3524	3415	133	3536	9507	-9581	28546	7	7	39	22	22	121	1
1985	69	19261	8	0.8	4	0	0	2	3	4	2297	2728	1589	166	4441	10573	3775	588	17	17	96	32	32	181	1
	70	23427	8	0.0	9	0	0	4	6	7	360	816	1702	170	5015	9004	5632	3716	8	9	40	23	24	135	1

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Table 3.2 : Event Summary Table 1986 - 2014

Event			Timing		Duration						Recession			Water Source					25 GL/d event			40 GL/d event			Season
Year	Event No	Peak Flow	Month of Peak Flow	Years Since Last event > 15000 ML/day	Greater than 15000 ML/day	Days above 25000 ML/day	Days above 40000 ML/day	Days within 5% of peak	Days within 10% of peak	Days within 20% of peak	2 Day Average Recession	4 Day Average Recession	7 Day Average Recession	Eildon	Rubicon/ Acheron	Trawool Remainder	GW	Lower Goulb	Peak Additional Eildon (GL/day)	Peak Total Eildon (GL/day)	Total Additional volume (GL)	Peak Additional Eildon (GL/day)	Peak Total Eildon (GL/day)	Total Additional volume (GL)	Exclude if event outside July - Nov
1986	71	35639	7	0.9	27	11	0	3	7	10	3095	4228	3654	158	4753	9083	6480	15166	2	2	7	21	21	97	1
	72	23976	8	0.1	5	0	0	2	3	4	1958	2781	1689	118	2774	5946	5706	9706	15	15	58	30	30	151	1
	73	30266	9	0.1	6	4	0	2	2	4	1718	2854	2990	125	2674	6588	7741	13989	2	2	11	21	21	110	1
	74	30623	10	0.1	8	5	0	2	3	5	1846	3143	2991	132	4448	9810	10206	7277	0	7	0	22	22	110	1
1987	75	28563	6	0.7	7	4	0	3	3	5	1760	3158	2814	201	3717	10597	11705	2343	5	5	21	24	24	124	0
	76	19094	7	0.1	3	0	0	1	3	3	2548	2775	1603	138	2594	7736	2443	6183	18	19	90	34	34	183	1
	77	37843	8	0.0	10	6	0	2	2	3	4743	4434	3803	113	2495	9399	17114	8723	0	5	0	20	20	88	1
1988	78	24737	6	0.9	5	0	0	2	2	3	4044	3365	1781	144	3342	8451	4730	8070	16	16	72	31	31	165	0
	79	23722	7	0.1	9	0	0	1	2	3	2254	2658	2192	139	2491	6064	4707	10322	14	14	77	29	29	171	1
	80	27242	9	0.1	8	3	0	3	4	5	1248	2417	2112	143	3839	10259	8254	4924	4	6	7	22	23	103	1
	81	20938	11	0.2	4	0	0	1	2	2	2867	3448	2414	3095	1292	6491	7450	2993	20	20	118	35	35	208	1
1989	82	15595	4	0.4	1	0	0	1	1	1	3125	2817	1833	488	962	2723	902	10631	22	22	175	37	37	303	0
	83	35832	6	0.2	17	12	0	2	3	6	3417	3628	3135	241	2532	8149	12033	12878	0	4	0	19	20	70	0
	84	23318	7	0.1	9	0	0	2	4	5	813	1542	1612	2181	2307	5921	3602	9307	10	12	43	25	27	131	1
	85	36585	9	0.1	42	24	0	4	9	17	2370	2898	2994	145	4208	12436	6494	13302	0	10	0	15	15	50	1
	86	18125	9	0.1	9	0	0	5	7	9	705	807	906	8955	2639	2333	1035	3393	12	20	84	27	35	177	1
	87	22012	11	0.1	16	0	0	6	10	13	1091	1574	2008	13263	2626	2305	1356	2771	12	19	74	27	34	166	1
1990	88	19224	7	0.7	4	0	0	2	2	4	1522	2376	1895	149	2986	4670	1233	10186	17	18	95	32	33	174	1
	89	38946	7	0.0	69	39	0	2	3	18	2956	2540	2266	295	4200	8279	12075	14063	0	10	0	11	12	32	1
1991	90	27836	7	1.0	5	1	0	1	1	3	4188	4164	2296	157	1145	5721	11554	9259	14	14	49	29	29	136	1
	91	25831	9	0.2	12	1	0	1	3	4	1809	2408	2231	141	3684	8404	4205	9535	9	15	33	24	24	112	1
	92	33377	9	0.1	29	16	0	4	7	16	417	759	688	3768	7410	12305	4299	5783	0	15	0	10	23	32	1
1992	93	26596	9	0.9	9	1	0	1	2	5	1857	1387	1555	305	2202	6424	7118	10793	4	10	10	19	19	81	1
	94	74752	10	0.1	50	36	4	1	2	2	13568	9961	6744	4269	4708	18558	23987	23311	0	12	0	0	12	0	1
	95	23079	11	0.1	23	0	0	6	7	13	460	581	993	10020	2482	3546	739	6819	5	17	19	20	32	105	1
	96	24408	12	0.1	12	0	0	6	8	10	731	920	1668	13290	1792	1383	1931	6401	7	18	34	22	33	131	0
1993	97	24630	7	0.5	7	0	0	3	3	6	1440	1790	2146	7050	2364	4892	3197	7127	10	17	62	25	32	162	1
	98	15772	8	0.1	1	0	0	1	1	1	966	969	1143	525	2025	4164	3675	5383	16	37	94	31	37	170	1
	99	23542	8	0.0	14	0	0	4	5	8	473	703	865	7480	3826	6745	2464	3217	5	46	18	20	46	101	1
	100	145732	10	0.1	50	45	31	1	2	2	21332	18714	13099	12938	4020	11736	10449	106765	0	46	0	0	46	0	1
	101	21104	11	0.1	12	0	0	4	7	9	464	526	752	11409	3618	3282	-119	3777	7	46	31	22	46	111	1
1994																									
1995	102	42198	6	1.6	10	7	2	2	2	4	4829	5339	4241	371	5734	13835	13547	8712	0	2	0	7	8	11	0
	103	44503	7	0.1	33	18	2	1	2	3	4641	3254	2309	406	3863	9832	9431	20971	0	2	0	5	5	5	1
1996	104	26875	6	0.9	19	4	0	4	5	10	1607	2074	468	198	2051	11110	4729	8786	6	7	13	21	22	79	0
	105	60253	8	0.1	31	21	8	2	3	5	3745	2653	3799	447	7862	18442	13709	19794	0	1	0	0	1	0	1
	106	15575	9	0.1	2	0	0	2	2	2	1196	1284	822	406	4477	6038	-776	5629	15	17	101	30	30	217	1
	107	58716	10	0.0	22	18	7	2	3	5	4976	4324	3496	814	9888	18556	10005	19768	0	17	0	0	17	0	1
1997																									
1998	108	15292	8	1.8	1	0	0	1	1	1	3273	2368	1607	249	1788	5380	2561	5315	21	21	185	36	36	286	1
	109	27658	9	0.2	4	1	0	1	1	2	4171	4671	3358	350	3653	8480	1068	14270	16	16	83	31	31	169	1
1999	110	17462	8	0.9	3	0	0	1	2	3	2706	1603	1260	136	2783	6801	2187	6426	15	15	123	30	30	218	1
	111	24397	8	0.0	4	0	0	2	2	3	4541	4336	2721	329	1980	7864	2418	11982	20	20	97	35	35	195	1
2000	112	25390	9	1.0	8	1	0	2	4	5	1704	2553	2333	189	6578	9364	496	8863	10	10	45	28	28	164	1
	113	17375	11	0.1	12	1	0	5	5	7	2534	2321	772	325	2180	3886	3094	8104	18	18	96	33	33	172	1
	114	26103	11	0.0	9	1	0	1	3	3	2928	1330	2073	153	2454	7510	5546	10713	5	8	29	20	20	118	1
2001																									
2002																									
2003	115	28883	7	2.7	5	2	0	1	2	3	3928	4187	2807	160	2843	10810	979	14136	13	13	52	28	28	137	1
	116	30240	8	0.1	5	2	0	1	2	2	4170	4381	2796	156	2702	8889	2909	15917	12	12	45	27	27	126	1
2004	117	16598	9	1.1	4	0	0	1	4	4	1338	1502	1427	146	3805	7280	1693	3819	17	18	124	32	33	216	1
2005	118	24057	2	0.4	3	0	0	1	2	2	6713	4902	3142	2317	1826	5656	2959	11420	22	22	150	37	37	250	0
	119	25680	9	0.6	4	1	0	1	2	2	3834	4199	2970	540	4132	9854	849	10618	16	16	80	33	34	200	1
2006																									
2007																									
2008																									
2009																									
2010	120	75480	9	5.0	38	11	4	1	1	1	15065	10033	6781	433	11217	21152	8769	33910	0	2	0	0	2	0	1
	121	17440	11	0.2	3	0	0	1	2	3	1725	2120	1548	132	3936	9710	-2335	5999	18	18	131	33	33	225	1
	122	57864	12	0.1	21	12	3	1	1	2	9810	7767	6102	203	4856	19383	9667	23756	0	5	0	2	5	2	0
2011	123	30251	1	0.1	7	4	0	1	3	4	4018	3992	3590	158	3058	9170	20570	-2503	4	6	22	26	26	152	0
	124	22770	2	0.1	4	0	0	1	1	3	2737	2397	1621	2654	2015	3102	8869	6155	12	12	74	27	27	167	0
	125	17653	7	0.4	15	0	0	3	5	15	532	533	295	6701	3852	5325	-260	2056	10	17	56	25	32	139	1
	126	22719	8	0.1	4	0	0	2	3	3	2489	2641	2104	1317	2625	6384	4182	8211	15	15	81	30	30	173	1
	127	17218	10	0.1	3	0	0	2	2	3	2526	2719	1713	266	3699	7085	979	5225	20	20	148	35	35	243	1
2012	128	38987	3	0.4	9	7	0	3	4	5	6100	6153	4836	549	1418	7833	10034	19155	1	9	1	26	26	127	0
	129	23576	7	0.4	31	0	0	3	5	8	1022	1008	942	5670	2977	5886	1811	7232	6	13	24	21	28	106	1
	130	22604	8	0.1	10	0	0	2	4	5	857	1356	966	2168	3487	9406	4844	2845	9	12	33	24	27	114	1
2013	131	16719	8	1.0	3	0	0	2	3	3	807	1639	1351	299	2166	3706	2395	8300	18	18	108	33	33	195	1
2014	132	15998	7	0.9	2	0	0	2	2	2	1378	1643	1262	1444	3374	3520	1146	6533	17	18	117	32	33	203	1

The peak flow for each of the events and the contribution to peak flow from Eildon, Trawool Inflows, Goulburn Weir Inflows and Lower Goulburn inflows is presented below in Figure 3.2. It can be seen that the Tributary inflows in the reach upstream of Trawool contribute consistently to the identified events at Shepparton. Lower Goulburn inflows, including from the Broken River also contribute significant proportions of events peak flows but is far more variable. Tributary inflow upstream of Goulburn Weir (and downstream of Trawool) also contributes a more variable proportion of peak flow and for most events is less than the contribution from Trawool tributaries or Lower Goulburn inflows. The contribution from Eildon is usually very low when there is no spill or pre-release from Lake Eildon. At times when Lake Eildon is spilling or making pre-releases the contribution to the event from Eildon can be around half the total flow at Shepparton.

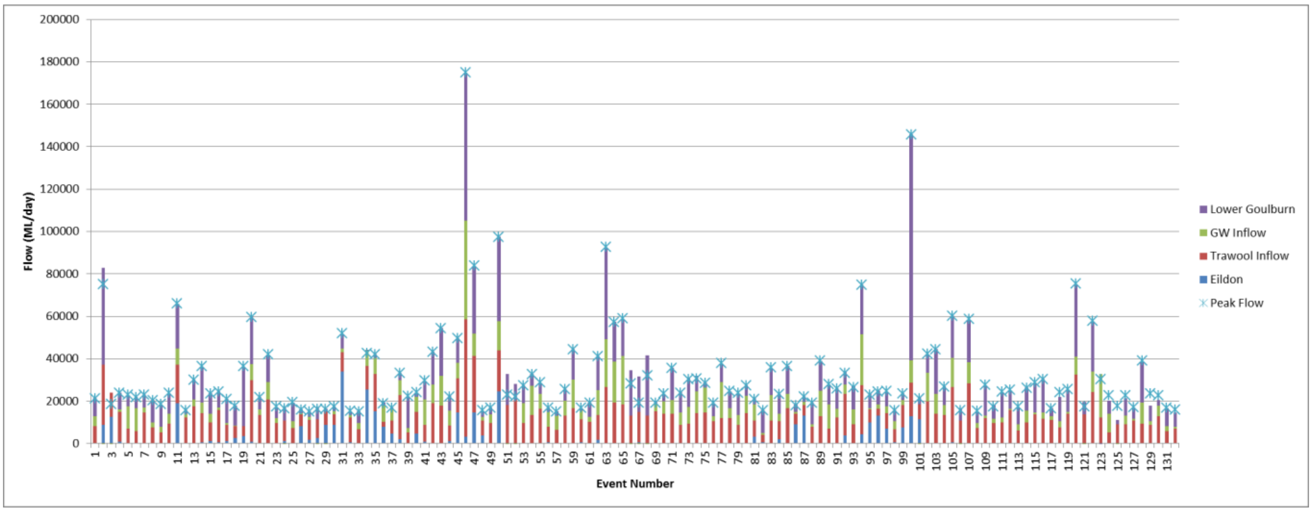

Figure 3.2 : Proportion of contribution to the day of peak flow of the event of the adjusted Shepparton flow for each event

The time series plots and the pie charts for every one of the 132 events are shown in Appendix A. In some events, particularly earlier in the period of record when there was more periods of missing or unreliable data, there are some spikes and negative inflows. In future the streamflow records could be examined in detail to review the quality of available data to identify the causes of these if required.

3.1 Description of Events

This section presents a description of the actual flow events from 1960 to 2014 which have been analysed as described above. 132 events were identified over 55 years, averaging 2.4 events per year. Events were classified as being flows in the Goulburn River at Shepparton above 15,000 ML/day (including water that was being diverted to Waranga Basin at the time – i.e. assuming diversions to Waranga Basin were ceased).

3.1.1 Scale of Events

Of the 132 events, 17 had peak flow rates above 50,000 ML/day. These represent events that already achieve the upper target flow of 40,000 ML/day. A summary of these events is presented below in Table 3.3. Significant Lake Eildon releases featured in eight of these events, with releases often increasing after the peak flow at Shepparton. Harvesting to Waranga Basin was generally quite low during these events. Of these events, 13 occur between August and October (mainly September/October), with three events before August and one after October.

Table 3.3 : Events above 50,000ML/day

Date	Peak Flow at Shepparton (ML/d)	Eildon Release (ML/d)	Waranga Diversion (ML/d)	Other events occurring before this event
September 1960	75,100	8,900	-	July
October 1964	66,000	19,100	400	-
June 1968	59,700	900	3,800	-
September 1970	51,900	34,100	700	May, July, July, Aug
September 1973	54,500	200	-	Feb, May, Jun, Jul, Aug
May 1974	174,900	3,300	400	-
October 1974	83,800	14,600	-	May
September 1975	97,400	24,500	3,300	Aug, Aug
July 1981	92,700	100	6,900	Jun
August 1983	57,300	100	400	-
September 1983	58,900	100	200	Aug
October 1992	74,800	4,300	100	Sep
October 1993	145,700	12,900	-	Jul, Aug, Aug
August 1996	60,300	400	300	Jun
October 1996	58,700	800	700	Jun, Aug, Sep
September 2010	75,500	400	400	-
December 2010	57,900	200	200	Sep, Nov

Of the 132 events, nine had peak flow rates between 40,000 and 50,000 ML/day which are presented below in Table 3.4. Large Eildon releases occurred during three of these events. Waranga Basin diversions have been useful in achieving the 40,000 ML/day flow peak in three events. Events are either early in the season (three in June/July) or occur later after multiple earlier events (with two events in Summer/Autumn).

Table 3.4 : Events between 40,000ML/day and 50,000ML/day

Date	Peak Flow at Shepparton (ML/d)	Eildon Release (ML/d)	Waranga Diversion (ML/d)	Events before
August 1968	42,000	100	800	Jun, July
October 1971	42,600	25,500	5,000	Jun, Sep
November 1971	42,100	15,100	400	Jun, Sep, Oct
August 1973	43,300	400	-	Feb, May, July, July
October 1973	49,600	14,500	-	Feb, May, Jun, Jul, Aug, Sep, Oct
October 1979	44,400	100	100	Aug, Aug, Sep
June 1981	41,200	1,700	3,400	-
June 1995	42,200	400	3,500	-
July 1995	44,500	400	-	Jun

There are 33 events with peak flows in the range of 25,000 to 40,000 ML/day (occurring in 20 years) (see Table 3.5 below). These are events that fall within the target flow range when Waranga Basin diversions are ceased. Lake Eildon is usually not making significant releases during these events. Harvesting to Waranga Basin occurs in 21 of these 33 events, with ceasing diversions increasing the flow achieved (and lifting 11 events above the 25,000 ML/day minimum target flow). Of these events, 20 occur between August and October (12 in September), with 12 events before August and 2 after October.

Table 3.5 : Events between 25,000ML/day and 40,000ML/day

Date	Peak Flow at Shepparton (ML/d)	Eildon Release (ML/d)	Waranga Diversion (ML/d)	Events before
August 1965	30,000	100	8,400	July
September 1965	36,400	500	-	July, Aug
December 1966	36,300	3,400	6,300	Aug, Sep, Oct, Dec
February 1973	33,300	2,000	5,100	Feb
July 1973	29,600	1,000	6,600	Feb, May, Jun
July 1978	27,400	100	2,600	-
August 1978	32,700	100	1,300	July
September 1978	28,700	100	-	July, Aug
September 1979	25,700	100	-	Aug, Aug
August 1984	28,200	100	6,700	-
October 1984	32,000	100	3,400	Aug, Sep
July 1986	35,600	200	6,500	
September 1986	30,300	100	-	July, Aug
October 1986	30,600	100	300	July, Aug, Sep
June 1987	28,600	200	4,700	
August 1987	37,800	100	200	June, July
September 1988	27,200	100	100	June, July
June 1989	35,800	200	-	Apr
September 1989	36,600	100	300	Apr, June, July
July 1990	38,900	300	3,700	July
July 1991	27,800	200	5,800	-
September 1991	25,800	100	900	July
September 1991	33,400	3,800	100	July, Sep
September 1992	26,600	300	2,700	-
June 1996	26,900	200	10,600	-
September 1998	27,700	300	6,800	Aug
September 2000	25,400	200	500	-
November 2000	26,100	200	-	Sep, Nov
July 2003	28,900	200	8,900	
August 2003	30,200	200	9,300	July
September 2005	25,700	500	7,100	Feb
January 2011	30,300	200	500	-
March 2012	39,000	500	7,000	-

There are 73 events with peak flows in the range of 15,000 to 25,000 ML/day (occurring in 26 years). Lake Eildon is releasing greater than 1,000 ML/day during 31 events (including 15 events greater than 5,000 ML/day). Waranga Basin would have been diverting during 54 events. Events occur throughout the year, with 40 in July/August, and 19 in September-November.

Table 3.6 below shows all flow events (in GL/day or 1,000 ML/day) and the months in which they occurred. Peak flow ranges are coloured as 50+ GL/d, 40-50 GL/d, 25-40 GL/d, and 15-25 GL/d. Years with no events are presented in red. Multiple events in the same month are shown separated by "/".

Table 3.6 : All Flow events greater than 15,000ML/day and the months in which they occurred

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1960							21		75		19	
1961								24				
1962							23					
1963						22	23	20/18		24		
1964										66		
1965							16	30	36			
1966								24	25	21		18/36
1967												
1968						60	22	42/17		17		
1969							19		16			
1970					15		16/16	17	52			
1971					15				15	43	42	
1972		18										
1973		17/33			22	24	30	43	54	22/50		
1974					175					84		
1975								16/17	97			
1976												
1977						23	22					
1978							27	33	29			
1979								17/15	26	44		
1980							17/19					
1981						41	93					
1982												
1983								57	59			
1984								28	19	32		
1985								19/23				
1986							36	24	30	31		
1987						29	19	38				
1988						25	24		27		21	
1989				16		36	23		37/18		22	
1990							19/39					

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991							28		26/33			
1992									27	75	23	24
1993							25	16/24		146	21	
1994												
1995						42	45					
1996						27		60	16	59		
1997												
1998								15	28			
1999								17/24				
2000									25		17/26	
2001												
2002												
2003							29	30				
2004									17			
2005		24							26			
2006												
2007												
2008												
2009												
2010									75		17	58
2011	30	23					18	23		17		
2012			39				24	23				
2013								17				
2014							16					

The number of events in ML/day flow ranges in each month are shown in Table 3.7 below.

Table 3.7 : Number of events by flow range and month in which they occurred

Flow Range	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
>50,000	-	-	-	-	1	1	1	2	6	5	-	1	17
40-50,000	-	-	-	-	-	2	1	2	-	3	1	-	9
25-40,000	1	1	1	-	-	3	6	5	12	2	1	1	33
15-25,000	-	4	-	1	2	5	19	21	7	5	7	2	73
Total	**1**	**5**	**1**	**1**	**3**	**11**	**27**	**30**	**25**	**15**	**9**	**4**	**132**

In summary:

- smaller flow events tend to occur earlier (July/August) in the winter/spring season, with larger events tending to occur later (September/October) in the season.
- the majority of events up to 40,000 ML/day have Waranga Basin harvesting water at the same time which allows flows to be easily increased (the flows above include this increase). Events with peak flows above 40,000 ML/day tend not to have Waranga Basin harvesting water (as they tend to be later in the winter/spring season, Waranga Basin is more likely to be full before the event).
- Lake Eildon is often releasing water during and after flow events above 40,000 ML/day, and for some events less than 25,000 ML/day. Significant existing releases reduce the available capacity to increase Lake Eildon releases to achieve desirable environmental flows.

3.1.2 Sequence and timing of events within the year

In the 55 years, 11 have no flow events, and therefore would not be considered for environmental releases. Of the remaining forty four years in the period of record, there are seven years with only one event. Most years (37) have 2 or more events. Figure 3.3 below shows the distribution of number of events per year for each year in the record from 1960 to 2014.

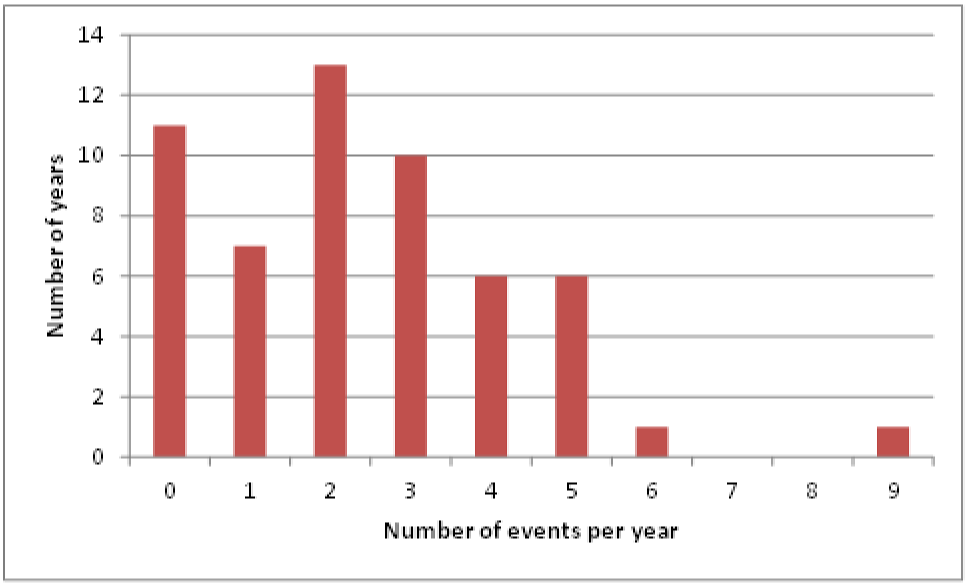

Figure 3.3 : Number of events per year

Figure 3.4 below presents the histogram of the number of events per year for years in which an event occurred in either May or June. There were thirteen years in which an event occurred in May or June and in each of these years one or more events occurred later in that year (although one of those was only in July). For example, in 1970, a 15,000 ML/day event in May is followed by two 16,000 ML/day events in July, a 17,000 ML/day event in August, and a 52,000 ML/day event in September. Table 3.6 above shows that in all of those years, the later events had peak flows of the same or greater magnitude. Hence based on these historical events, there would be no need to release environmental water in May/June, and they indicate later future events (although of uncertain size).

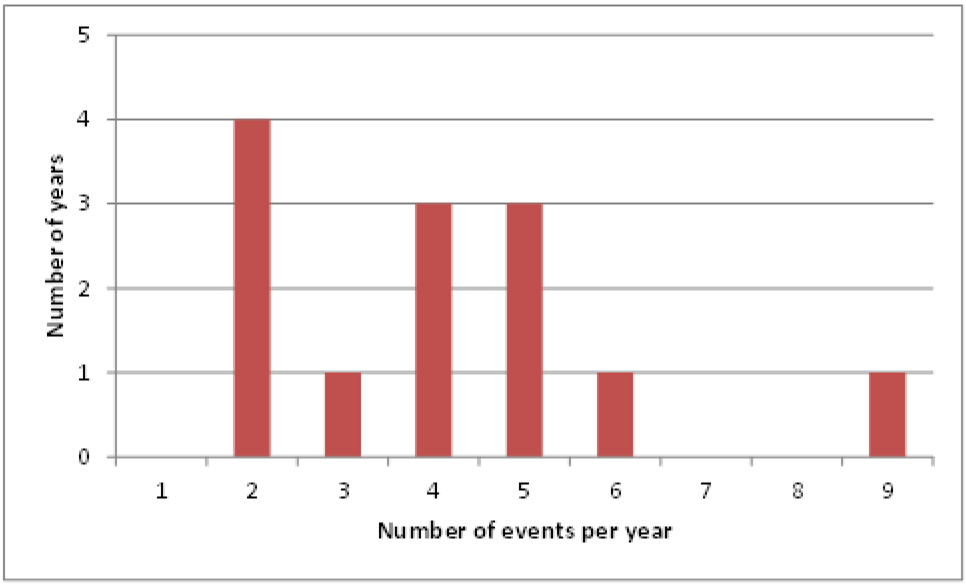

Figure 3.4 : Number of events per year which include an event in May or June

Similarly, there are 24 years with events in July, where 17 have similar or bigger events in later months and seven have years where the July events did not have later events (ie 1962, 1977, 1980, 1981, 1990, 1995, and 2014). Of these seven years, two were less than 20,000 ML/day, two were between 20,000 and 25,000 ML/day, and three were greater than 39,000 ML/day (with three providing reasonable environmental watering on their own). Hence, not releasing environmental water in July would prevent watering in seven years (with three providing reasonable watering on their own).

Not releasing environmental water before August would allow better use of environmental water, targeting potentially larger and later flow events in five years (in 1965, 1978, 1989, and 1991) and so using less water, and avoiding watering in four years (i.e. natural events occur later in 1960, 1970, 1973, and 1993). The opportunity to water would be missed in 4 years..

It is also preferable not to water after October, as the risk of blackwater events from floodplain watering increases in warmer weather. Furthermore, agricultural damage from inundation tends to increase with later flooding (although October is still too late to avoid significant agricultural damage). There are no years where later events (after October) provide watering opportunities not available earlier in the year.

Therefore the target watering months can be reduced from winter/spring to August to October..

3.1.3 Sequence and timing of events between years

An initial assessment has been undertaken to narrow the potential years in which environmental flow releases might be considered. The environmental objective for the lower Goulburn floodplain is to achieve inundation of river redgum trees between four and six times per 10 years on average, with a maximum period between events of five years.

Hence this implies that a watering is desirable every two years on average, with perhaps every second or third year considered for environmental releases (to allow a buffer to ensure floodplain inundation occurs at least every five years).

Natural successful watering events (without Waranga Basin ceasing diversions) greater than 40,000 ML/day (and events between 25,000 and 40,000 ML/day) occurred in the years as presented in Table 3.8 below. Years with no events with peak flows greater than 15,000ML/day are presented in red. Years of potential for environmental release are included based on the criteria that at least two years has passed since an event with a peak flow greater than 40,000ML/day has occurred and it is not a year without any events reaching a peak flow of 15,000ML/day.

Table 3.8 : Events greater than 40,000ML/day and between 25,000 - 40,000ML/day

Year	>40,000 ML/day	25,000-40,000 ML/day	Potential Years of Release
1960	Sep		
1961			
1962			Yes
1963			
1964	Oct		
1965		Sept	
1966		Dec	Yes
1967			
1968	Jun/Aug		
1969			
1970	Sep		
1971	Nov/Oct		
1972			
1973	Aug/Sep/Oct	Feb/Jul	
1974	May/Oct		
1975	Sep		
1976			
1977			Yes
1978		Aug/Sep	
1979	Oct	Sep	
1980			
1981	Jul	Jun	
1982			
1983	Aug/Sep		
1984		Oct	
1985			Yes
1986		Jun/Aug/Sep	
1987		May/Jul	
1988		Sep	Yes
1989		Jun/Sep	
1990		Jul	
1991		Sep/Sep	Yes
1992	Oct		
1993	Oct		
1994			
1995	Jul	Jun	
1996	Aug/Oct		
1997			

Year	>40,000 ML/day	25,000-40,000 ML/day	Potential Years of Release
1998			Yes
1999			
2000		Sep/Nov	Yes
2001			
2002			
2003			Yes
2004			
2005			Yes
2006			
2007			
2008			
2009			
2010	Sep/Dec		
2011		(Jan)	
2012		(Mar)	Yes
2013			
2014			Yes

In the wetter sequences of years (e.g. 1968 to 1983), there is little need to make releases to provide a desirable frequency of flooding. From 1984 to 1991, it would be desirable to top up existing smaller events (although only two of the three events shown would be preferable – ie perhaps only target every third year). In the drought sequence from 1997 to 2009, opportunities are very limited.

Given the limitations of watering in any particular year, it is unlikely that all of the potential target years for watering would actually result in watering events.

3.1.4 Flow Duration and Rates of Recession

The event plots in Appendix A show the desirable duration of watering events at 25,000 ML/day and 40,000 ML/day, presuming additional environmental water releases start to increase the flow at Shepparton from the day of peak flow onwards. Many of these show that the current peak duration is quite short, and the rate of fall in the flow after the peak is relatively fast. Hence, the analysis indicates significant releases from storage would be required to maintain the flow duration after the natural peak has passed.

Statistics are presented in Table 3.1 and Table 3.2 on the duration of peak flow, rate of recession and the maximum Eildon flow releases that would be required to maintain a target flow. In many events, these maximum releases are considered too high as they increase flows after the event has passed (rather than during the event), which is unrealistic.

Further analysis is required to evaluate the duration of flow events, rates of recession and the timing of releases to increase events.

This initial analysis of maximum Eildon flow releases required to provide indicative flow rates included some simplified assumptions, such as:

- estimating the release required from Eildon based on a straight lag of four day travel time with perfect knowledge

- no allowance for operational constraints of rise and fall and
- the effect of attenuation in the river as the additional Eildon release flows downstream.

Further analysis will involve potential release strategies, operational constraints and the impact of the attenuation of releases as they flow from Eildon to Shepparton.

3.1.5 Source of River Flows

The graphs in Appendix A show where the water comes from in the catchment for each flow event. The flows are divided up into three areas – between Eildon and Trawool, between Trawool and Goulburn Weir, and downstream of Goulburn Weir. This is summarised in Table 3.1, Table 3.2 and in Figure 3.2. Within these areas, flows from different tributaries are shown.

These show that flow events are usually generated from the whole catchment, but the balance between different parts of the catchments can change significantly between events. As noted earlier, Lake Eildon releases can be a significant source of water in some flow events. In considering triggers for flow releases, triggers in different parts of the catchment will potentially target different events.

Of particular note, the ungauged catchment upstream of Trawool generates significant flow in most events. Approaches to reduce the uncertainty of the where in the ungauged area that these flows originate from (such as additional flow gauging) need to be further considered. The ungauged catchment downstream of Trawool generally generates comparatively little runoff, indicating adequate flow measurement of tributaries in this reach.

4. References

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