GOULBURN BROKEN CATCHMENT MANAGEMENT AUTHORITY

# Goulburn River Environmental Flows Hydraulics Study

## – Hydrologic analysis

## Streamflow data assessment and

## Tributary inflow analysis

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# 1. INTRODUCTION

The Goulburn Broken Catchment Management Authority (Goulburn Broken CMA) has commissioned the Goulburn River Environmental Flow Hydraulics Study. The study is required to undertake hydraulic and hydrologic modelling of the Goulburn River from Lake Eildon to the River Murray.

This report documents the hydrologic analysis undertaken as part of the Goulburn River Environmental Hydraulics Study; its particular focus is on streamflow data availability and quality, and tributary inflow correlations.

The hydrologic analysis was undertaken by Water Technology, with expert input and review by Erwin Weinmann.

The study brief outlined the following project tasks:

- Data collation and review – Collation and review of the available topographic and streamflow data information.
- Topographic data gap identification – Identify the gaps in the available topographic data, and suggest potential mediation options.
- Asset mapping – Locate and map known public and private assets along the Goulburn River and adjacent surrounds.
- Hydrologic analysis – Investigate relative contribution from downstream tributaries, and assess design flood hydrographs for the Goulburn River catchment.
- Hydraulic analysis and flow behaviour – Assess flow behaviour of the Goulburn River over a range of potential environmental flows.
- Socioeconomic assessment – Evaluate the social and economic costs of potential Goulburn River environmental flows.
- Real time flow management – Review and scope real time flow management framework.
- Management option assessment – Scope feasibility of management options for environmental flow releases.

This document reports on aspects of the first and fourth project tasks.

The structure of this report is as follows:

- Section 2: provides an overview of the scope of this report and the approach taken to complete it.
- Section 3: outlines the availability and quality of streamflow data in the Goulburn River Catchment.
- Section 4: details statistical flow characteristics of the data at gauging stations along the Goulburn River and its gauged tributaries.
- Section 5 describes the analysis of flow concurrency at streamflow gauges on the Goulburn River and its gauged tributaries.
- Section 6 contains the conclusions and key outcomes

# 2. SCOPE AND APPROACH

As part of the environmental flow recommendations for the Goulburn River below Lake Eildon (Cottingham et al 2003), the Goulburn River has been split into five reaches. These reaches have been defined using the general geomorphological and hydrologic characteristics. The five reaches were defined as follows:

- Eildon – Molesworth/Yea (Reach 1)
- Molesworth/Yea – Seymour (Reach 2)
- Seymour – Nagambie (Reach 3)
- Nagambie – Shepparton (Reach 4)
- Shepparton – the River Murray confluence (Reach 5)

A good understanding of the flow regimes for each of the five reaches, shown in Figure 2-1, underpins an effective and efficient modelling approach to support real-time environmental flow management.

The hydrologic analysis explored the potential impact of the tributary flows on the Goulburn River flows during winter/spring (when environmental releases are expected to be made). Key questions related to the tributary characteristics include:

- can they be relied on to provide additional flow (to that released from Lake Eildon) that we can use productively to increase inundation of the floodplain further down the catchment;
- what risk do they pose for exceeding acceptable flood levels and causing a problem?

The key issues relate to:

- the typical flow rates individual tributaries (or groups of tributaries) provide during the expected period of environmental releases;
- how fast the flow rates can be expected to vary during a high flow event (probably more risk on the rise and useful flow on the fall);
- whether the tributaries typically act together or high flow events in different tributaries are somewhat independent (together probably means they are reacting to broad scale weather patterns and are more predictable, but produce cumulative impacts)

Within the Goulburn River catchment there are two relevant considerations to decide on locations of interest:

- the general geomorphological characteristics of river reaches and the variation of bankfull flow capacities along the Goulburn River and its anabranch system;
- the entry points of major tributaries that could contribute significantly to flood flows in downstream river reaches.

From these considerations the major locations of interest identified were:

- Molesworth/Yea
- Seymour
- Nagambie
- Shepparton

These points of interest and the corresponding river reaches are highlighted in Figure 2-1.

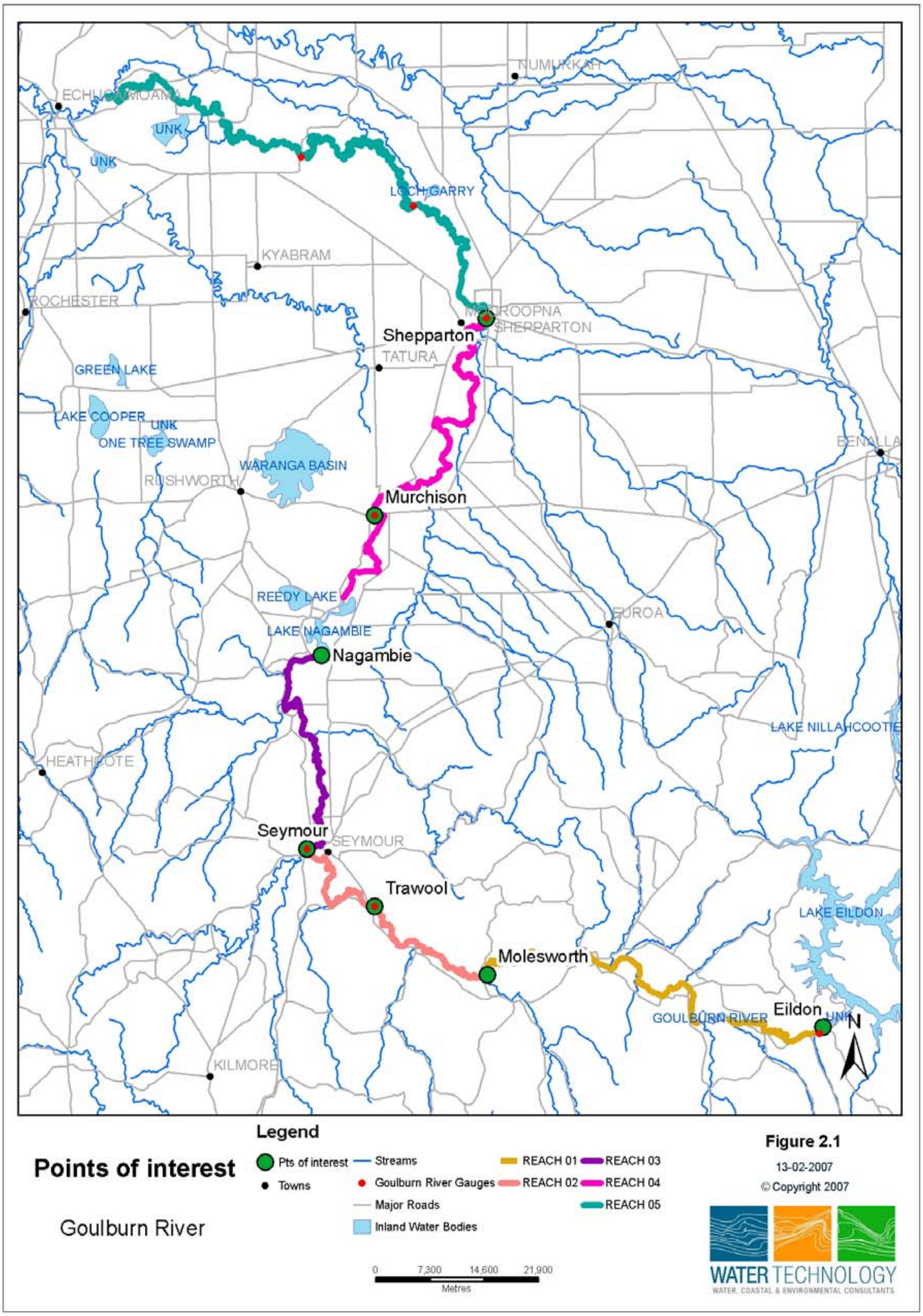



**Figure 2-1: Points of interest and Goulburn River reaches**

As any environmental releases are likely to fall into the period between July and November, the flow characteristics in this season are of most direct interest. Comparisons with annual flow characteristics provide a more general context and the months within the July period have been analysed individually to gain a more detailed understanding.

The hydrologic analysis within this study is largely exploratory. Initially the project team developed a number of key question and responses. These key questions and responses were refined through discussions with the GBCMA.

Table 2-1 shows these key questions, the proposed method of analysis and the corresponding report section; they provide a structure to the analyses undertaken and summarised in this report.

**Table 2-1: Key questions and answers**

| **Question to be answered** | **Method of analysis** | **Report Section** |
|---|---|---|
| What is the *availability and quality of the flow data* at gauging stations within the Goulburn River catchment below Eildon? | Preparation of a spreadsheet listing key characteristics of the flow data at stations with useful lengths of record (see list in Appendix A) | 3: data availability and quality |
| What are the overall flow characteristics of the Goulburn and its tributaries below Eildon (for the post-Eildon period):<br>• on an annual basis<br>• on a seasonal basis (July-November)?<br>• On a monthly basis for months of July to November | Derivation of overall flow regime characteristics by application of standard time series analysis tools to daily flow time series for whole year, selected season or months | 4.2: General statistics |
| What are typical flow hydrograph shapes in the Goulburn River and its tributaries during the July to November season and what is the relationship between flow events in the same year? | Plot of flow hydrographs (July – Nov) for key stations on the Goulburn and its tributaries (selection of years to show typical range of flow hydrographs for dry, normal, wet years | 4.3.2: Seasonal Hydrographs |
| What are the characteristics of high flow and flood events in the Goulburn River and its major tributaries below Eildon:<br>• estimated flood magnitude for ARIs ranging from 2 to 100 years (for whole year and selected season)<br>• typical duration, frequency and excess volume of flow events that exceed a set of nominal threshold flows (for whole year and selected season)? | Flood frequency analysis of mean daily flow series and instantaneous peak series (based on annual maxima and exceedance series for whole year and for selected season)<br>High flow spell analysis for say 6 flow thresholds ranging from mean daily flow to 2-year flood (for complete daily flow time series and daily flow series for selected season) | 4.3.5 Baseflow contributions and flood event durations<br>4.4: Flood frequency analysis<br>4.5: High flow spell analysis |
| How do typical hydrographs at gauging sites in the Goulburn River system below Eildon relate to each other? | Superposition of recorded daily flow hydrographs at a number of sites for selected periods of interest (for a range of typical flow situations) | 4.3.3: Event Hydrographs<br>4.3.4 Eildon Spill Events |

| Question to be answered | Method of analysis | Report Section |
|---|---|---|
| What are the typical hydrograph (peak flow) lag times between gauging sites and points of interest on the Goulburn River (eg tributary confluence points)? | Analyse hydrograph information, eg from (4), to estimate typical lag times along tributary reaches and Goulburn River reaches | 4.3.6 Discussion |
| To what extent are flows in different tributaries and in the Goulburn River *concurrent*:<br>• On basis of recorded flows at gauging sites<br>• On basis of total estimated flow contributions to points of interest along Goulburn River? | Graphical correlation analysis of daily flow data from pairs of stations, using flood quantiles as thresholds (plus extraction of correlation statistics)<br>Graphical correlation analysis of total lagged flows for two groups of stations, using proportions of estimated bankfull flow at point of interest as thresholds | 5: Tributary flow concurrency and correlation |

The data and methods employed in these analyses, and the results and conclusions obtained from them, are discussed in detail in the following sections of the report.

The hydrologic analyses summarised in this report reflect the climate, catchment and system operating conditions over the period of the current historic flow records. It is reasonable to assume that the results for the tributary catchments give a satisfactory indication of likely future conditions over the medium term (10 years approx.) but streamflows will be more significantly affected by the impacts of climate change over the longer term. Future flow regimes along the Goulburn River, particularly the contributions made by releases and spills from Eildon, will depend strongly on future system operating scenarios.

# 3. STREAMFLOW DATA AVAILABILITY AND QUALITY

## 3.1 Overview

The Goulburn River catchment has numerous streamflow gauges on the Goulburn River and its larger tributaries. Figure 3-1 shows the location of the gauges discussed throughout this report.

An assessment of the streamflow data availability and quality has been undertaken, with findings discussed in Section 3.2 for the Goulburn River, and in Section 3.3 for the tributaries. Further discussion of the data availability and quality is provided in Section 3.4. Figure 3-1 also shows the quality code for the streamflow data at key sites.

The quality of individual streamflow recordings at each gauging station (e.g. daily flow at the gauge for a particular day) is classified into two categories, Good Quality and Poor Quality/No Data. These classifications are made using the Thiess data quality codes for each gauge. The split between the two classifications has been made at the data quality code of 150; all recordings over the 150 threshold have either poor quality or no data available.

Further, the overall data quality at each gauge is assessed on the percentage of poor quality/no data as follows:

- Good < 2% of the record is poor/no data
- Fair: 2% -10% of the record is poor/no data
- Poor: > 10% of the record is poor/no data

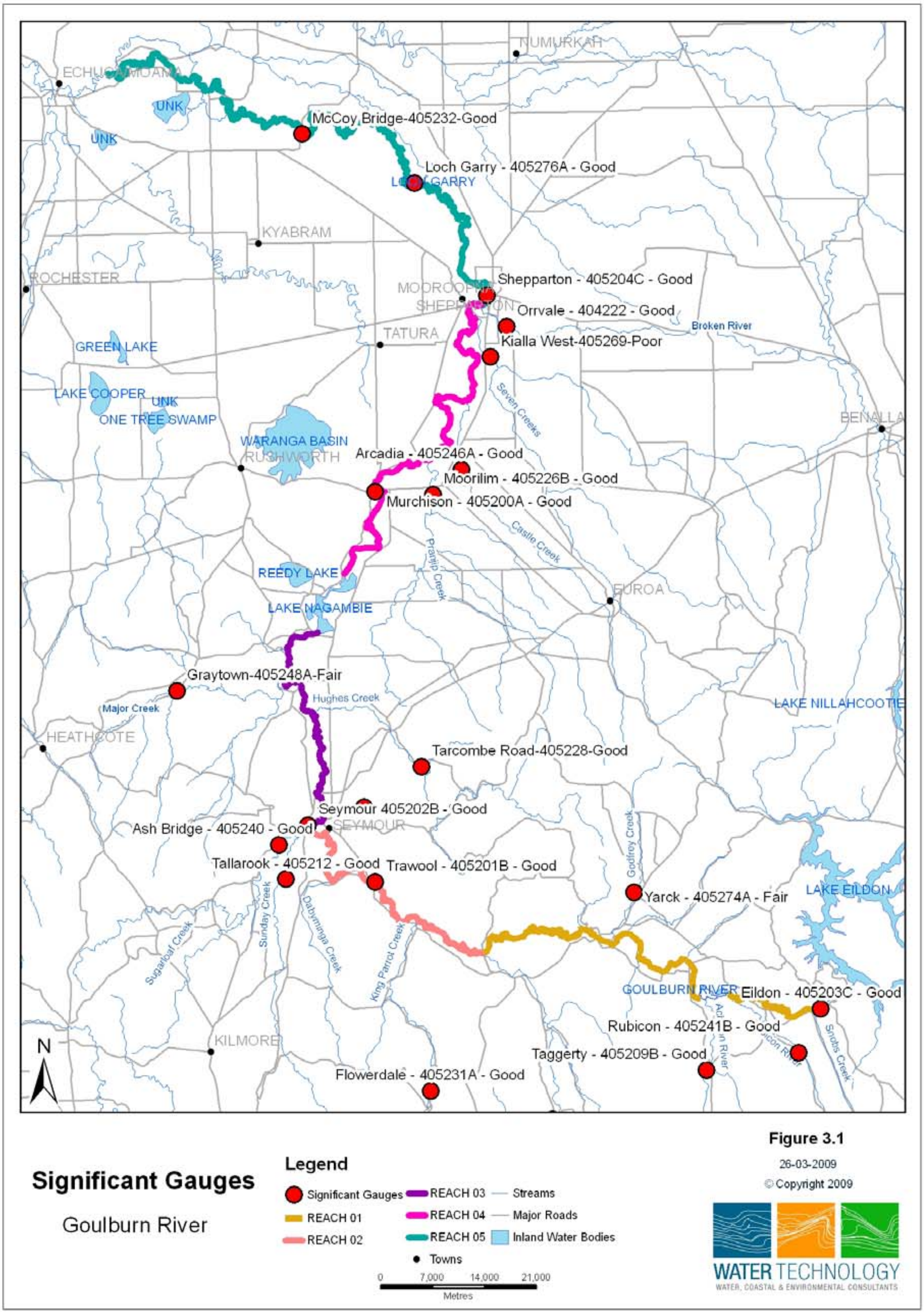



**Figure 3-1: Significant gauges in the Goulburn River catchment and their overall data quality**

## 3.2 Goulburn River

Table 3-1 shows the availability and quality of the data that is available along the Goulburn River below Eildon. Also shown in Table 3-1 is the ungauged catchment between the Goulburn River gauge and the upstream tributary/river gauges.

**Table 3-1: Goulburn River streamflow data availability and quality**

| Reach | No. | Name | Area (km2) | Ungauged catchment below upstream gauges | Start Date Continuous Data | Start Date Daily Data | End Date of Data Analysed | No. of Complete Yrs of Record (Continuous data) | Overall Quality Rating of Station |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 405203 | Goulburn River at Eildon | 3911 | Not applicable | 1/12/1974 | 02/01/1916 | 10/12/2007 | 31 | Good |
| 2 | 405201 | Goulburn River at Trawool | 7335 | 1948 $km^2$ (57%) | 5/12/1974 | 02/01/1908 | 06/11/2007 | 32 | Good |
| 3 | 405202 | Goulburn River at Seymour | 8601 | 320 $km^2$ (25%) | 11/06/1975 | 21/12/1957 | 07/11/2007 | 29 | Good |
| 4 | 405200 | Goulburn River at Murchison | 10772 | 1418 $km^2$ (65%) | 27/11/1984 | 15/06/1881 | 06/11/2007 | 22 | Good |
| 5 | 405204 | Goulburn River at Shepparton | 16125 | 389 $km^2$ (7 %) | 1/04/1974 | 09/06/1921 | 17/12/2007 | 30 | Good |
| 5 | 405232 | Goulburn River at McCoy Bridge | 16806 | 681 $km^2$ (100%) | 4/11/1976 | 24/08/1965 | 17/12/2007 | 27 | Good |

## 3.3 Goulburn River Tributaries

Table 3-2 shows the availability and quality of the data available for the major Goulburn River tributaries. Each gauge has been given an overall quality rating.

**Table 3-2: Goulburn River Tributaries Streamflow data Availability and Quality**

| Reach | No. | Station Name | Area km2 | Start Date Continuous Data | Start Date Daily Data | End Date of Data Analysed | No. of Complete Yrs of Record | Overall Quality Rating of Station |
|---|---|---|---|---|---|---|---|---|
| 1 | 405241 | Rubicon River at Rubicon | 129 | 12/12/1973 | 02/05/1922 | 10/12/2007 | 31 | Good |
| 1 | 405209 | Acheron River at Taggerty | 619 | 12/12/1973 | 13/12/1945 | 10/12/2007 | 32 | Good |

| Reach | No. | Station Name | Area km2 | Start Date Continuous Data | Start Date Daily Data | End Date of Data Analysed | No. of Complete Yrs of Record | Overall Quality Rating of Station |
|---|---|---|---|---|---|---|---|---|
| 1 | 405274 | Home Creek at Yarck | 187 | 9/06/1977 | 10/06/1977 | 10/12/2007 | 28 | Fair-Good |
| 2 | 405217 | Yea River at Devlins Bridge | 360 | 17/04/1975 | 27/03/1954 | 10/12/2007 | 30 | Good |
| 2 | 405231 | King Parrot Creek at Flowerdale | 181 | 30/12/1974 | 27/05/1961 | 10/12/2007 | 29 | Good |
| 2 | 405212 C/D | Sunday Creek at Tallarook | 337 | 3/02/1961 | 22/11/1945 | 10/12/2007 | 45 | Good |
| 2 | 405240 | Sugarloaf Creek at Ash Bridge | 609 | 5/02/1973 | 05/021973 | 18/11/2007 | 33 | Good |
| 3 | 405291 | Whiteheads Creek at Whiteheads Creek | 51 | 15/09/1988 | 16/09/1988 | 10/12/2007 | 16 | Good |
| 3 | 405228 | Hughes Creek at Tarcombe Road | 471 | 15/05/1975 | 17/19/1958 | 06/11/2007 | 29 | Good |
| 3 | 405248 | Major Creek at Graytown | 282 | 19/04/1971 | 20/04/1971 | 18/11/2007 | 33 | Fair-Good |
| 4 | 405226 | Pranjip Creek at Moorilim | 787 | 8/05/1974 | 11/12/1957 | 06/11/2007 | 32 | Good |
| 4 | 405246 | Castle Creek at Arcadia | 164 | 5/12/1973 | 01/05/1966 | 07/11/2007 | 33 | Good |
| 4 | 405269 | Seven Creeks at Kialla West | 1505 | 21/06/1977 | 22/06/1977 | 06/11/2007 | 10 | Poor[1] |
| 4 | 404222 | Broken River at Orrvale | 2508 | 23/06/1977 | 24/06/1977 | 10/12/2007 | 25 | Good[2] |

Notes:
1. Missing data during high flow periods (backwater effects from Goulburn River)
2. Flows affected by large upstream diversions into Lake Mokoan and Broken Creek systems

## 3.4 Discussion

Throughout the Goulburn River catchment, two types of streamflow gaugings have been undertaken. Streamflow gauging before the mid 1970s, consisted of daily readings of a staff gauge. From this gauging, a mean daily streamflow was determined. These mean daily flows do not account for variation of streamflow between daily staff readings. This variation is typically greater in smaller catchments, and less for larger catchments.

From the mid 1970's, continuous streamflow recorders were introduced. The continuous recorders measure the water level (stage) over the entire day, and thus provide instantaneous streamflow data.

Streamflow data from the daily read staff gauges and continuous recorders were considered. The daily read staff data (mean daily flow) informed the general streamflow characteristics, while the continuous data was employed in flood frequency analysis. Section 4 outlines the nature of the streamflow data used in the various analyses.

Continuous streamflow records from the Goulburn River gauges generally date from the mid 1970's (except Goulburn River at Murchison 1984). Available daily streamflow data sets at the Goulburn River gauges extend for a considerably longer period, with the longest available period for the Goulburn River at Murchison going back to 1881.

A similar pattern of streamflow data availability is seen for the Goulburn River tributaries. Continuous streamflow data is generally available for the mid 1970's. The availability of daily streamflow data is varied, with the longest daily flow record available for the Rubicon River at Rubicon since 1922.

Despite of the number of streamflow gauges, there is considerable ungauged catchment area below tributary gauges and on smaller, ungauged tributaries, as documented in column 5 of Table 3-1. In particular, 57% (1948 $km^2$) of the catchment between Eildon and the Trawool gauge is ungauged, and 65% of the tributary catchment between the Seymour and Murchison gauges. Most of the ungauged catchment area consists of the lower parts of gauged tributaries (the area downstream of the gauge to the junction with the Goulburn River) but there are also a number of minor tributaries without any streamflow gauging. Later analysis revealed that considerable runoff can be generated from these ungauged catchment areas.

The lack of gauged flow data limits the extent to which complete water balances can be calculated for different Goulburn River reaches and their tributary catchments. In particular, in some of the reaches (e.g. between Molesworth and Tallarook) it is difficult to identify how much of the total inflows is lost by transmission losses in the Goulburn River and its floodplain.

At most of the gauging stations, the records of daily and continuous streamflow data have only a few gaps, and the overall streamflow data quality has thus been rated as "good". The exceptions are Home Creek at Yarck and Major Creek at Graytown, where the data quality is judged to be "fair to good", and Seven Creeks at Kialla West, where the data quality is rated as "poor", because high flow data are missing for most of the period of record. This station is affected by backwater effects from high flows in the Goulburn River. The flow records for the Broken River at Orrvale are affected by large diversions from this catchment into the Lake Mokoan system (from 1971) and into the Broken Creek system.

In summary, the assessment of streamflow data in the Goulburn River catchment below Eildon has indicated that the geographical coverage of stream gauges, and the availability and quality of data is sufficient to provide a clear indication of the annual and seasonal flow regime of the Goulburn River and its major tributaries under current catchment and climate conditions. It should also provide a satisfactory basis for the development of rainfall-runoff models of the major tributary catchments.

# 4. STREAMFLOW DATA ANALYSIS

## 4.1 Overview

There has been a large number of streamflow statistics drawn from the streamflow data collected at each gauge. This section presents a subset of these statistics and discusses the following elements:

- General Statistics (Section 4.2)
- Flow Hydrographs (Section 4.2.5)
- Flood Frequency Analysis (Section 4.4)
- High Flow Spells Analysis (Section 4.5)

## 4.2 General statistics

### 4.2.1 Approach

The flow characteristics at each gauge have been analysed over three periods: annually, seasonally and monthly. The seasonal analysis looked at all the data from the start of July to the end of November as this is the time of year any environmental releases are likely to occur. The monthly analysis was restricted to the five months within this season. To account for the influence of flow regulation since the completion of Lake Eildon, the streamflow data used in the general statistics are limited to the period from 1956 onwards.

The statistics assessed include;

- Mean daily flow (MDF)
- Mean Daily Flow per catchment area (MDF/A)
- Ratio of MDF at a site to MDF at Trawool (as an indicator of relative flow contribution)
- Mean of annual maximum flow (MMF) – the MMF is the mean of the highest instantaneous flow values from the selected periods.
- Mean of maximum flow per catchment area (MMF/A)
- The ratio of Mean of Maximum Flow (MMF) to Mean Daily Flow (MDF)

### 4.2.2 Annual series

Table 4-1 shows the range of statistics determined on an annual basis. The gauges on the Goulburn River are in bold text.

The streamflow records analysed reflect the flow regime for the post-Eildon conditions, which are heavily modified from the natural flow regime. Releases from Eildon reflect complex operational decisions for the Goulburn System. Due to the very large size of the Eildon storage, there are only relative few years when the storage is full and unregulated spills occur.

The Mean Daily Flows (MDF) show Lake Eildon making by far the largest contribution to the flows at Trawool gauging station and the Acheron and Rubicon making up the majority of the remainder. There are large ungauged contributions from the Yea River and King Parrot Creek. The Acheron River shows as the most significant MDF contributor to flows upstream of Trawool. The MDFs for Trawool and Seymour are similar.

The tributary contributions between Seymour and Lake Nagambie are relatively minor. The reduction in mean daily flows (MDF) at Murchison is due to major irrigation diversions at Goulburn Weir. Downstream of Murchison, increases in mean flows occur from tributary contributions (Pranjip Creek, Castle Creek, Seven Creeks and Broken River).

Using the streamflow data from the gauges on Pranjip, Castle, Seven Creeks and Broken River (at Orrvale), the gauged catchment between Murchison and Shepparton is 93% of the total difference in catchment areas, but the sum of MDFs of these four gauged tributaries is only 38% of the difference in MDF of Shepparton and Murchison. This highlights possible uncertainties in the available streamflow data, and further detailed data checking is recommended.

The MDF/km$^2$ ratio shows the upper Goulburn River tributary catchments to produce a higher rate of runoff per unit area. This is expected because of the higher rainfalls and steeper slopes but also because of higher runoff coefficients, reflecting lower losses in the conversion of rainfall to runoff. The Rubicon River has the highest unit runoff, with 2.41 ML/d of runoff per km$^2$ of catchment area. This is in sharp contrast to the tributaries in the middle reaches of the Goulburn River, which generally contribute only 0.1 to 0.3 ML/d of runoff per km$^2$ of catchment area.

The reducing MDF/km$^2$ ratio in the Goulburn River on its way from Eildon to the Murray reflects the combined effects of smaller tributary contributions, transmission losses in the river and its floodplain, and diversions for irrigation and water supply purposes.

The ratio of Mean Maximum Flow (MMF) to MDF reflects the degree of peakiness in the catchment response. The higher ratios were found for the tributary catchments entering the Goulburn River, adjacent to Seymour such as Sunday Creek, Sugarloaf Creek, Whiteheads Creek and Major Creek. For Home Creek, two large flood events in 1988 and 1993 (peak flows 14400 ML/d & 1993 17300 ML/d respectively) resulted in a higher MMF and ratio of MDF/MMF than adjacent catchments.

For the gauges on the main stem of the Goulburn River, the relatively low ratios of MMF/ km$^2$ reflect the flood mitigating effect of Lake Eildon and the flood routing effects of the substantial floodplain areas along the river.

The low MMF/ km$^2$ ratio for Seven Creeks reflects the poor streamflow data quality in the high flow regime (streamflow data for the high flow periods are generally missing).

**Table 4-1: Flow statistics for the selected gauges calculated on an annual basis.**

| Reach No. | Stream Name | Catchment Area ($km^2$) | Period of streamflow data used for mean daily flow assessment | Mean Daily Flow (ML/d) | Mean Daily Flow per unit catchment ($ML/d/km^2$) | % of Trawool Mean Daily | Period of streamflow data used for instantaneous flow assessment | Mean of Annual Max.(ML/d) (instantaneous flow) | Mean Annual Max. Flow per unit catchment ($ML/d/km^2$) | Ratio of MMF/MDF |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **Goulburn River at Eildon** | **3911** | **01/01/1956 - 10/12/2007** | **3920** | **1.0** | **60.1%** | **1/12/1974 - 5/03/2008** | **13043** | **3.3** | **3.1** |
| 1 | Rubicon River at Rubicon | 129 | 01/01/1956 - 8/01/2008 | 311 | 2.41 | 4.8% | 12/12/1973 - 17/03/2008 | 2799 | 21.7 | 8.6 |
| 1 | Acheron River at Taggerty | 619 | 01/01/1956 - 1/01/1956 | 812 | 1.31 | 12.6% | 12/12/1973 - 18/03/2008 | 6190 | 10.0 | 7.3 |
| 2 | Home Creek at Yarck[1] | 187 | 10/06/1977-10/12/2007 | 67 | 0.36 | 1.0% | 9/06/1977 - 4/03/2008 | 6580 | 35.19 | 258.6 |
| 2 | Yea River at Devlins Bridge | 360 | 01/01/1956 - 8/01/2008 | 271 | 0.75 | 4.2% | 17/04/1975 - 18/03/2008 | 5143 | 14.3 | 18.7 |
| 2 | King Parrot Creek at Flowerdale | 181 | 10/06/1977 - 10/12/2007 | 92 | 0.51 | 1.4% | 30/12/1974 - 18/03/2008 | 2493 | 13.8 | 27.0 |
| **2** | **Goulburn River at Trawool** | **7335** | **01/01/1956 - 9/11/2007** | **6431** | **0.88** | **100.0%** | **5/12/1974- 14/02/2008** | **22228** | **3.0** | **3.4** |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | Sunday Creek at Tallarook | 337 | 13/03/1975 - 10/12/2007 | 92 | 0.27 | 1.4% | 3/02/1961 - 14/08/2008 | 7207 | 21.4 | 78.6 |
| 2 | Sugarloaf Creek at Ash Bridge | 609 | 18/07/1975 - 10/12/2007 | 160 | 0.26 | 2.5% | 5/02/1973 – 13/08/2008 | 14207 | 23.3 | 88.8 |
| **3** | **Goulburn River at Seymour** | **8601** | **21/12/1957 - 7/11/2007** | **6569** | **0.76** | **102.1%** | **11/06/1975 - 13/02/2008** | **30013** | **3.5** | **4.5** |
| 3 | Whiteheads Creek at Whiteheads | 51 | 16/09/1988 - 10/12/2007 | 8 | 0.16 | 0.1% | 15/09/1988 - 3/09/2008 | 1057 | 20.7 | 131.0 |
| 3 | Hughes Creek at Tarcombe Road | 471 | 17/09/1958 - 10/12/2007 | 201 | 0.43 | 3.1% | 15/05/1975 - 6/03/2008 | 8402 | 17.8 | 41.8 |
| 3 | Major Creek at Graytown[1] | 282 | 18/07/1975 - 18/11/2007 | 35 | 0.12 | 0.5% | 19/04/1971 - 20/11/2007 | 4645 | 16.5 | 136.0 |
| **4** | **Goulburn River at Murchison** | **10772** | 2/11/1984 - 10/12/2007 | **2057** | **0.19** | **32.0%** | 27/11/1984 - 17/03/2008 | **21874** | **2.0** | **10.6** |
| 4 | Pranjip Creek at Moorilim | 787 | 11/12/1957 - 25/12/2007 | 153 | 0.19 | 2.4% | 8/05/1974 - 31/03/2008 | 3420 | 4.3 | 22.3 |
| 4 | Castle Creek at Arcadia | 164 | 1/12/1990 - 10/12/2007 | 32 | 0.20 | 0.5% | 5/12/1973 - 12/03/2008 | 1468 | 9.0 | 45.5 |
| 4 | Seven Creeks at Kialla West[2] | 1505 | 26/10/1996 - 10/12/2007 | 108 | 0.07 | 1.7% | 21/06/1977 - 27/03/2008 | 1230 | 0.8 | 11.4 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 4 | Broken River at Orrvale[3] | 2508 | 11/08/1999 - 10/12/2007 | 251 | 0.10 | 3.9% | 23/06/1977 - 12/03/2008 | 10495 | 4.2 | 41.8 |
| **5** | **Goulburn River at Shepparton** | **16125** | 01/01/1956 - 9/11/2007 | **4218** | **0.26** | **65.6%** | 1/04/1974 - 17/03/2008 | **31413** | **1.9** | **6.5** |
| **5** | **Goulburn River at McCoy Bridge** | **16806** | 25/08/1965 - 10/12/2007 - | **3916** | **0.23** | **60.9%** | 4/11/1976 - 9/10/2008 | **34179** | **2.0** | **8.7** |

**Notes:** **1) Data quality rating "Fair to Good"**
**2) Data quality rating "Poor"**
**3) Flows affected by major diversions upstream**

### 4.2.3 Seasonal series (July to November)

Table 4-2 shows the range of statistics determined on a seasonal basis. The gauges on the Goulburn River are in bold text. The same periods of streamflow data as the annual series assessment were used for the seasonal series.

The MDF coming from Lake Eildon is significantly less during the July – November period than over the whole year (5500 ML/d annually to 3911 ML/d seasonally). This reflects that the expected environmental release season covers part of the non-irrigation period. Also the period includes the initial part of the irrigation season, when demands are typically low and can mostly be satisfied from tributary inflows below Eildon. While spills from Eildon are most likely to occur in late winter and spring, they are relatively rare and can thus be expected to make only a small contribution to the seasonal MDF.

The majority of the tributaries of the Goulburn River have a significantly larger MDF during the expected environmental release season, with a large proportion approximately doubling their MDF compared to MDF for the whole year. This is consistent with catchments experiencing the highest rainfalls and runoffs during late winter and spring.

The portion that each tributary is adding to the flow at Trawool has increased considerably for the expected environmental flow season. On an annual basis Lake Eildon contributes 84% of the flow at Trawool but during the July to November period it makes only a contribution of 38%. ***This observation confirms that the July to November period offers significant opportunities to enhance environmental releases from Eildon with flow contributions from the tributaries.***

The seasonal MMF values for the all gauges are lower than the annual MMF values. This reflects the fact that only some of the largest annual flood events occur during the July to November period. This reduction in MMF values and the larger seasonal MDF values combine to produce a significant reduction in MMF/MDF ratios at all sites.

**Table 4-2: Flow statistics for the selected gauges calculated on a seasonal basis (July to November)**

| Reach No. | Station Name | Catchment Area (km2) | Mean Daily Flow (ML/d) | Mean Daily Flow (Ml/d/km2) | % of flow at Trawool | Mean of Seasonal Max.(ML/d) (instantaneous flow) | Ratio of MDF/MMF |
|---|---|---|---|---|---|---|---|
| **1** | **Goulburn River at Eildon** | **3911** | **3328** | **0.85** | **43.9%** | **9928** | **2.98** |
| 1 | Rubicon River at Rubicon | 129 | 492 | 3.82 | 6.5% | 2578 | 5.24 |
| 1 | Acheron River at Taggerty | 619 | 1367 | 2.21 | 18.0% | 5382 | 3.94 |
| 2 | Home Creek at Yarck[1] | 187 | 138 | 0.74 | 1.8% | 5986 | 43.40 |
| 2 | Yea River at Devlins Bridge | 360 | 476 | 1.32 | 6.3% | 4052 | 8.52 |
| 2 | King Parrot Creek at Flowerdale | 181 | 165 | 0.91 | 2.2% | 1835 | 11.09 |
| **2** | **Goulburn River at Trawool** | **7335** | **7578** | **1.03** | **100.0%** | **21439** | **2.83** |
| 2 | Sunday Creek at Tallarook | 337 | 173 | 0.51 | 2.3% | 5678 | 32.73 |
| 2 | Sugarloaf Creek at Ash Bridge | 609 | 331 | 0.54 | 4.4% | 13221 | 39.99 |
| **3** | **Goulburn River at Seymour** | **8601** | **8053** | **0.94** | **106.3%** | **28267** | **3.51** |
| 3 | Whiteheads Creek at Whiteheads | 51 | 47 | 0.92 | 0.6% | 938 | 20.04 |
| 3 | Hughes Creek at Tarcombe Road | 471 | 379 | 0.80 | 5.0% | 7968 | 21.03 |
| 3 | Major Creek at Graytown[1] | 282 | 71 | 0.25 | 0.9% | 4226 | 59.19 |
| **3** | **Goulburn River at Murchison** | **10772** | **4369** | **0.41** | **57.7%** | **20714** | **4.74** |
| 4 | Pranjip Creek at Moorilim | 787 | 315 | 0.40 | 4.2% | 3252 | 10.33 |
| 4 | Castle Creek at Arcadia | 164 | 75 | 0.46 | 1.0% | 1169 | 15.53 |
| 4 | Seven Creeks at Kialla West[2] | 1505 | 219 | 0.15 | 2.9% | 1072 | 4.90 |
| 4 | Broken River at Orrvale[3] | 2508 | 362 | 0.14 | 4.8% | 10245 | 28.32 |
| **5** | **Goulburn River at Shepparton** | **16125** | **7978** | **0.49** | **105.3%** | **31139** | **3.90** |
| **5** | **Goulburn River at McCoy Bridge** | **16806** | **7574** | **0.45** | **100.0%** | **24196** | **3.19** |

**Notes:** **1) Data quality rating “Fair to Good”**
**2) Data quality rating “Poor” (backwater effects during high Goulburn River flows)**
**3) Flows affected by major diversions upstream**

### 4.2.4 Monthly series

Streamflow data was analysed on a monthly basis to assess seasonal variations in the flow regime for the Goulburn River and its main tributaries. Figure 4-1 shows the typical pattern of variation of mean monthly flows over the year. It is evident that the seasonal pattern of flows in the Goulburn River at Eildon is mainly determined by releases from the storage in response to irrigation demands. In contrast to this, the seasonal flow pattern of the tributaries (represented by the Acheron River and Sunday Creek) is determined by heavy rainfalls and runoffs that tend to occur predominantly in late winter and spring. The seasonal patterns for the tributaries to the different river reaches appear to be quite similar.

The flow regime at stations along the Goulburn River is determined by a combination of these upstream influences. At Trawool, there are two high flow seasons: during late winter and spring (from high tributary inflows) and in summer and early autumn (from large Eildon releases). At Shepparton, the flow regime is mostly influenced by tributary inflows, as most of the Eildon releases are diverted at Goulburn Weir.

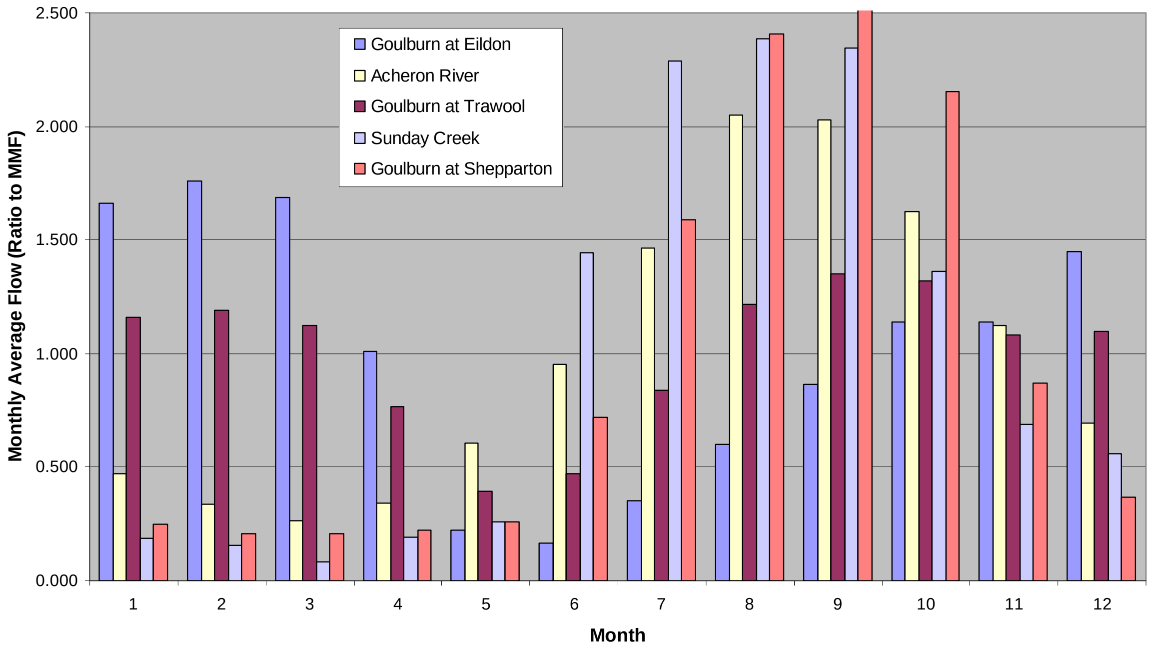



**Figure 4-1 Monthly flow pattern in Goulburn River and selected tributaries (period of analysis: 1956-2007)**

The remainder of the analysis on a monthly basis focused on the environmental flow release season. Table 4-3 shows the range of statistics determined on a monthly basis for the period July to November. The gauges on the Goulburn River are in bold text. The same periods of streamflow data as the annual series assessment were used for the monthly series.

The analysis on a monthly basis focused on MDF and MMF, and highlights the month with the highest value in each category. This gives an indication of the variation of flow characteristics within the environmental release season.

The gauge below Lake Eildon showed the highest MDF and MMF in October. For all other Goulburn River gauges, the analysis revealed that September had the highest MDF and MMF.

All the tributaries (except Major Creek and Broken River) have their highest MDF and MMF in August or September. These larger flows in late winter/early spring reflect the larger number of rainfall events to be expected around that time of the year.

***The results of the monthly analysis indicate that, in a typical environmental release season, the highest tributary inflows are likely to occur in the first half of the season, about two months earlier than the highest Eildon releases to irrigation demands. However, there is still a good chance of significant tributary flows in October.***

**Table 4-3 Goulburn River and tributaries – monthly flow statistics (July to November)**

| Station Number | Stream Name | Mean Daily Flow (ML/d) | | | | | Mean of Monthly Max. (ML/d) (Instantaneous Flow) | | | | | Month with highest mean | Month with Peak Max. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jul | Aug | Sept | Oct | Nov | Jul | Aug | Sept | Oct | Nov | | |
| **405203** | **Goulburn River at Eildon** | **1453** | **2438** | **3502** | **4638** | **4609** | **2374** | **3598** | **6119** | **7518** | **7174** | **October** | **October** |
| 405241 | Rubicon River at Rubicon | 422 | 566 | 602 | 512 | 359 | 1391 | 1514 | 1913 | 1467 | 915 | September | September |
| 405209 | Acheron River at Taggerty | 1195 | 1687 | 1671 | 1338 | 942 | 2871 | 3726 | 3867 | 3104 | 1864 | August | September |
| 405274 | Home Creek at Yarck[1] | 191 | 209 | 171 | 86 | 33 | 2305 | 3057 | 2691 | 2127 | 1038 | August | August |
| 405217 | Yea River at Devlins Bridge | 432 | 616 | 598 | 436 | 295 | 1876 | 2295 | 2319 | 1918 | 1137 | August | September |
| 405231 | King Parrot Creek at Flowerdale | 144 | 201 | 204 | 164 | 114 | 747 | 854 | 936 | 743 | 530 | September | September |
| **405201** | **Goulburn River at Trawool** | **5451** | **7932** | **8792** | **8613** | **7099** | **11929** | **13434** | **16616** | **13907** | **10200** | **September** | **September** |
| 405212C/D | Sunday Creek at Tallarook | 200 | 220 | 229 | 152 | 66 | 2541 | 2093 | 2468 | 1823 | 1335 | September | July |
| 405240 | Sugarloaf Creek at Ash Bridge | 399 | 434 | 430 | 307 | 83 | 4601 | 6365 | 6600 | 6160 | 926 | August | September |
| **405202** | **Goulburn River at Seymour** | **5892** | **8569** | **9429** | **9177** | **7198** | **16915** | **17696** | **19097** | **16292** | **9958** | **September** | **September** |
| 405291 | Whiteheads Creek at Whiteheads Creek | 22 | 25 | 28 | 12 | 3 | 438 | 398 | 457 | 325 | 50 | September | September |
| 405248 | Major Creek at Graytown[1] | 81 | 84 | 92 | 87 | 14 | 1547 | 1958 | 2785 | 211 | 4226 | September | November |
| 405228 | Hughes Creek at Tarcombe Road | 426 | 512 | 497 | 327 | 134 | 3153 | 3749 | 4127 | 3132 | 1104 | August | September |
| **405200** | **Goulburn River at Murchison** | **3563** | **5344** | **6697** | **4505** | **1737** | **9719** | **12777** | **13562** | **11735** | **4507** | **September** | **September** |
| 405226 | Pranjip Creek at Moorilim | 371 | 466 | 393 | 268 | 76 | 1586 | 1517 | 1659 | 1335 | 313 | August | September |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 405246 | Castle Creek at Arcadia | 76 | 90 | 106 | 71 | 34 | 568 | 639 | 632 | 545 | 160 | September | August |
| 405269 | Seven Creeks at Kialla West[2] | 240 | 327 | 272 | 137 | 119 | 796 | 958 | 641 | 287 | 297 | August | August |
| 404222 | Broken River at Orrvale[3] | 204 | 300 | 536 | 252 | 517 | 5208 | 5078 | 5470 | 4952 | 1753 | September | September |
| 404200/216 | Broken River at Goorambat | 132 | 223 | 408 | 228 | 507 | 2545 | 4293 | 5071 | 7505 | 1994 | November | October |
| **405204** | **Goulburn River at Shepparton** | **6901** | **10254** | **10648** | **8532** | **3554** | **15335** | **18245** | **19600** | **17361** | **5388** | **September** | **September** |
| **405232** | **Goulburn River at McCoy Bridge** | **5760** | **9288** | **10373** | **8484** | **3967** | **9341** | **13092** | **17663** | **16413** | **6273** | **September** | **September** |

**Notes: 1) Data quality rating "Fair to Good"**
**2) Data quality rating "Poor" (backwater effects during high Goulburn River flows)**
**3) Flows affected by major diversions upstream**

### 4.2.5 High flow events

As discussed, the likely period for environmental flow releases is July to November. The likelihood of unregulated high flows (from the tributary catchments) occurring during this period is a key concern in the management of environmental flow releases. For each tributary gauge, the number of events above the 2-year ARI event was assessed on an annual and environmental flow season (July – November) basis. Figure 4-3 shows the percentage of years when the 2-year ARI peak flow is exceeded on whole-of-year basis, and inside and outside the environmental flow release season.

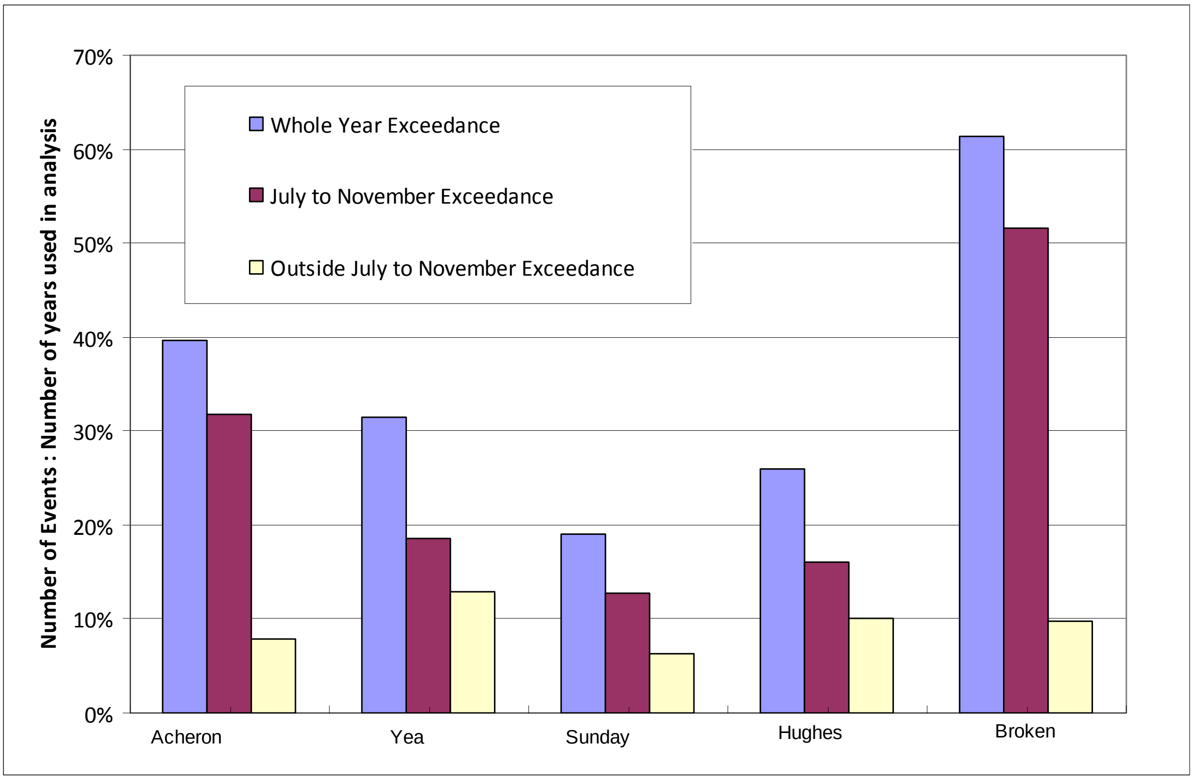



**Figure 4-2 Goulburn River Tributaries: Distribution of high flow events**

Figure 4-3 indicates that the high flow events exceeding the 2-year ARI flow are more likely to occur during the period July – November. For example in the Acheron River, the 2 year ARI flow was exceeded in about 40 % of years, with a considerable majority of these exceedances occurring in the period July – November. The bias towards exceedances in the period July – November reduces for tributaries lower in the Goulburn River catchment. The results for the Broken River may be affected by the diversions upstream.

## 4.3 Flow hydrographs

### 4.3.1 Approach

To assess the general nature of flow behaviour over a season and during an event, visual inspection of flow hydrographs has been undertaken.

The seasonal hydrographs have been extracted over the expected environmental flow period (July – November). These hydrographs have been classified by wet season, dry season and significant flood season. This assessment enabled the identification of distinct classification of the seasonal flow regime. Details are provided in Section 4.3.2.

The event-based hydrographs have been examined to gain an understanding of how a hydrograph moves down the Goulburn River and what portions of the hydrograph at Goulburn River gauges are made up of tributary flows and ungauged catchment flows. .

Since the construction of Eildon Dam, there has been a limited number of flood 'spill' events from Lake Eildon. The combination of controlled flood releases from Eildon and high flow events in the downstream tributaries gives rise to significant floodplain inundation. Section **Error! Reference source not found.** examines the interaction of Eildon flood releases with downstream tributary flows.

The duration of flow events can be assessed through the separation of the baseflow component from the total flow hydrograph. For key tributaries and Goulburn River gauges, a baseflow separation procedure has been applied. Section 4.3.5 details the baseflow separation and assessment of flow event duration.

A discussion of the key findings is provided in Section 4.3.6.

### 4.3.2 Seasonal Hydrographs (July to November)

The seasonal hydrographs were classified into wet, dry and significant flood significant flood seasons, by applying the following criteria:

- Dry : < 25 % of time above seasonal mean daily flow
- Significant flood season: One peak flow above the 5 year ARI peak flow
- Wet: > 75 % of time above seasonal mean daily flow

Table 4-4 shows the breakdown of seasons into the above flow classifications for selected gauges.

**Table 4-4: Seasonal flow classification : Selected tributaries**

| Gauge | Percentage of seasons (%) | | |
|---|---|---|---|
| | Dry | Wet | Significant flood season |
| Acheron River at Taggerty | 43% | 11% | 7% |
| Yea River at Devlins Bridge | 46% | 4% | 6% |
| Sunday Creek at Tallarook | 75% | 0% | 2% |
| Hughes Creek at Tarcombe Road | 54% | 0% | 5% |
| Broken River at Orrvale | 50% | 0% | 7% |

Table 4-4 suggests the occurrence of a dry season is relative consistent between the selected tributaries. Sunday Creek at Tallarook appears to have a higher occurrence of dry seasons. Wet seasons appear more likely in the upper tributaries (Acheron and Yea). No clear pattern has emerged for the significant flood seasons.

Typically the dry years have no significant flow events, the wet years have a number of consistent peaks and the significant flood season years have one or two sharp peaks (See Figure 4-3 for an example on the Acheron). Figure 4-3 shows superimposed hydrographs for a wet year, dry year and a significant flood year in the Acheron River. The hydrographs are plotted over the environmental release season of July to November.

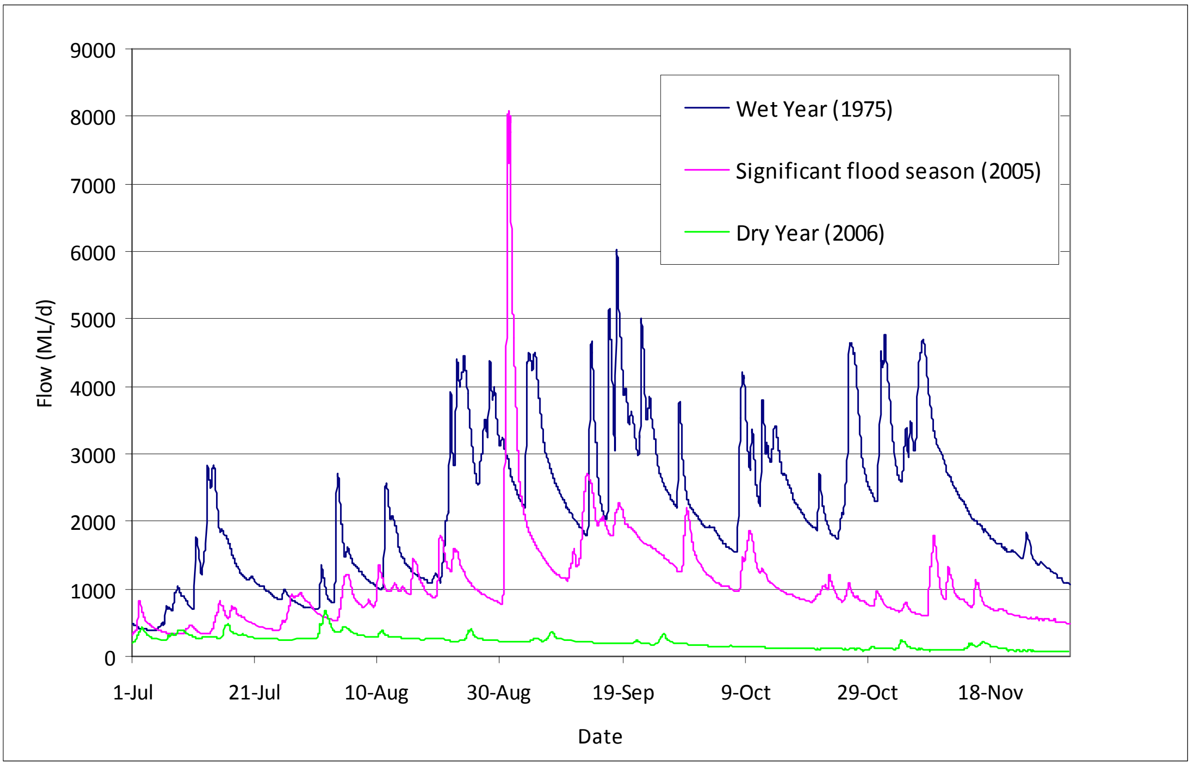



**Figure 4-3: Seasonal flow hydrographs - Acheron River**

Using the above criteria, the following years were selected as representative of the classification across the selected gauges:

- Dry: 2006
- Significant flood: 2005
- Wet: 1996

Figure 4-4 to Figure 4-9 show the seasonal hydrographs for the representative years at key selected tributary gauges plus key Goulburn River gauges.

The hydrographs for the 'dry' season (2006) show that the Goulburn River flows above the Goulburn Weir were dominated by releases from Eildon, with no significant contribution from the tributaries and no substantial flows in the lower Goulburn River.

For the significant flood season (2005), the highest Goulburn River flows at Trawool and Seymour resulted entirely from tributary contributions, while Eildon releases contributed to other flow events. Eildon releases appear to have had no influence on high flows below Goulburn Weir.

For the 'wet' season (1996), the high flow events at Trawool and Seymour in the earlier part of the season resulted from tributary inflows, and an Eildon spill event in October was responsible for a second peak in the flood hydrographs to Lake Nagambie but had little influence on flows downstream of Goulburn Weir.

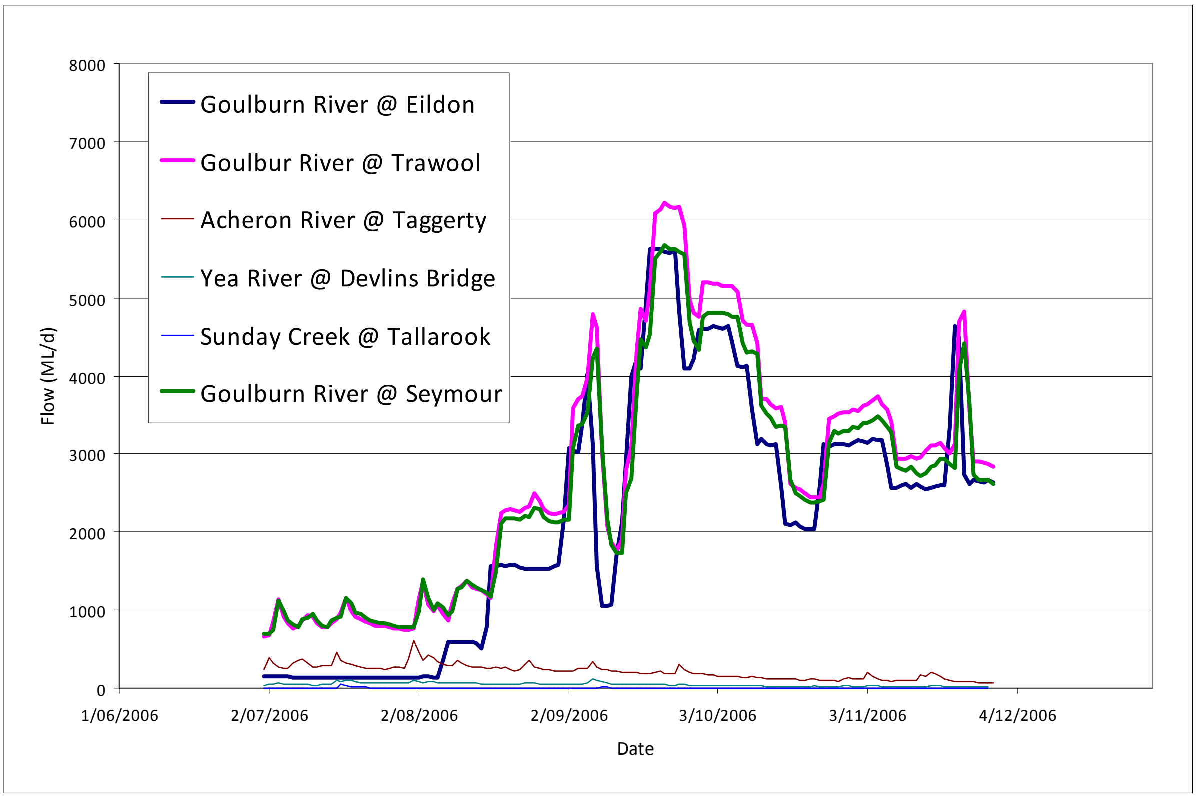



**Figure 4-4: Seasonal flow hydrographs - Dry season (2006) – Goulburn River above Seymour**

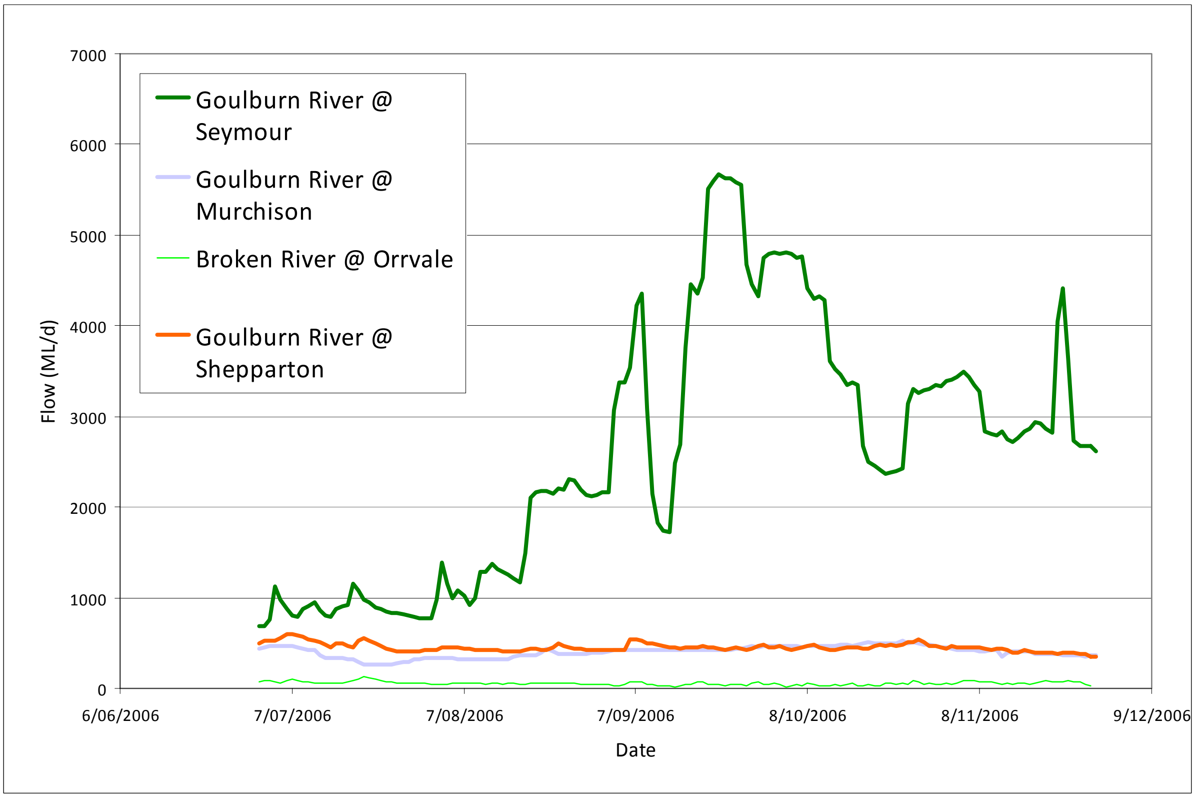



**Figure 4-5: Seasonal flow hydrographs - Dry season (2006) – Goulburn River below Seymour**

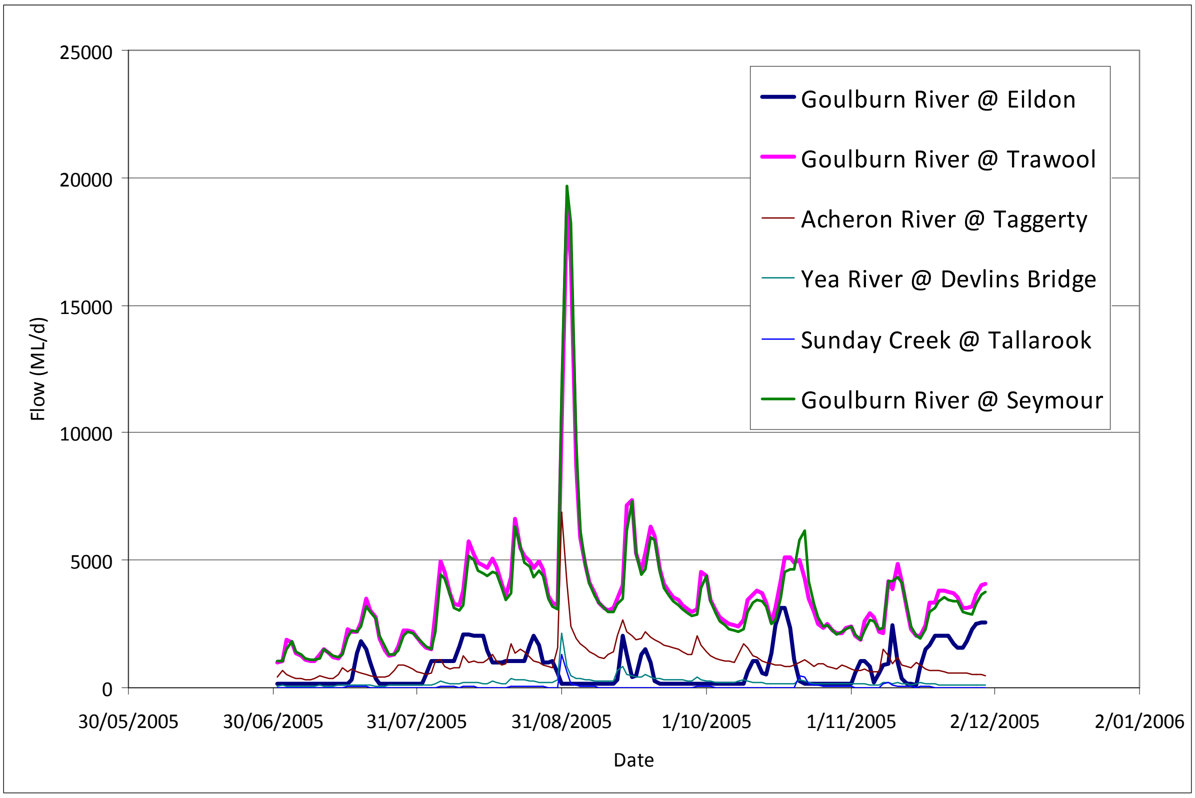



**Figure 4-6: Seasonal flow hydrographs - Significant flood season (2005) – Goulburn River above Seymour**

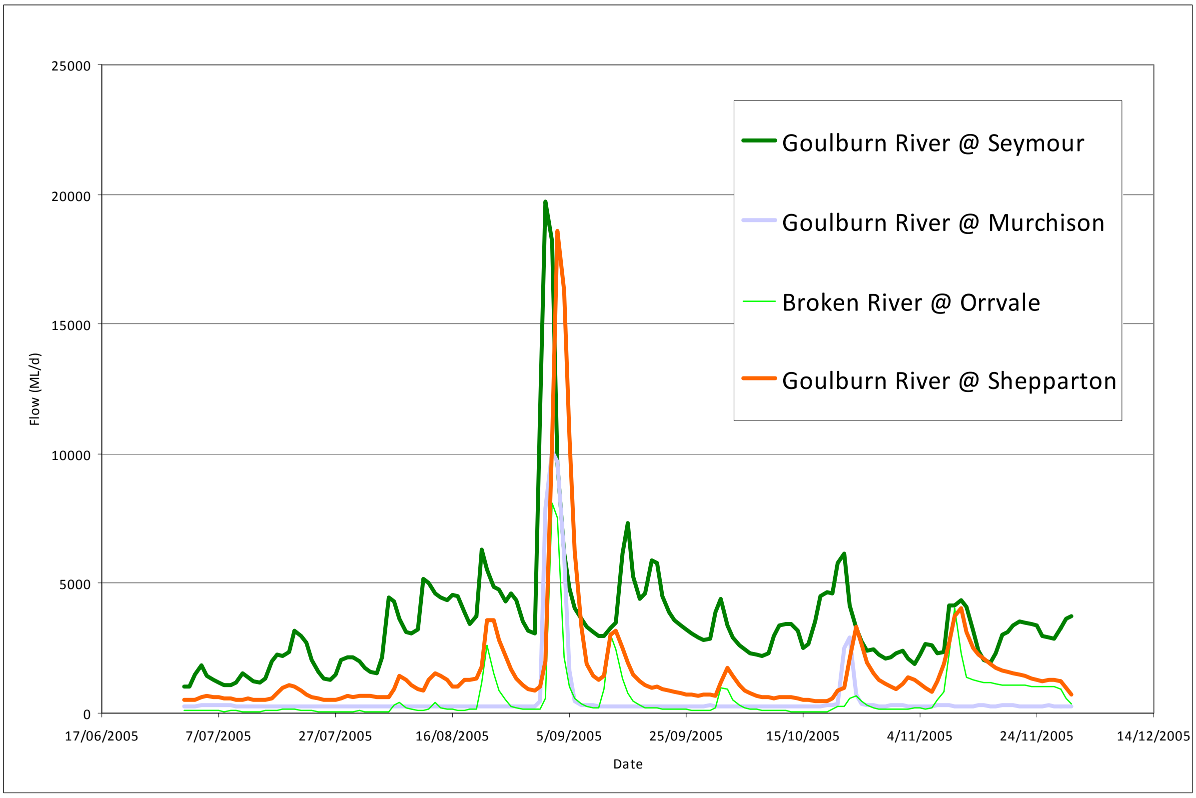



**Figure 4-7: Seasonal flow hydrographs – Significant flood season (2005) – Goulburn River below Seymour**

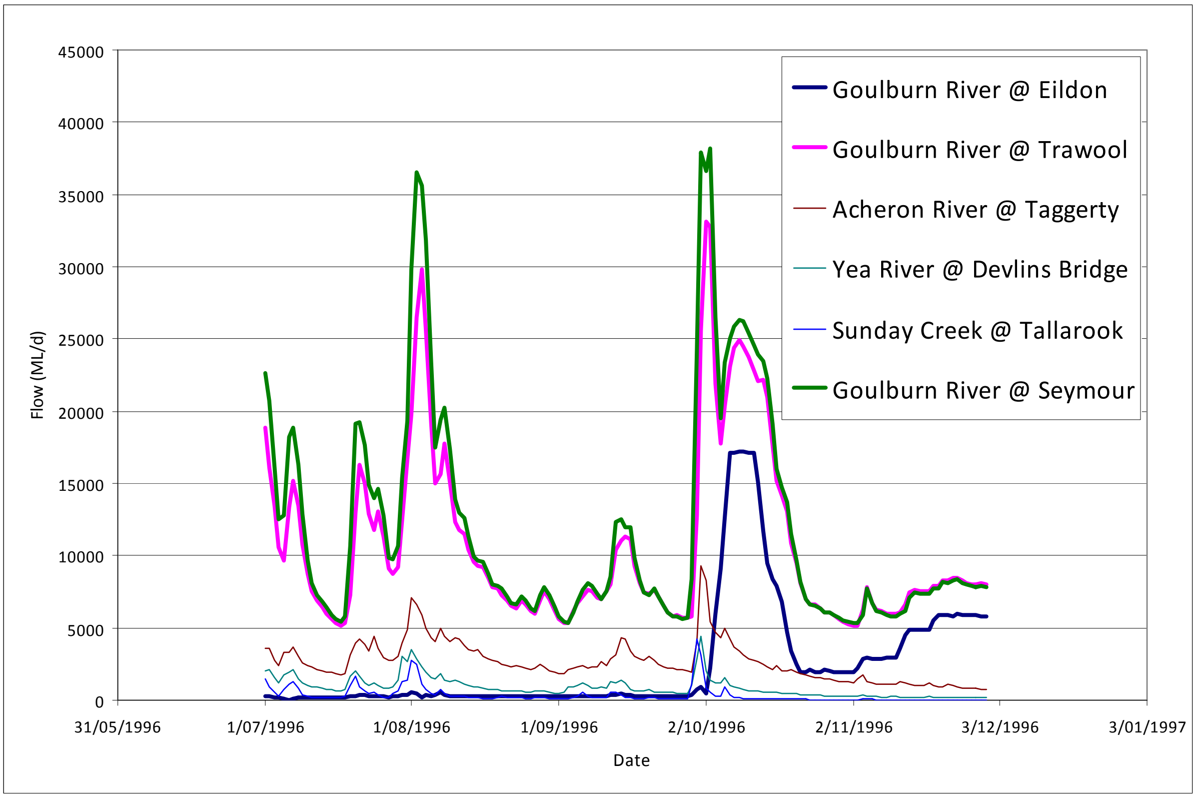



**Figure 4-8: Seasonal flow hydrographs – Wet (1996) – Goulburn River above Seymour**

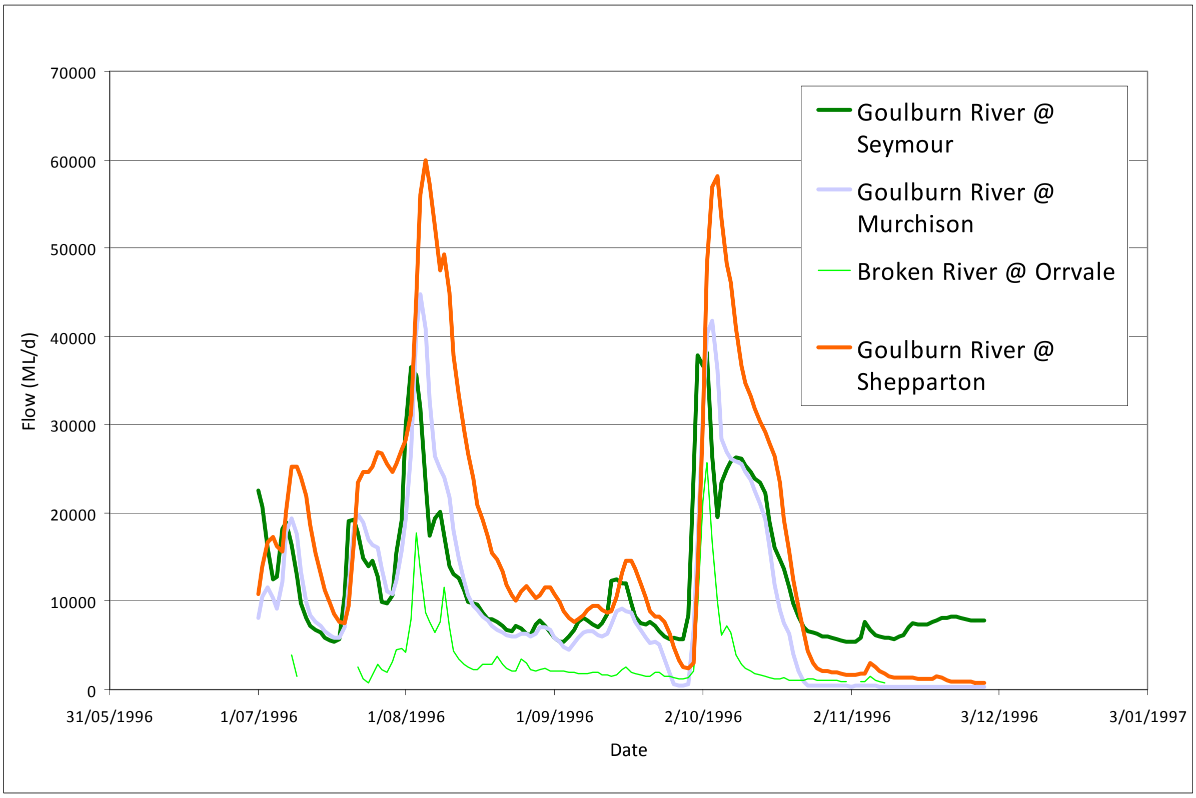



**Figure 4-9: Seasonal flow hydrographs – Wet (1996) – Goulburn River below Seymour**

### 4.3.3 Event Hydrographs

The two selected events are September 1991 and August 1996. The hydrographs have been plotted in the two following groupings:

- All Goulburn River gauges: This grouping provides insight into how the flow hydrograph progresses along the Goulburn River.
- Key Goulburn River gauges with their upstream tributaries: This grouping provides insight into the contribution made by the tributaries to the flow at key Goulburn River gauges.

***September 1991***

Figure 4-10 shows gauged hydrographs on the Goulburn River during the September 1991 event.

The September 1991 event had a large contribution from Lake Eildon, which peaked several days after the inflows from the tributaries in the reaches between Eildon and Seymour. The influence of the Lake Eildon hydrograph can be seen in both the Trawool and Seymour hydrographs. At Murchison, the flow hydrograph shape reflects the impact of the routing and regulating effects of Lake Nagambie (Goulburn Weir). The Shepparton gauge has recorded the highest peak through the 1991 event. The hydrograph downstream at McCoy's Bridge has a broader hydrograph which indicates that there is a large amount of flow attenuation through that reach of the river.

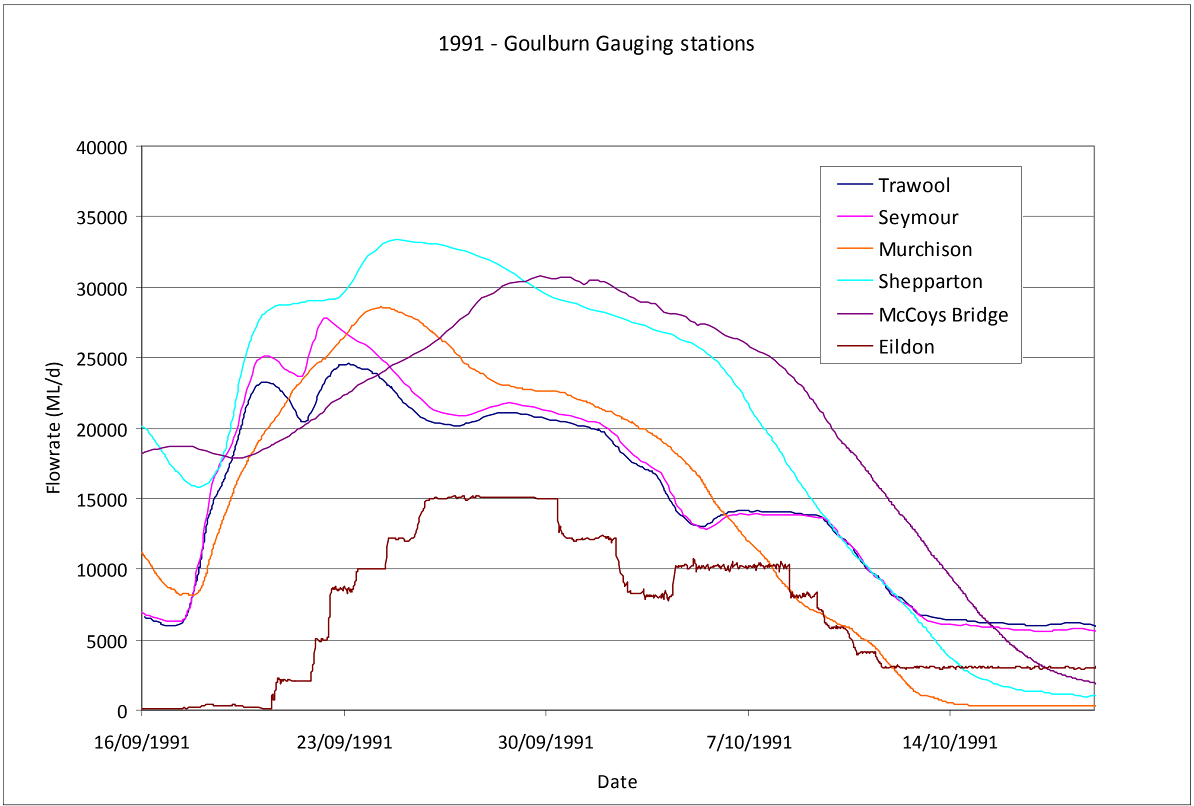



**Figure 4-10: Hydrographs for the Goulburn River gauging stations during the September 1991 event**

Figure 4-11 shows hydrographs from the Trawool and Eildon gauging stations, as well as from the gauged tributaries upstream of Trawool, during the September 1991 event.

The Acheron River provides the largest contribution of the tributaries to the flow at Trawool. The hydrograph for the Rubicon River has a similar shape but makes a smaller contribution. Early in the Trawool hydrograph the shape resembles the Acheron/Rubicon hydrographs but there is a large difference in the flow magnitudes. This difference is a result of ungauged catchment areas making a large contribution to the flow in the Goulburn River. It appears that approximately 50 % of the flow at Trawool is made by ungauged catchment areas during the early stages of the flood event, consistent with the earlier observation that 57% of the total tributary catchment is ungauged.

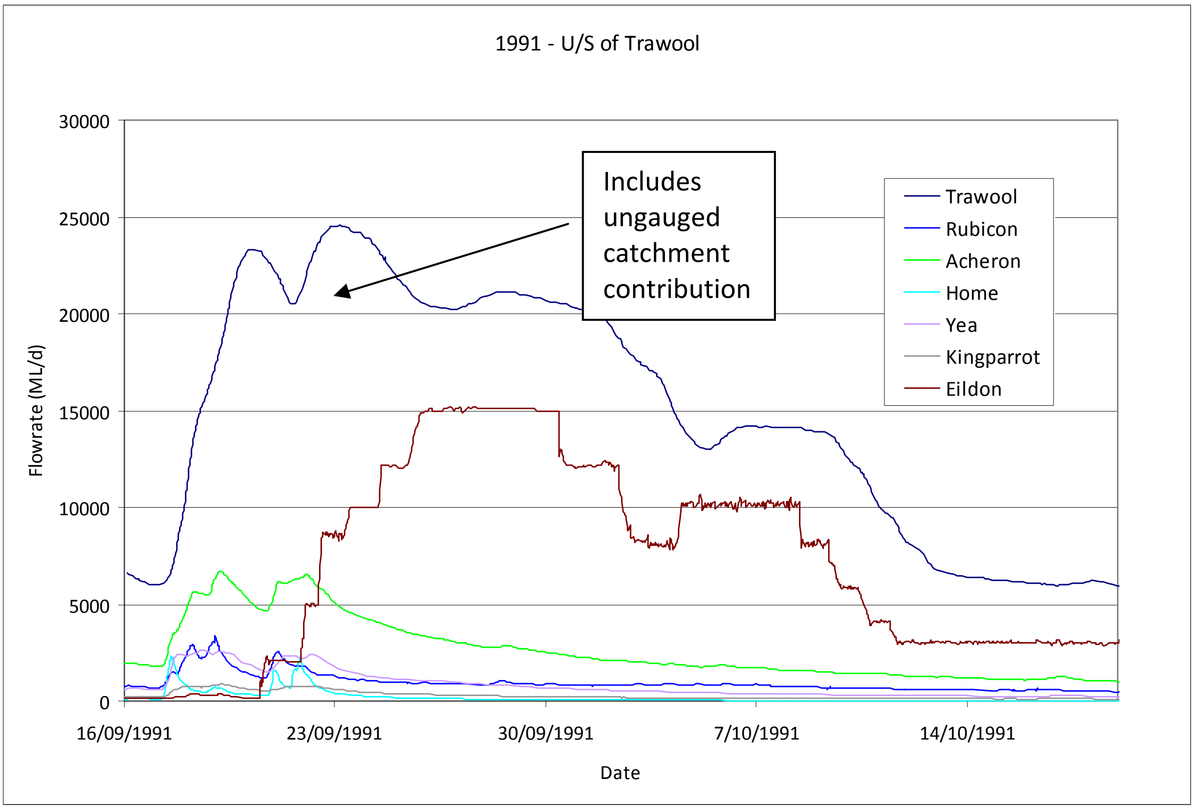



**Figure 4-11: Hydrographs for the Trawool gauging station and it tributaries during the September 1991 event**

Figure 4-12 shows hydrographs from the Trawool and Seymour gauging stations, as well as the gauged tributary contributions between these stations, during the September 1991 event.

Between the Trawool and Seymour gauging stations there is a slight increase in the flow in the Goulburn River. This increase in flow corresponds closely with the gauged inflows from Sugarloaf Creek and Sunday Creek, and therefore there is only a limited contribution from ungauged catchment areas.

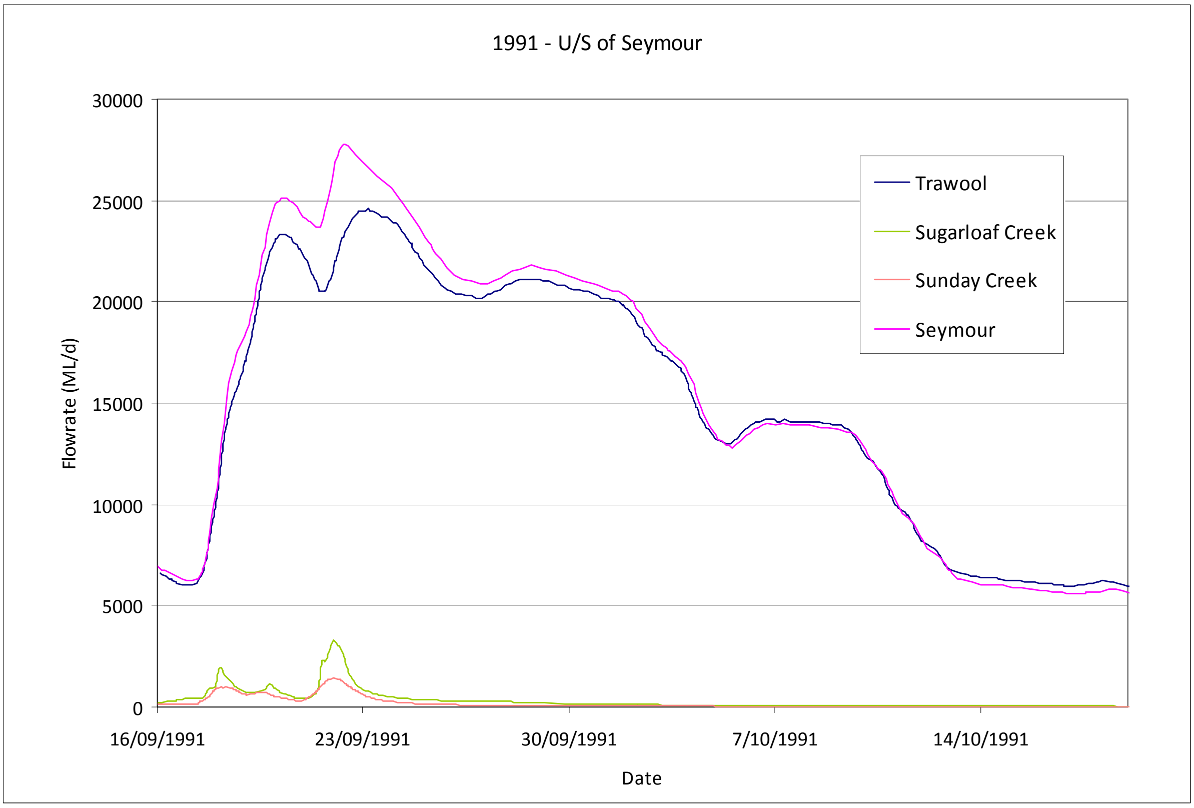



**Figure 4-12: Hydrographs for the Seymour gauging station and its contributors during the September 1991 event**

Figure 4-13 shows hydrographs from the Seymour, Shepparton and McCoy's Bridge gauging stations, as well the hydrographs for the gauged tributaries between these stations, during the September 1991 event.

There are several tributaries adding to the Goulburn River flow between Seymour and McCoy's Bridge. The two largest of these tributaries are Seven Creeks and the Broken River. The Broken River flows were taken at Goorambat. A travel time of about 2 days is likely from Goorambat to Shepparton, with considerable attenuation due to the extensive floodplain along this reach. In the 1991 event the Broken River has the largest contribution peaking just below 10,000 ML/d. The Seven Creek flows appear to be severely underestimated. It appears that flows from Seven Creeks and the Broken River determine the early part of the peak at Shepparton, with contributions from the upper Goulburn contributing to the extended flat peak.

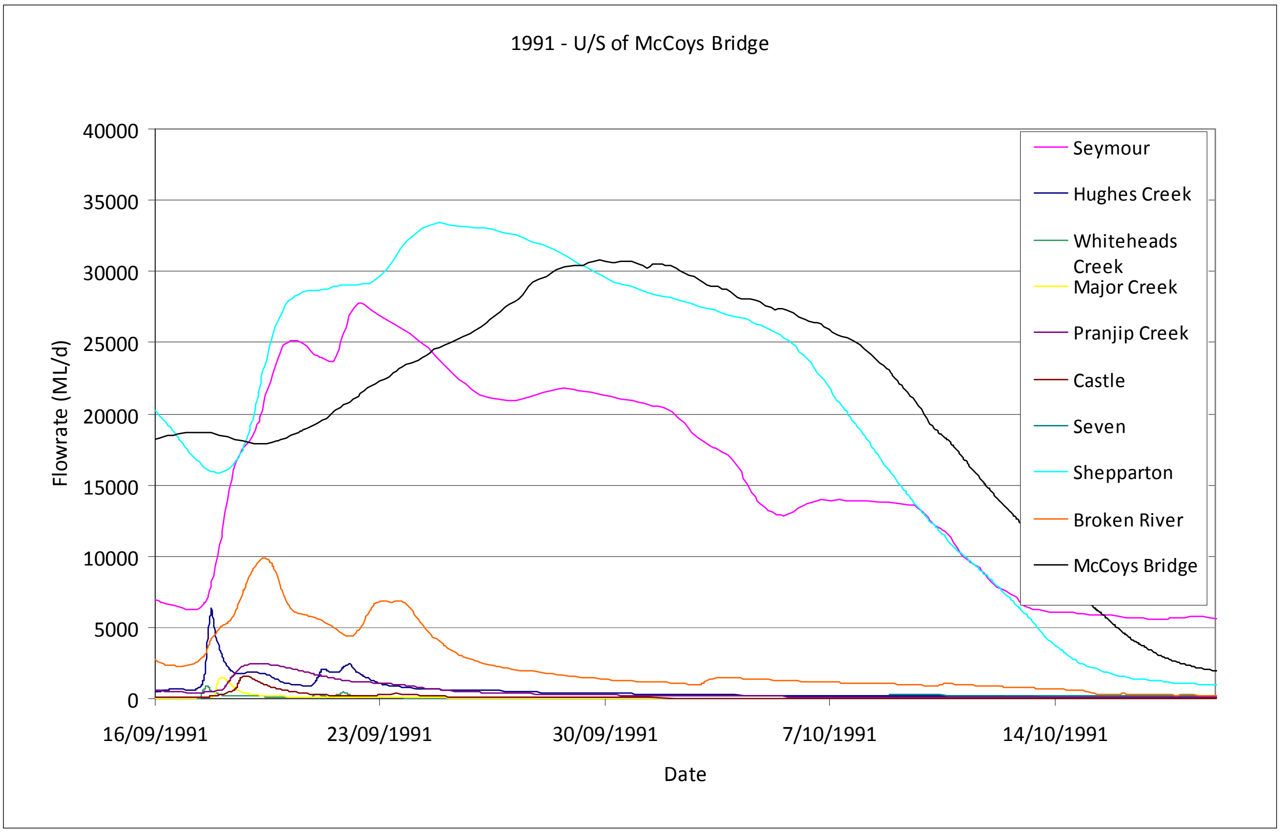



**Figure 4-13: Hydrographs for the Shepparton gauging station and neighbouring gauging stations during the September 1991 event**

During the 1991 event, the most significant ungauged catchment areas appear to be the Murrindindi/Yea River and the King Parrot Creek below the gauge.

### *August 1996*

Figure 4-14 shows hydrographs from the Goulburn River gauging stations during the August 1996 event.

During the 1996 event, there is a minimal contribution from Lake Eildon but this event produced a higher peak flow than the 1991 event at all downstream gauging sites. Similar to the 1991 event, Shepparton has the highest peak flow, with outflows at Loch Garry leading to a lower peak flow at McCoy's Bridge. Differences in the hydrographs at Trawool and Seymour reflect the contribution from tributaries.

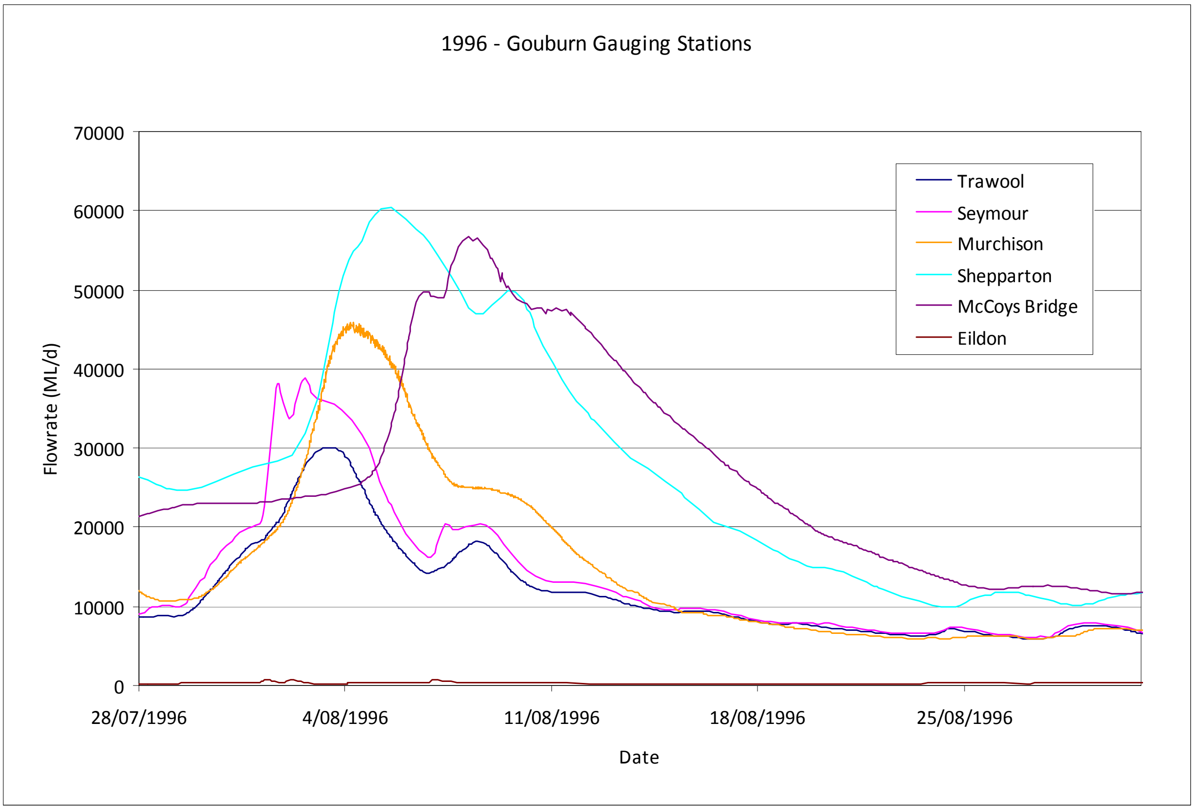



**Figure 4-14: Hydrographs for the Goulburn River gauging stations during the August 1996 event**

Figure 4-15 shows hydrographs from the Lake Eildon and Trawool gauging stations, as well the gauged tributaries upstream of Trawool, during the August 1996 event.

Similar to the 1991 event, the combined flows from the gauged parts of the tributaries upstream of Trawool are not enough to cause a peak of the size seen at Trawool. This is likely to be a result of large contributions made from ungauged catchment areas. The Acheron River has made the largest contribution to the Goulburn River flows, with the Yea River and Home Creek also making sizable contributions.

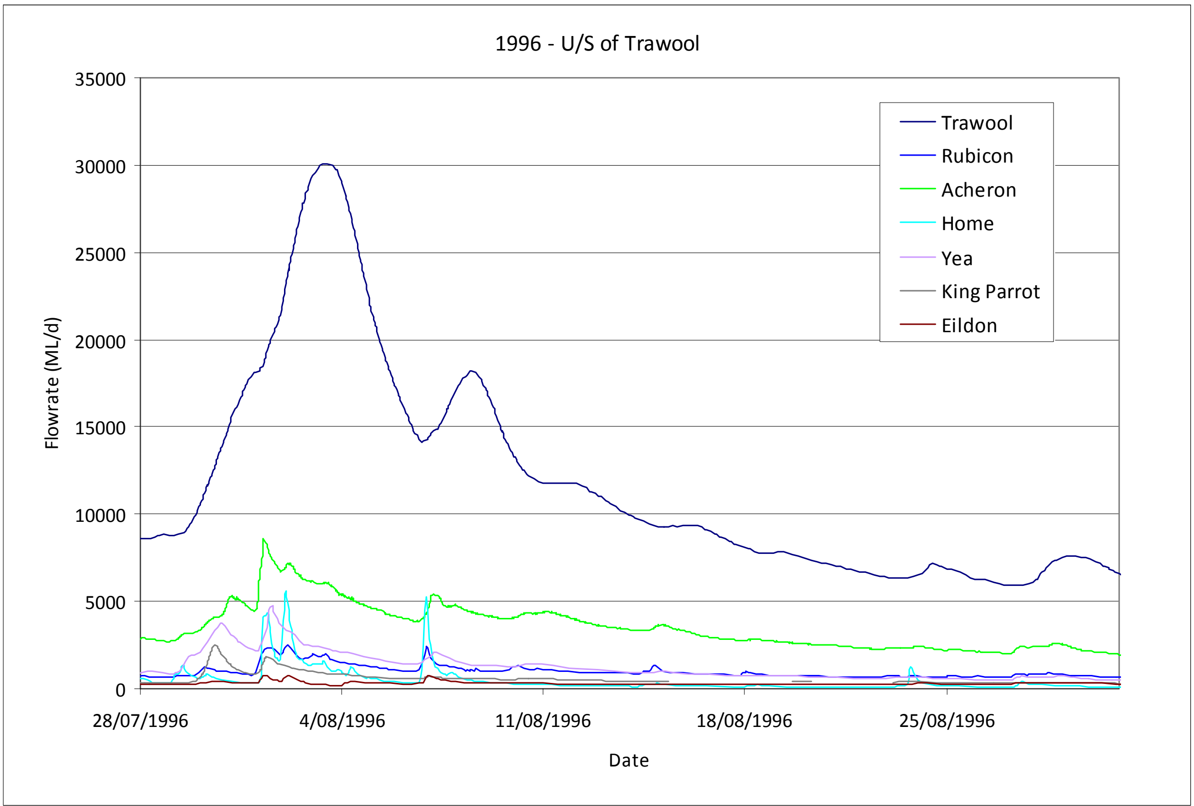



**Figure 4-15: Hydrographs for the Trawool gauging station and it tributaries during the August 1996 event**

Figure 4-16 shows hydrographs from the Trawool and Seymour gauging stations, as well the additional tributary contributions to Seymour, during the August 1996 event.

The volume and peak of the Goulburn River hydrograph has increased significantly from Trawool to Seymour. This increase is similar to that of the additional gauged inflow from Sugarloaf Creek and Sunday Creek.

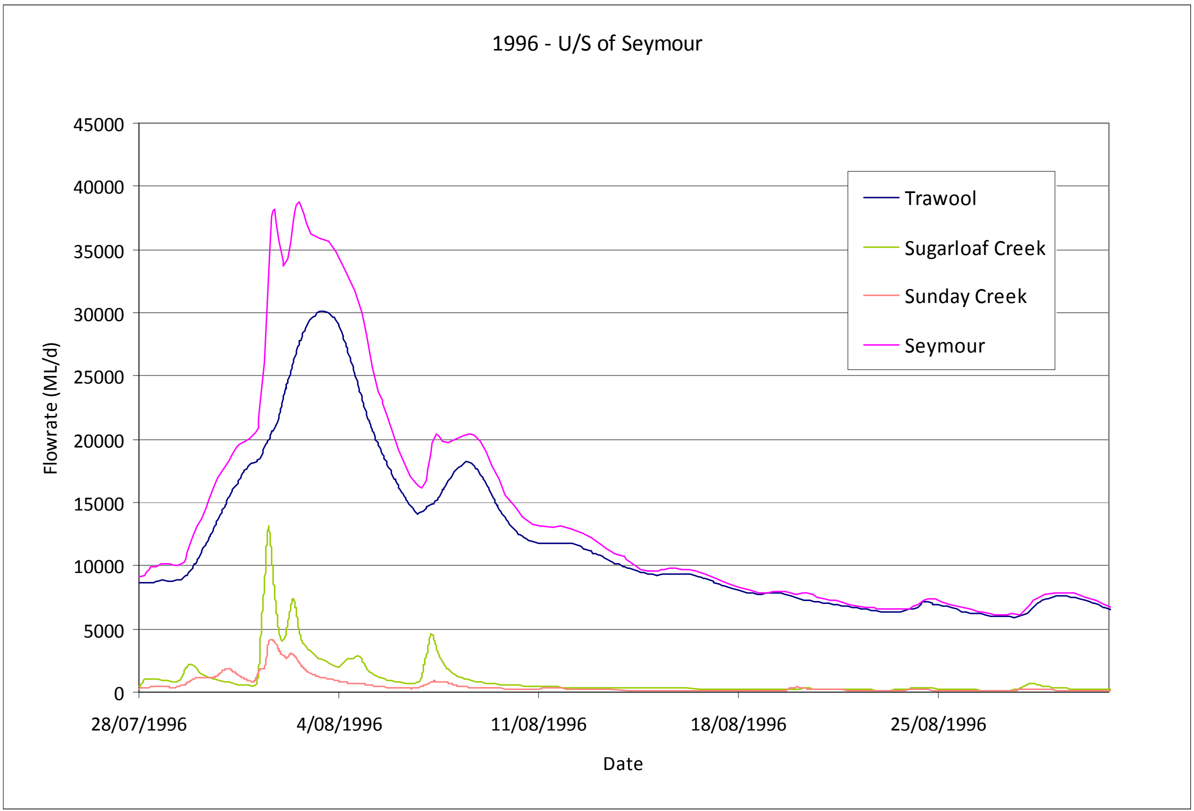



**Figure 4-16: Hydrographs for the Seymour gauging station and its contributors during the August 1991 event**

Figure 4-17 shows hydrographs from the Seymour and McCoy's Bridge gauging stations, as well the gauged contributions to flow at these stations, during the August 1996 event.

There is a reasonable contribution to the Shepparton gauging station hydrograph from a number of tributaries below Murchison and from the Broken River but the inflows from Sevens Creeks appear to be severely underestimated. The remainder of contribution is sourced from the ungauged catchment.

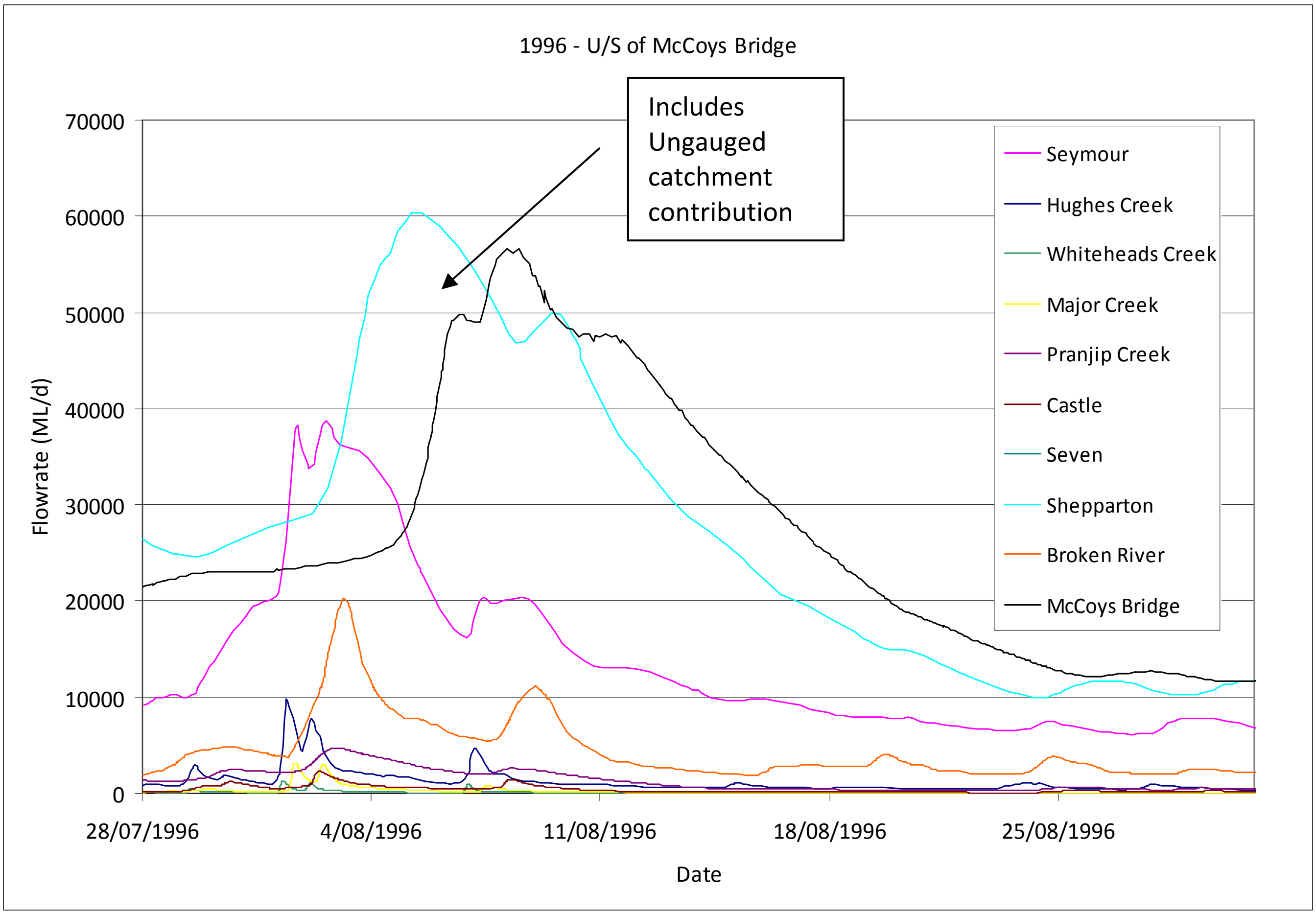



**Figure 4-17: Hydrographs for the McCoys Bridge, Shepparton and neighbouring gauging stations during the August 1996 event**

### 4.3.4 Flood releases from Lake Eildon

Flood overflows through Eildon spillway are controlled by radial gates. 'Spills' during flood events are thus in the form of controlled flood releases, in accordance with a complex set of flood operating rules, which aim to achieve balanced outcomes in terms of flood safety of the dam, water conservation, power generation and potential downstream flooding and erosion impacts.

From the mean daily flow data at Eildon, there have been 7 flood release events from Lake Eildon since the completion of construction (1956). These flood release events include (listed in of order of decreasing magnitude):

- September - October 1993
- September 1975
- October 1971
- August 1970
- October 1974

- October 1973
- October 1964

The flow hydrographs for the 1993, 1975 and 1971 spill events are presented in Figure 4-18 to Figure 4-23. It can be seen that in all these three events the spills from Eildon make a major contribution to the downstream flood hydrographs right through to the Lower Goulburn.

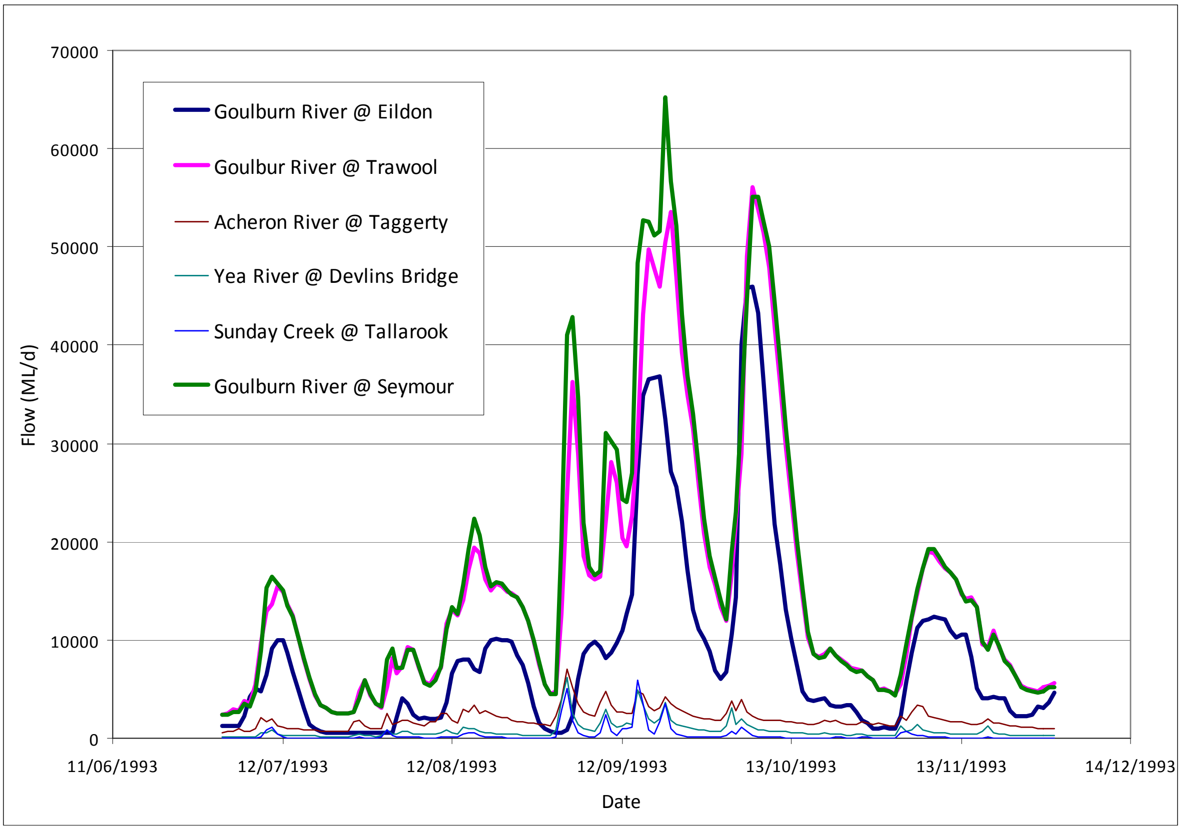



**Figure 4-18: Eildon spill event flow hydrographs – July – November 1993 – Goulburn River and tributaries above Seymour**

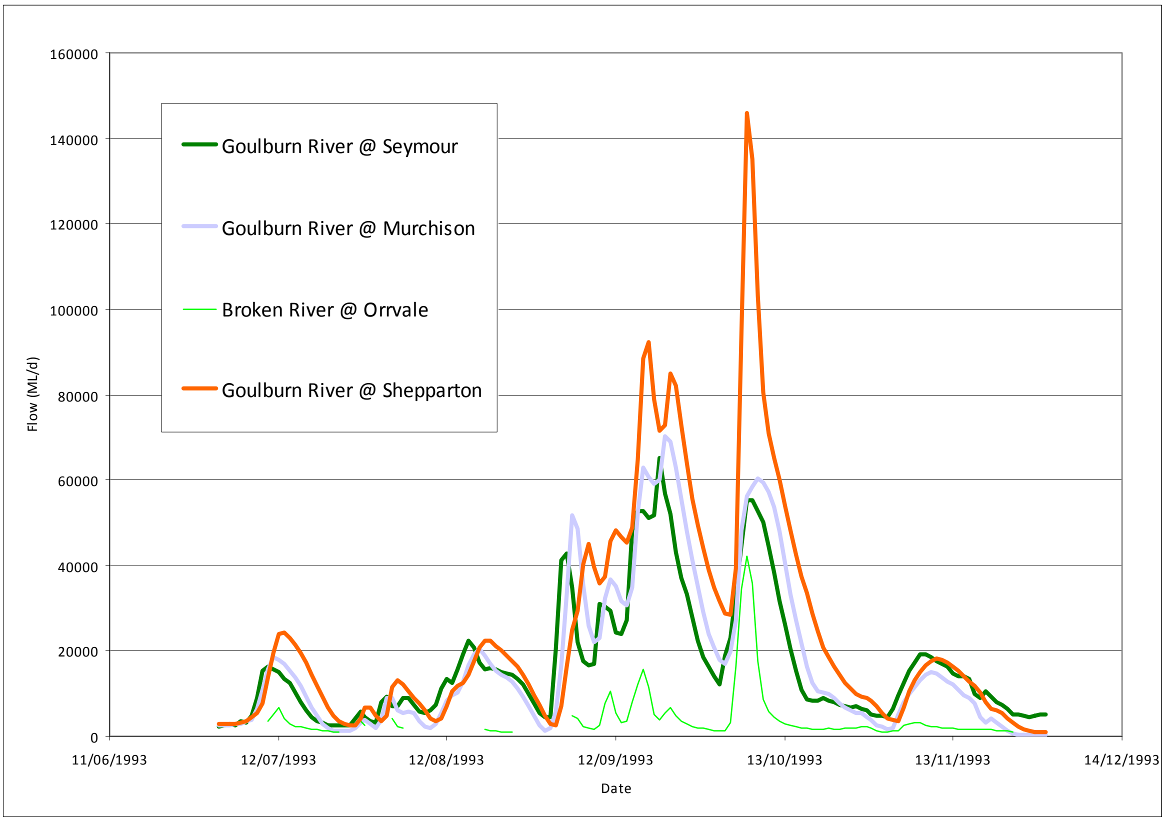



**Figure 4-19: Eildon spill event flow hydrographs – July – November 1993 – Goulburn River below Seymour**

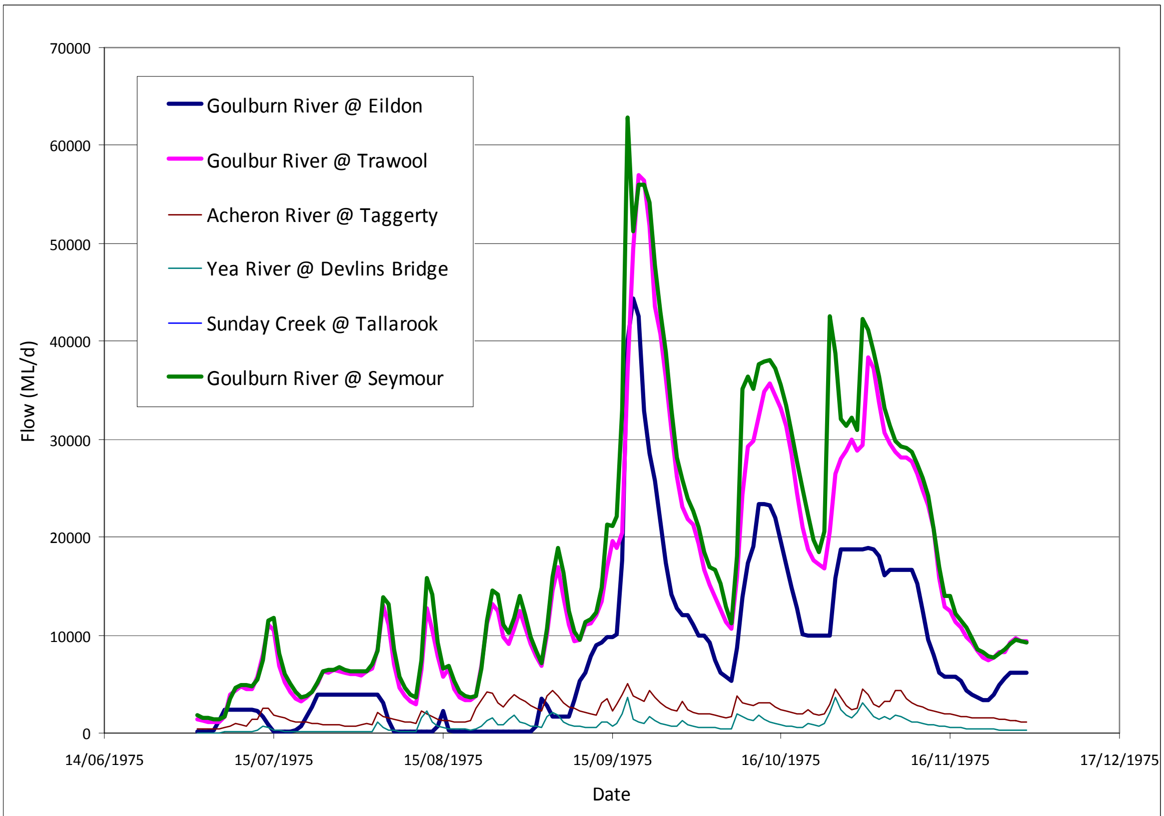



**Figure 4-20: Eildon spill event flow hydrographs – July – November 1975 – Goulburn River and tributaries above Seymour**

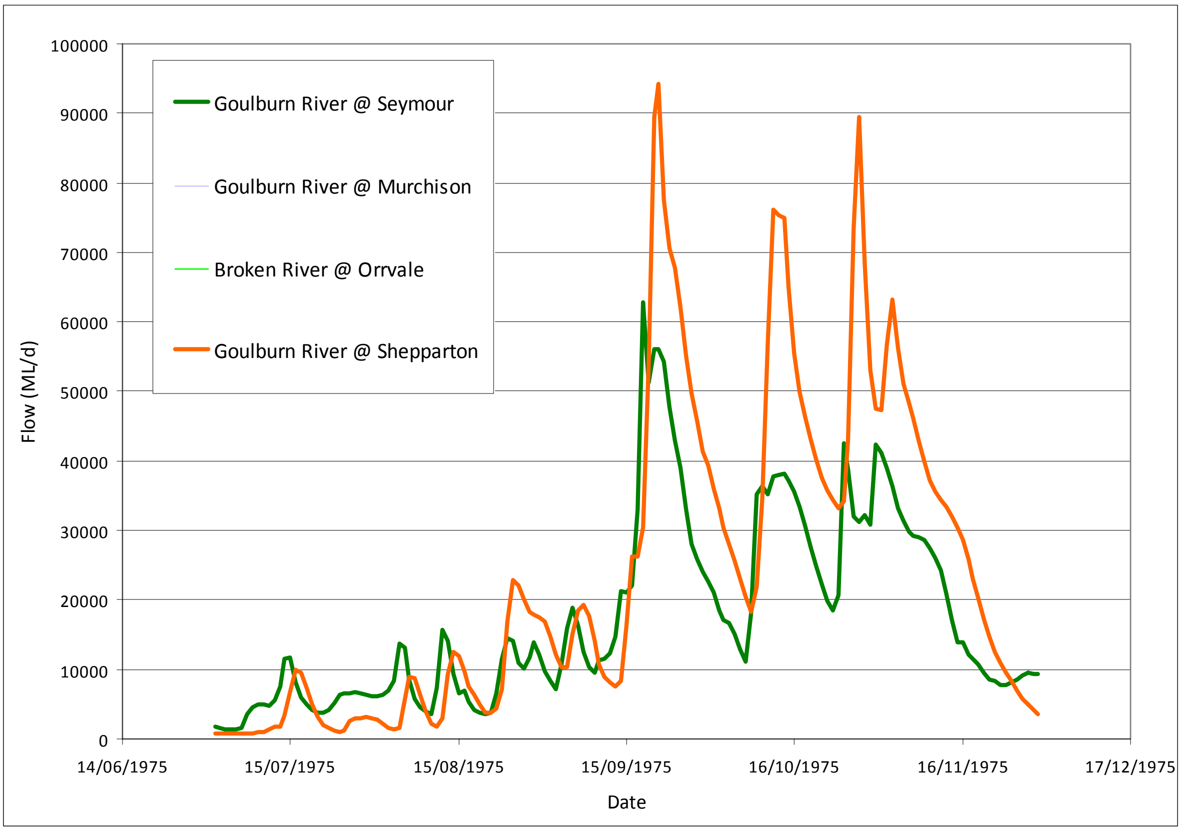



**Figure 4-21: Eildon spill event flow hydrographs – July – November 1975 – Goulburn River below Seymour (Note Missing data for Goulburn River at Murchison & Broken River at Orrvale)**

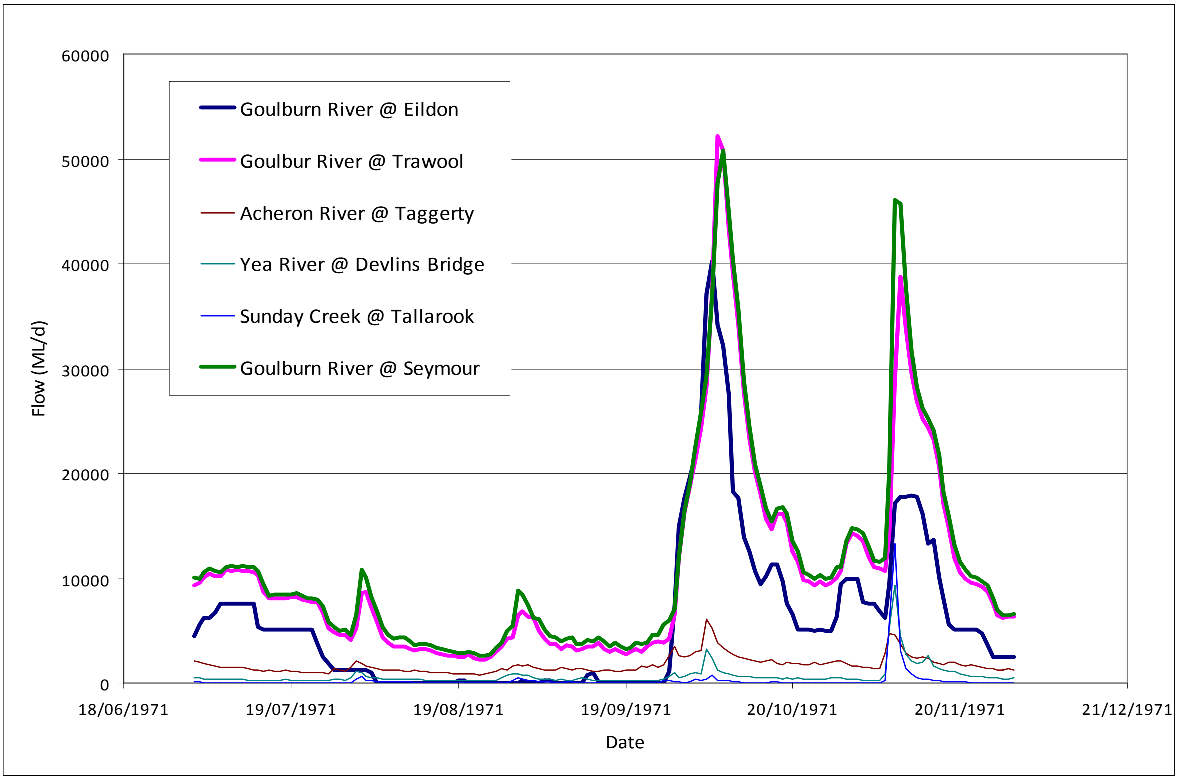



**Figure 4-22: Eildon spill event flow hydrographs – July – November 1971 – Goulburn River and tributaries above Seymour**

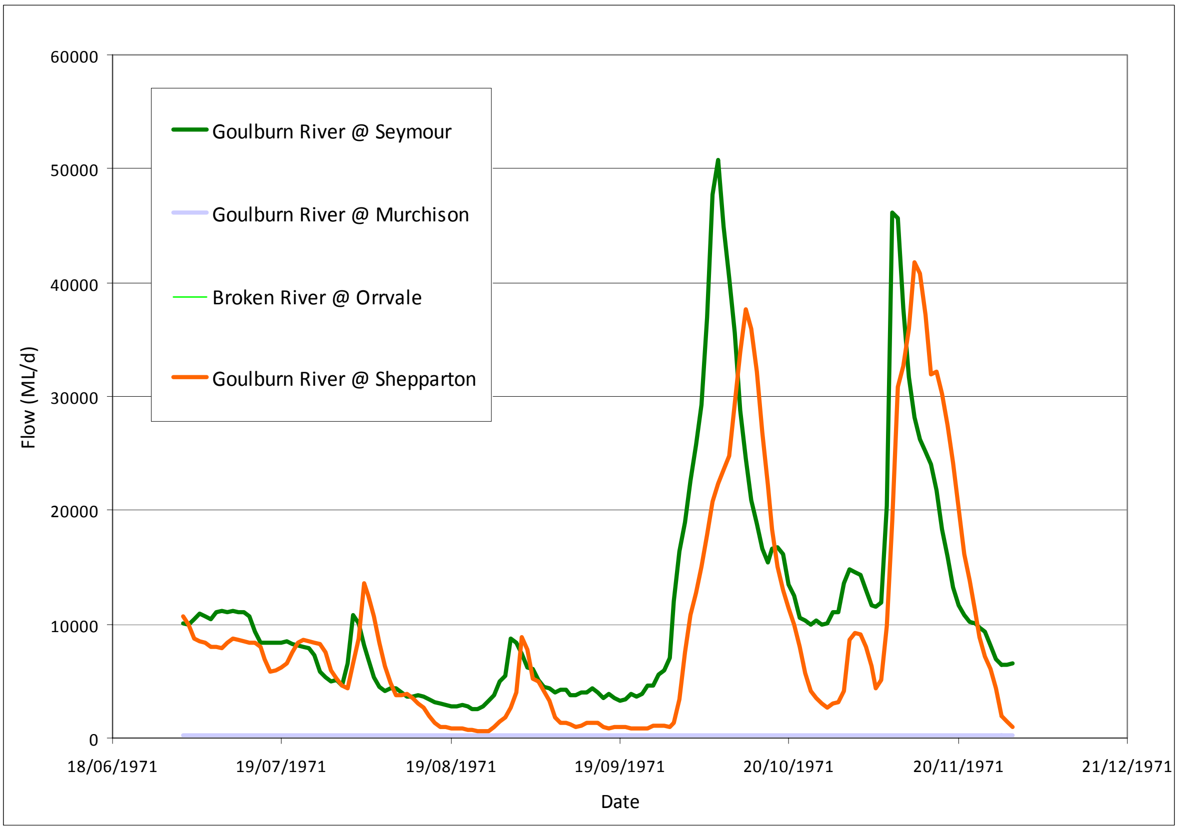



**Figure 4-23: Eildon spill event flow hydrographs – July – November 1971 – Goulburn River below Seymour**

### 4.3.5 Baseflow contributions and flood event duration

To assess the typical duration of flood events, the daily flow hydrographs were separated into the surface runoff and baseflow components. BaseJumper (SKM 2007) was applied for the baseflow separation, and then RAP (eWater 2007) was employed to assess duration of flow events. BaseJumper assesses the baseflow index (BFI), which is the ratio of the baseflow component to the total flow volume.

Table 4-5 displays the baseflow index (BFI) and mean duration of surface runoff flow events.

**Table 4-5: Base flow contribution and flood event durations: Goulburn River and selected tributaries**

| Gauge | Baseflow index | Mean duration of flow events |
|---|---|---|
| Acheron River at Taggerty | 0.71 | 3.7 days |
| Yea River at Delvins Bridge | 0.59 | 4.0 days |
| Goulburn River at Trawool | 0.73 | 5.1 days |
| Sunday Creek at Tallarook | 0.29 | 4.0 days |
| Goulburn River at Seymour | 0.73 | 4.8 days |

| | | |
|---|---|---|
| Hughes Creek at Tarcombe Road | 0.50 | 3.4 days |
| Goulburn River at Murchison | 0.50 | 7.9 days |
| Broken River at Orrvale | 0.39 | 6.0 days |
| Goulburn River at Shepparton | 0.51 | 8.5 days |

The relatively high BFI value of the Acheron River at Taggerty reflects a large baseflow (groundwater) contribution to flows at this site, consistent with the strongly perennial nature of the flow regime of streams in this area. In contrast, Sunday Creek shows a much smaller baseflow contribution, typical of the more intermittent flow regime of the tributaries in the lower part of the catchment. The high baseflow index of the Goulburn River at Trawool and Seymour is not indicative of groundwater contributions but rather of the dominance of regulated releases from Eildon.

A typical example of the 'baseflow' contribution is provided in Figure 4-24 for the Goulburn River at Trawool July-August 1996. The points where the two lines meet indicate the beginning and end of a tributary inflow event, and the difference between the two lines is indicative of the tributary contributions to the flow at Trawool.


**Figure 4-24 Goulburn River at Trawool: Baseflow July-August 1996**

### 4.3.6 Discussion

*Lag times*

The plots of event hydrographs provide an approximate indication of the lag times between flow peaks at different sites along the Goulburn River. Table 4-6 shows the six Goulburn River gauges and their distance to the next gauge, average slope, estimated travel time and average water speed between gauges.

The lag time between each gauging station along the Goulburn River has been calculated using the significant flood season hydrographs discussed in section 4.2.3: Seasonal series (July to November).

Several events have been used for each gauging station, with the average travel time rounded to the nearest half day.

The slope has been calculated using the same events as in the calculation of lag time. The water surface elevation at each peak has been taken from each gauging station and the difference divided by the distance between the two gauging stations.

The lag times are expected to vary with flow magnitude (typically reducing with increasing flood size) and they also depend on the previous flow history and on the hydrograph shape (which influence the amount of attenuation provided by the flood plains). More detailed information on lag times will be provided by the hydraulic modelling results.

Flood peaks can be expected to travel much faster through the inundated reaches of the Goulburn River at Lake Nagambie, as the (dynamic) travel speed of the flood wave in these reaches is proportional to the square root of the average water depth (rather than being proportional to the flow velocity).

**Table 4-6: Distance, slope, lag time and average speed for the five Goulburn River reaches**

| River Reach | Distance (km) | Slope (m/km) | Gauged Travel Time (days) | Gauged Average Speed (km/hr) |
|---|---|---|---|---|
| Eildon - Trawool | 121.0 | 0.55 | 2 | 2.40 |
| Trawool - Seymour | 11.4 | 0.72 | 0.5 | 2.86 |
| Seymour - Murchison | 82.1 | 0.25 | 1 | 3.42 |
| Murchison - Shepparton | 63.1 | 0.07 | 2 | 1.29 |
| Shepparton – Loch Garry | 37.8 | 0.12 | 0.5 | 3.03 |
| Loch Garry – McCoy's Bridge | 50.5 | 0.11 | 1 | 1.91 |

*Hydrograph shape*

As the flood hydrograph moves from the upper tributaries down the river, its base broadens (typically from 2 to 3 days in the tributaries for moderate events to several weeks in the lower Goulburn for larger events), and the peak flattens out.

*Relative importance of different tributaries*

The relatively large contribution of the tributaries to the reach above Trawool means that these tributaries have the greatest potential for making a positive contribution to environmental flood events. The relatively flashy flood response of the tributaries in the middle reach means that these tributaries may pose a significant threat to creating or aggravating unintentional flood consequences in the reaches further downstream. Detailed hydrologic modelling will be required to provide a more quantitative assessment of these potential benefits and impacts.

*Ungauged catchment areas*

As there are substantial ungauged tributary catchment areas, data from existing stream gauging stations may not be sufficient to support the requirements for the operational management of environmental flow releases.

## 4.4 Flood frequency analysis

### 4.4.1 Approach

Flood frequency analysis provides design flood estimates for a range of average recurrence intervals (ARIs). In this project, design flood estimates were employed for the following two purposes:

- Design flood mapping along the Goulburn River: Design flood estimates required along the Goulburn River for 20, 50 and 100 year ARI events.
- Tributary flow concurrency and correlation: Design flood estimates required along the Goulburn River and for key tributaries for 2, 5, 10, 20 and 50 year ARI events

The design flood mapping focuses on the major urban centres; Seymour and Shepparton-Mooroopna. Recent flood studies for these centres (WBM 2001 and SKM 2002) included design flood peak flow and hydrograph estimation. Given the absence of significant events since the completion of the previous investigations, this project has adopted these previous studies' design flood estimates for flood mapping purposes. These previous investigations are discussed in Section 4.4.2.

Additional flood frequency analysis (FFA) has been completed to help understand the correlation of flood flows from each Goulburn River tributary, with details provided in Section 4.4.3. The outcomes of these frequency analyses are employed in the flow concurrency assessment, as detailed in Section 5.

### 4.4.2 Previous investigations – Goulburn River at Seymour, Murchison and Shepparton

***Goulburn River at Seymour***

The Seymour Floodplain Mapping Study (WBM 2001) undertook runoff routing modelling and flood frequency analysis to determine design flood hydrographs at Seymour. WBM (2001) considered the influence of Lake Eildon on downstream design flows.

Table 4-7 displays the design peak flow estimates sourced from WBM (2001).

**Table 4-7: Design peak flows: Goulburn River at Seymour (WBM 2001)**

| Location | Design peak flow (ML/d) | | | | |
|---|---|---|---|---|---|
| | 5 year | 10 year | 20 year | 50 year | 100 year |
| Goulburn River at Seymour | 45,100 | 60,820 | 87,610 | 128,300 | 162,000 |

***Goulburn River below Murchison***

The Shepparton –Mooroopna floodplain Management Study (SKM 2002) undertook flood frequency analyses at the following locations:

- Goulburn River at Murchison
- Goulburn River at Shepparton
- Seven Creeks at Kialla West
- Broken River at Orrvale

The flood frequency analyses undertaken considered both peak flows and flood volumes. A rigorous review of available streamflow data underpinned the flood frequency analyses. Table 4-8 displays the design peak flow estimates sourced from SKM (2002).

**Table 4-8: Design peak flows: Goulburn River and major tributaries below Murchison (SKM 2002)**

| Location | Design peak flow (ML/d) | | | | | |
|---|---|---|---|---|---|---|
| | 5 year | 10 year | 20 year | 50 year | 100 year | 200 year |
| Goulburn River at Murchison | 51,900 | 68,400 | 87,000 | 114,000 | 134,000 | 158,000 |
| Goulburn River at Shepparton | 73,400 | 102,000 | 137,000 | 180,000 | 219,000 | 261,000 |
| Seven Creeks at Kialla West | 21,200 | 27,400 | 42,000 | 57,800 | 69,900 | 89,400 |
| Broken River at Orrvale | 21,400 | 27,500 | 33,000 | 39,000 | 43,500 | 48,300 |

Design flood hydrographs were derived by scaling observed flood hydrographs at the following locations:

- Goulburn River at Murchison
- Goulburn River at Kialla West (now known as Arcadia Downs)
- Seven Creeks at Kialla West
- Broken River at Orrvale

This study adopted the above design flood hydrograph for use in the design flood mapping component for the Goulburn River below Murchison.

Table 4-9 displays the indicative ARI of significant historical flood events.

**Table 4-9: Indicative ARI for significant historical flood events: Goulburn River below Murchison (SKM 2002)**

| Location | Indicative ARI for significant historical flood events | |
|---|---|---|
| | May 1974 | October 1993 |
| Goulburn River at Murchison | ~ 50 years<br>(Peak flow 111,000 ML/d) | ~ 13 years<br>(Peak flow 73,700 ML/d) |
| Goulburn River at Shepparton | ~ 75 years<br>(Peak flow 191,000 ML/d) | ~ 35 years<br>(Peak flow 150,000) |

### 4.4.3 Additional investigations – Goulburn River tributaries

As discussed, flood frequency analyses have been undertaken for key Goulburn River tributaries, as outlined in Table 3-1 and Table 3-2. The frequency analyses considered the annual maximums for each year from the instantaneous flow record. Generalised Extreme Value (GEV) distributions were fitted using L- moments. At each gauge, low flows were excluded from the frequency analysis. Table 4-10 displays the design peak flow estimates for the key Goulburn River tributaries.

An analysis of estimated design peak flows vs. catchment area indicates some possible inconsistencies in the values shown in Table 4.10 for the different catchments (e.g. the estimated design peak flows for the Pranjip Creek at Moorilim appear too low). Some more detailed data checking is desirable.

**Table 4-10: Design peak flows: Goulburn River tributaries**

| Gauge | Design peak flow (ML/d) | | | | | |
|---|---|---|---|---|---|---|
| | 2 year | 5 year | 10 year | 20 year | 50 year | 100 year |
| Rubicon River at Rubicon | 2456 | 3733 | 4767 | 5928 | 7722 | 9323 |
| Acheron River at Taggerty (low flows excluded below 2500 ML/d) | 5956 | 8300 | 10200 | 12340 | 15680 | 18644 |
| Home Creek at Yarck | 6366 | 10220 | 12540 | 14600 | 17060 | 18760 |
| Yea River at Devlins Bridge | 4315 | 8235 | 11320 | 14730 | 19870 | 24360 |
| King Parrot Creek at Flowerdale | 1789 | 3892 | 5911 | 8511 | 13200 | 18060 |
| Sunday Creek at Tallarook | 5551 | 11660 | 16950 | 23220 | 33510 | 43260 |
| Sugarloaf Creek at Ash Bridge (low flows excluded below 3000 ML/d) | 8757 | 21850 | 30700 | 38760 | 48290 | 54750 |
| Whiteheads Creek at Whiteheads Creek (low flows excluded below 250 ML/d) | 1658 | 2307 | 2573 | 2749 | 2901 | 2976 |
| Major Creek at Graytown (low flows excluded below 500 ML/d) | 4566 | 9755 | 14890 | 21660 | 34200 | 47550 |
| Hughes Creek at Tarcombe Road (low flows excluded below 600 ML/d) | 8480 | 14440 | 18680 | 22980 | 28910 | 33640 |
| Pranjip Creek at Moorilim (low flows excluded below 600 ML/d) | 3242 | 6483 | 9794 | 14270 | 22830 | 32190 |
| Castle Creek at Arcadia (low flows excluded below 600 ML/d) | 1545 | 2642 | 3384 | 4121 | 5116 | 5895 |

## 4.5 Spells Analysis

### 4.5.1 Approach

Streamflow spells analysis is a useful tool to examine flow behaviour in specified flow ranges, above or below given threshold flows, as indicated in Figure 4-24. A *high flow spell* is a flow event during which flows are continuously above the nominated threshold value, the duration of this event is referred to as the *spell duration*, and the period between such events is the *spell interval.*

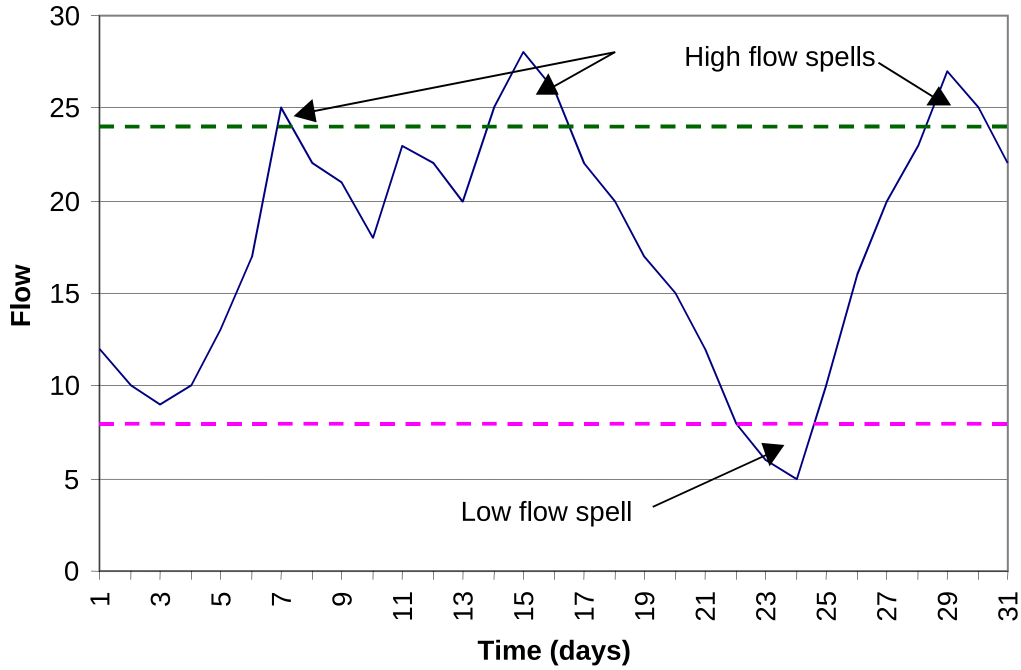



**Figure 4-24 Part of streamflow hydrograph illustrating the definition of flow spells**

A high flow spells analysis has been completed for the Acheron River, as an example of the information that could be obtained from a similar analysis of the flow data from the remaining gauges in the catchment. The assessment considered the period July – November.

There are three values which need to be defined for a high flow spells analysis:

- Threshold – the flow which must be exceeded to trigger the analysis. During this analysis two threshold have been considered: Mean daily flow (MDF) 1403 ML/d and Mean maximum flow (MMF) 5382 ML/d
- Minimum duration – any flow events that are shorter than the minimum duration are ignored. For this analysis 3 days has been set as the minimum duration.
- Independence – flow independence is used to ignore small gaps between flow events and treat them as a single spell. The flow independence criterion has been set as 1 day in this analysis.

### 4.5.2 High flow spell assessment

Spell analysis examines the characteristics of flow events above a number of thresholds. As an example, Table 4-11 shows the high flow spells assessment for the Acheron River considering the period July to November. The flow thresholds assessed ranged between mean daily flow and the 2 year ARI peak flow.

**Table 4-11: Acheron River at Taggerty : High flow spell assessment (July – November)**

| Statistic | Threshold | | | | |
|---|---|---|---|---|---|
| | **Mean Daily Flow: 1403 ML/d** | **2543 ML/d** | **3683 ML/d** | **4823 ML/d** | **2-Yr ARI Flow: 5956 ML/d** |
| Number of High Spells | 159 | 123 | 91 | 48 | 24 |
| Mean Duration of High Spell | 26 Days | 10 Days | 4 Days | 2 Days | 1 Day |
| Longest High Spell | 275 Days | 163 Days | 23 Days | 7 Days | 3 Days |
| Total Duration of High Spells | 3992 Days | 4402 Days | 373 Days | 107 Days | 33 Days |
| Mean period Between High Spells | 108Days | 162 Days | 228 Days | 430 Days | 857 Days |
| Longest period Between High Spells | 634 Days | 666 Days | 1343 Days | 2759 Days | 4097 Days |
| Mean Magnitude of High Spell | 3226 ML/d | 4402 ML/d | 5297 ML/d | 6315 ML/d | 7387 ML/d |

As the threshold increased, the mean and longest periods between spells increased. Whereas for the number of spells, mean duration of spells and longest spell duration decreased with increased threshold. This indicates clearly that the opportunities for enhancing environmental releases with tributary inflows will be more limited for larger tributary flow events.

The considerable increase in the mean period between high spells for the higher threshold indicates that in the Acheron River the mean annual maximum flow is exceeded infrequently.

# 5. TRIBUTARY FLOW CONCURRENCY AND CORRELATION

## 5.1 Overview

The ability to achieve high flows in the Goulburn River reaches below Eildon (Reaches 1-5) is highly dependant on the ability to sustain or supplement natural flow events in the Goulburn River tributaries with releases from Lake Eildon and Lake Nagambie. A good understanding of the way rainfall events affect the flows in each tributary and their concurrence to the surrounding tributaries, is needed to understand which tributaries are likely to be major contributors in a rainfall event, during the likely release season. There is also a need to understand the risk of an undesirable flow magnitude causing flooding in critical locations.

The flow concurrence assessment followed the methodology presented in Koltun and Sherwood (1998): "Factors Related to the Joint Probability of Flooding on Paired Streams".

Two groupings of flow concurrence were assessed as follows:

- Tributaries of Goulburn River: to evaluate the correlations between flows in pairs of tributaries. (Section 5.2
- Goulburn River and upstream tributaries: to evaluate the concurrent contribution of specific tributaries to Goulburn River flows (Section 5.3)

The flow concurrency plots use design peak estimates which have been derived from a flood frequency analysis using an annual maximum series of MDFs. This flood frequency analysis has been completed using MDFs rather than instantaneous flows (shown in Section 4.4) because the MDFs give a better representation of the volume of a hydrograph which is more relevant in concurrency of two streams.

The design peak estimates are used to provide an indication of relative flow magnitudes of the paired gauges. Flow concurrency plots have been prepared for the period July-November using the mean daily flows at the two gauging stations on the same day (i.e. no lagging of flows). Lagging was applied for a single assessment to evaluate the sensitivity of the flow concurrency plot to this assumption. Flows in the Goulburn River have had the Eildon release volume extracted from the gaugings to remove the impact of irrigation releases. Indicative travel times were applied to the Eildon releases to allow for lagging.

This section presents examples of the flow concurrence assessment for the two grouping outlined above.

## 5.2 Goulburn Tributaries pairs

Figure 5-1 shows the flow concurrency plot for the tributary catchments of the Yea and Acheron Rivers. There is a moderate to high degree of correlation between the flows in the Yea and Acheron Rivers, especially at the lower flows. Once the flows get above the 2 year threshold the correlation weakens.

Figure 5-2 shows the flow concurrency plot for the tributary catchments of the Rubicon and Acheron Rivers. The Rubicon and Acheron Rivers also have a relatively high correlation at the lower flows less than two year ARI. Once above the 20 year ARI threshold, there is no correspondence of flow in these two rivers.

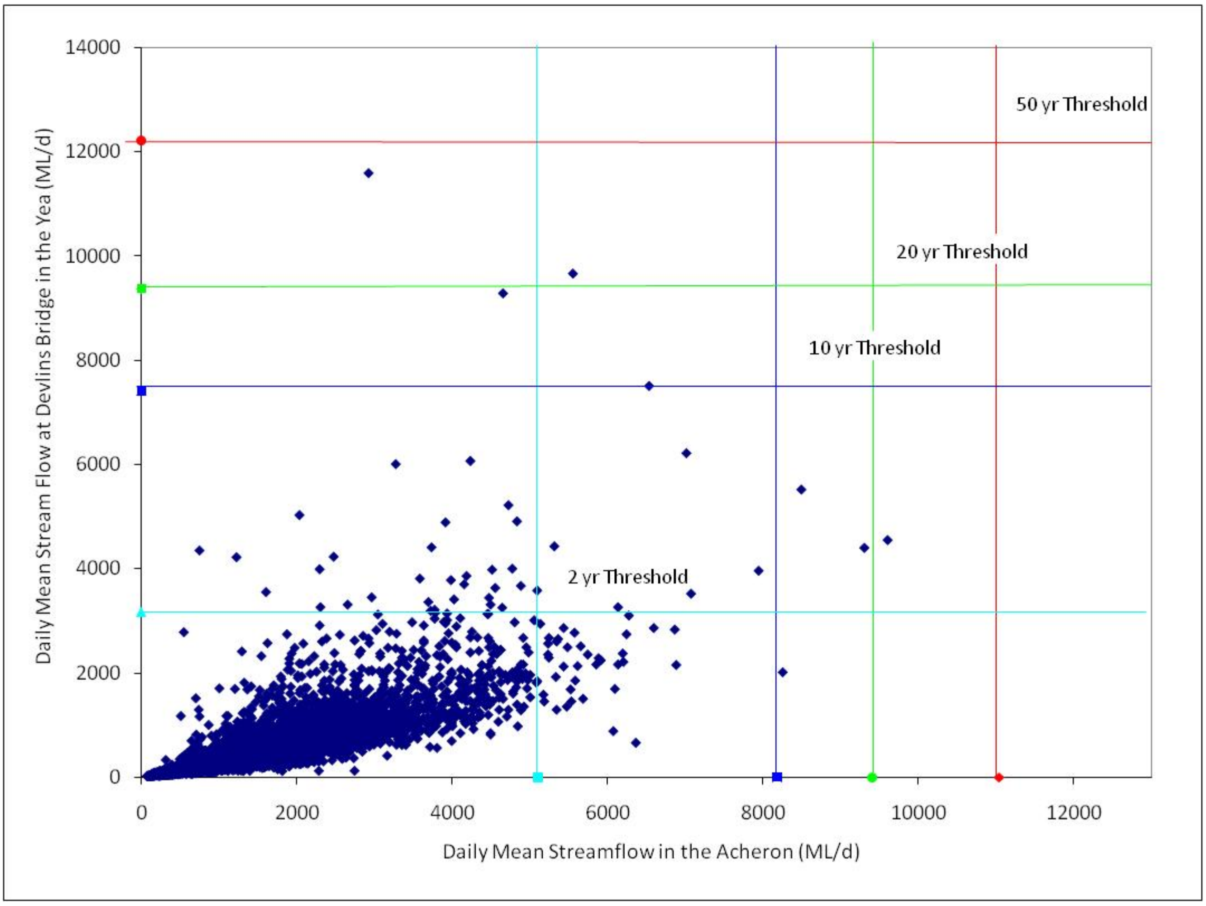



**Figure 5-1: Flow concurrency plot: Yea River vs. Acheron River**

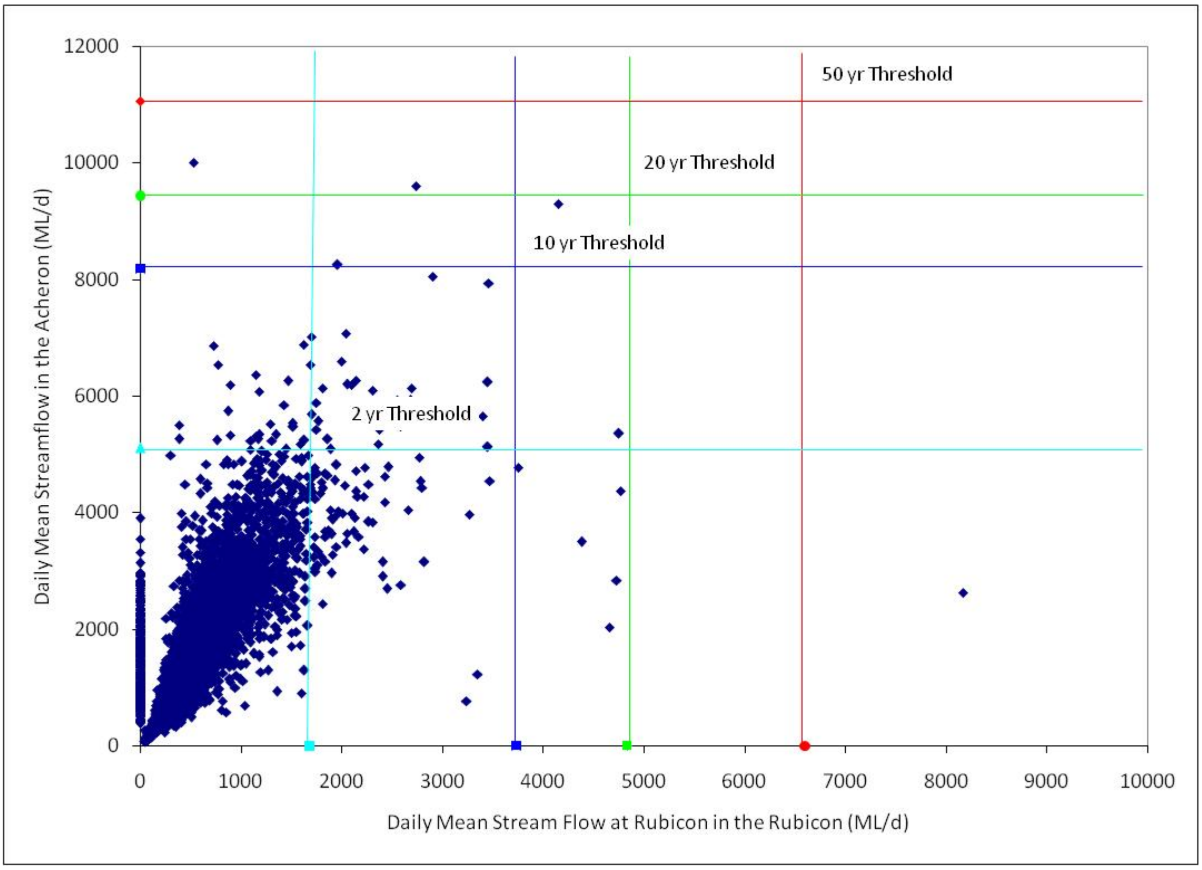



**Figure 5-2: Flow concurrency plot: Rubicon River vs. Acheron River**

Figure 5-3 shows the flow concurrency plot for the tributary catchments of Hughes and Sunday Creeks. Hughes Creek and Sunday Creek flows do exhibit a small degree of correlation below a 2 year flow. Above the 2 year flow there is no evidence of flow concurrency.

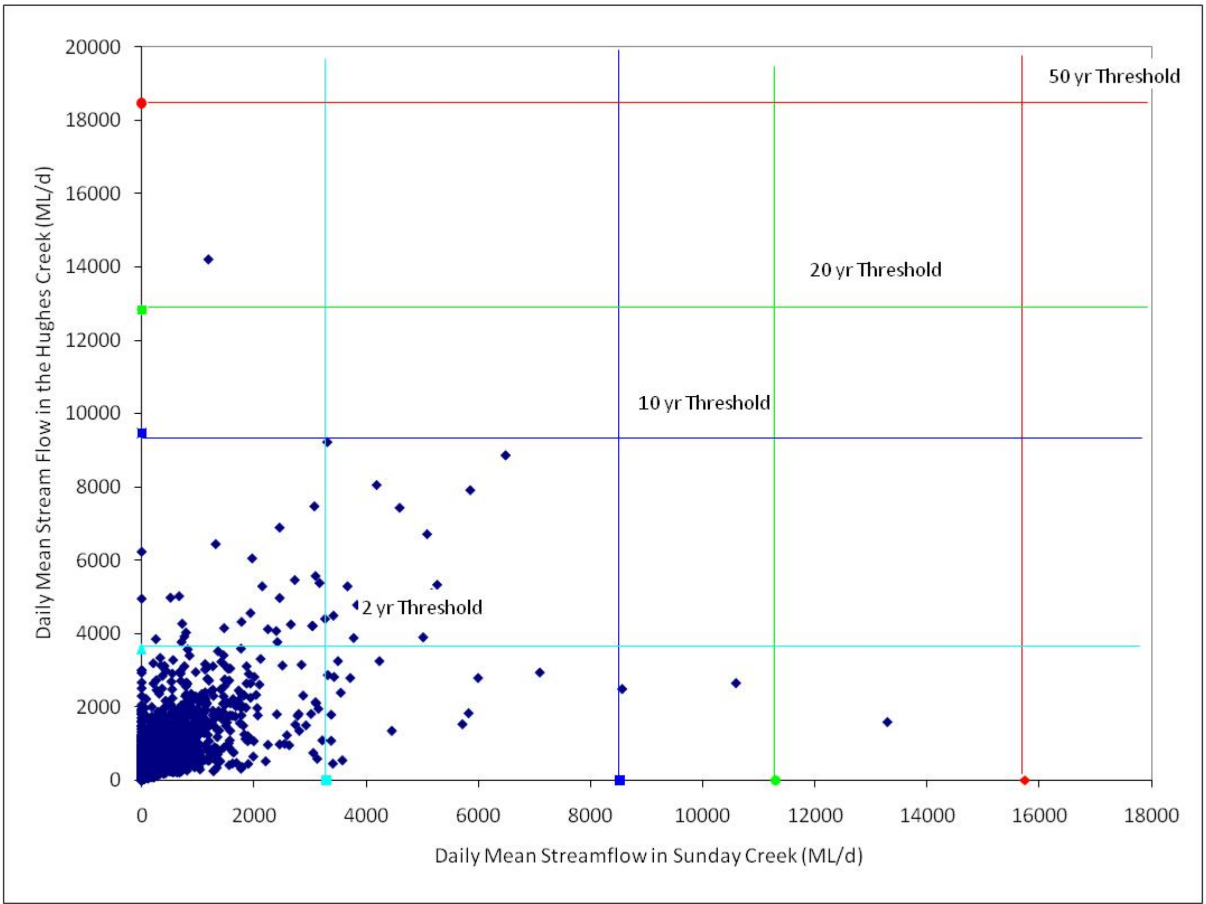



**Figure 5-3: Flow concurrency plot: Hughes Creek vs. Sunday Creek**

Figure 5-4 shows the flow concurrency plot for the tributary catchments of Seven Creeks and Broken River. Due to a significant portion of missing data for the Seven Creeks at the Kialla West gauge, the plot is of limited value.

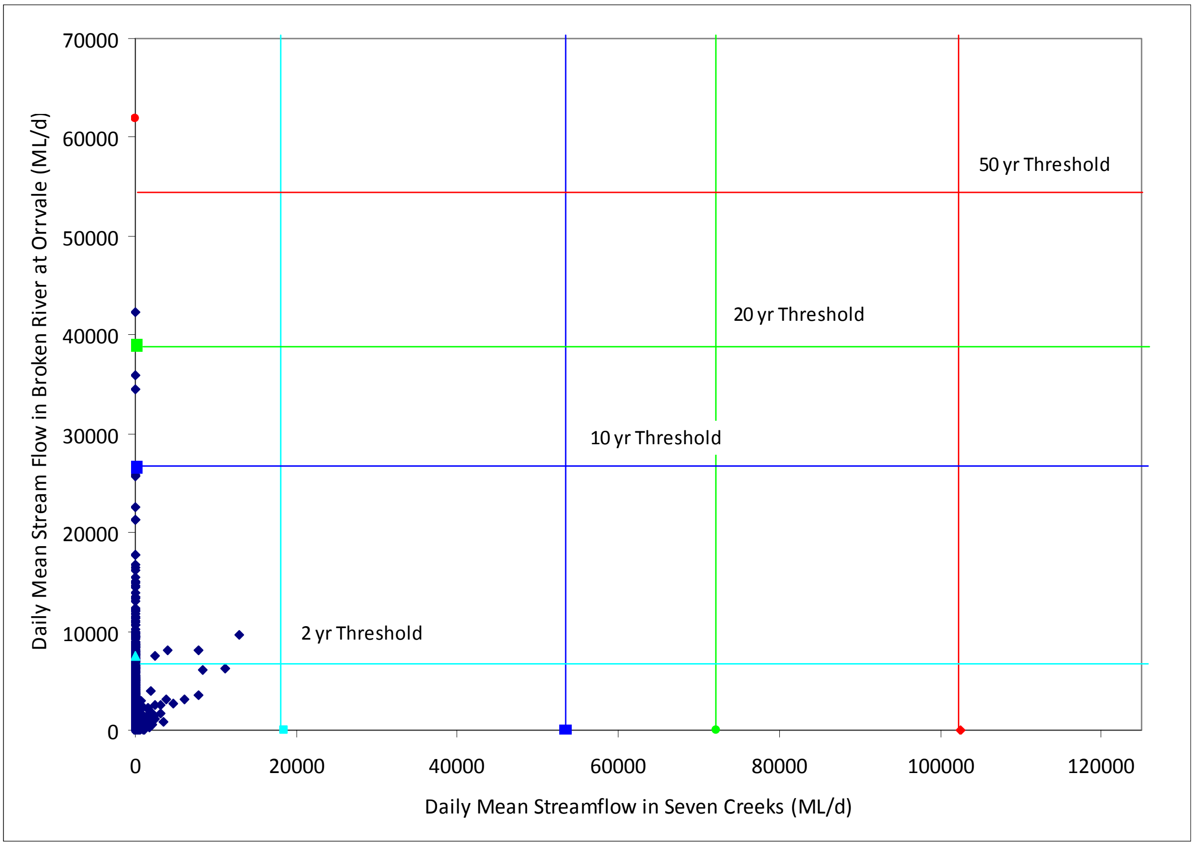



**Figure 5-4: Flow concurrency plot: Seven Creeks vs. Broken River**

## 5.3 Goulburn River and tributary pairs

Figure 5-5 shows the flow concurrency plot for the tributary catchment of the Acheron River and releases from Lake Eildon.

The plot indicates that there is little correlation between Acheron River flows and larger releases or spills from Eildon. Releases from Eildon to downstream irrigation demands take into account likely inflows from downstream tributaries (including the Acheron River). This is reflected by indications of negative correlation in the lower end of the correlation plot.

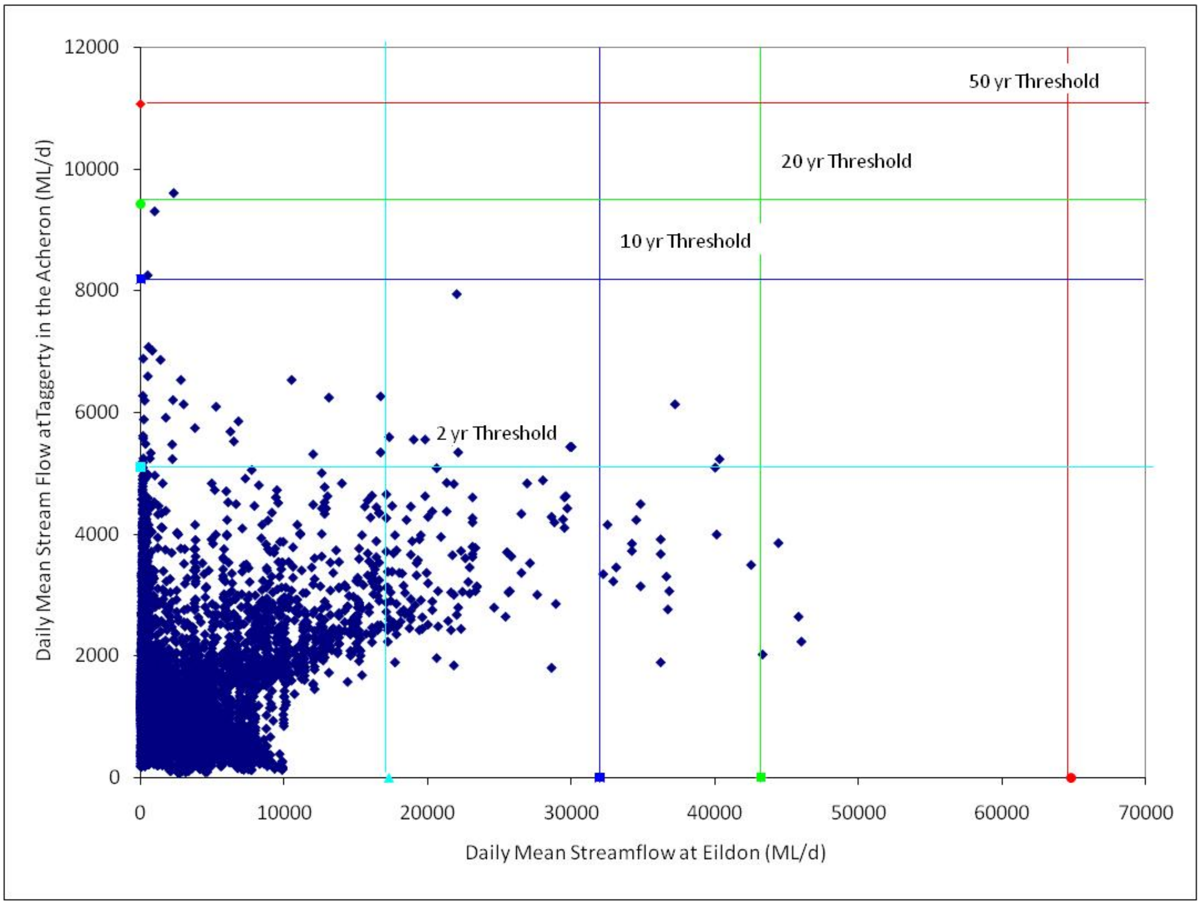



**Figure 5-5: Flow concurrency plot - Acheron River vs. Lake Eildon releases.**

Figure 5-6 shows the flow concurrency plot for the tributary catchment of the Sunday Creek and the Goulburn River flows at Trawool (including Eildon releases), with Figure 5-7 showing the flow concurrency plots excluding lagged Eildon releases. This latter figure examines the concurrency of the Sunday Creek catchment and upstream unregulated catchment flows.

The Sunday Creek flows are considerably smaller than the adjusted Goulburn flows (the combined tributary catchment between Eildon and Trawool is about an order of magnitude larger than the gauged Sunday Creek catchment). This plot shows little correlation, indicating that the Sunday and Sugarloaf Creek catchments are generally affected by different storm rainfall patterns to those occurring over the upper tributary catchments.

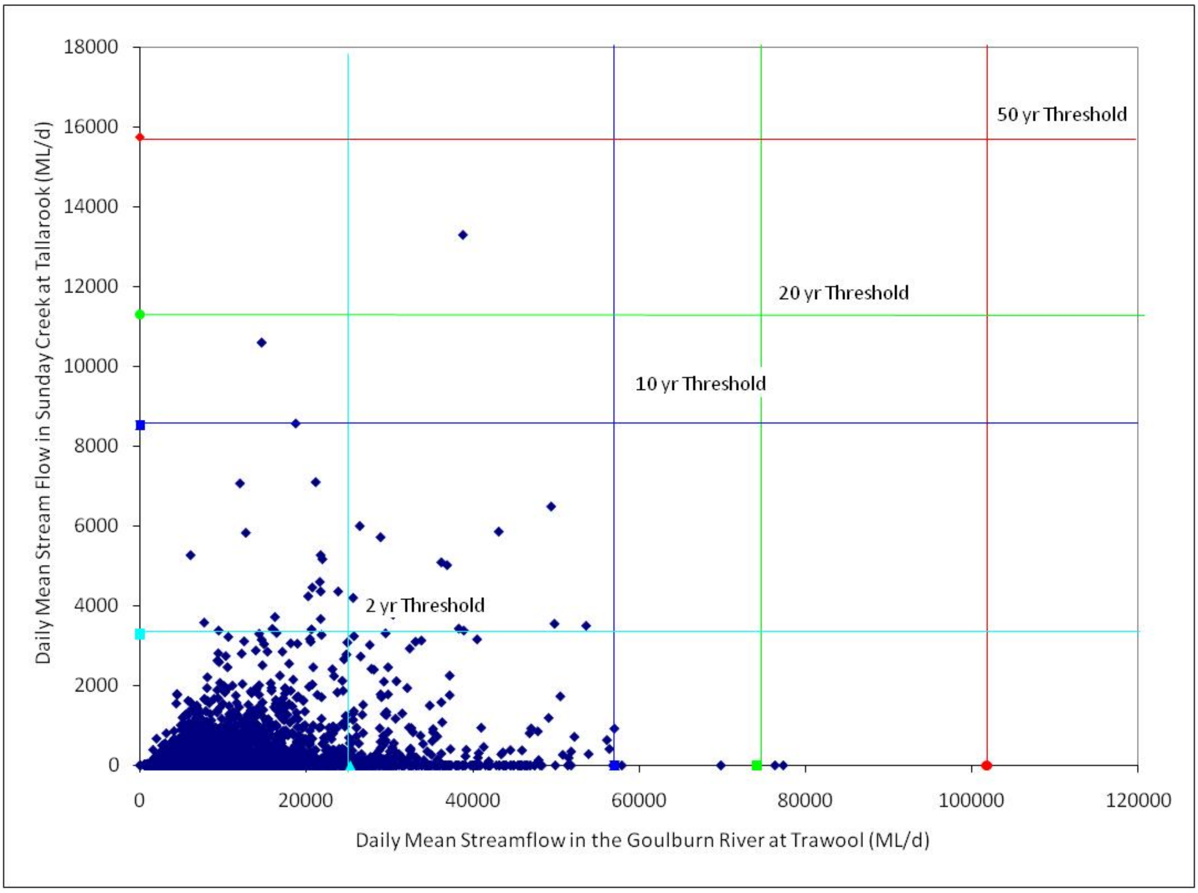



**Figure 5-6: Flow concurrence plot - Sunday Creek vs. Goulburn River at Trawool**

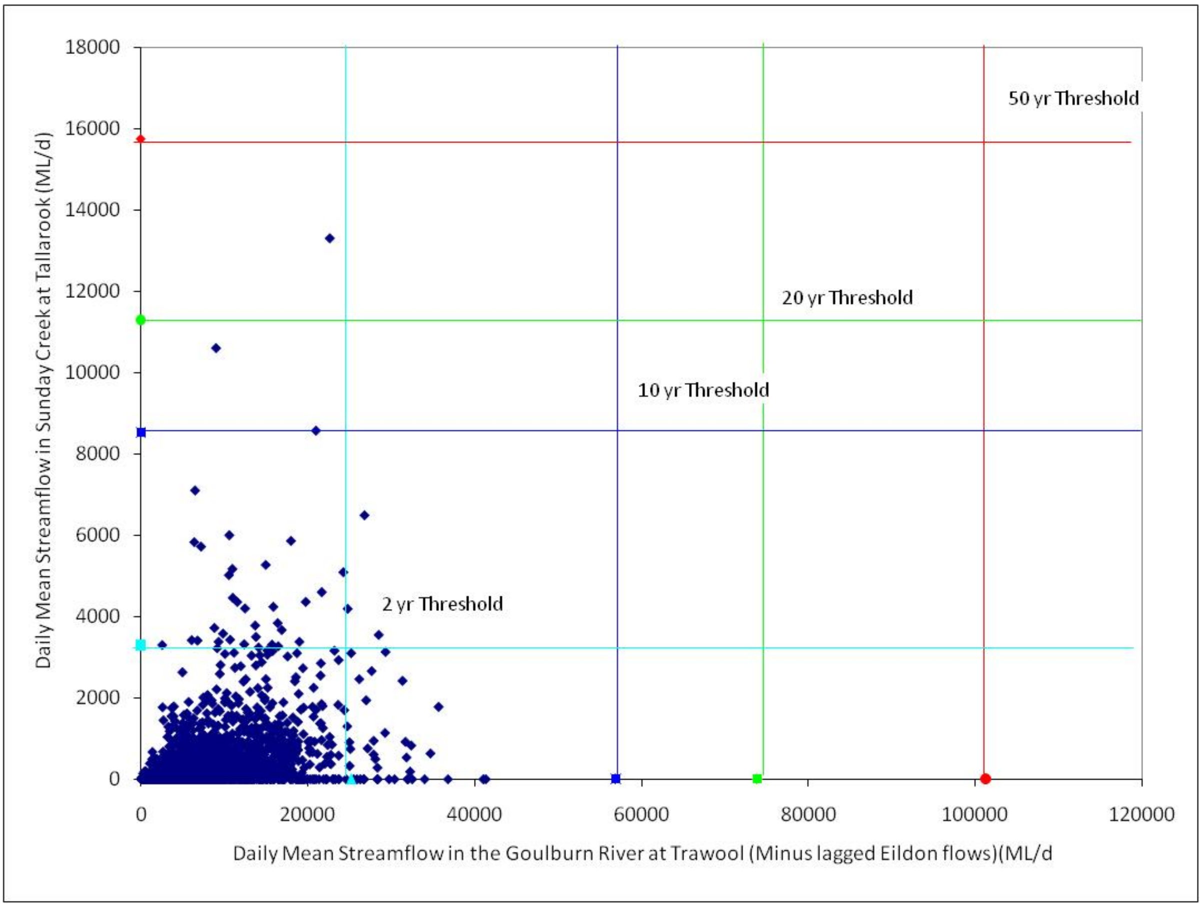



**Figure 5-7: Flow concurrence plot Sunday Creek vs. Goulburn River at Trawool (minus lagged releases from Lake Eildon)**

## 5.4 At locations other than gauging stations

The question of direct interest in concurrent flow analyses is how likely it is that high flows in the Goulburn River upstream of a point of interest will coincide with high flows in one or several tributaries entering in the vicinity of this point. This question cannot be addressed by direct analysis of data at gauging sites but requires some processing of the data before analysis.

As an example, if the point of interest is Nagambie, the correlation between appropriately lagged flows at Trawool (representing the contributions from Eildon and the upper tributaries) and the lagged and summed flows from Sunday, Sugarloaf, Hughes and Major Creeks (representing the contribution from the middle tributaries) could be analysed.

Similarly, for Shepparton as the point of interest, the correlation between lagged Murchison flows and lagged and summed tributary inflows from Pranjip, Castle and Seven Creeks and Broken River could be examined.

These analyses have not been undertaken so far.

# 6. CONCLUSIONS

**Streamflow data quantity and quality**

The Goulburn River and major tributaries have good availability of streamflow data, with instantaneous streamflow data available for generally about 30 years. Mean daily flows records were generally available for a longer period. Several long term gauges on the Goulburn River have over 80 years of record. There were 18 streamflow gauges identified for use in this analysis.

Despite of this number of streamflow gauges, a large portion of the tributary catchment area is ungauged (over 50% of the tributary catchment between Eildon and Trawool and between the Seymour and Murchison). Data from existing stream gauging stations may not be sufficient to support all the requirements for operational management of environmental flow releases.

Except for the stations on the Home Creek and Major Creek rated as “fair to good”, and the station on Seven Creeks rated as “poor” in relation to high flows, the records of daily and continuous streamflow data have been judged to be “good”. The flow records for the Broken River are affected by large diversions from this catchment into the Lake Mokoan system (from 1971) and into the Broken Creek system.

**General statistics**

The portion of the flow at Trawool added by the tributaries is considerably higher for the expected environmental flow release season (July – November) than for the rest of the year. On an annual basis Lake Eildon contributes 60% of the flow at Trawool but during the July to November period there is only a contribution of 44%. This observation confirms that the July to November period offers significant opportunities to enhance environmental releases from Eildon with flow contributions from the tributaries.

The seasonal pattern of flows varies considerably along the Goulburn River. At Eildon it is mainly determined by releases from the storage in response to irrigation demands, and the gauge below Lake Eildon shows the highest mean daily flow (MDF) and mean maximum flow (MMF) in October. The seasonal flow pattern of the unregulated tributaries is determined by heavy rainfalls and runoffs that tend to occur predominantly in late winter and early spring. All the tributaries (except Major Creek and Broken River) thus have their highest MDF and MMF in August or September. The gauges on the middle and lower Goulburn River reflect a combination of these upstream influences, with the highest MDF and MMF occurring in September.

The results of the monthly analysis indicate that, in a typical environmental release season, the highest tributary inflows are likely to occur in the first half of the season, about two months earlier than the highest Eildon releases to irrigation demands. However, there is still a good chance of significant tributary flows in October.

**Flow hydrographs**

The flow hydrographs during the environmental release season show distinct differences between ‘dry’, ‘wet’ and ‘significant flood’ years, and controlled flood releases from Eildon in some seasons also have a distinct influence on the flow hydrographs at various sites along the Goulburn River. In dry seasons, releases from Eildon play a dominant role, while in wet and flood seasons the influences of tributary inflows and flood releases from Eildon predominate.

The analysis of the hydrographs for three flood events provided some information on typical flood travel times and flood hydrograph shapes. As the flood hydrograph moves from the upper tributaries down the river, its base broadens (typically from 2 to 3 days in the tributaries for moderate events to several weeks in the lower Goulburn for larger events), and the peak flattens out.

Examination of flow hydrographs suggests that a significant contribution to the flow at Trawool is sourced from the ungauged catchment between Eildon and Trawool. It appears that approximately 50 % of the flow at Trawool is from ungauged catchment areas during the early stages of the flood event.

The relatively large contribution of the tributaries to the reach above Trawool means that these tributaries have the greatest potential for making a positive contribution to environmental flood events. The relatively flashy flood response of the tributaries in the middle reach means that these tributaries may pose a significant threat to creating or aggravating unintentional flood consequences in the reaches further downstream. Detailed hydrologic modelling will be required to provide a more quantitative assessment of these potential benefits and impacts.

**Flood frequency analyses**

As reliable flood frequency analysis results are available from recent studies for the Goulburn River at Seymour, Murchison and Shepparton, additional flood frequency analyses within this study were only undertaken for 12 key sites on tributary streams. The results of these analyses are mainly intended as a frame of reference for the high flow spells analysis; further data checking and possible revision is recommended, if these results are to be used for other purposes.

**Spell analysis**

The analysis of spells above a given threshold flow in one of the tributaries (Acheron River) indicated that the mean and longest periods between high flow spells increased with increasing threshold flow. However, the number of high flow spells, the mean duration of spells and the longest spell duration all decreased with increased threshold. This indicates that for larger tributary low events there are significantly less opportunities for environmental releases being enhanced by tributary inflows.

**Flow concurrence**

The upper tributary catchments (Yea, Acheron and Rubicon) show some correlation for frequent flood events (up to 2-year ARI), with limited correlation for larger flood events. A similar pattern was found for the mid-catchment tributaries (Hughes, Sugarloaf, Sunday).

Further, mid catchment tributaries (Sunday and Sugarloaf Creeks) are generally affected by different storm rainfall patterns than those occurring over the upper tributary catchments (Yea, Acheron and Rubicon).

There is scope for more detailed flow concurrence investigations to assess the degree of correlation between flows in different parts of the system, to inform future hydrologic model development

**Application of results**

The analyses described in this report were of an exploratory nature, aimed at better understanding of the high flow behaviour of the Goulburn River tributaries and the interaction between flows in the tributaries and the Goulburn River itself. The relationships identified from the analyses are not considered sufficient to be directly applicable in operational decision making for environmental flow releases from Lake Eildon. However, the findings will inform the development of a rainfall-runoff model to support operational decision making, in conjunction with real-time data and short-term forecasts of rainfall data. Specifically, the results of the analyses have provided clear pointers to the desirable spatial resolution of the model and the associated rainfall inputs.

The results of the analyses reflect climate and system operating conditions experienced over the last 40 years. Modelling to support environmental flow release management will need to represent current operating rules for Eildon Dam under normal and flood release conditions, including specific modifications to these rules to enhance environmental flows.

# APPENDIX A THIESS DATA QUALITY CODES

Thiess Services

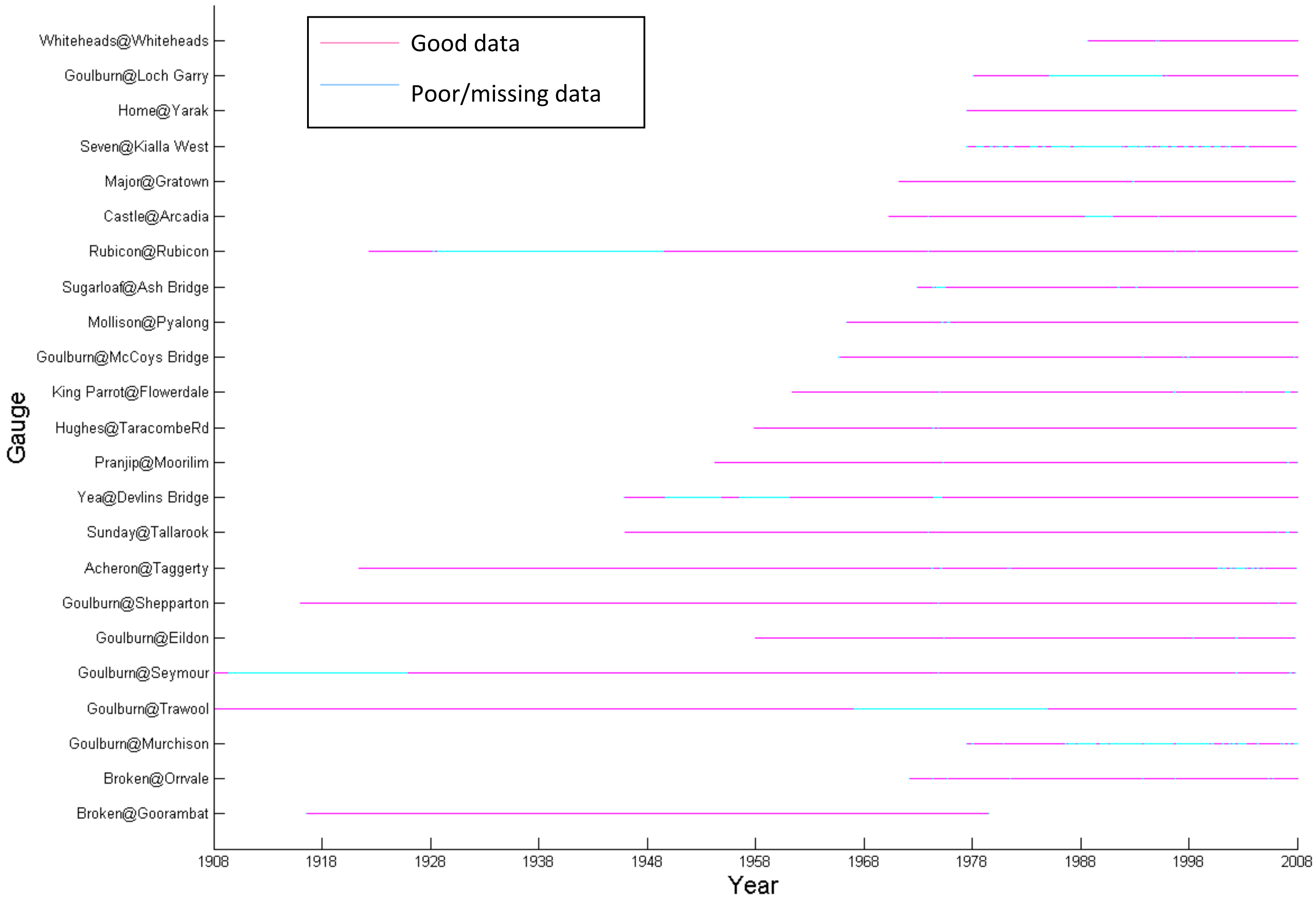
6/02/2004
13:51

| Quality Codes Report | Quality Print qual Text |
|---|---|
| 1 | Good continuous records |
| 2 | Good quality edited data |
| 3 | Linear infill to first value in block (no data lost) |
| 4 | Temporary coded for currumbeene data |
| 5 | Drawdown - chart rating applies |
| 6 | $ Phased Rating Applicable-gradual changing of control&channel |
| 8 = | Pool reading only |
| 9 | Pool dry - no data collected |
| 10 | D Data transposed from recorder chart |
| 11 | V DATA USED FOR OPERATIONAL PURPOSES (data to be validated) |
| 15 K | Minor editing |
| 20 F | Edited to measurements |
| 26 G | Daily read records (MW - Good periodic data) |
| 27 G | MW - Good periodic data (Other Authority) |
| 30 + | Good Meas. - mult. point, 40 sec timing (Good acc. data - MW) |
| 31 # | Good Meas. - Adeq. verts & obs, 40 sec timing (Good acc. data - MW) |
| 32 | Fair Measurement - Weighted mean gauge height, turbulent flow, flow angle |
| 33 3 | Point Measurement - Applicable in narrow sections eg. sewers etc. |
| 34 | Bucket Measurement - Applicable to weirs, pipe outflow etc. |
| 35 | Composite Measurement - Segments taken from several gaugings to create |
| 36 | Measurement for sampling purposes. Rough estimate |
| 41 | MW - Good data not validated by other means - No editing required |
| 50 | Z Medium editing >Q=15 (1996 on & MW) or HYMAN data import (pre1996) |
| 60 | LATROBE VALLEY DATA |
| 65 # | Other authorities data |
| 75 \ | Height correction applied |
| 76 ~ | Reliable interpolation |
| 77 C | Correlation with other station, same variable |
| 78% | Reliable Daily Read Data (MW) |
| 80 A | Accumulated |
| 81 W | Wet day within accumulated rainfall period |
| 82 L | Linear interpolation across gap in records. |
| 83 BCC | Below Instrument Range |
| 90 I | Salinity interpolation |
| 92 ! | PROJECT SITE U/S DATA USED |
| 95 J | Irregular time rate data weekly/monthly read. |
| 100 ? | Irregular data use with caution. |
| 101 E | Reliable Data Estimate (MW) |
| 104 E | Records estimated |
| 120 E | Estimated data not using correlation (MW) |

| | |
|---|---|
| 130 E | Estimated periodic data (MW) |
| 140 O | Estimated Accumulated Data (MW) |
| 146 | Drawdown - no rating applies |
| 148 @ | Theoretical rating table applied |
| 149 | Raw data as received from Serco (MW) |
| 150 | R Rating extrapolated due to insufficient gauging (Unrel. data - MW) |
| 151 U | Data lost due to natural causes - NRE approved loss |
| 152 Q | Refer station file |
| 153 T | PROBE OUT OF WATER/BELOW INSTUMENT THRESHOLD |
| 155 ^ | ABOVE INSTRUMENT THRESHOLD |
| 160 B | Backed-up by d/s influence. (Unreliable periodic data - MW) |
| 161 * | Debris Effecting Sensor. |
| 165 | Suspect or bad data supplied by other authority |
| 170 | Y Raw unedited data stored in archive (Unrel. accum. data - MW) |
| 180 | M Equipment malfunction |
| 190 | Data unavailable station discontinued |
| 200 | Data available but not digitised |
| 201 | N Data not rec. - no correlation available (Station not op. - MW) |
| 235 | Poor Measurement - Not enough verticals or observations, not enough |
| 236 | Suspect or Incomplete Measurement - Equipment suspect or giving problems |
| 237 | Surface Velocities - Velocity measurements taken on surface only. |
| 238 | Control Leaking - Control leaking, either as noted on measurement or chart. |
| 239 | Backed up Flow Measurement - Measurement is affected by backup. |
| 240 | Not Coded Measurement - Measurement not coded as per HYDSYS System. |
| 250 S | Rating table suspended |
| 253 | Brisbane Quality code |
| 254 X | Rating table exceeded |
| 255 " | No Data Exists (Lost data - MW) |

# APPENDIX B INSTANTANEOUS STREAMFLOW DATA QUALITY

Goulburn River Gauges


Good data
Poor/missing data
Whiteheads@Whiteheads
Goulburn@Loch Garry
Home@Yarak
Seven@Kialla West
Major@Gratown
Castle@Arcadia
Rubicon@Rubicon
Sugarloaf@Ash Bridge
Mollison@Pyalong
Goulburn@McCoys Bridge
King Parrot@Flowerdale
Hughes@TaracombeRd
Pranjip@Moorilim
Yea@Devlins Bridge
Sunday@Tallarook
Acheron@Taggerty
Goulburn@Shepparton
Goulburn@Eildon
Goulburn@Seymour
Goulburn@Trawool
Goulburn@Murchison
Broken@Orrvale
Broken@Goorambat
Gauge
1908
1918
1928
1938
1948
1958
1968
1978
1988
1998
2008
Year