Goulburn Constraints Business Case Hydrology Analysis

Goulburn Broken Catchment Management Authority

Project Report

Final

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Executive Summary

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

The objectives of this project were to use historical flow events to:

- Assess whether environmental releases from Lake Eildon can be added to tributary flows to create desirable environmental events in the range of 25,000 ML/day to 40,000 ML/day in the lower Goulburn River as measured at Shepparton (Gauge 405204).
- Assess what the flow rates are in the Goulburn River in various reaches (particularly in the mid-Goulburn River) when the environmental releases are made.
- Assess methods to limit the occurrence of undesirable outcomes such as the target flow rate not being achieved or the maximum target rate being exceeded.

The project has been undertaken in the following stages:

- Collation of historical stream flow data
- Identification of flow events at Shepparton which exceed a threshold of 15,000 ML/day when adjusted for the historical diversion at Goulburn Weir to Waranga Basin
- Analysis of the contribution to the flood events at Shepparton by different parts of the Goulburn catchment
- Characterisation of the flood events in terms of magnitude, duration and the source of the flow expressed as the relative contribution of each tributary to the flood event at Shepparton
- Investigation of potential triggers to commence an environmental flow release from Lake Eildon including flow travel time to Shepparton from various locations in the Goulburn and Broken catchments
- Modelling scenarios of additional releases from Lake Eildon to increase flow at Shepparton

Flood Event Characterisation

Daily historical stream gauging information from July 1960 to December 2014 has been evaluated to characterise flood events at Shepparton, adjusting it for the flow diverted at Goulburn Weir. This was done on the basis that when catchment runoff occurs, water is often diverted at Goulburn Weir to Waranga Basin to store for later use. It is relatively easy to not divert that water and so to increase flow peaks downstream. This option is available for the majority of flow peaks and can add up to 7,200 ML/day (although diversions don’t usually occur at the maximum rate). This work assumed that this option was used whenever available.

The adjusted flow at Shepparton was then analysed to find events with a peak greater than 15,000 ML/day. 132 events were identified over the period examined. Of these, 17 had peak flow rates above 50,000 ML/day. Nine had peak flow rates between 40,000 and 50,000 ML/day. There were 33 events with peak flows in the range of 25,000 to 40,000 ML/day (occurring in 20 years) There are 73 events with peak flows in the range of 15,000 to 25,000 ML/day (occurring in 26 years).

It was found that:

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

In the 55 years of record evaluated, 11 had no flow events in the Goulburn River at Shepparton above 15,000 ML/day, and therefore would not have been considered for environmental releases. Of the remaining forty four years in the period of record, there were seven years with only one event. Most years (37) had two or more events. There were 13 years in which an event occurred in May or June, and in each of these years one or more events occurred later in that year. Similarly, there were 24 years with events in July, where 17 have similar or bigger events in later months. Therefore, not releasing environmental water before August would allow better use of environmental water, targeting potentially larger and later flow events. It is also preferable not to water after October due to the increased risk of blackwater events and because agricultural damage from inundation tends to increase with later flooding (although October is still too late to avoid significant agricultural damage). Therefore the target watering months can be reduced from winter/spring to August to October.

The peak flow at Shepparton for each of the events and the contribution to peak flow from Eildon, tributary inflows upstream of Trawool, tributary inflows upstream of Goulburn Weir and Lower Goulburn inflows (including Broken River) was assessed. It was found that tributary inflows in the reach upstream of Trawool contribute consistently to the identified events at Shepparton. Lower Goulburn inflows, including from the Broken River also contribute significant proportions of event peak flows but their contribution is far more variable in terms of the proportion they contribute to the peak flow of an event. Tributary inflow upstream of Goulburn Weir (and downstream of Trawool) also contributes a more variable proportion of peak flow, and for most events the volume is less than the contribution from Trawool tributaries or Lower Goulburn inflows. The contribution from Eildon is usually very low when there is no spill or pre-release. At times when Lake Eildon is spilling or making pre-releases, the contribution to the event from Eildon can be around half the total flow at Shepparton. A schematic of the Goulburn-Broken tributaries is shown in Figure E-1.

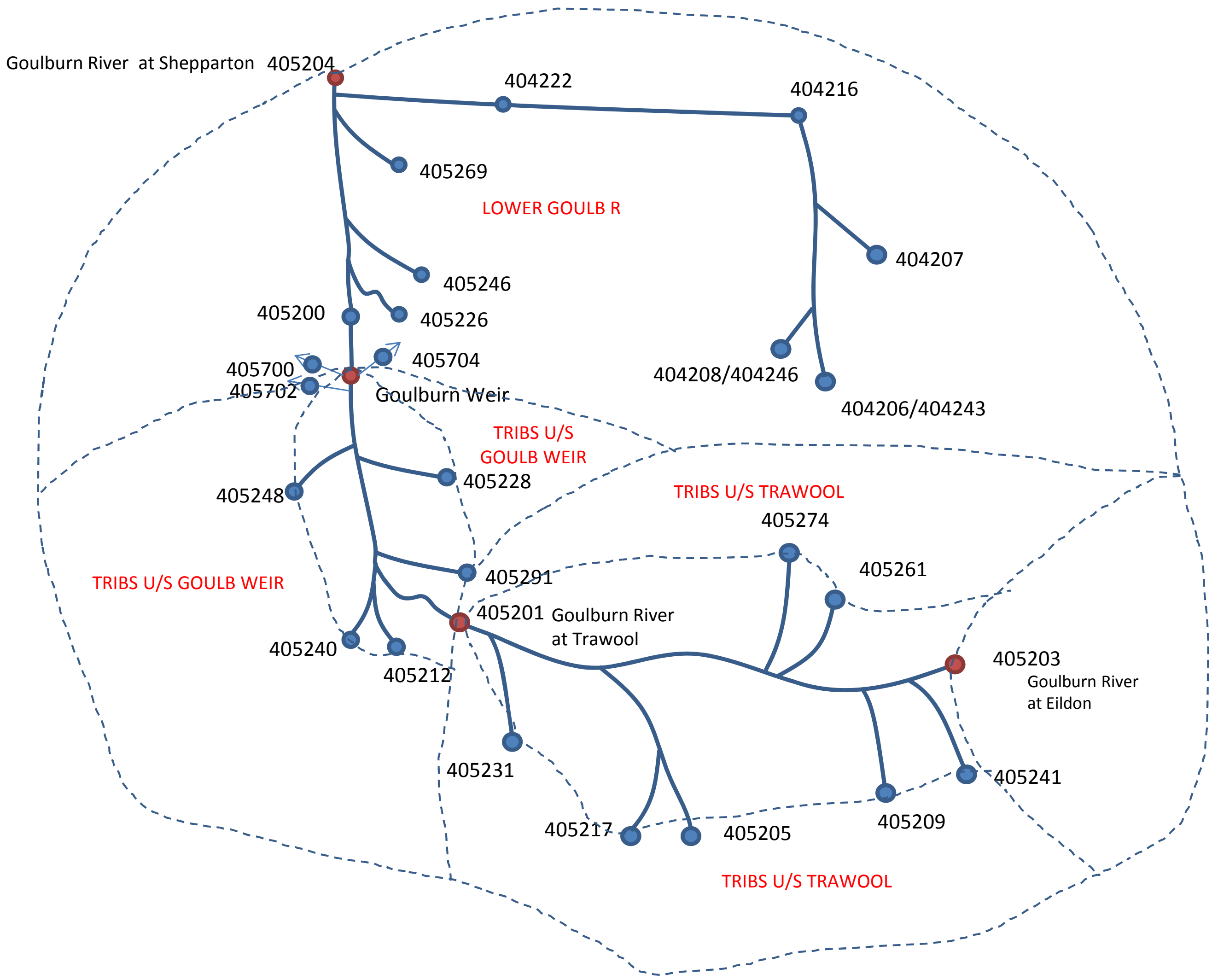

Figure E-1 : Goulburn-Broken catchment tributary schematic

Environmental Releases from Lake Eildon

The first objective of this project was to assess whether environmental releases from Lake Eildon can be added to tributary flows to create desirable environmental events in the range of 25,000 ML/day to 40,000 ML/day in the lower Goulburn River. It has been found that it could be possible, but given travel time in the river system and constraints on the rate of rise of release, environmental releases will need to rely on good forecasting of future streamflow and rainfall up to 7 days ahead to get peak rates of release added to peak flows in the Lower Goulburn River.

It has been shown that making releases based only on observed streamflow or rainfall results in the peak of the released flow generally arriving after the peak flow at Shepparton, resulting in many event peaks being less than a target flow threshold. Sometimes releases were initiated based on streamflows but then increased further due to subsequent rainfall, resulting in increases to flood peaks above 40,000 ML/day which may exceed a maximum flow threshold target.

If forecast information of both streamflow and rainfall is included in the release initiation process and management of release rate once it has commenced, the number of events failing to reach a target threshold or exceeding a maximum flow rate is reduced. The more accurate the forecast is, the better the outcome in the number of events achieving the desired flow target without exceeding a maximum flow rate at Shepparton. The development of streamflow forecasting techniques in future is an important aspect to the ability to reduce the risk of adverse outcomes from the release of water from Eildon to achieve environmental flow targets in the Goulburn River at Shepparton.

Some initial environmental release strategies investigated made an assumption that the streamflow forecast could be perfect (ie the recorded streamflow at Shepparton was used adjusted for diversions at Waranga Basin) up to seven days in advance. In these scenarios assuming perfect foresight, there is still a risk to achieving the target due to constraints on the rate of rise of flow release rate from Eildon and assumed constraints within the Goulburn River in reaches downstream.

The flow rates in various reaches of the mid-Goulburn River for a number of scenarios have been assessed. The results show that assuming a release constraint downstream of the Acheron River in the range from 10,000 to 15,000 ML/day increases flows up to around 35,000 ML/day at Trawool, 40,000 ML/day at Seymour, and 40,000 ML/day at Murchison. These flow rates appear high given the peak flow rate at Shepparton is 40,000 ML/day, and there is usually considerably more inflow to the Goulburn River from downstream of these locations. The reason for this is that shorter higher peak flows can occur in the Goulburn River due to tributary inflow which are then attenuated as they pass downstream. There is also the issue of timing, in that the peak flow rates from different parts of the catchment do not coincide at Shepparton, rather they arrive at timing based on their travel time from Shepparton. Another issue is that a flow event may have secondary flow peaks.

Historically the rate of rise and fall of flow in the Goulburn and Broken rivers and in particular their tributaries can be much less than one day. Analysis of sub-daily timestep data shows that the peak flow can be significantly higher than the average daily flow. The significant difference in the instantaneous and daily flow rates for tributaries means that additional work will be required to evaluate peak flow rates at a sub daily timestep. This information would allow the assessment of additional variability and how to manage it, particularly upstream of the Alexandra/Molesworth area where river channel capacity is limited. In critical areas, additional continuous stream and rainfall monitoring may be required to characterise flow responses and provide more warning time for operational response to be made.

Methods to limit the occurrence of undesirable outcomes such as the target flow rate not being achieved or the maximum target rate being exceeded include further development of streamflow forecasting techniques, operational management of releases at Eildon and at Goulburn Weir and review of the allowable rate of rise and fall of releases from Lake Eildon.

Uncertainty

A number of limitations and uncertainty in this analysis have been discussed. Further work is required to address many aspects of uncertainty.

Losses

An important assumption in this analysis is that losses applied to additional releases are zero. In reality there will be losses which will be variable depending on the conditions into which the release is made. Further work will be required in future to quantify the amount of environmental releases lost, and then to incorporate this loss into release planning and management. This may include developing models to simulate the losses of overbank flows in various reaches of the river.

Travel time

The assessment of historic flow data shows a four day travel time from Eildon to Shepparton on average. The limitation on the allowable rate of rise of releases from Eildon results in another two to four days delay from the event being started to reaching a target rate. Therefore from the time an event is initiated the peak of the release from Eildon will begin to arrive at Shepparton 6-8 days later. Further analysis of travel time using data at a sub-daily timestep could be undertaken to refine travel times.

Event contribution

The flood event characterisation showed many events where a large proportion of the peak flow originated from the ungauged catchment area upstream of Trawool. This catchment area has a travel time of between 2.5 and 4 days to Shepparton.

Many of the events had inflow contributed from the Broken River. Analysis of the Broken River flow at Orrvale showed that in most cases a large proportion of this flow originated from upstream of the gauged sites of the Broken River at Moorngag, Holland Creek at Kelfeera and Moonee Creek at Lima. All these sites are approximately three days travel time to Shepparton. Using the gauged flow upstream as an indicator allows more warning time than relying on flow at Orrvale (however introduces more uncertainty due to the local catchment contribution downstream of these sites).

The contribution from other areas in the Goulburn Broken catchment can also be very high in certain events.

Impact of rainfall/days/duration/rate of rise and fall

A comparatively low risk release strategy in terms of flood risk could be to wait until a peak event is measured at streamflow gauging stations and there is no forecast rainfall and then initiate a release.

Analysis of events at Shepparton with adjusted flow peaks in the range of 20,000-40,000 ML/day show that they fall typically at a rate in the order of 5,000 ML/day/day once the peak has passed and there is no subsequent rainfall in the days following the event which caused the peak flow. Events at Shepparton in the range 15,000 ML/day to 20,000 ML/day typically fall at the rate in the order of 3,000 ML/day/day.

Therefore if releases are made from Eildon based on observed streamflow at Shepparton and if there is no further rainfall to increase the peak flow at Shepparton, the rate of rise would need to be greater than 3000-5000 ML/day (before routing and losses are considered which limits the rate of rise at Shepparton for a given rise at Eildon). Current operational rate of rise is 3,500 ML/day/day.

Therefore it is not possible to increase the peak flow at Shepparton on the basis of initiating a release using gauged streamflow where no further subsequent rainfall occurs to supplement the peak. Where releases are initiated based on observed streamflow, increases to the peak flow at Shepparton are only possible if subsequent rainfall occurs. It may be possible to extend the duration of the event if the rate of rise from Eildon is high enough.

Therefore to manage the risk of an undesirable outcome, forecast rainfall and streamflow would need to be utilised to initiate and manage an Eildon release.

Methods are required to increase the amount of time in advance an event can be predicted. Using observed rainfall to estimate future streamflow potentially provides up to an additional day, but involves additional uncertainty in forecasting the catchment runoff response from the observed rainfall.

Therefore methods that involve forecasting of rainfall, runoff and river flow are required.

Forecasting

A forecast of streamflow one day in advance can be based largely on gauged streamflow on the Goulburn and Broken Rivers and nearby tributaries such as Sevens Creek. As more days in advance are forecast, the more the forecast streamflow would rely on forecast rainfall and forecast runoff (and hence be more uncertain).

If releases are being managed with the aim of increasing flow at Shepparton, then a forecast flow at Shepparton without any environmental release is required. If a perfect forecast of streamflow at Shepparton was possible, it has been shown that if a release is initiated 7 days before the peak flow (allowing for 2 to 3 days for the release to be increased and 4 days travel to Shepparton), that peak flow rates at Shepparton can be increased.

Note the accuracy of currently available forecasting has not been tested as part of this project.

Management of flows during releases using forecast information

In practice this could potentially be achieved by initiating a release based on forecast streamflow (which incorporates the effect on streamflow of forecast rainfall). As the rate of release at Eildon increases, there would be opportunity to reduce the flow rate (subject to the rate of fall constraints at Eildon) to then cease the release if forecast conditions change. Also, some of the release up to approximately 7,000 ML/day could be harvested into Waranga Basin via Stuart Murray Canal and Cattanach Canal.

Scenarios assuming a maximum constraint in the total flow of Eildon release plus Rubicon River plus Acheron River in the range of 10,000 ML/day to 15,000 ML/day have shown it is possible to increase the peak flow at Shepparton in a number of events by initiating the release prior to the event. If forecast flow at Shepparton in four days' time is expected to exceed 40,000 ML/day (assuming a perfect forecast) and the release is reduced, then the number of events which are increased above 40,000 ML/day are reduced.

If a forecast of flow at Shepparton is used to manage releases, the target flow may still be exceeded or not achieved due to limits on the maximum rate of rise and fall of Eildon release. It has been seen that if a release is initiated from Eildon and a subsequent rainfall event occurs, peak flow in the Goulburn River at locations such as Trawool, Seymour and Murchison can be increased in flow rates in the range up to 40,000 ML/day and potentially higher depending on the tributary inflows during an environmental release.

These scenarios only adjusted flow based on the total Eildon, Rubicon and Acheron flow and the forecast Shepparton flow. Further work would be required to examine potential management of releases also including the potential flow rates at other locations in the river.

For all of the work discussed here, perfect forecasting of streamflows is assumed. In future a streamflow forecasting technique should be developed and adopted and the success of these scenarios re-tested.

Given the limitations and uncertainty noted, the outcomes of this study are not intended to be used for operational releases. Further work would be needed to investigate potential risks and operational management requirements before such approaches could be implemented in practice.

Further Work

This study has identified a number of aspects that require further work. These include:

Sub daily timestep modelling

Observed rainfall and streamflow data have been used on a daily timestep. This has an issue that streamflow data is reported on a day from midnight to midnight, while rainfall is reported from 9am to 9am. Observed rainfall could be used as a trigger for events which could possibly provide additional time before the peak flow at Shepparton occurs. This could potentially be explored further using rainfall and streamflow data at a timestep of less than one day.

Also, it has been observed that sub-daily data may give a better representation of peak flows and time lag, particularly for some tributary catchments. It is recommended that sub-daily date be used to improve these estimates in future as well as provide better information for triggering or adjusting releases.

Forecasting rainfall and streamflow

Much of the analysis undertaken in this report assumes perfect knowledge of future streamflow and rainfall, however in practice forecast data is required.

It is understood that the Bureau of Meteorology and CSIRO are undertaking current research into short term streamflow forecasting. Techniques include using conceptual rainfall runoff modelling approach for sub-daily/daily flow forecasting out to 7 days using rainfall inputs with modelling outputs adjusted using a site specific correction scheme. Another approach is based on Bayesian Joint-probability methods. Outcomes from such research could potentially be incorporated into a process to forecast flow from the tributaries and also combining it with gauged streamflow data to quantify the flow already in transit in the rivers to forecast flow in the Goulburn River in various reaches.

Forecast rainfall products from the Bureau of Meteorology are available in different forms. A gridded form of forecast rainfall across the catchment could potentially be used to be input to a rainfall runoff catchment model to simulate future streamflow events. This could be evaluated in future as a decision support tool for managing environmental releases. There is considerable uncertainty in the forecast rainfall in terms of total rainfall depth and the spatial and temporal variability over an area as large as the Goulburn and Broken catchments during a rainfall event, and potentially for multiple rainfall events over a period of days. The flood risk associated with an event being more intense or at a larger scale than forecast would need further investigation. There is also risk that a rainfall event may be smaller and runoff not sufficient to enable release flows together with catchment runoff to meet a flow rate of over 25,000 ML/day at Shepparton.

Once a forecast data set is established trigger scenarios should be re-evaluated using this data.

Losses

Further work will be required in future to quantify changes in losses associated with overbank environmental releases and for this to be incorporated into release planning and management. This may include developing models to simulate the losses of overbank flows in various reaches of the river.

Duration of event releases

This work has focussed on how to increase the peak river flow at Shepparton. It has shown that current flow peaks tend to be relatively short with sharp recessions, making it difficult to achieve the desired 4 to 5 day durations, unless there is follow up rainfall. It may be that peak flows need to target a higher flow, to provide the desirable duration at a lower flow (eg target 40,000 ML/day to provide 4 days at 35,000 ML/day). Alternatively the possibility of a shorter event duration could be explored.

Operational Management at Goulburn Weir

Alternative management arrangements may be possible for Waranga Basin, for the Basin to be held lower to retain some airspace to re-regulate environmental releases if required. If this were done, the Waranga Basin could be refilled by subsequent water harvesting opportunities with no impact on overall water resource availability. If the Waranga Basin didn’t refill, environmental water entitlements could be debited for the water not harvested. Further study would be required to assess if such an operating scenario was possible to ensure that impacts on allocations could be avoided through use of environmental allocations. The further study would also need to evaluate the benefits and risk of such an arrangement.

Evaluation of stream gauge and rainfall gauge network

It was noted in the flood characterisation section that the ungauged catchment upstream of Trawool generates significant flow in most events. Approaches to reduce the uncertainty of where in the ungauged area these flows originate from (such as additional flow gauging) need to be further considered. This may include gauging of key tributaries closer to their confluence with Goulburn River.

Constraints to rate of rise and fall in releases

Given the potential impact that the rate of rise constraint has on the amount of time required to deliver an environmental flow event to Shepparton, further investigation into the maximum rate of rise downstream of Eildon is recommended.

The rate of fall also impacts on the ability to reduce a release in response to downstream flow conditions or potentially to forecast conditions. It is recommended that the allowable rates of rise and fall for Eildon releases are investigated.

Other Assessments

It has been noted in this study that there are offtakes from Stuart Murray Canal which provide water for irrigation demands. In times when high flow events occur in the Goulburn, this may coincide with low or no irrigation demand. However at other times there may be demand which would still need to be supplied. The analysis to date has not evaluated the significance of this which could be explored further.

Also, due to data availability the historical diversions to Lake Mokoan were not added back to Broken River flows. The impact of this assumption could also be further examined.

It was found that in some events, particularly earlier in the period of record when there were more periods of missing or unreliable data, there are some spikes and negative inflows. In future, the streamflow records could be examined in more detail to review the quality of available data to identify the causes of these if required.

Contents

Important note about your report

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

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

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

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

This study is a purely desktop assessment of existing information, relevant to the characterisation of flow events in the Goulburn River and its tributaries. Investigations were carried out using daily streamflow and rainfall data. They provide an assessment of potential approaches for making environmental flow releases. This work is of a preliminary nature to investigate possible approaches. It is not intended to be used for operational releases. Further work would be needed to investigate potential risks and operational management requirements before such approaches could be implemented in practice.

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

1. Introduction

1.1 Background

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

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

1.2 Previous Studies

DSE (2011) identified target flows of 25,000 ML/day to 40,000 ML/day for 4 to 5 days to water wetlands and the floodplain within the lower Goulburn levee system.

Water Technology (2010) examined issues with generating out-of-bank environmental flows which concluded that environmental flows of up to 40,000 ML/day may provide the majority of the environmental benefits with the least economic cost. The primary constraint to making environmental releases was the first reach below Lake Eildon (Eildon to Alexandra) where flooding occurs at flows of less than 20,000 ML/day. This is due to inundation of agricultural land, buildings, roads and bridges in the reaches immediately downstream of Lake Eildon. Flows up to 40,000 ML/day could however be met by adding smaller releases of up to 20,000 ML/day to align with natural rainfall runoff events and also by reducing diversions to Waranga Basin. A locality plan including streamflow gauge locations is presented in Figure 2.1.

Water Technology (2009) report described the behaviour of the Goulburn River and its tributaries. Typical flow events were analysed to understand the Goulburn River and tributary hydrological behaviour, including contributions from gauged tributaries, flow timing, and change in flows as they move downstream. The large contribution to flow made by tributaries upstream of Trawool indicated that these have the greatest potential for contributing to environmental flow events. Inflows from the more flashy downstream tributaries are more likely to pose a threat to providing targeted flows due to the creation or aggravation of unintentional (and undesirable) flood consequences in the reaches further downstream. The 2009 study did not include scope to evaluate operational strategies for making environmental releases to add to natural rainfall runoff events from all of the Goulburn and Broken tributaries upstream of Shepparton. This work has been undertaken as part of this hydrology analysis for the Goulburn Constraints business case.

An initial scoping of the potential to enhance natural tributary inflow events with environmental releases from Lake Eildon was undertaken by Sinclair Knight Merz in 2012 using the daily timestep Source model of the Goulburn River. The development of the Source model is documented in both (SKM, 2012) and in the draft extract from “Trialling eWater Models in River Management – Application in the Goulburn and Ovens Catchment” (GBCMA, 2012).

The daily inflows to the Source model were adopted from the daily REALM model of the Goulburn, Broken Campaspe and Loddon valleys. These REALM inflows were derived based on disaggregation of monthly timestep inflows from the Goulburn Simulation Model which is maintained by DELWP. Disaggregation was based on daily recorded flow data or daily rainfall runoff modelling results. A limitation of this daily data set is that as the flows are derived from monthly data then disaggregated, rather than being derived based on daily data. As travel time and daily routing are a very important aspect of the delivery of environmental flows, the historical daily recorded data was applied in this project in preference to the model input data. The project relies largely on the daily flow at the key gauging stations on the Goulburn River at Eildon, Trawool, Goulburn Weir, Murchison and Shepparton.

1.3 Project Objectives

The objectives of this project are to evaluate historical flow events to:

- Assess whether environmental releases from Lake Eildon can be added to tributary flows to create desirable environmental events in the range of 25,000 ML/day to 40,000 ML/day in the lower Goulburn River as measured at Shepparton (Gauge 405204).
- Assess what the flow rates are in the Goulburn River in various reaches (particularly in the mid-Goulburn River) when the environmental releases are made.
- Assess methods to limit the occurrence of undesirable outcomes such as the target flow rate not being achieved or the maximum target rate being exceeded.

The method adopted to assess whether environmental releases can be added to tributary flows was to identify all historical flow events above a given flow threshold in the Goulburn River at Shepparton. Then each event was analysed in terms of the source of the flow at Shepparton and other characteristics of the event such as the time of year, the peak flow, the duration and rate of recession. This enabled the investigation of common attributes of events which may inform the strategies for making environmental releases.

The project has been undertaken in the following stages:

- Collation of historical stream flow data
- Identification of flow events at Shepparton which exceed a given threshold when adjusted for the historical diversion at Goulburn Weir to Waranga Basin. The threshold of 15,000 ML/day was nominated by GBCMA.
- Analysis of the contribution to the flood events at Shepparton by different parts of the Goulburn catchment.
- Characterisation of the flood events in terms of magnitude, duration and the source of the flow expressed as the relative contribution of each tributary to the flood event at Shepparton.
- Investigation of potential triggers to commence an environmental flow release from Lake Eildon including flow travel time to Shepparton from various locations in the Goulburn and Broken catchments
- Modelling scenarios of additional releases from Lake Eildon to increase flow at Shepparton

2. Historical Time Series Analysis

2.1 Collation of historical daily flow time series

Daily flow time series at a number of key locations on the Goulburn and Broken rivers and their tributaries were collated. For the Goulburn and Broken river main stems, data were available for the following gauges:

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

Each of these flow time series was downloaded from the Victorian Water Measurement Information System (http://data.water.vic.gov.au/monitoring.htm) including daily data quality codes. The location of stream gauging stations is shown in Figure 2.1.

In addition, flow data for diversions from Goulburn Weir and the Goulburn Weir storage volume were provided by GMW and included in the analysis.

A second time series of "adjusted" flow in the Goulburn River at Shepparton was created by adding the flow that was historically diverted to Waranga Basin to the historical flow at Shepparton after allowing for routing effects (described in Section 2.2). This includes all of Cattanach Canal and Stuart Murray Canal flow. The adjusted flow time series was created to approximate the flow at Shepparton if no harvesting to Waranga Basin had taken place. This was assumed because of an agreement between GMW and environmental water managers, that harvesting could potentially be ceased or reduced for a period of time and the reduction in diversions deducted from environment's stored water. Accounting for this diverted water reduces the amount of additional water required to be released from Lake Eildon to meet the environmental flow targets at Shepparton.

Some flow in the Stuart Murray Canal is used to supply irrigation demand offtakes from the canal. These users may still need to be supplied, even if all diversions to Waranga Basin cease to assist delivery of environmental flows. However, as part of the assessment undertaken to date, the separation of this flow has not been estimated. Generally during times when there has been significant rainfall and runoff in the catchment upstream of Shepparton, there will also have been rainfall in the irrigation areas supplied by the Stuart Murray Canal, hence demand may be low or zero. However there may be some events for example during Summer when the event is generated by a localised storm upstream and there is still irrigation demand. At these times, this limitation may need to be reviewed as these diversions may be significant as the total combined capacity of the offtakes from Stuart Murray Canal is in the order of 2,400 ML/day. This could be done by regressing historical diversions from the offtakes on the Stuart Murray Canal with a data source with similar use characteristics such as the East Goulburn Main Channel (405704) total offtake flow.

The flow diverted to Lake Mokoan from the Broken River data set was only available from 1987 onwards and has not been included in the adjusted flow calculation. This is a significant diversion of up to 2,650 ML/day in total from both the Broken River and Hollands Creek. Therefore it is recommended that it be allowed for in future more detailed analyses.

Data for the following tributaries of the Goulburn River downstream of Eildon were also collated. The data availability for each of these tributaries is presented in Table 2.1.

- 405241 - Rubicon River @ Rubicon
- 405209 - Acheron River @ Taggerty
- 405261 - Spring Creek @ Fawcett
- 405274 - Home Creek @ Yarck
- 405205 - Murrindindi River @ Murrindindi above Colwells
- 405217 - Yea River @ Devlins Bridge
- 405231 - King Parrot Creek @ Flowerdale
- 405212 - Sunday Creek @ Tallarook
- 405240 - Sugarloaf Creek @ Ash Bridge
- 405291 - Whiteheads Creek @ Whiteheads
- 405228 - Hughes Creek @ Tarcombe Road
- 405248 - Major Creek @ Graytown
- 405293 - Gardiner Creek @ Puckapunyal
- 405226 - Pranjip Creek @ Moorilim
- 405246 - Castle Creek @ Arcadia
- 405269 - Seven Creeks @ Kialla West

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

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

Based on available data, flow events were analysed from July 1960 to December 2014.

Sometimes there was missing flow data on the Goulburn River itself or in the offtake data at Goulburn Weir. In a small number of cases this was infilled where appropriate gauged data was available to do so reliably. There were periods in the record where gauged flow data could not be infilled reliably, in which case infilling was not done and the periods were flagged as events with missing data. For example during 1983 and 1984 there was a significant period of missing data in the flow record for the Goulburn River at Murchison where no other data was available to reliably infill this period. For the purposes of this study, it was decided that it was preferable to flag periods of missing data rather than to infill them with uncertain data.

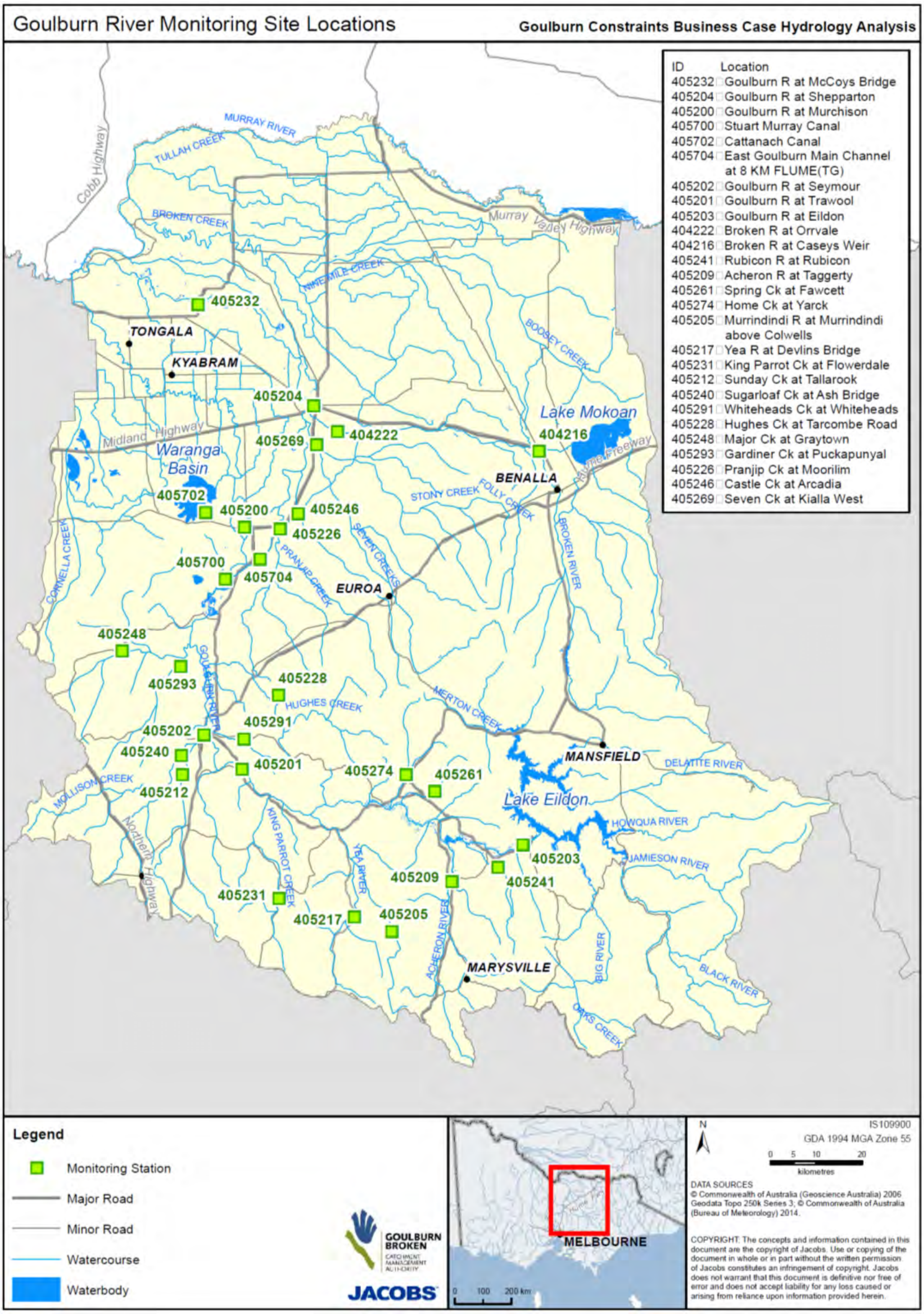

Figure 2.1 : Location of Stream Gauging Sites

Table 2.1 : Stream Gauge data period of record and quality

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

2.2 Flow Routing

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

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

The key sites which were used were:

- Goulburn River at Eildon (405203)

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

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

For the purposes of this study local inflows between major gauges on the mainstream are termed "ungauged inflows". These are calculated using a water balance in each reach and can be negative which represents loss.

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

2.2.1 Eildon to Trawool

This reach included the following inflows:

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

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

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

The routing groups in this reach were:

- Group 1
    - 405203 - Goulburn River @ Eildon
    - 405241 - Rubicon River@ Rubicon
    - 405209 - Acheron River @ Taggerty

- Group 2
    - 405205 - Murrindindi River @ Murrindindi above Colwells
    - 405217 - Yea River @ Devlins Bridge
    - 405261 – Spring Creek @ Fawcett
    - 405274 - Home Creek @ Yarck
- Group 3
    - 405231 - King Parrot Creek @ Flowerdale

A schematic of the tributaries and gauges in this reach is shown in Figure 2.2.

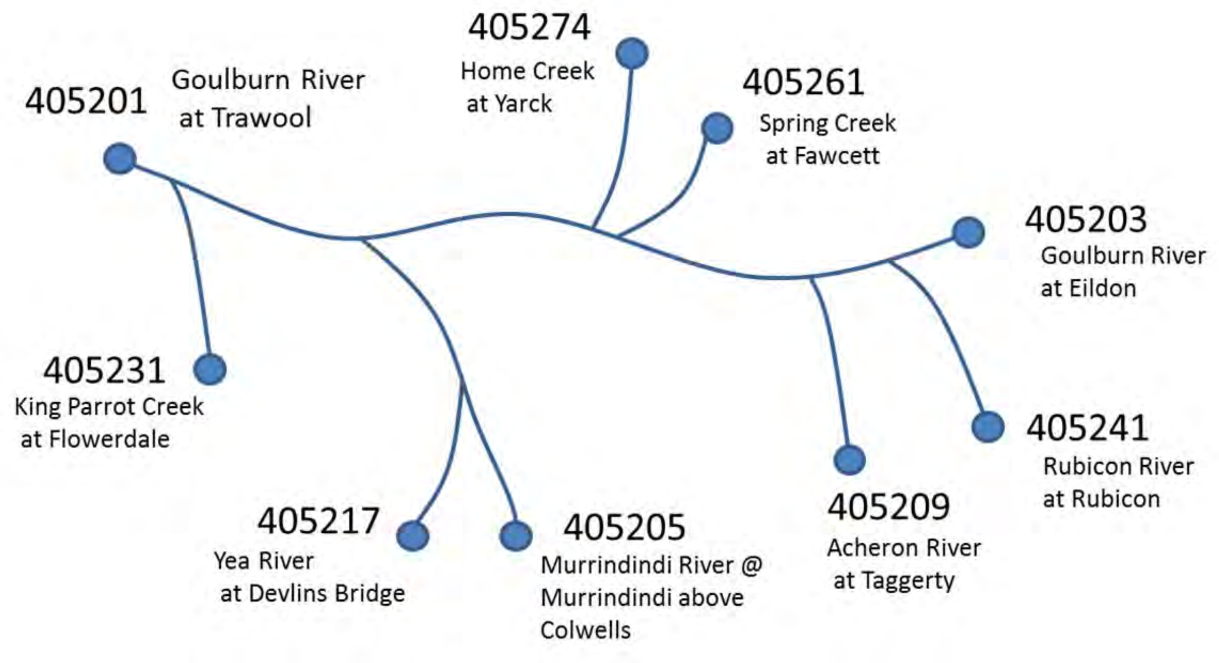

Figure 2.2 : Eildon to Trawool Reach Schematic

The routing parameters were then calibrated using a number of different events to calculate the routed flow at Trawool and the difference between the routed Eildon flow and the Trawool flow.

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

The routing parameters which resulted in the best fit are presented in Table 2.2. The parameter of x is equal to 0.5 implies minimal attenuation in this reach.

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

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

To ensure numerical stability of this approach using Muskingum routing, K, x and Δt must meet the following criteria (Ladson, 2008):

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

As the above parameters do not meet the numerical stability criteria, simple lag routing of 1.55 days was applied to group 1 and 0.8 days for group 2. No lag was applied to group 3. This provides a similar solution with a lag of the same time but is numerically stable, therefore Muskingum routing was not applied in this reach.

The November 2011 event is shown in Figure 2.3. The lines on the plot show:

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

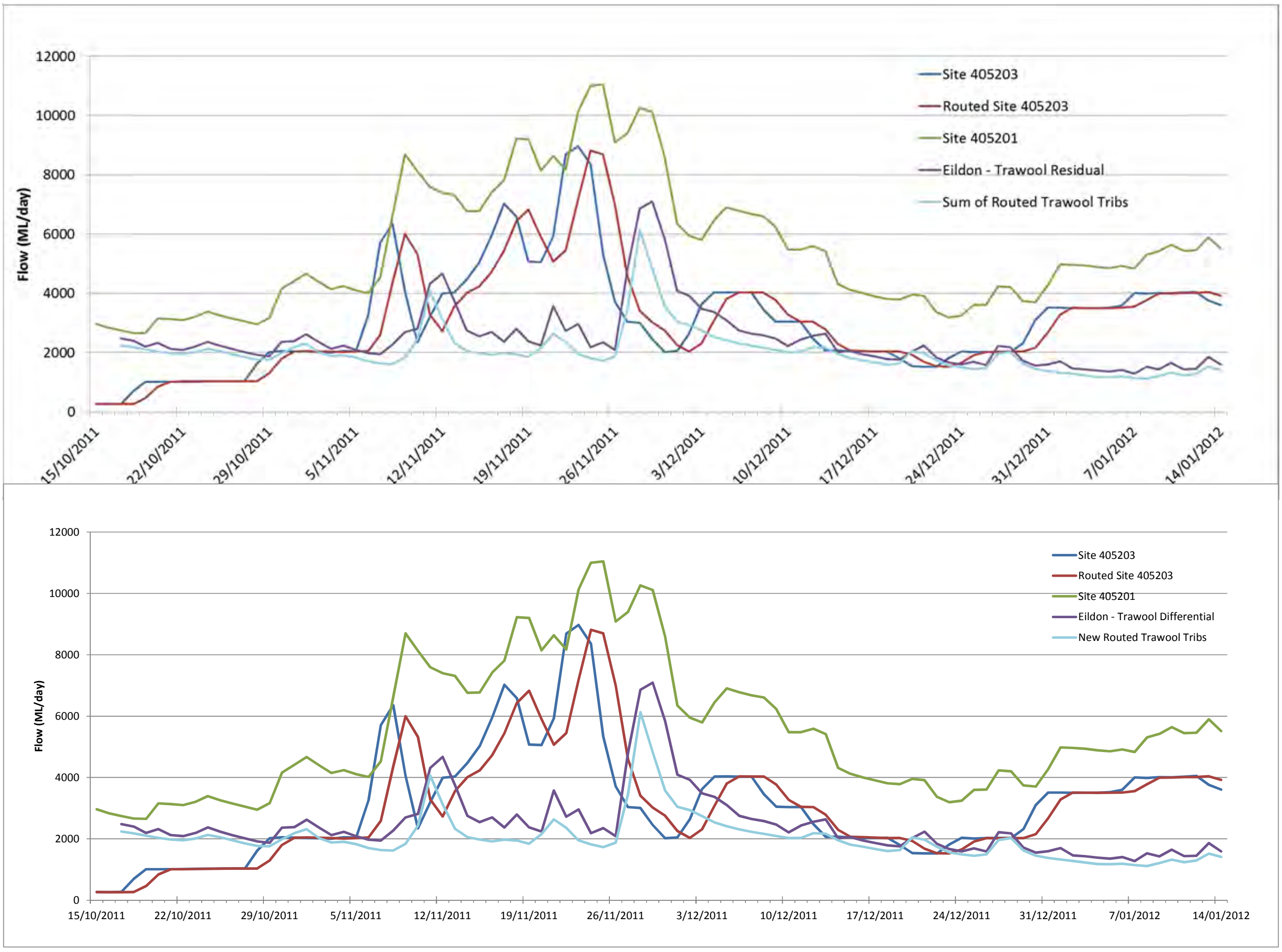

Figure 2.3 : Hydrographs for the Eildon - Trawool reach in November 2011

2.2.2 Trawool to Goulburn Weir

This reach included the following inflows:

- 405201 - Goulburn River @ Trawool
- 405212 - Sunday Creek @ Tallarook
- 405240 - Sugarloaf Creek @ Ash Bridge
- 405291 - Whiteheads Creek @ Whiteheads
- 405228 - Hughes Creek @ Tarcombe Road
- 405248 - Major Creek @ Graytown
- 405293 - Gardiner Creek @ Puckapunyal

The outflow of the reach is inflow to Goulburn Weir. As there is no stream gauge available for the inflow to Goulburn Weir, this was estimated using the outflow from Goulburn Weir and the change in storage of Goulburn

Weir Pool. The outflow was estimated using the sum of recorded flow at Goulburn River at Murchison (405200), Stuart Murray Canal (405700), Cattanach Canal (405702) and East Goulburn Main Channel (405704).

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

The routing groups in this reach were:

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

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

A schematic of the tributaries and gauges in this reach is shown in Figure 2.2.

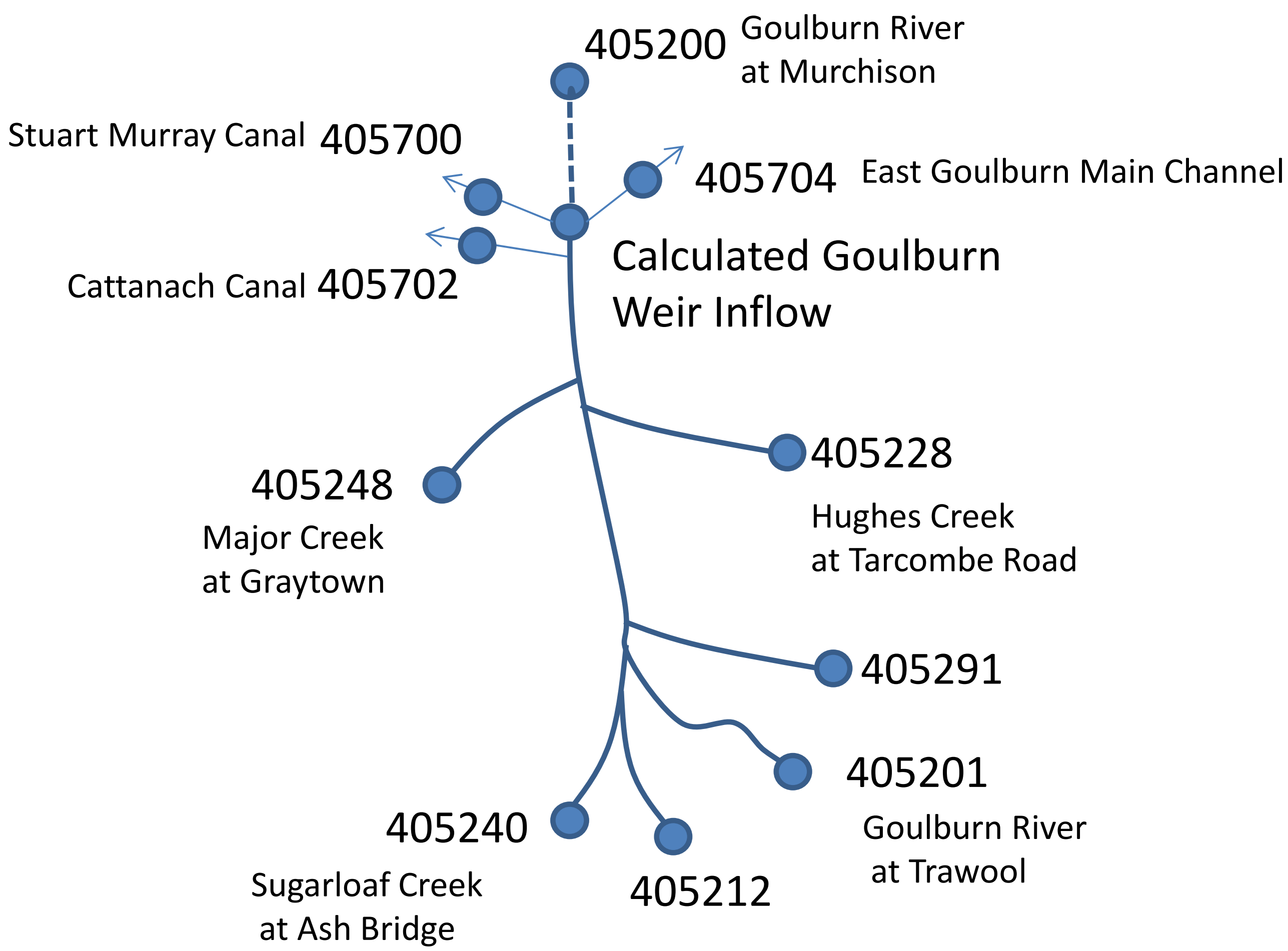

Figure 2.4 : Trawool to Goulburn Weir Reach Schematic

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

The routing parameters applied are presented in Table 2.3.

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

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

Again in this reach, the best fit in terms of Muskingum routing did not meet the stability criteria, therefore simple lag routing was applied. For group 1, a lag of 0.79 days was applied and no lag was applied to group 2.

An event in 2012 is shown in Figure 2.5. The lines on the plot show:

- Historical Trawool gauged flow (Labelled “Site 405201”)

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

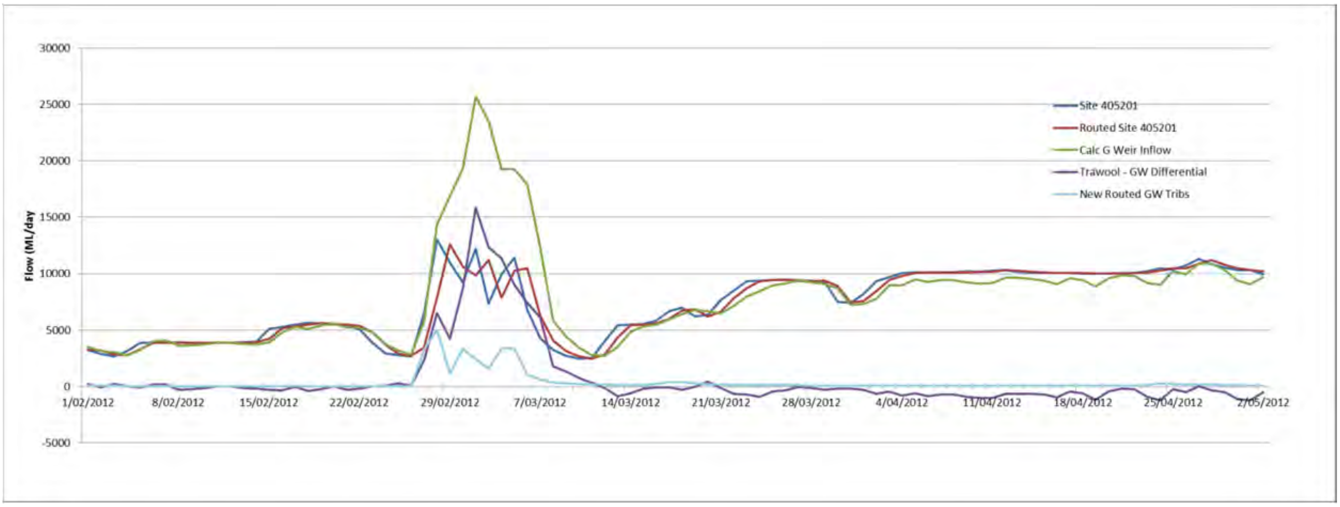

Figure 2.5 : Hydrographs for the Trawool – Goulburn Weir reach in March 2012

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

2.2.3 Goulburn Weir to Shepparton

This reach included the following inflows:

- 405200 – Goulburn River at Murchison
- 404222 - Broken River at Orrvale, infilled and extended using Broken River at Casey’s Weir (404216)
- 405226 - Pranjip Creek @ Moorilim
- 405246 - Castle Creek @ Arcadia
- 405269 - Seven Creeks @ Kialla West

The outflow was Goulburn River at Shepparton (405202).

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

The routing groups in this reach were:

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

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

A schematic of the tributaries and gauges in this reach is shown in Figure 2.6.

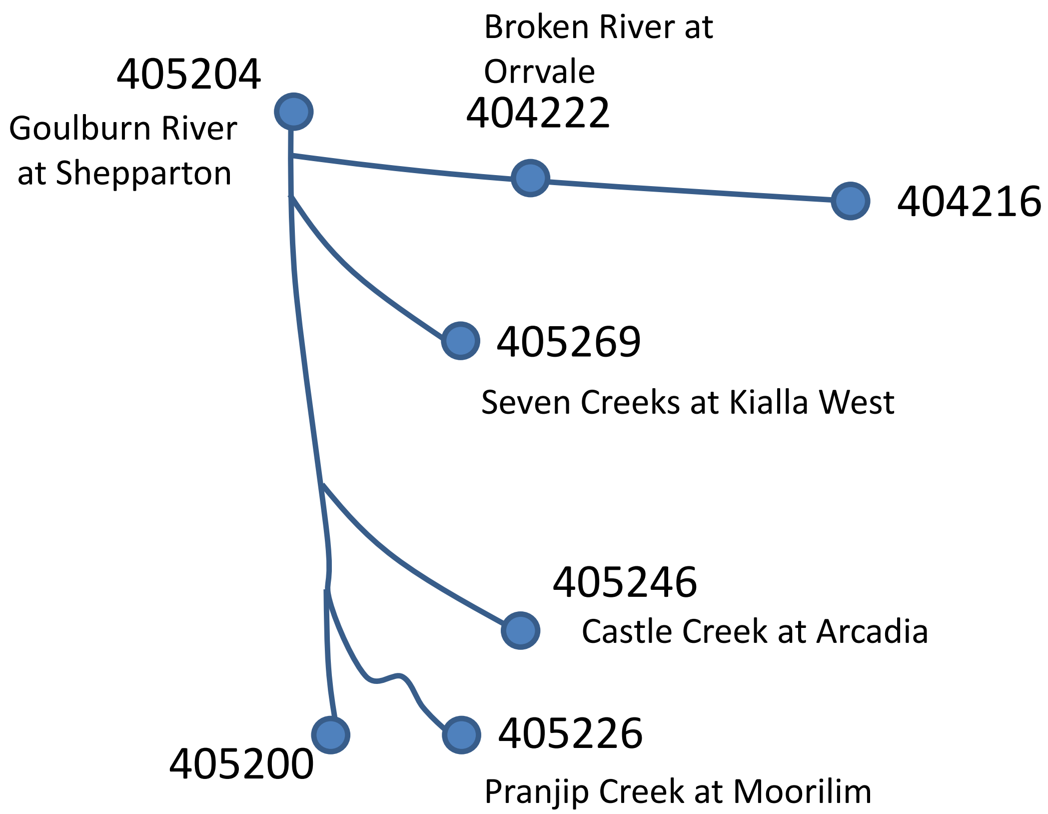

Figure 2.6 : Goulburn Weir to Shepparton Reach Schematic

The routing parameters applied are presented in Table 2.4.

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

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

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

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

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

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

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

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

An event in 2013 was used as one of the events to calibrate the routing parameters for the Casey's Weir - Orrvale reach. This event is shown in Figure 2.7. The lines on the plots show:

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

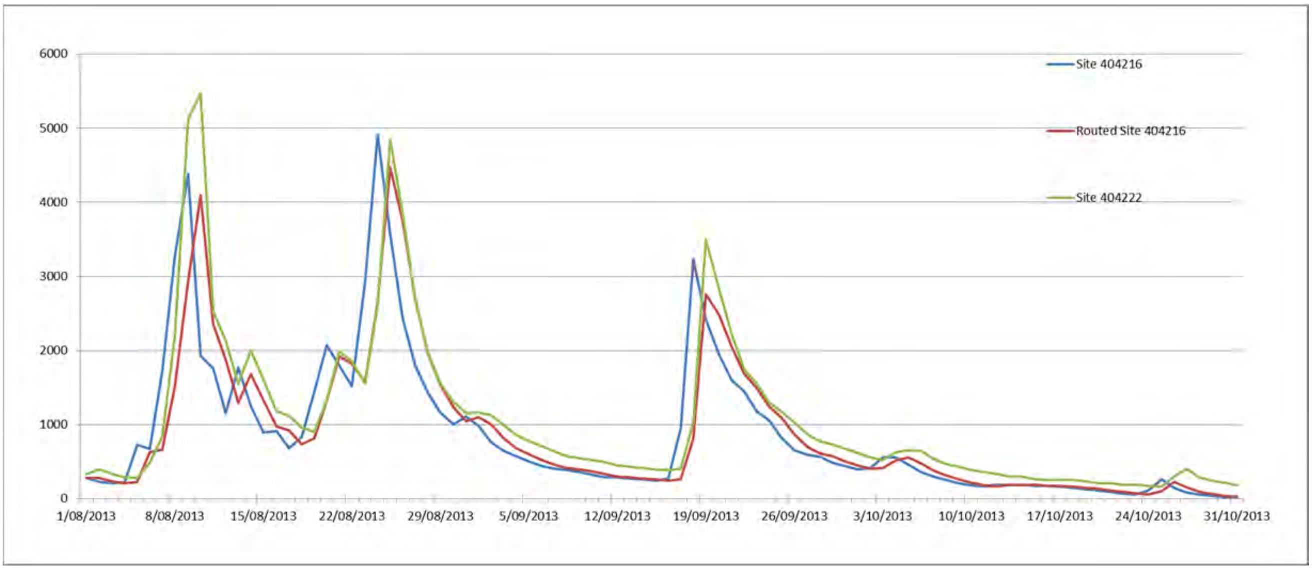

Figure 2.7 : Hydrographs for the Casey's Weir - Orrvale reach in Spring 2013

The same event in 2013 was used as one of the events to calibrate the routing parameters for the Murchison to Shepparton reach. This event is shown in Figure 2.8. The lines on the plot show:

- Historical Murchison gauged flow (Labelled "Site 405200")

- The historical Murchison gauged flow routed to Shepparton using the routing parameters of group 1 in Table 2.4 (Labelled “Routed Site 405200”)

- Historical Shepparton gauged flow (Labelled “Site 405204”)

- The difference between the gauged flow at Shepparton and the routed Murchison flow. This is the calculation of total net inflow in this reach (Labelled “Murchison-Shepparton Differential”). This difference is significantly affected by the chosen routing parameters for Group 1.

- “Routed Lower Goulb Tributaries” which is the gauged tributary flow routed according to the parameters of group 1 and 2 in Table 2.4.

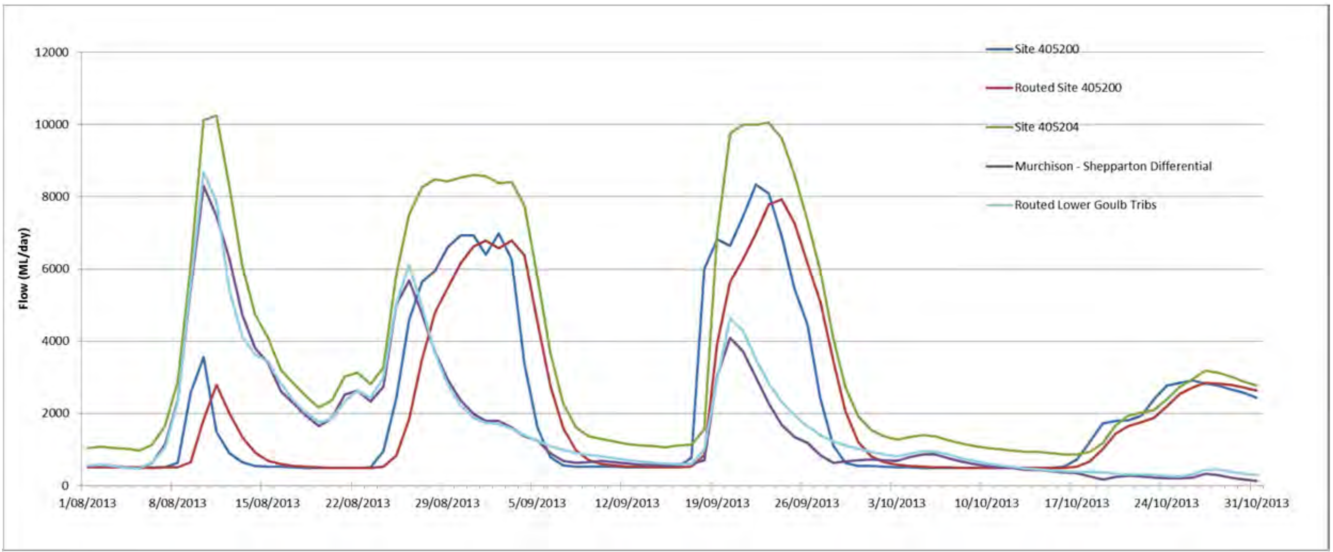

Figure 2.8 : Hydrographs for the Murchison - Shepparton reach in Spring 2013

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

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

3. Flood Event Characterisation

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

Also calculated was the rate of environmental release that would be required from Lake Eildon to create flow at Shepparton of 25,000 ML/day and 40,000 ML/day assuming perfect foresight of future inflows, and assuming no diversions to Waranga Basin. The outcome of this analysis cannot be used directly as a management tool, because perfect knowledge of future inflows is an unrealistic assumption. However the results provide some quantification of the flow rates required in various reaches of the Goulburn River downstream of Eildon in order to achieve the target flows, and also provide an additional source of information to help formulate appropriate delivery strategies. Note also the release rate is calculated simply as a four day lag flow and does not allow for any attenuation of flows or any operational constraints on the rate of rise or fall of Eildon releases. Note that the rate of rise and fall downstream of Lake Eildon is an important constraint and has been included in later analysis in this project as described in Section 4.2 – “Eildon releases".

As described in Section 1.2, DSE (2011) identified target flows of a lower bound of 25,000 ML/day to an upper bound of 40,000 ML/day. MDBA (2012) identified two discrete events at Shepparton as follows.

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

Frequencies to achieve these events assuming a target low and high uncertainty are described in MDBA, 2012. Frequencies are expressed as a proportion of years are:

- 70% - 80% of years for the 25,000 ML/day event with a maximum period between events of 3 years, and
- 40% - 60% of years for 40,000 ML/day with a maximum period between events of 5 years.

This frequency has not been applied as part of project as the analysis has been applied to all events in the period of record to ensure as much of the historical record was used to evaluate variability between events.

The calculated flow at Shepparton assumes a rate of rise of 0.8 m/day from the peak of the historical event and a rate of fall of 0.72 m/day. This rate of rise and fall is specified in Cottingham et al (2003).

The time series of the contribution of each inflow to the Shepparton flow is shown in Figure 3.1 for an example event. To create a time series of flows that would have occurred if diversions were not made, the Shepparton flow has been adjusted by the routed impact of diversions at Goulburn Weir to Waranga Basin (assumed to be the total Stuart Murray and Cattanach Canal flows) plus the change in Goulburn Weir storage which is sometimes drawn down.

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

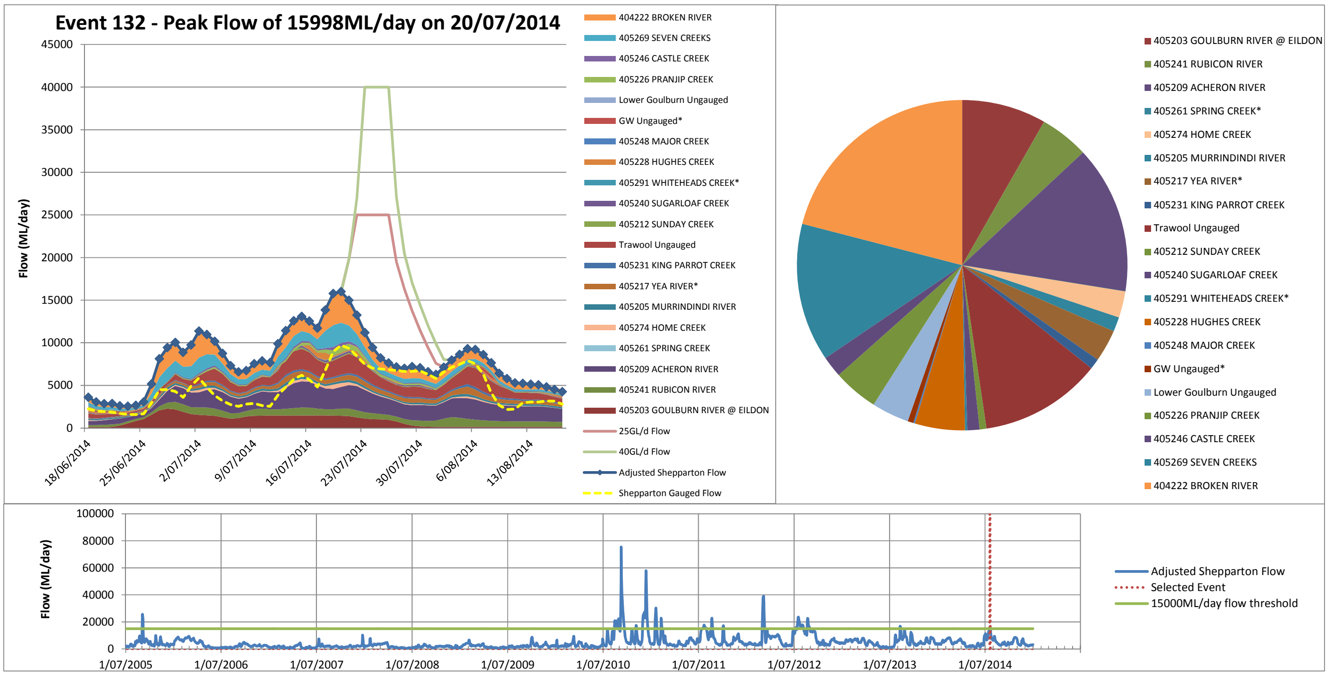

Figure 3.1 : Adjusted Shepparton flow and inflow contributions to the hydrograph

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

- Event
  - Year (this is by calendar year so that the preferred timing of environmental watering events from June to November are captured in the one year for reporting the number of events)
  - Event No
  - Peak Flow (ML/day)
- Timing
  - Month of Peak Flow (Month Number)
  - Years Since Last event > 15 GL/day
- Duration
  - Greater than 15,000 (Days greater than 15,000 ML/day)
  - Days within 5% of peak (Number of days flow is within 5% of the peak flow and greater than 15,000 ML/day)
  - Days within 10% of peak (Number of days flow is within 10% of the peak flow and greater than 15,000 ML/day)
  - Days within 20% of peak (Number of days flow is within 20% of the peak flow and greater than 15,000 ML/day)
- Recession (Recession over the days following the day of peak flow (ML/day/day))

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

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

The formatting has been applied to the following columns:

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

Table 3.1 : Event Summary Table 1960 - 1985

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

Table 3.2 : Event Summary Table 1986 - 2014

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

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

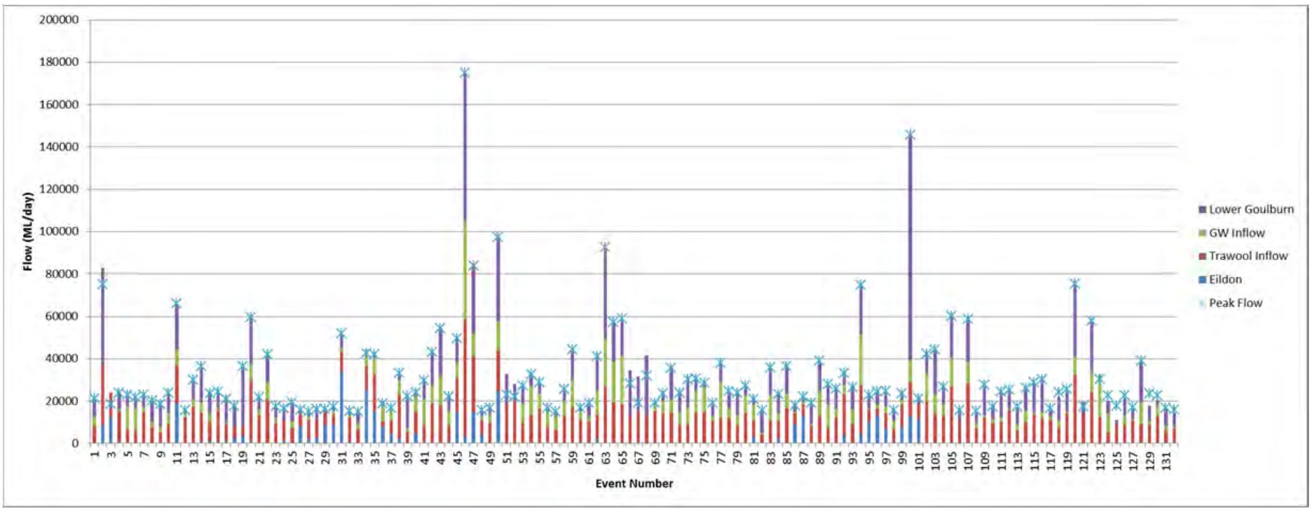

Figure 3.2 : Proportion of contribution to the day of peak flow of the event of the adjusted Shepparton flow for each event

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

3.1 Description of Events

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

3.1.1 Scale of Events

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

Table 3.3 : Events above 50,000 ML/day

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

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

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

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

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

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

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

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

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

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

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1960							21		75		19	
1961								24				
1962							23					
1963						22	23	20/18		24		
1964										66		
1965							16	30	36			
1966								24	25	21		18/36
1967												
1968						60	22	42/17		17		
1969							19		16			
1970					15		16/16	17	52			
1971					15				15	43	42	
1972		18										
1973		17/33			22	24	30	43	54	22/50		
1974					175					84		
1975								16/17	97			
1976												
1977						23	22					
1978							27	33	29			
1979								17/15	26	44		
1980							17/19					
1981						41	93					
1982												
1983								57	59			
1984								28	19	32		
1985								19/23				
1986							36	24	30	31		
1987						29	19	38				
1988						25	24		27		21	
1989				16		36	23		37/18		22	
1990							19/39					
1991							28		26/33			
1992									27	75	23	24

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

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

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

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

In summary it was found that:

- smaller flow events tended to occur earlier (July/August) in the winter/spring season, and larger events tended to occur later (September/October) in the season.
- the majority of events up to 40,000 ML/day had Waranga Basin harvesting water at the same time (which would allow flows to be easily increased by ceasing diversions to Waranga Basin). Events with peak flows above 40,000 ML/day tended not to have Waranga Basin harvesting water (as they tended to be later in the winter/spring season and Waranga Basin was more likely to be full before the event).
- Lake Eildon was often releasing water during and after flow events above 40,000 ML/day, and for some events less than 25,000 ML/day. It was noted that significant existing releases reduces the available capacity to increase Lake Eildon releases to achieve desirable environmental flows.

3.1.2 Sequence and timing of events within the year

In the 55 years of record evaluated, 11 had no flow events in the Goulburn River at Shepparton above 15,000 ML/day, and therefore would not have been considered for environmental releases. Of the remaining 44 years, there were seven years with only one event. Most years (37) had 2 or more events. Figure 3.3 shows the distribution of number of events per year for each year from 1960 to 2014.

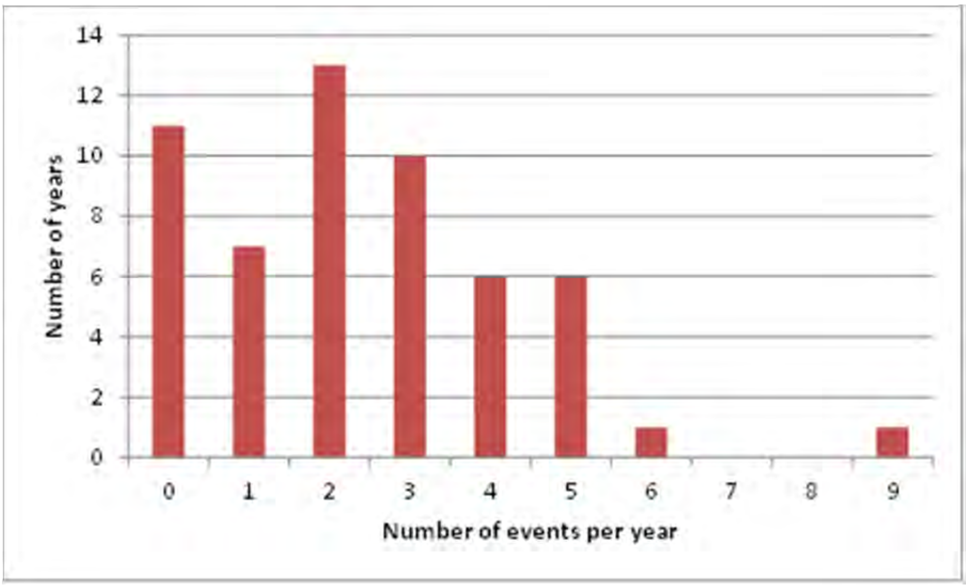

Figure 3.3 : Number of events per year

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

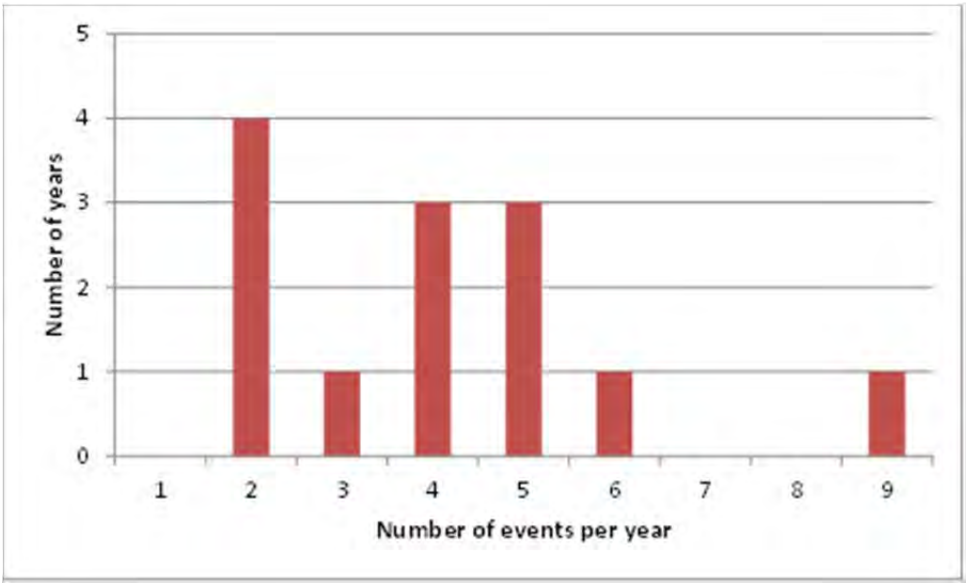

Figure 3.4 : Number of events per year which include an event in May or June

Similarly, there are 24 years with events in July, where 17 have similar or bigger events in later months and seven have years where the July events did not have later events (ie 1962, 1977, 1980, 1981, 1990, 1995, and 2014). Of these seven years, two were less than 20,000 ML/day, two were between 20,000 and 25,000 ML/day, and three were greater than 39,000 ML/day (with two of these three exceeding the 40,000 ML/day environmental watering threshold and the third almost achieving the threshold.). Hence, not releasing environmental water in July would mean no watering in seven years (with three achieving or almost achieving the 40,000 ML/day threshold without any additional release.).

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

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

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

3.1.3 Sequence and timing of events between years

As described above, all events above a flow threshold of 15,000 ML/day were identified in the record to examine the individual characteristics of every flow event to ensure as wide a range of historical events as possible could be analysed. This section describes an initial assessment that was undertaken to identify the potential years in which environmental flow releases would be most efficiently released to maximise Shepparton event peak magnitude, within an ecologically suitable period, for the least volume of water released.

The environmental objective for the lower Goulburn floodplain is to achieve inundation of river redgum trees between four and six times per 10 years on average, with a maximum period between events of 5 years.

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

Natural successful watering events (without Waranga Basin ceasing diversions) greater than 40,000 ML/day (and events between 25,000 and 40,000 ML/day) occurred in the years presented in Table 3.8. Years with no events with peak flows greater than the nominated threshold for event identification of 15,000 ML/day are presented in red. Years of potential for environmental release are included based on the criteria that at least two years has passed since an event with a peak flow greater than 40,000 ML/day has occurred and the year has at least one event in the year exceeded the peak flow of 15,000 ML/day.

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

Year	>40,000 ML/day	25,000-40,000 ML/day	Potential Years of Release
1960	Sep		
1961			
1962			Yes
1963			
1964	Oct		
1965		Sep	

Year	>40,000 ML/day	25,000-40,000 ML/day	Potential Years of Release
1966		Dec	Yes
1967			
1968	Jun/Aug		
1969			
1970	Sep		
1971	Nov/Oct		
1972			
1973	Aug/Sep/Oct	Feb/Jul	
1974	May/Oct		
1975	Sep		
1976			
1977			Yes
1978		Aug/Sep	
1979	Oct	Sep	
1980			
1981	Jul	Jun	
1982			
1983	Aug/Sep		
1984		Oct	
1985			Yes
1986		Jun/Aug/Sep	
1987		May/Jul	
1988		Sep	Yes
1989		Jun/Sep	
1990		Jul	
1991		Sep/Sep	Yes
1992	Oct		
1993	Oct		
1994			
1995	Jul	Jun	
1996	Aug/Oct		
1997			
1998			Yes
1999			
2000		Sep/Nov	Yes
2001			
2002			
2003			Yes
2004			

Year	>40,000 ML/day	25,000-40,000 ML/day	Potential Years of Release
2005			Yes
2006			
2007			
2008			
2009			
2010	Sep/Dec		
2011		(Jan)	
2012		(Mar)	Yes
2013			
2014			Yes

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

3.1.4 Flow Duration and Rates of Recession

The event plots in Appendix A show the desirable duration of watering events at 25,000 ML/day and 40,000 ML/day, presuming additional environmental water releases start at the peak flow. Many of these show that the current peak duration is quite short, and the rate of fall in the flow after the peak is relatively fast (Generally in the order of the maximum rate of fall specified in Cottingham et al (2003) of 0.72 m/day) Hence, the analysis indicates significant releases from storage would be required to maintain the flow duration after the natural peak has passed.

Statistics are presented in Table 3.1 and Table 3.2 on the duration of peak flow, rate of recession and the maximum Eildon flow releases that would be required to maintain a target flow. In many events, these maximum releases need to be very high as they have to increase flows after the event peak has passed (rather than during the event). This resulted in simulated releases from Eildon at a rate which would cause unacceptable flood damage in the reaches downstream, which is unrealistic.

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

- estimating the release required from Eildon based on a straight lag of four day travel time with perfect knowledge
- no allowance for operational constraints of rise and fall, and
- not accounting for the effect of attenuation in the river as the additional Eildon release flows downstream.

Further more detailed analysis to evaluate the duration of flow events, rates of recession, and the timing of releases to increase events is presented in Section 4.

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

3.1.5 Source of River Flows

The graphs in Appendix A show where the water comes from in the catchment for each flow event. The flows are divided up into three areas – between Eildon and Trawool, between Trawool and Goulburn Weir, and downstream of Goulburn Weir. This is summarised in Table 3.1, Table 3.2 and in Figure 3.2. Within these areas, flows from different tributaries are shown. These show that flow events are usually generated from the whole catchment, but the balance between different parts of the catchments can change significantly between events. As noted earlier, Lake Eildon releases can be a significant source of water in some flow events.

Of particular note, the ungauged catchment upstream of Trawool generates significant flow in most events. The high yield of this catchment area is important to the potential delivery of environmental flow from Eildon due to its proximity to Eildon, as this means releases from Eildon are more likely to be able to enhance these events than if the source of the water was further from Eildon. Approaches to reduce the uncertainty of where in the ungauged area that these flows originate from (such as additional flow gauging) need to be further considered. In order to potentially make environmental releases to coincide with catchment rainfall runoff, it is important to know where in the catchment the flow is generated from and how much there is in order to manage the timing and rate of release. The ungauged catchment downstream of Trawool generally generates less runoff.

4. Environmental Release Constraints

A number of aspects of the hydrology and water infrastructure of the Goulburn and Broken rivers impose constraints on the ability to deliver environmental flow events from Lake Eildon to Shepparton. These include:

- the flow travel time from unregulated tributaries to Shepparton and from Lake Eildon to Shepparton
- the maximum rate of rise and fall of Eildon releases based on operational constraints
- the maximum flow rate in the Goulburn River in reaches from Lake Eildon to Shepparton

4.1 Travel Time

The initial assessment of the potential release rates from Lake Eildon required to achieve a target flow and duration at Shepparton of 25,000 ML/day and 40,000 ML/day (as discussed in Section 3 above) assumed that the release from Eildon would start to arrive at Shepparton on the day of peak flow and increase at a rate according to the environmental target of 0.8m/day.

This assessment showed that in many events, the release required from Lake Eildon was too high, which would cause unacceptable flood damage in the reaches downstream of Eildon and would also use very large amounts of environmental water in storage. This is because the releases mainly increase flows after the event has passed rather than during the event. An example of the September 1998 event is shown in Figure 4.1. This had a peak flow rate of over 27,000 ML/day, but to achieve an event of 25,000 ML/day for five days, the rate of release required is approximately 16,000 ML/day assuming that the flow release from Eildon reaches Shepparton after the peak of the event.

It can be seen that there are four days in this event which are greater than 17,000 ML/day, therefore if the release from Eildon could increase the rising limb of the hydrograph (on 25/9/1998) by around 7,000 ML/day and continue through the peak of the event to also increase the flow three days after the peak by around 11,000 ML/day the target flow rate of 25,000 ML/day for five days could be achieved with significantly lower releases.

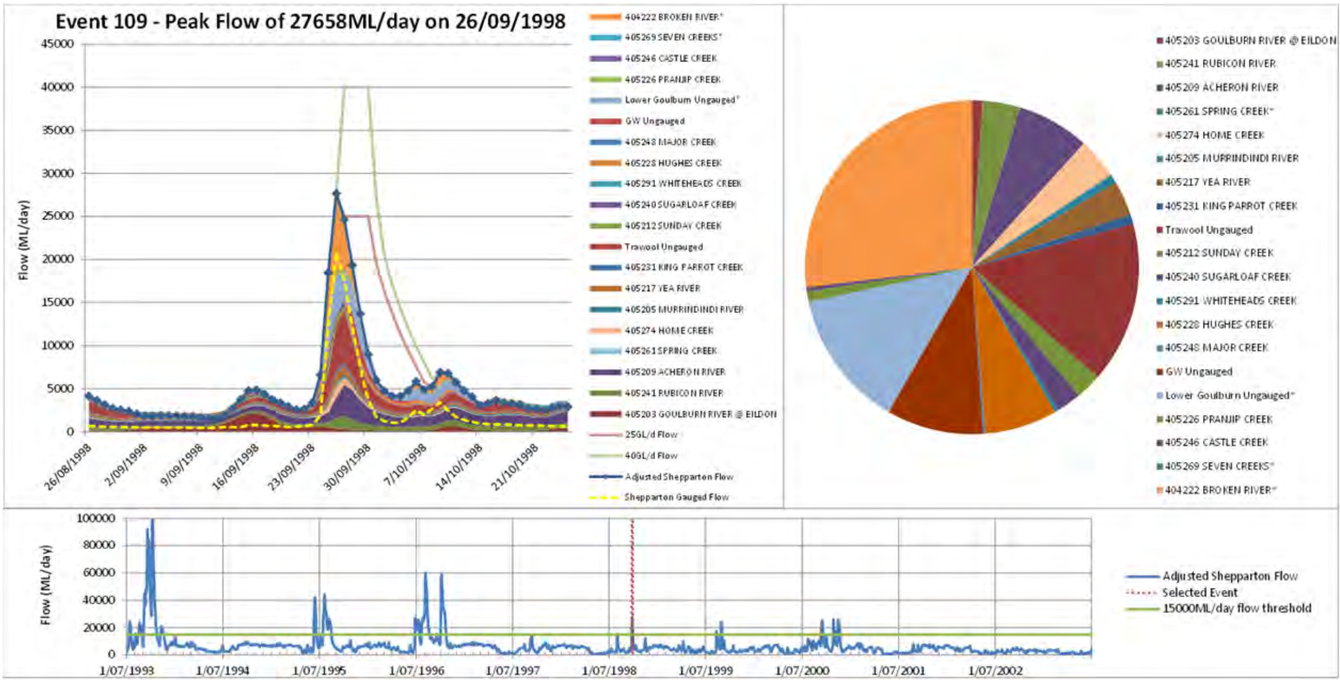

Figure 4.1 : September 1998 event

In order to consider the timing of environmental flow releases reaching Shepparton and coinciding with tributary inflows, the timing of potential releases has been further investigated.

The travel time for flows from Eildon to Shepparton, based on calibrated routing parameters presented in Section 2.2, is a total of four days. This consists of 1.6 days from Eildon to Trawool, 0.8 days from Trawool to Goulburn Weir/Murchison and 1.6 days from Murchison to Shepparton. Travel time on the Broken River based on the routing parameters was 1.2 days from Casey's Weir to Orrvale and 0.7 days from Orrvale to Shepparton. Examination of the flow record upstream of Casey's Weir to Moorngag and Moonee Creek indicate a travel time of approximately one day (See Appendix B). This means that there is a total travel time in the Broken catchment from the upper catchment at Moorngag and Moonee and Hollands Creek gauging stations to Shepparton of approximately three days.

A schematic of travel times in the Goulburn and Broken Rivers is shown in Figure 4.2.

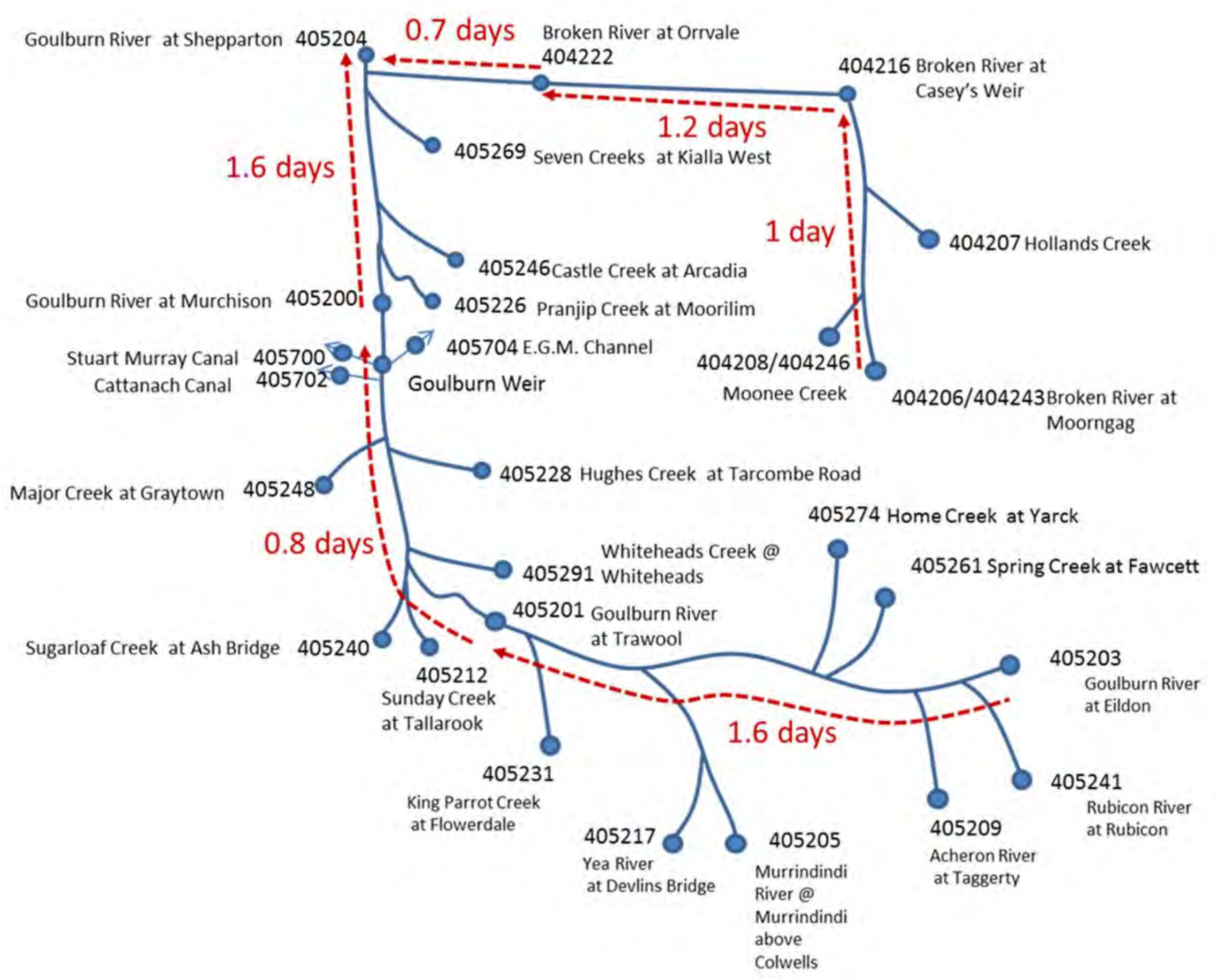

Figure 4.2 : Travel time schematic

This shows that the flow travel time from Lake Eildon to Shepparton is longer than any other flow travel time in the Goulburn (excluding upstream of Eildon) and Broken valleys. Of particular note is that the flow characterisation review identified that of the flood events, a large proportion of the flow was contributed by the ungauged catchment area upstream of Trawool. This area is between zero and 1.5 days downstream of Lake Eildon. The Broken River at Orrvale was also identified as an important contributor to a significant number of events. This is over 3 days travel time downstream of Eildon. Therefore if a release was initiated from Eildon on the basis of waiting for a peak flow at Orrvale to occur, the increase in flow rate due to the release from Lake Eildon would not arrive at Shepparton until three days later.

It is noted that Figure 4.2 shows travel times based on calibrated values using daily timestep data. Events vary in travel time to some degree. Further work could be undertaken using data at a timestep less than a day such as hourly data to investigate variations in travel time.

4.2 Eildon releases

The maximum release rate

The maximum rate of release from Lake Eildon is not limited by infrastructure at the lake. The maximum release rate is however limited by the maximum acceptable flood damage in the reaches downstream. The maximum acceptable release rate will be determined as part of the wider Goulburn Constraints project.

Maximum rate of rise and fall of Eildon releases

The current operational constraint on the rate of increase in release from Lake Eildon applied by Goulburn Murray Water is 3,500 ML/day/day. Constraints on the rate of decrease are based on rates of change in river levels.

Environmental flow recommendations for this reach of the mid-Goulburn (Cottingham, et al, 2014) state that the maximum rate of rise as defined by today's flow divided by yesterday's flow is 2.0 – 2.7. The maximum rate of fall is specified as 0.8 as ratio of todays flow divided by yesterdays flow.

Assuming a first day increase of 3,500 ML/day, the maximum increase in flow for these three rates is presented in Table 4.1. This shows that the current GMW operational constraint on rate of rise is more of a limitation on releases than the 2.0 -2.7 multiple of yesterdays flow as recommended by Cottingham et al (2014).

It can be seen that the constraint on maximum rate of rise affects how quickly Eildon releases can be made for an environmental release. Depending on the flow rate required, the rate of rise constraint adds two to four days to the time required from the initiation of the event to the time the target release rate arrives at Shepparton.

Therefore, a release would need to have been initiated from Lake Eildon between six to eight days in advance of the peak flow at Shepparton occurring due to tributary inflow downstream of Eildon.

Table 4.1 : Rates of Rise of Eildon Releases

Day Number	Rate (3500 ML/d/d)	Rise (Q2/Q1) = 2.0	Rise (Q2/Q1) = 2.7
1	3,500	3,500	3,500
2	7,000	7,000	9,450
3	10,500	14,000	25,515
4	14,000	28,000	
5	17,500		
6	21,000		

Given the potential impact that this rate of rise constraint has on the amount of time required to make significant environmental release rates from Lake Eildon, further investigation into the maximum rate of rise downstream of Eildon is recommended in terms of the current GMW operational constraint and potentially also the range recommended range as per Cottingham et al (2014).

4.3 Maximum flow rate in the Goulburn River in reaches from Lake Eildon to Shepparton

Constraints on flow rates in reaches of the Goulburn River downstream of Eildon are currently being reviewed as part of the Goulburn Constraints Strategy. This process may result in maximum desired flow rates in various reaches of the river. Therefore potential environmental releases from Eildon may be constrained by the maximum downstream flow requirements.

5. Potential Environmental Release Strategies

An objective of the this study was to assess whether environmental releases from Lake Eildon can be added to tributary flows to create desirable environmental events in the range of 25,000 ML/day to 40,000 ML/day in the lower Goulburn River. Undesirable outcomes include a release being made and not increasing either the flow rate or duration above 25,000 ML/day, or for a release to cause an increase in flow above this range which may cause flood damage.

This section describes potential release strategies for delivery of environmental events. An environmental release strategy may include:

- the target flow and duration at Shepparton
- conditions to trigger the start of an environmental release
- consideration of operational constraints such as the maximum rate of rise and fall of the release and maximum rate of flow in different reaches of the Goulburn River and flow travel time discussed in Section 4
- responses to available information during the event to modify the release
- operation of infrastructure downstream of Lake Eildon to help manage risk of exceeding the target flow or not reaching target flow
- environmental water available in the environmental water accounts

These are discussed in the sections below.

5.1 Target flow and duration at Shepparton

As discussed in Section 3, MDBA (2012) describes the following two flow events:

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

Department of Sustainability and Environment (2011) indicates that there is likely to be environmental benefit to achieving flows between these target flow rates, and potential to also achieve environmental benefits with lower durations.

Therefore, an environmental release strategy could include a target flow and duration at Shepparton, or potentially target *an increase* in flow and duration at Shepparton.

The objective of *an increase* in flow and duration may be to achieve an incremental environmental benefit by increasing the flow rate from say 30,000 ML/day for 1 day to 35,000 ML/day for three days.

The preliminary analysis of the releases required for the two fixed targets of 25,000 ML/day and 40,000 ML/day (as discussed in Section 3) showed that very large releases were required for many events which are not practical due to potential flood damages in the reaches of the Goulburn River downstream of Lake Eildon and the large volume of environmental water that would be used in one event. Therefore an alternative is to assume an upper flow limit in a given reach of the Goulburn River and assess potential release strategies given a constraint.

5.2 Conditions to initiate an environmental release

Conditions to initiate an environmental release may include:

- time of year
- years since a previous event
- the number of events that have already occurred in the current year
- flow rates and rates of recession in rivers and creeks in the Goulburn and Broken valleys.
- rainfall and forecast rainfall
- forecast streamflow

The last three conditions are based on the current and forecast river and catchment conditions. These are described in sections 5.2.1 to 5.2.3.

The first three conditions are all based on preceding events or within-year timing, so they are independent of current and forecast river and catchment conditions. However it should be noted that the target flow and duration of the event being considered is important. For example a 25,000 ML/year flow event for five days may have occurred last year but a 40,000 ML/day event had not occurred for three years.

- Time of Year. As described in section 3.1.2, the preference is for release between August to October inclusive.
- Years since a previous event. As described in Section 3, environmental watering is not required every year, it has been assumed that if an event occurred in the previous year of the target flow that a release is not required in the current year.
- The number of events that have already occurred in the current year. If an event in the current year has already met the required flow target, then a release is not required. As discussed in section 3.1.3, in most years with an event greater than 15,000 ML there is more than one event, with the greater magnitude events usually occurring later in the season.

5.2.1 Flow rates and rates of recession in rivers and creeks in the Goulburn and Broken valleys

Analysis of events at Shepparton with adjusted flow peaks in the range of 20,000-40,000 ML/day typically fall at a rate in the order of 5000 ML/day/day once the peak has passed if there is no subsequent rainfall in the days following the rainfall event which caused the peak flow. Events at Shepparton in the range 15,000 ML/day to 20,000 ML/day typically fall at the rate in the order of 3,000 ML/day/day.

Therefore if releases are made from Eildon based on observed streamflow, and if there is no further rainfall to increase the peak flow at Shepparton, the rate of rise would need to be greater than 3,000-5,000 ML/day (before routing and losses are considered which limits the rate of rise at Shepparton for a given rise at Eildon) . Current operational rate of rise is 3,500 ML/day

Theoretically, an ideal method to trigger an environmental release would be to have a perfect forecast of the flow at Shepparton up to eight days in advance taking into consideration future rainfall (excluding environmental flow) to then calculate how much additional flow is required to meet a given target flow and duration. This would allow time to begin the release with appropriate rate of rise to then reach a target flow taking into account travel time. Assuming perfect forecast of tributary inflows, then maximum flow constraints in the Goulburn River could be considered in the calculation of the release rate.

The gauged streamflow in the Goulburn and Broken tributaries and the Goulburn River itself could potentially be used as information to trigger an environmental release. However, gauged streamflow alone does not provide a very effective trigger to start an event due to the shorter travel time for the tributary gauged flow to Shepparton than for a release made from Lake Eildon to Shepparton.

5.2.2 Rainfall and forecast rainfall

Rainfall that has already fallen but has not yet translated to streamflow at tributary gauging stations can potentially provide valuable information as it provides additional time in advance for triggering releases. Based on an analysis of daily recorded rainfall data with daily streamflow data, in catchments the size of those in the Goulburn the additional time is in the order of up to one day for peak flows. (This analysis was limited by the differences in the definition of the daily data. Daily streamflow data is reported from midnight to midnight, while rainfall data is reported as the rainfall to 9am each day. To refine this estimate it is recommended that this analysis be undertaken at a sub-daily timestep).

Forecast rainfall products from the Bureau of Meteorology are available in different forms. The Australian Digital Forecast Database (ADFD) contains forecast rainfall and other weather types, presented in a gridded format and covering the next seven days (http://www.bom.gov.au/weather-services/about/forecasts/australian-digital-forecast-database.shtml). A gridded form of forecast rainfall across the catchment could potentially be used as input to a rainfall runoff catchment model to simulate future streamflow events. This is not within the scope of this project, however this could be evaluated in future as a decision support tool for managing environmental releases.

A potential release strategy might include making no release if forecasts indicate that a rainfall event is likely in order to minimise the risk of uncertain catchment runoff, or an alternative strategy may be to make a release based on adding to the runoff from a forecast rainfall event.

There is considerable uncertainty in the forecast rainfall in terms of total rainfall depth and the spatial and temporal variability over an area as large as the Goulburn and Broken catchments during a rainfall event and potentially for multiple rainfall events over a period of days. The flood risk associated with an event being more intense or at a larger scale than forecast would need further investigation. There is also a risk that a rainfall event may be smaller and runoff not sufficient to enable release flows together with catchment runoff to meet a flow rate of over 25,000 ML/day at Shepparton.

5.2.3 Forecast streamflow

Streamflow for unregulated tributaries may be forecast using rainfall runoff modelling techniques or potentially estimated using rates of recession from current flow rates under scenarios of no future rainfall.

The Bureau of Meteorology has recently launched a streamflow forecast product (http://www.bom.gov.au/water/7daystreamflow/) out to seven days. This is currently limited to a small number of tributaries, but if expanded this information could also potentially be used.

If the flow in the Goulburn and Broken tributaries could be forecast up to six to eight days in advance with reasonable accuracy this would provide the required travel time to initiate an Eildon release and increase it to a rate to achieve a target flow.

The forecast flow at Shepparton (without the environmental release) will be important information which could be used to initiate an event or to inform whether an existing release should continue and if so at what rate.

Flow at Shepparton can be forecast out to four days using a number of approaches. River Regulation Operators make estimates of flow in the system into the future for the purposes of managing flows in the system. Typically operators use information on flow already in transit in the system, together with estimates (or scenarios) of future inflows. Such scenarios may be based on no further rainfall, in which case future inflow may be based on the rate of recession from the current flow rate into the future. Alternatively, it could be based on historically similar events or rainfall runoff modelling techniques.

Using streamflow data available on a real time basis, it is possible to estimate the total tributary inflow in various parts of the Goulburn and Broken valleys (assuming no additional rainfall). This can be done using the existing network of streamflow gauges. For example, in order to forecast flow at Shepparton one day in advance, hydrologic routing of flow already passing (or passed) streamflow gauging stations could potentially be used which would capture most of the flow which will arrive at Shepparton (assuming it is not just a local inflow event close to Shepparton from for example Sevens Creek).

Forecast of flow at Shepparton further days in advance can be made using a combination of flow already in the river and a projection of future flow from those catchments which are closer to Shepparton. This could be made using forecast streamflow conditions based on a recession factor assuming no further rainfall, or potentially by using a rainfall-runoff model with forecast rainfall.

5.3 Available information during the event to modify the Lake Eildon release

As discussed above, use of observed streamflow data will be important to manage releases from Lake Eildon, as will forecast streamflow. If forecast streamflow at Shepparton is available, the rate of release from Lake Eildon could be adjusted during the release to achieve the target. If forecast streamflow at locations on the Goulburn River further upstream and of tributaries was available, flow releases could be modified based on expected conditions in the Goulburn River in reaches between Eildon and Shepparton.

5.4 Operation of infrastructure downstream of Lake Eildon

Goulburn-Murray Water maintain major water infrastructure at Goulburn Weir including the Weir structure itself and the offtake structures to the three channels: Stuart Murray Canal, Cattanach Canal and the East Goulburn Main Channel.

5.4.1 Stuart Murray Canal and Cattanach Canal

Stuart Murray Canal and Cattanach Canal convey water to Waranga Basin and together they have a combined capacity of approximately 7200 ML/day. The flood characterisation assessment assumed that flow diverted to Waranga Basin via these channels was included in the Shepparton flow (after allowing for the effects of routing). Conversely, if an environmental release was made from Lake Eildon and the subsequent downstream inflow was higher than expected, and potentially the flow may cause unacceptable flood damage downstream, the operation of these channels during an event would allow the flow at Shepparton to be reduced by up to the capacity of the two channels. This could only happen if capacity in Waranga Basin existed to store the flow or the flow could be passed downstream of Waranga Basin to other locations such as Greens Lake, Lake Cooper or Campaspe River.

5.4.2 Goulburn Weir Pool

Goulburn Weir has a capacity of 25,500 ML. Therefore there is some potential to manage the water level in Goulburn Weir prior to and during an event to either increase the flow rate at Shepparton or decrease it. By drawing down the level of the weir pool, the flow rate in the Goulburn River downstream of the Weir can be increased by releasing some of the stored volume in Goulburn Weir. The ability to gravitate flow to the channels would potentially be impacted if the weir is drawn down too low. This limits the available active capacity of the weir pool.

6. Testing of Strategies

In order to test a number of potential environmental release strategies, the flow characterisation spreadsheet tool was further developed. The development included:

- Adding observed daily rainfall (rainfall to 9am). This was used for testing triggers associated with rainfall and also as a proxy for forecast rainfall (assuming perfect knowledge). The following sites were included in the flow characterisation model:
  - Site 082061 Swanpool (in Upper Broken area)
  - Site 088001 Alexandra
  - Site 088067 Yea
  - Site 088053 Seymour
  - Site 082016 Euroa
- Adding functionality to simulate the triggering of an environmental release from Lake Eildon which can be related to observed streamflow, forecast streamflow, rainfall, and forecast rainfall. This assumes that the release is subject to the same streamflow routing process as described in Section 2.2 above.
- No loss has been assumed. Depending on the conditions into which the releases are made it is expected that losses will be variable. If releases are made into existing high flow conditions, losses may be lower than if the release was made into low flow conditions. Further work will be required in future to quantify losses of environmental releases and be incorporated into release planning and management.
- Simulation of the release from Eildon being routed to Trawool, then to Goulburn Weir and then to Shepparton.
- Additional information was included on the event analysis plots: average daily rainfall for the five rainfall sites listed above, the resulting flow at Shepparton because of the additional Eildon release, and the time series of the Eildon release at Lake Eildon.

6.1 Triggers based on observed streamflow

Initial release strategies used observed streamflow and assumed no forecast rainfall. They were trialled using streamflow as follows.

6.1.1 Eildon to Trawool Tributaries and ungauged catchment area inflows

Flood event characterisation (Section 3) identified that the Goulburn catchment upstream of Trawool is a quite consistent contributor to events at Shepparton. In particular, the ungauged catchment often provides high inflows. This was further investigated to identify whether existing flow gauges can be used to identify times when the ungauged catchment inflow is high (and preferably when Rubicon River and Acheron River are relatively low in order to maximise the potential airspace for release from Eildon). The gauged flow at Trawool excluding the gauged tributaries of Acheron and Rubicon Rivers was trialled. Using gauged flow at Trawool (travel time of 2.4 days from Shepparton) potentially limits the time to initiate an event, as the peak may already be 1 – 2 days downstream of Eildon.

An example event at Shepparton in late September/early October 1963 is presented in Figure 6.1. The flow at Trawool rises quickly on the 1/10/1963. The total flow excluding the impact of the routed Eildon, Acheron and Rubicon River flows rose to 11,250 ML/day from 430 ML/day on the previous day.

If it is assumed that the environmental release can be initiated on the same day and on average is 3,500 ML/day on 1/10/1963, then the following flow hydrograph at Shepparton is achieved. It can be seen that the peak flow is only increased by the slightest amount and most of the flow arrives at Shepparton after the peak has passed. The line on the chart labelled “Additional Eildon Release” is the flow at Eildon (ie not routed to Shepparton). The line labelled “Resulting flow at Shepparton” is the adjusted flow at Shepparton plus the routed additional release from Eildon at Shepparton. “Rainfall” is the daily average of the five sites listed above.

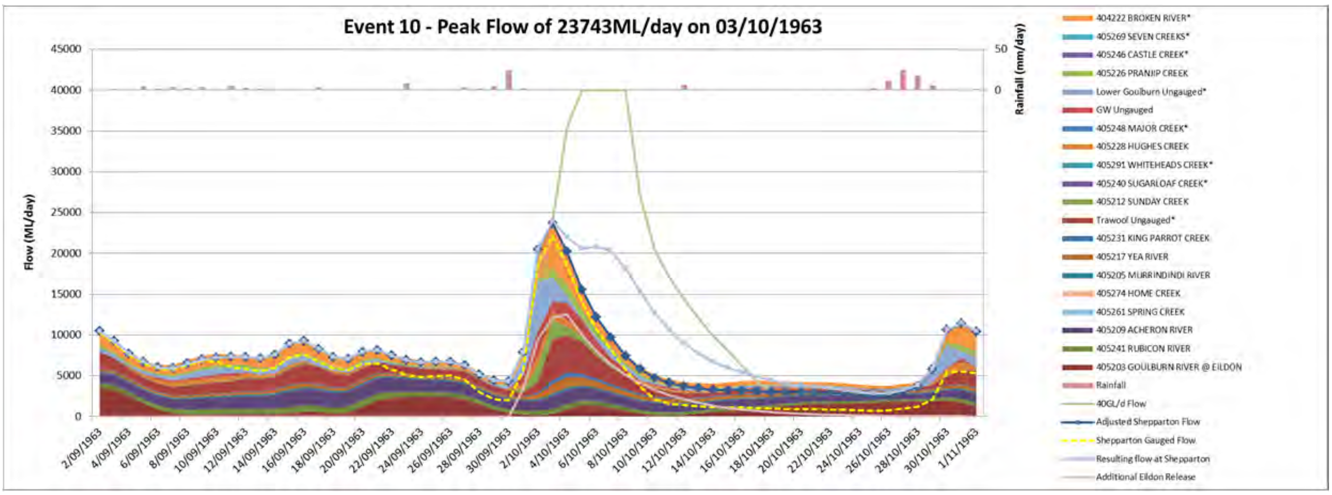

Figure 6.1 : Simulated Environmental Release in 1963 using Trawool flow trigger

An example of a longer duration event with a slower recession is shown in Figure 6.2. It shows that the longer duration flow event is caused by extended rainfall over a period of several days. Using triggers of streamflow early in the event results in the release arriving at Shepparton to coincide with a peak from catchment inflow, but this is only due to the subsequent rainfall that fell in between triggering the release and the flow arriving at Shepparton. The potential to trigger releases based on forecast rainfall is discussed in Section 6.2.

The total flow at Trawool excluding the impact of the routed Eildon, Acheron and Rubicon River flows rose to 11,500 ML/day on 1/7/1980. If the release were to be initiated on this day then the peak release would coincide with the peak from tributary inflows at Shepparton, but only because the rainfall that fell after the release was initiated.

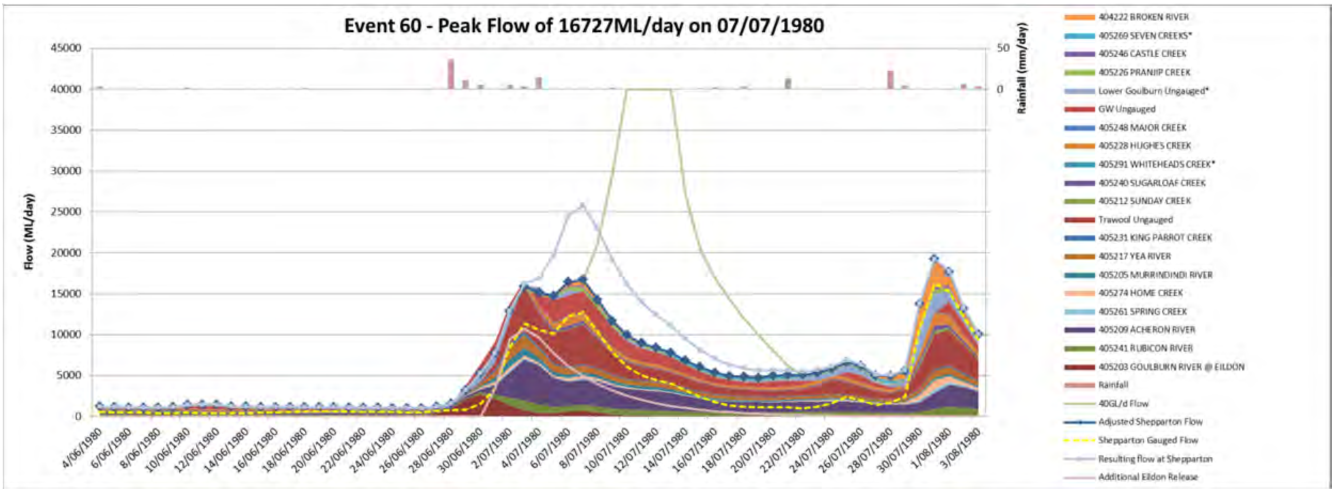

Figure 6.2 : Simulated Environmental Release in 1980

It was assumed that a simple flow trigger of observed streamflow at Trawool excluding the contribution from Eildon, Rubicon and Acheron of 11,000 ML/day is used and only made in the months from August to October and the number of releases calculated. The release assumed that there was a constraint to the maximum release of 15,000 ML/day for the total release from Eildon plus Rubicon and Acheron Rivers gauged flow.

This resulted in 54 releases being triggered out of 70 possible events. Of these, six made no impact on flow at Shepparton with a total of twenty making an impact of less than 1,000 ML/day. Of events with peak flows at Shepparton already greater than 40,000 ML/day, ten events were significantly increased further (by more than 1,000 ML/day).

Figure 6.3 presents each of the 54 events as a column chart with the Shepparton peak flow and the increased peak due to the triggered release. This illustrates that a simple trigger based on observed streamflow alone is not an appropriate strategy as the releases firstly can be too late and make no impact on the peak, or secondly can be initiated based on streamflows that then increase further due to subsequent rainfall then result in increases to flood peaks above 40,000 ML/day which may exceed a maximum flow threshold target.

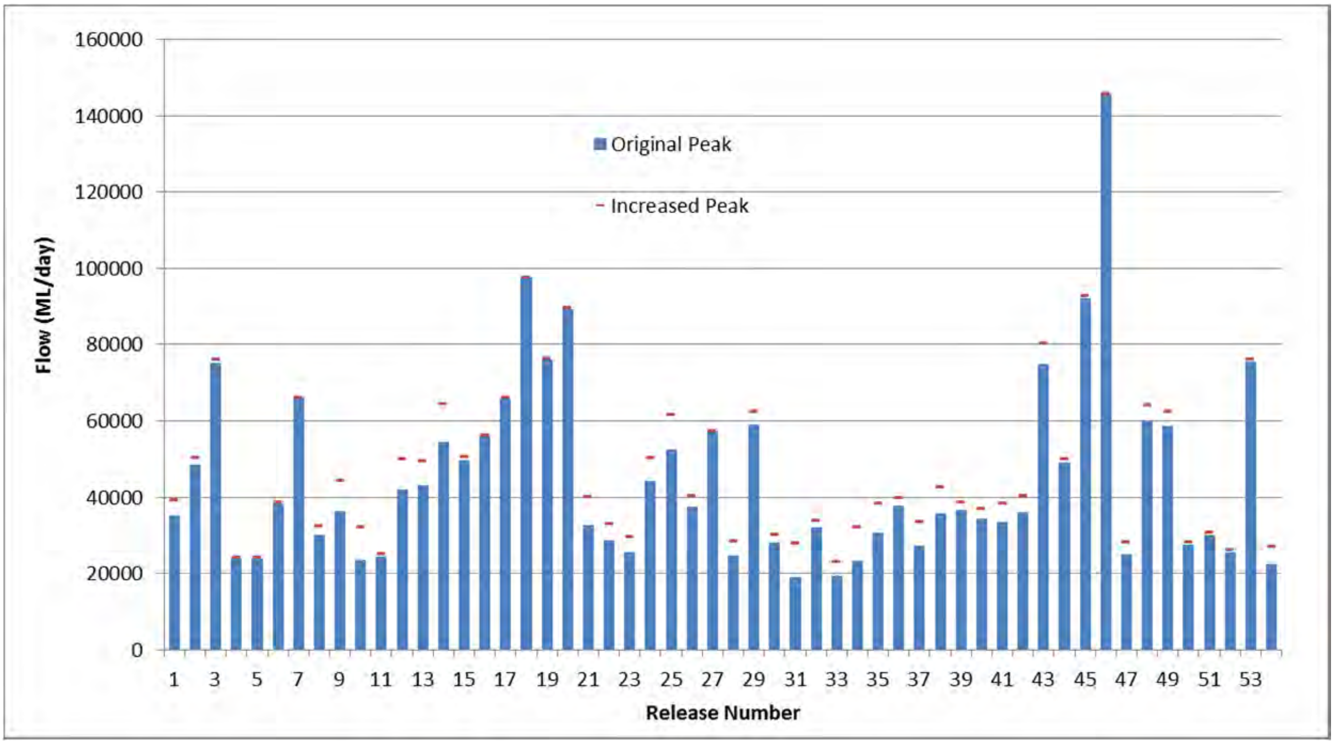

Figure 6.3 : Adjusted Shepparton peak flow events impacted by a release trigger of 11000 ML/day at Trawool (Ex Eildon, Rubicon & Acheron)

Table 6.1 : Summary of event increase (out of 54 events)No Increase	Little Increase (<1000 ML/day)	Increase >1000 ML/day		
		Does not reach 25,000 ML/day threshold	Desirable increase (increase in peak flow between 25000 ML/day – 40,000 ML/day)	Undesirable increase (Greater than 40,000 ML/day)
6	14	1	19	14
11%	26%	2%	35%	26%

6.1.2 Upper Broken River and Holland and Moonee Creeks

As discussed in Section 3.1.5, the Broken River contributes a significant proportion of the flood peak and volume at Shepparton for some events. In most events, the majority of this flow is from the gauged upper Broken River at Moorngag, Hollands Creek and to a lesser extent, Moonee Creek. The travel time for the flow from these three gauging stations to Shepparton is around three days.

In the example event shown in Figure 6.4, the Upper Broken gauged flow rises to 4,400 ML/day on 30/9/1963. If it is assumed that a release from Eildon is initiated on 30/9/1963 to 3,500 ML/day on that day, the impact at Shepparton is slightly improved with regard to the peak flow, but still most of the released flow arrives on the recession of the event and only extends the peak flow for around a day.

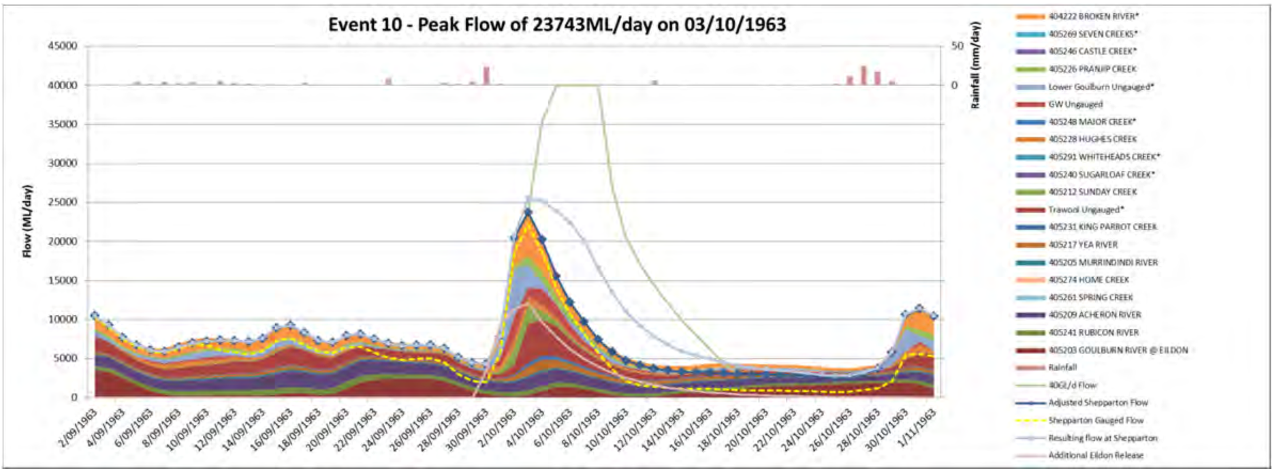

Figure 6.4 : Simulated Environmental Release in 1963 with a day earlier release using Upper Broken flow trigger

It was assumed that a simple flow trigger of observed streamflow of the sum of the Upper Broken gauged flow (Broken River at Moorngag, Holland Creek and Moonee Creek) of 4,000 ML/day is used and only made in the months from August to October, and the number of releases calculated. The release assumed that there was a constraint to the maximum release of 15,000 ML/day for the total release from Eildon plus Rubicon and Acheron Rivers gauged flow.

This resulted in 59 releases being triggered out of 70 possible events. Figure 6.5 presents each of the 59 events as a column chart with the Shepparton peak flow and the increased peak due to the triggered release. This illustrates a number of events can be increased using this simple trigger however it is noted that this simple trigger results in a number of already large events that exceed target flow threshold being increased further.

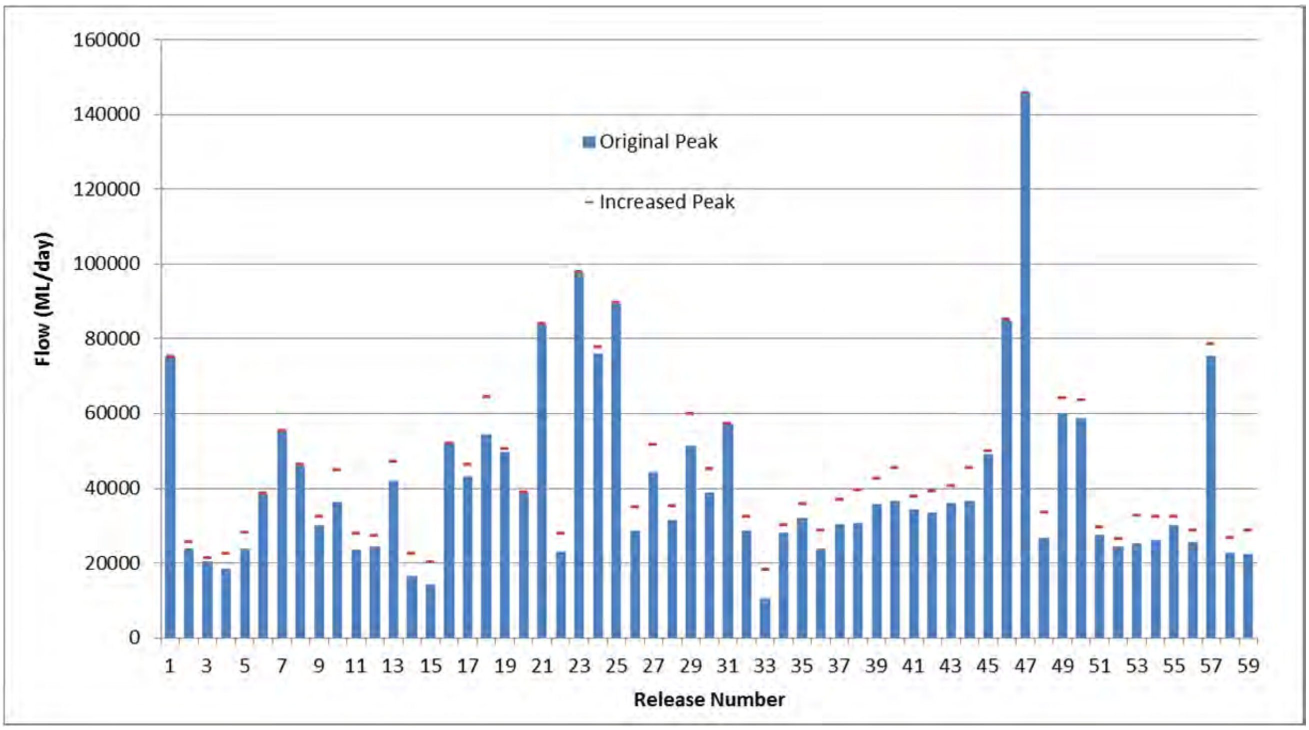

Figure 6.5 : Adjusted Shepparton peak flow events impacted by a release trigger of 4000 ML/day of Upper Broken (Broken River at Moorngag + Hollands Creek + Moonee Creek)

Table 6.2 : Summary of event increase (out of 59 events)

No Increase	Little Increase (<1000 ML/day)	Increase >1000 ML/day		
		Does not reach 25,000 ML/day threshold	Desirable increase (increase in peak flow between 25000 ML/day – 40,000 ML/day)	Undesirable increase (Greater than 40,000 ML/day)
4	11	4	25	15
7%	19%	7%	42%	25%

6.1 Triggers based on observed rainfall

Observed rainfall could be used as a trigger for events and potentially provide additional time before the peak flow at Shepparton occurs. In an example event in 1963, using daily rainfall data up to 9am does not improve the amount of time in advance of the peak flow at Shepparton that the release can be made.

Average rainfall for the five selected rainfall sites on 30/9/1963 was 24mm [with only a small amount of rainfall the following day (2mm)]. If the release commenced on 30/9/1963 at 3,500 ML/day, the peak flow at Shepparton is only marginally increased and most of the additional flow released from Eildon trails on the recession of the event. This date of the initiation of the release is the same as using the Upper Broken streamflow trigger in this example, so the same end result of the timing and peak flow at Shepparton is achieved.

This could potentially be explored further using rainfall and streamflow data at a timestep of less than one day.

It is understood that the Bureau of Meteorology and CSIRO are undertaking current research into short term streamflow forecasting. Techniques include using conceptual rainfall runoff modelling approach for sub-daily/daily flow forecasting out to 7 days using rainfall inputs with modelling outputs adjusted using a site specific correction scheme. Another approach is based on Bayesian Joint-probability methods. Outcomes from such research can potentially be incorporated into a process to forecast flow from the tributaries and also combining it with gauged streamflow data to quantify the flow already in transit in the rivers to forecast flow at Shepparton.

6.2 Triggers based on forecast rainfall

This section describes the potential to use forecast rainfall as a trigger. As historical forecast rainfall is not available, this analysis assumes perfect forecast (ie the historical observed rainfall).

In the example event of September 1963, the significant daily rainfall of 24mm was recorded on 30/9/1963 (to 9am). If the forecast was used to initiate a release on the 28/9/1963 to 3,500 ML/day and then increased to 9,450 ML/day on the 29/9/1963, then the peak flow could be increased substantially as shown in Figure 6.6.

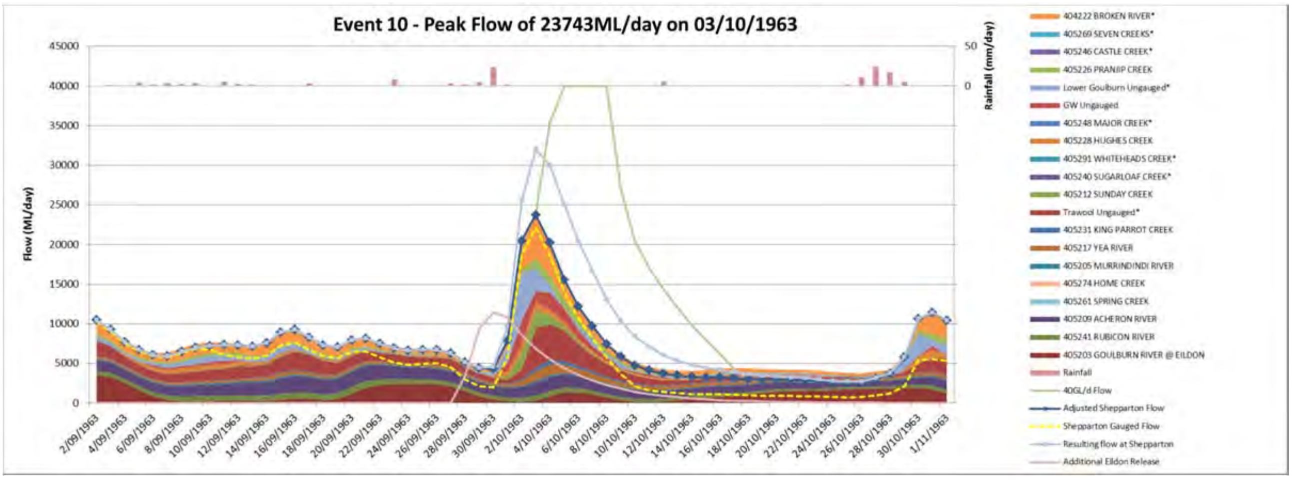

Figure 6.6 : Simulated Environmental Release in 1963 with release using forecast rainfall trigger

If the release were to be initiated two days earlier still on the 26/9/1963 then the peak of the release would coincide with the peak of the tributary inflows and the total flow peak would increase further as shown in Figure 6.7.

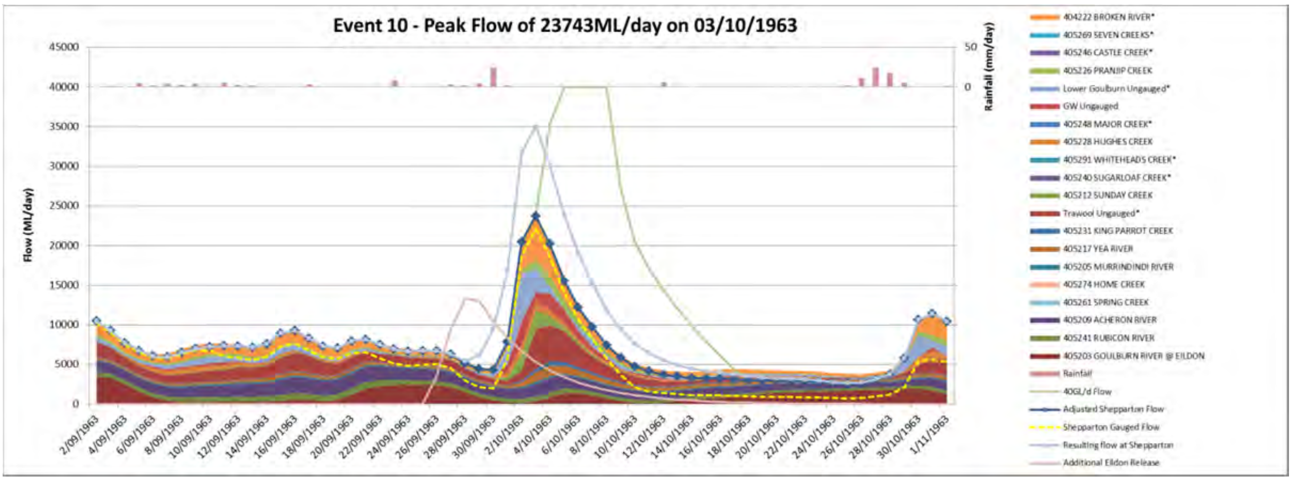

Figure 6.7 : Simulated Environmental Release in 1963 with using earlier forecast rainfall trigger

While these results show the potential benefits of using forecast rainfall, they must be considered in combination with the difficulty of accurately predicting future rainfall volumes and their precise geographic locations. It is recommended that use of forecast rainfall be further tested using actual forecast data rather than observed rainfall.

6.3 Triggers based on forecast streamflow

A combination of observed streamflow, observed rainfall and forecast rainfall could potentially be used to forecast streamflow in the Goulburn River at Shepparton and in various upstream reaches of the river and its tributaries.

Assuming a perfect forecast of streamflow is possible, a number of scenarios were run for each of the 132 events assuming a maximum flow constraint in the Goulburn River downstream of Rubicon and Acheron Rivers of three flow rates:

- 10,000 ML/day
- 12,500 ML/day
- 15,000 ML/day

The release was assumed:

- to begin seven days prior to the forecast flood peak at Shepparton
- at a maximum rate of 3,500 ML/day on the first day
- followed by an increase at 2.7 times yesterday's flow
- a maximum rate of fall of 0.8 of yesterday's flow
- the forecast flow at Shepparton is not used to constrain the release if the resultant flow will exceed 40,000 ML/day

Note that where the rate of increase in flow in the Rubicon and Acheron Rivers exceed the maximum rate of fall of 0.8, the maximum target flow of 10,000 ML/day, 12,500 ML/day or 15,000 ML/day may be exceeded.

The exceedance of peak flow (for each of the 132 events) in the Goulburn River at Shepparton for each of the scenarios is presented in Figure 6.8.

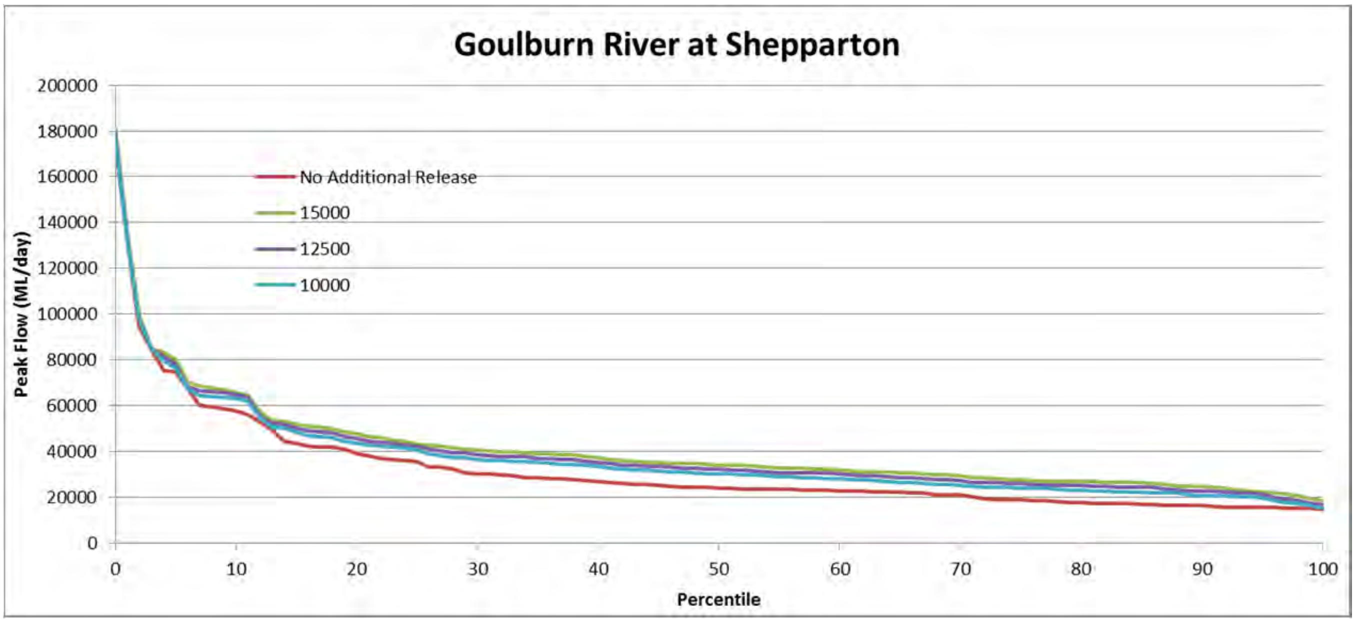

Figure 6.8 : Peak flow exceedance for the 132 events at Shepparton for no release and three scenario releases

Table 6.3 presents the number of the 132 events which exceed flow thresholds between 25,000 ML/day and 40,000 ML/day in the four scenarios. It shows that a significant number of events could be raised that would exceed each of the flow thresholds in these scenarios (remembering that ceasing diversions from Waranga Basin has already raised flows in the 'no additional release' scenario).

Table 6.3 : Number of events which peak flow exceeds given flow thresholds between 25,000 ML/day and 40,000 ML/day

Peak Flow Threshold	No Additional Release	Scenario: Constraint of 10,000 ML/day	Scenario: Constraint of 12,500 ML/day	Scenario: Constraint of 15,000 ML/day
<25,000	72	39	26	16
25,000 - 30,000	17	25	26	28
30,000 - 35,000	9	21	26	26
35,000 - 40,000	8	13	18	20
>40,000	26	34	36	42

The table shows that there are 60 events out of 132 which already meet the 25,000 ML/day flow target (with Waranga Basin diversions ceased). Allowing flows from Lake Eildon up to a combined limit (Eildon/Acheron/Rubicon) of 10,000 ML/day would provide a further 33 events (to provide a total of 93). Lifting the combined flow limit to 12,500 and then to 15,000 ML/day would provide a further 13 and 10 events respectively. Of the 16 events which were not able to be increased to 25,000 ML/day they were all either:

- only just above 15,000 ML/day without the release and just below 25,000 ML/day with the release, or
- they had high Eildon releases in the base case so this limited the additional Eildon release that was possible.

At higher targeted flows, there are less existing flow events, and increased releases generate less additional flow events meeting the flow thresholds.

There are 26 events out of 132 which already would meet the 40,000 ML/day flow target (with Waranga Basin diversions ceased). Allowing flows from Lake Eildon up to a combined limit (Eildon/Acheron/Rubicon) of 10,000 ML/day would provide a further 8 events (to provide a total of 34). Lifting the combined flow limit to 12,500 ML/day and then to 15,000 ML/day would provide a further 2 and 8 events respectively.

Overall, it is relatively easy to generate additional watering events for wetlands needing a 25,000 ML/day flow at Shepparton. It becomes progressively harder to generate higher flow events to water trees on the lower Goulburn floodplain up to the 40,000 ML/day flow rate. On average, 1 to 2 extra flow events per decade are required to meet the target frequency, or 5.5 to 11 events over the period of events being analysed.

The constraint on Lake Eildon releases limits the increase in flows that can be achieved. With a flow constraint of 15,000 ML/day for example, the additional peak Eildon release is up to around 12,000 ML/day (depending on Rubicon and Acheron River flows and the historical Eildon release). After the impact of routing the additional flow to Shepparton, the increase in peak flow is up to around 10,000 ML/day. In the no additional release scenario there are 17 events in the range from 30,000 to 40,000 ML/day. It can be seen that with the 15,000 ML/day constraint scenario that an additional 16 events (42-26) have been increased to above 40,000 ML/day.

The number of events exceeding 35,000 ML/day without release is 34. With the release constraint of 10,000 ML/day the number of events provided at 40,000 ML/day increases from 26 to 34 (i.e. most of the events that were between 35,000 to 40,000 ML/day without release have been increased to above 40,000 ML/day, while 5 events in the range from 30,000 to 35,000 ML/day have been increased to 40,000 ML/day).

The exceedance of peak average daily flow (for each of the 132 events) of the combined Eildon release, Rubicon and Acheron Rivers for each of the scenarios is presented in Figure 6.9.

Similar plots are presented for flow in the Goulburn River at Trawool, Seymour and Murchison in Figure 6.10 to Figure 6.12. The Murchison flow is adjusted for the impact of Goulburn Weir Diversions.

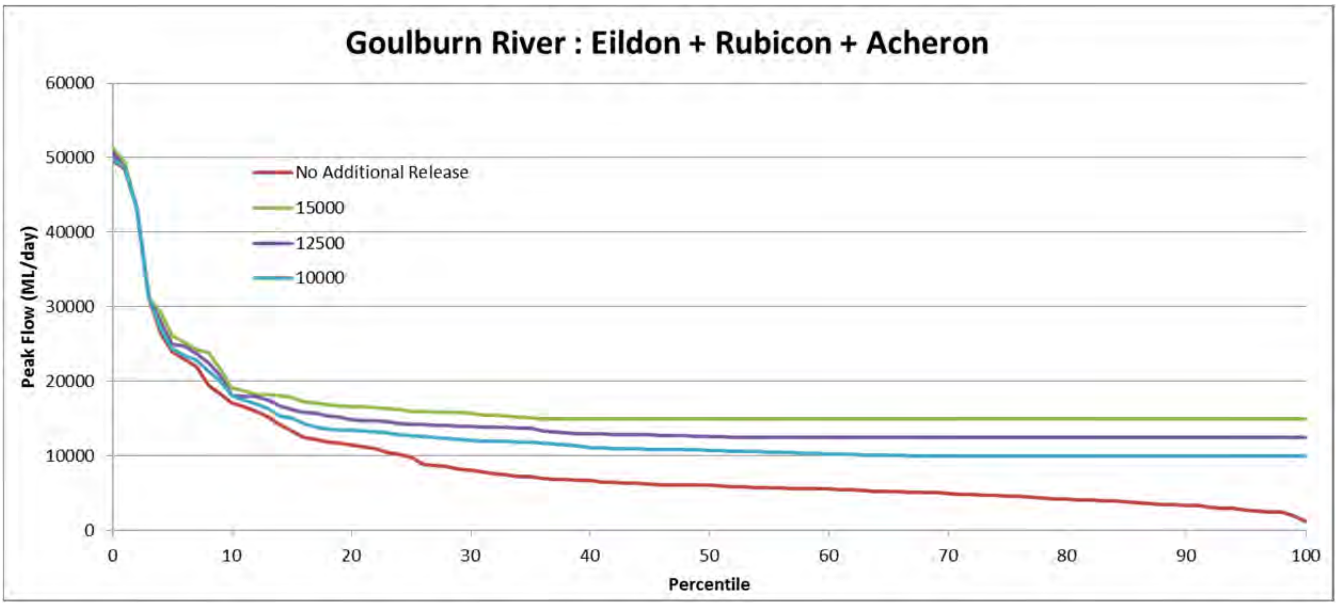

Figure 6.9 : Peak flow exceedance for the 132 events for combined Eildon, Rubicon and Acheron Rivers flow for no release and three scenario releases

The graph shows what proportion of events exceed a particular combined flow, for each scenario. Hence for the 10,000 ML/day constraint scenario (light blue line), all events now achieve 10,000 ML/day, whereas only 25% did in the without release scenario (red line). The number of events above 10,000 ML/day also increases as Eildon flows are not reduced quickly enough when Acheron and Rubicon flow rise. This is due to the rate of fall constraint assumed at Eildon of 0.8 times the previous days flow.

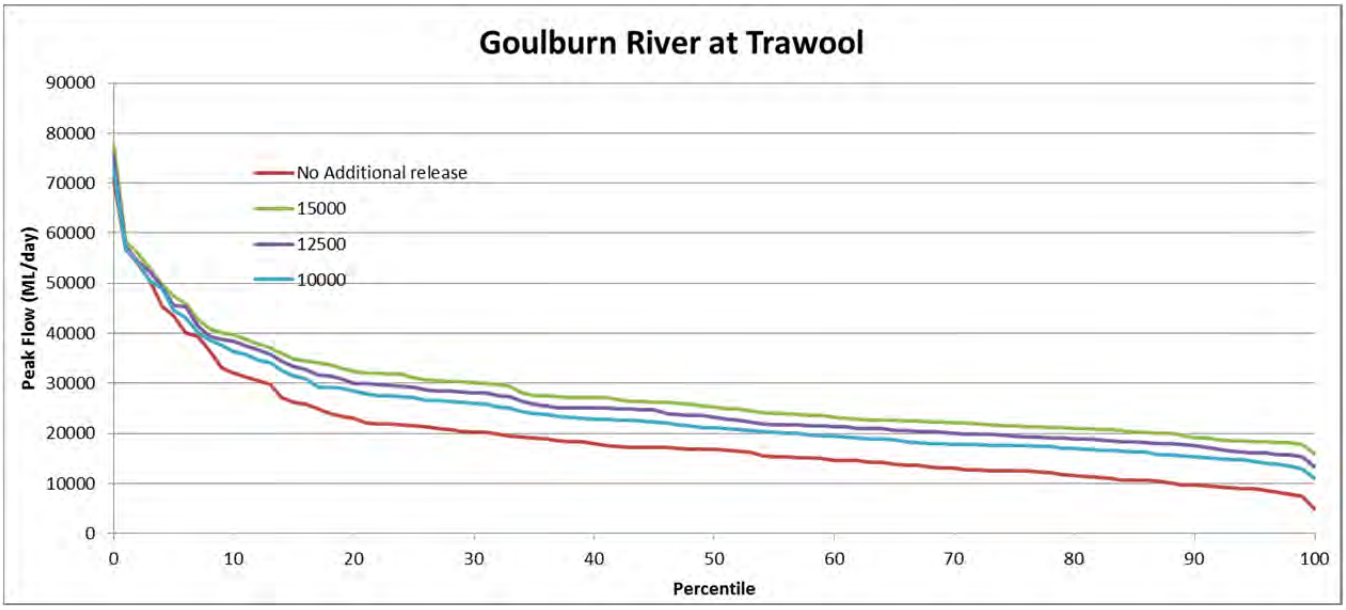

Figure 6.10 : Peak flow exceedance for the 132 events at Trawool for no release and three scenario releases

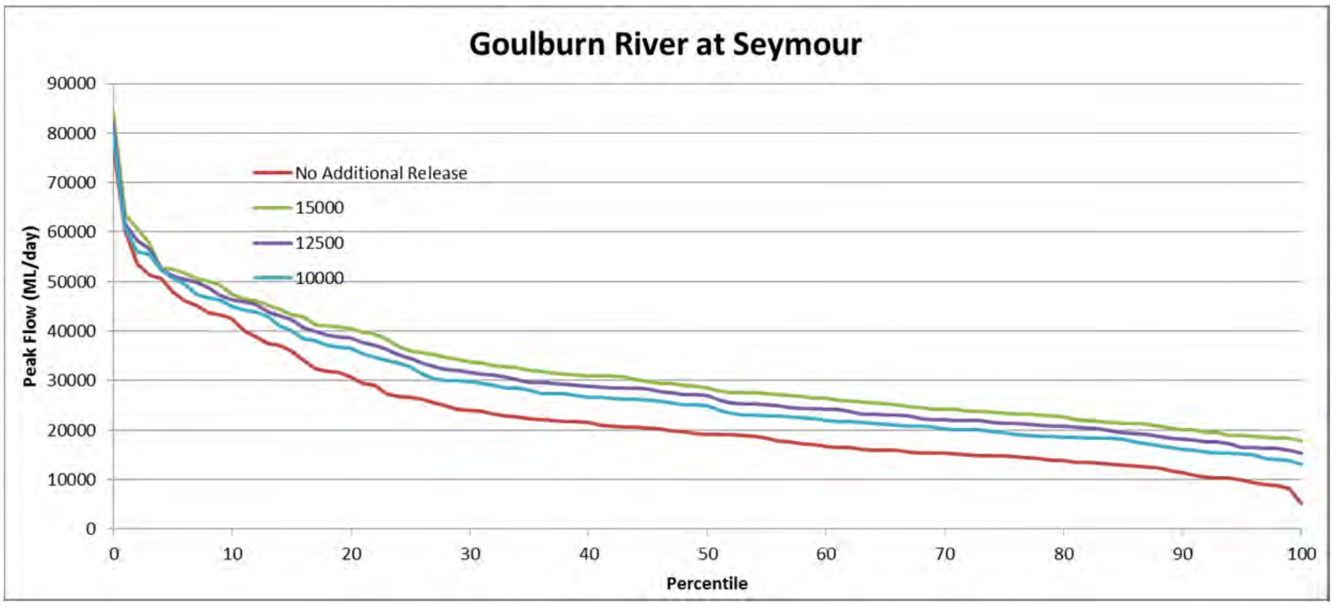

Figure 6.11 : Peak flow exceedance for the 132 events at Seymour for no release and three scenario releases

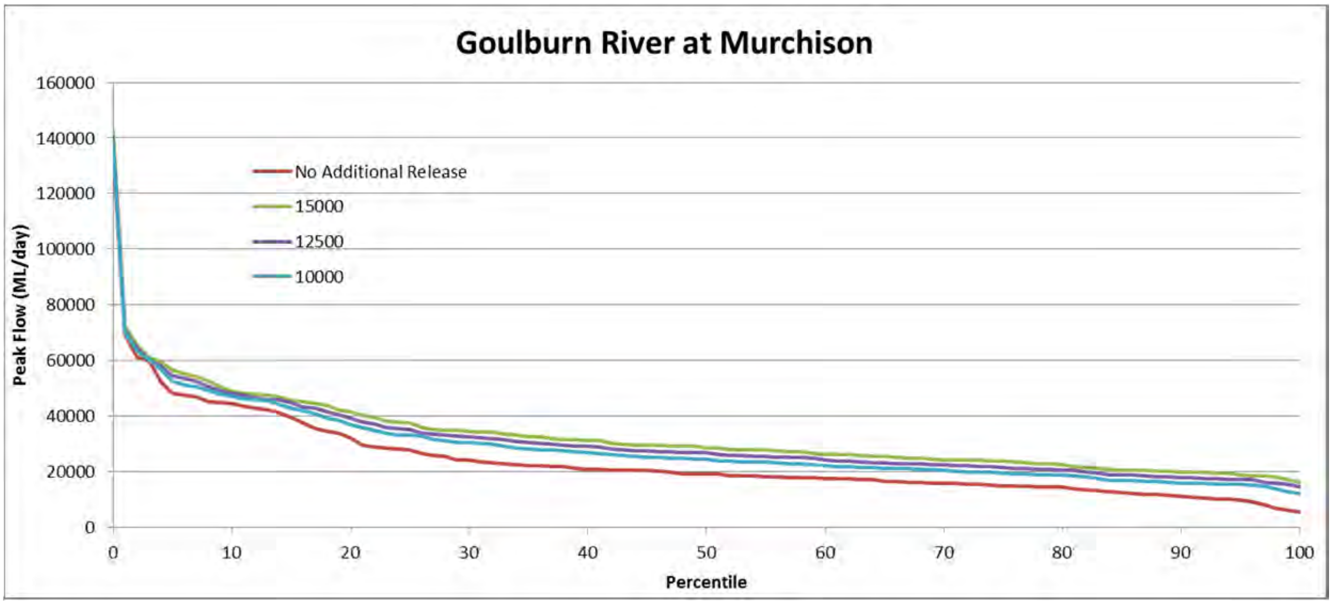

Figure 6.12 : Peak flow exceedance for the 132 events at Murchison for no release and three scenario releases

This analysis has looked at what is the result of increasing every possible event. This means that the number of events where the flow at Shepparton exceeds 40,000 ML/day is increased, along with potential flood risk. As can be seen in the Murchison graph, it is also increasing those events which are above 40,000 ML/day at Murchison.

6.3.1 Adjustment to reduce flood risk

To try to counter the number of instances where flow exceeds 40,000 ML/day, the next analysis assumes that the release from Eildon is reduced if the flow at Shepparton is forecast to exceed 40,000 ML/day. The number of events achieved in these modified scenarios is presented in Table 6.4.

This still assumes that releases are initiated based on a forecast streamflow up to 7 days in advance, however it is assumed that releases can be reduced if the forecast streamflow at Shepparton in 4 days' time is expected to exceed 40,000 ML/day (again assuming a perfect forecast).

Table 6.4 : Number of events which peak flow exceeds given flow thresholds between 25,000 ML/day and 40,000 ML/day

Peak Flow Threshold	No Additional Release	Scenario: Constraint of 10,000 ML/day	Scenario: Constraint of 12,500 ML/day	Scenario: Constraint of 15,000 ML/day
< 25,000	72	39	29	16
25,000 - 30,000	17	27	23	28
30,000 - 35,000	9	21	27	26
35,000 - 40,000	8	13	20	28
>40,000	26	32	33	34

With Eildon releases reduced in higher flow events, compared to Table 6.1, the number of flow events is the same or one or two events less than in Table 6.1 for most scenarios and flow thresholds, but is significantly reduced for the 40,000 ML/day threshold under the 15,000 ML/day constraint scenario (from 42 to 34 events). This shows that the 40,000 ML/d forecast flow at Shepparton is not very good at reducing high flows for the 10,000 ML/d and 12,500 ML/d cases. It may be that a slightly higher forecast flow (say 45,000 rather than 40,000 ML/day) may be required.

Using the 40,000 ML/d forecast trigger significantly reduces the increase in flow at higher flows (top 20% of flows) as shown in Figure 6.14 to Figure 6.17. Of the 132 events in the 15,000 ML/day scenario, six were not initiated at all due to the constraint on total flow at Eildon plus Rubicon and Acheron Rivers. 61 were reduced due to the forecast flow at Shepparton in four days' time exceeding 40,000 ML/day.

The exceedance of peak flow (for each of the 132 events) at Shepparton for each of the scenarios is presented in Figure 6.13.

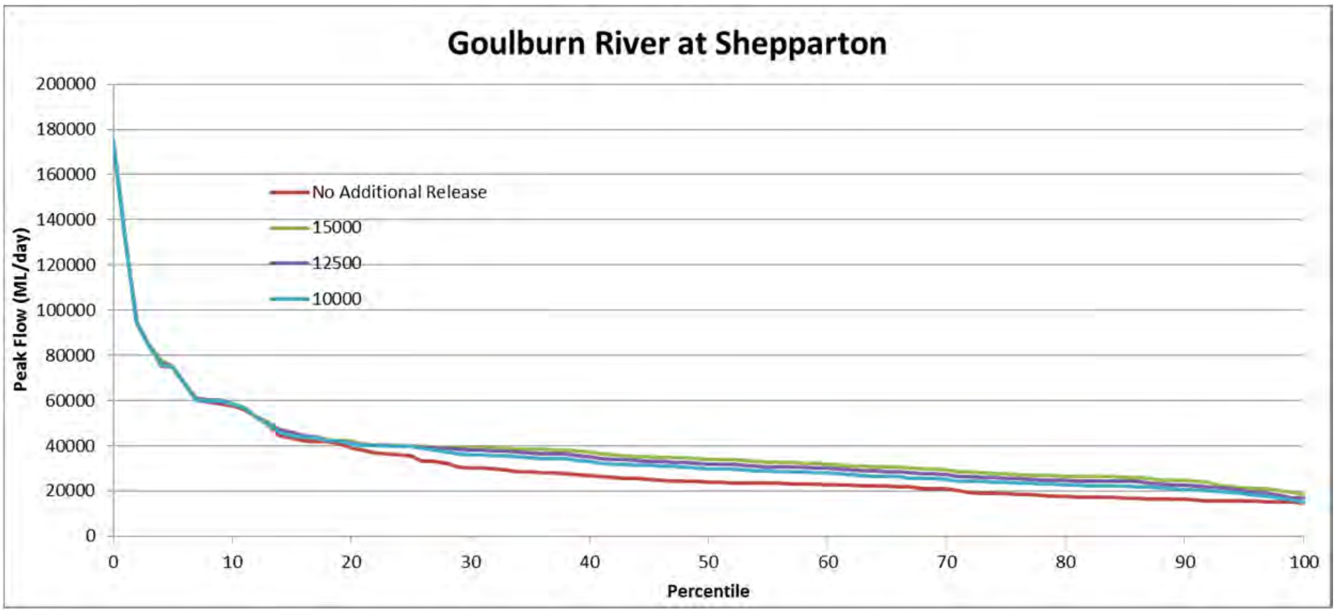

Figure 6.13 : Peak flow exceedance for the 132 events at Shepparton for no release and three scenario releases

The exceedance of peak flow (for each of the 132 events) of the combined Eildon release, Rubicon and Acheron Rivers for each of the scenarios is presented in Figure 6.14.

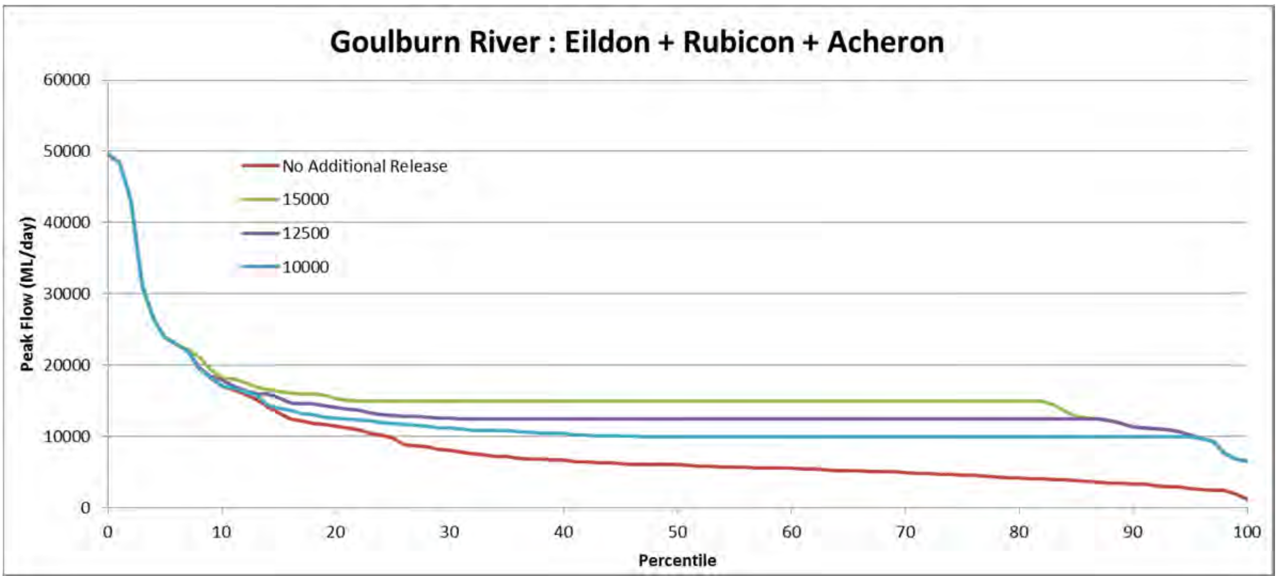

Figure 6.14 : Peak flow exceedance for the 132 events for combined Eildon, Rubicon and Acheron Rivers flow for no release and three scenario releases

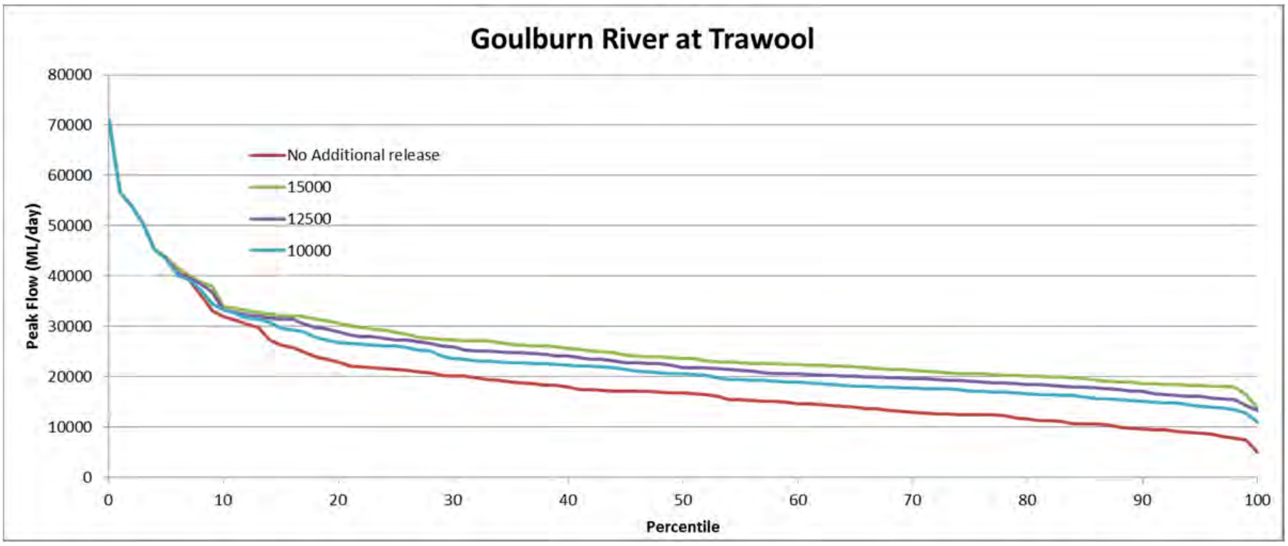

Figure 6.15 : Peak flow exceedance for the 132 events at Trawool for no release and three scenario releases

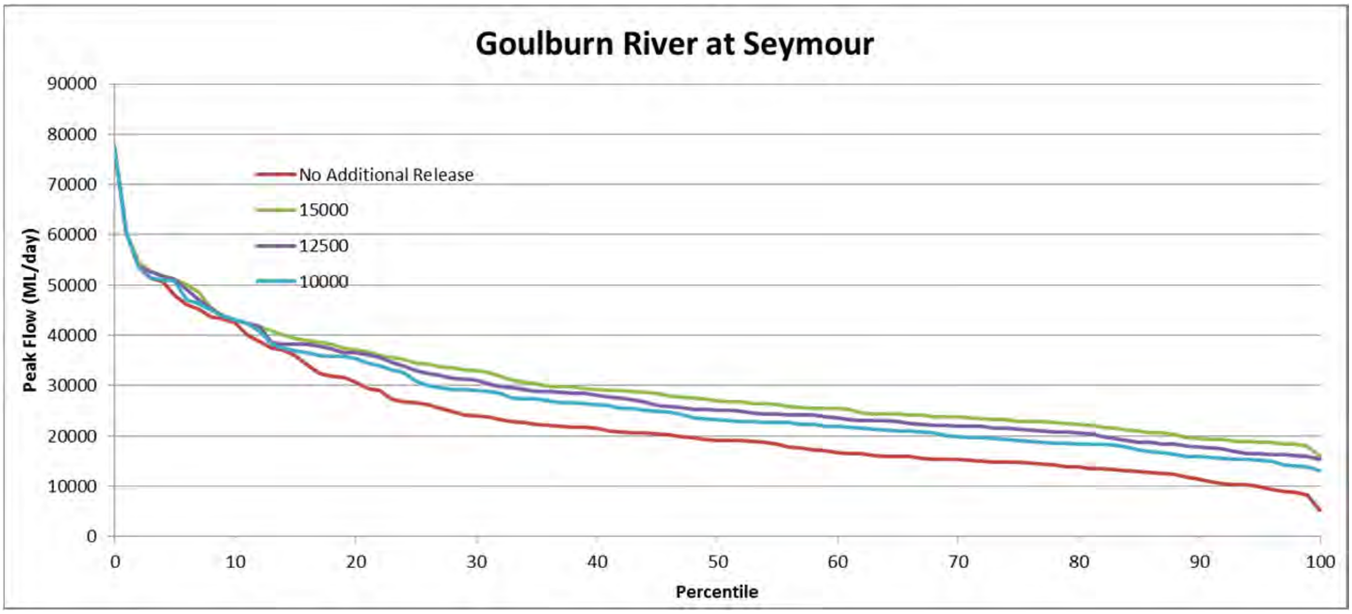

Figure 6.16 : Peak flow exceedance for the 132 events at Seymour for no release and three scenario releases

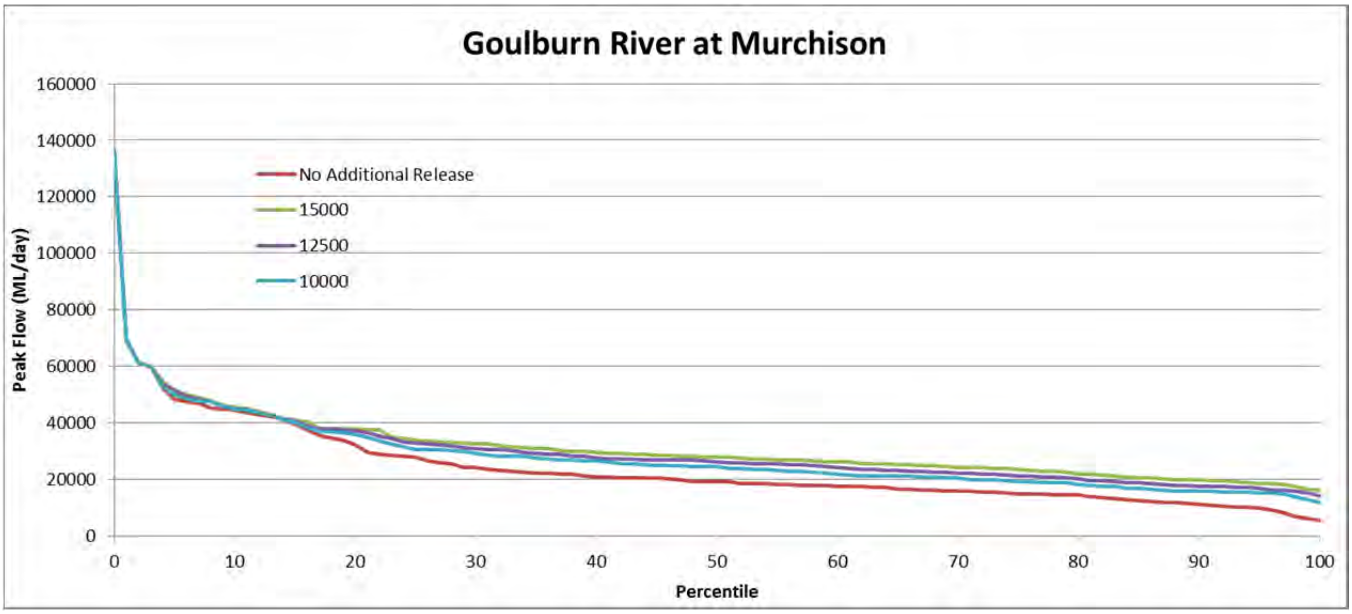

Figure 6.17 : Peak flow exceedance for the 132 events at Murchison for no release and three scenario releases

The limiting of releases from Eildon for high forecast Shepparton flows effectively means flows over 38,000 ML/day at Murchison are not increased.

Figure 6.13 to Figure 6.17 indicate that the release constraints downstream of the Acheron River in the range from 10,000 to 15,000 ML/day result in increased flows up to around 35,000 ML/day at Trawool, 40,000 ML/day at Seymour, and 40,000 ML/day at Murchison.

These flow rates appear high given the peak flow rate at Shepparton is 40,000 ML/day and there is usually considerably more inflow to the Goulburn River from downstream of these locations. However, the reason for these high flows is that shorter higher peak flows can occur in the Goulburn River due to tributary inflows, which are attenuated as they pass downstream. There is also the issue of timing, in that the peak flow rates from different parts of the catchment do not coincide at Shepparton, rather they arrive at a time based on their travel time from Shepparton.

Another issue is that there may be secondary peaks during a flow event. For example in event 59 in October 1979 the maximum daily flow rates are as follows:

- 44,000 ML/day at Shepparton (Adjusted for Goulburn Weir diversions) on 2/10/1979
- 36,000 ML/day at Murchison (Adjusted for Goulburn Weir diversions) on 1/10/1979
- 44,000 ML/day at Seymour on 6/10/1979
- 21,000 ML/day at Trawool on 30/9/1979

The peak flow at Seymour occurs due to 31,000 ML/day flowing in from Sunday Creek and Sugarloaf Creek which is a few days after the peak flow at the other sites (note the flow at Trawool on this day is around 9,000 ML/day). This peak flow is increased by the release from Eildon in this release scenario. This highlights the potential for high flows to occur in tributaries downstream of Eildon once a release has been made and is already in transit. The ability to forecast such streamflow events which occur in response to intense local rainfall may be limited. Further work to evaluate the potential for forecasting to input to management of releases in response to this risk is required.

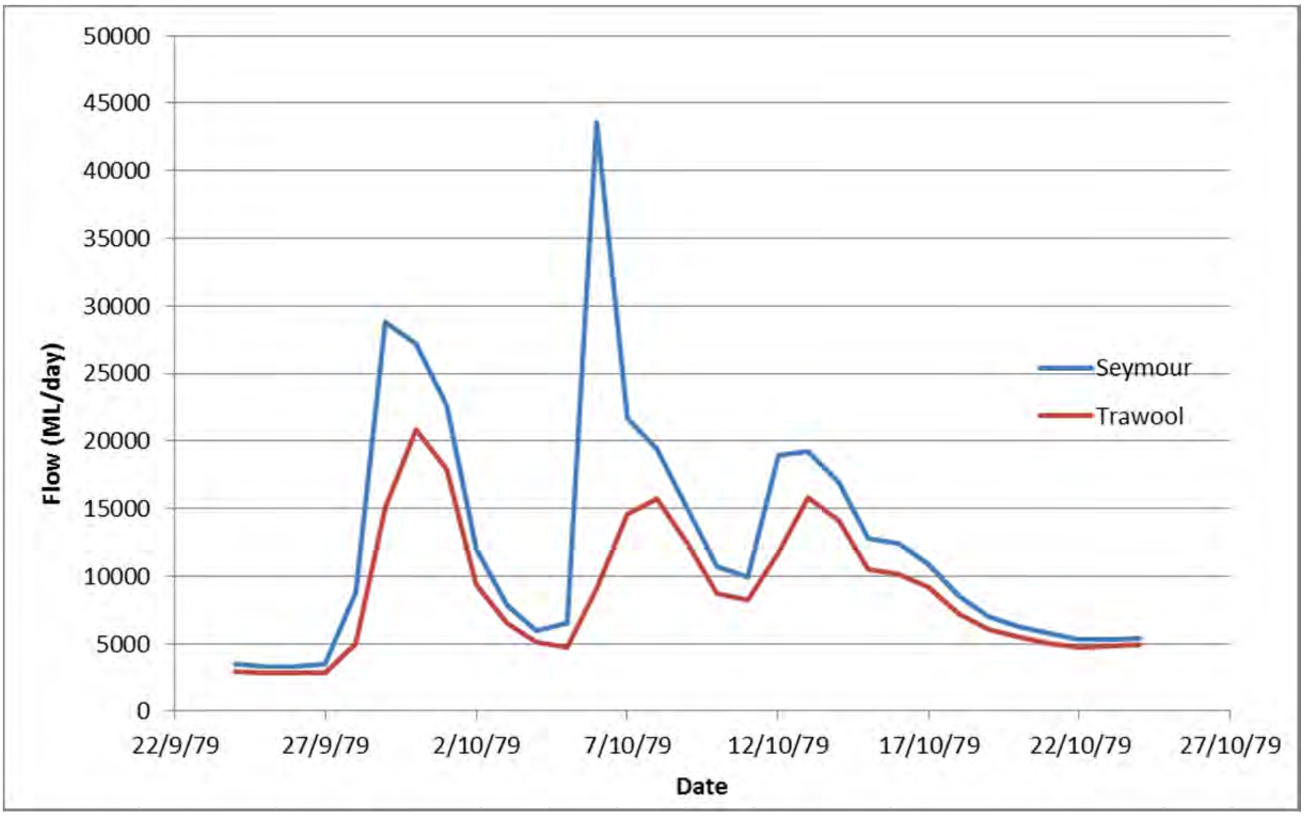

Figure 6.18 : Daily flow in the Goulburn River at Seymour and Trawool in October 1979

6.4 Discussion

Testing of triggers based on observed streamflow showed that releases could not be made early enough to coincide with the flood peak unless the peak was extended by a subsequent rainfall event. This is due to a combination of travel time effects and constraints of the rate at which flows can increase.

The example using a simple trigger of the Upper Broken gauged streamflow of 4,000 ML/day resulted in 59 releases being made out of a possible 70 events between August and November. Of these releases, it increased the number of events of peak flow at Shepparton above 25,000 ML/day from 45 to 54 events. It also means that there was increase in peak flow at Shepparton above 25,000 ML/day in 54 of the 59 events. If there is considered to be incremental benefit for increases in peak flow between 25,000 ML/day and 40,000 ML/day, then the majority of these releases have a positive impact even if they don’t meet the target flow. Note however a number of releases increased peak flows to well above 40,000 ML/day which would cause additional undesirable flooding.

The median increase in peak flow at Shepparton for these events was in the order of 4,000 ML/day (varying between 0 ML/day to 10,000 ML/day) assuming the same constraint of Eildon + Rubicon + Acheron of 15,000 ML/day. The reason for the lower rate of around 4,000 ML/day (compared to the 10,000 ML/day increase at Shepparton with perfect forecasting) is due to the release arriving after the peak flow.

Including observed rainfall in the trigger improves results slightly by giving an extra days’ notice of an event but does not substantially reduce the events where the release is too late for the peak.

Assuming a perfect forecast of streamflow, results show that it would be possible to increase the number of events which reach the 25,000 ML/day threshold and also the number that reach the 40,000 ML/day threshold. As noted in the section above, the increase in peak flow at Shepparton was approximately 10,000 ML/day for the maximum constraint scenario tested of 15,000 ML/day of total Eildon release plus Rubicon and Acheron River gauged flow.

The incremental testing of different strategies has shown that making releases based only on observed streamflow or rainfall conditions results in many events exceeding a maximum flow rate at Shepparton. As forecast information of both streamflow and rainfall is included into the release initiation process and management of release rate once it has commenced, the number of events failing to reach a target threshold or exceeding a maximum flow rate is reduced.

The allowed rate of increase in Eildon releases has been shown to be a significant constraint.

The more accurate the rainfall and streamflow forecast is, the better the outcome in numbers of events achieving the desired flow target without exceeding a maximum flow rate. The development of streamflow forecasting techniques is an important aspect of the ability to achieve desirable flow events, and to reduce the risk of adverse outcomes from the release of water from Eildon to achieve environmental flow targets in the Goulburn River at Shepparton.

It is recommended that the above approaches be tested in future with forecast data to determine their true probability of success.

6.5 Management during releases

Given the reliance on forecasts to initiate releases, it will be important to actively adjust the release rate from Lake Eildon during an event in response to catchment conditions, forecast conditions, and actual rainfall and flows as they occur. As discussed above, even if perfect forecasting (including forecasting of losses) were possible, there is still the risk of either not achieving an increase in the flow peak at Shepparton which could be due to restrictions of rate of rise and fall of Eildon releases, or the risk of exceeding a maximum flow rate. There is potential for some management of the flow at Goulburn Weir.

6.5.1 Goulburn Weir, Stuart Murray Canal and Cattanach Canal Operation

As discussed in Section 5.4, once a release has been made from Eildon, the flow can potentially be managed to some degree by operations at Goulburn Weir. The combined capacity of the Stuart Murray Canal and Cattanach Canal to pass flow to Waranga Basin is approximately 7,200 ML/day.

The analysis presented in this report has been undertaken assuming no diversions to Waranga Basin. Therefore there may be scope to divert flow and re-regulate at Waranga Basin if conditions change and it is apparent that the Eildon release will either not meet the environmental flow target, or that the release may exacerbate downstream flooding.

The potential for diversion to Waranga Basin will depend on available airspace in Waranga Basin and also the potential release rates from Waranga Basin to the Waranga Western Channel downstream. A schematic of Waranga Basin, Waranga Western Channel, Stuart Murray Canal and Cattanach Canal is shown in Figure 6.19.

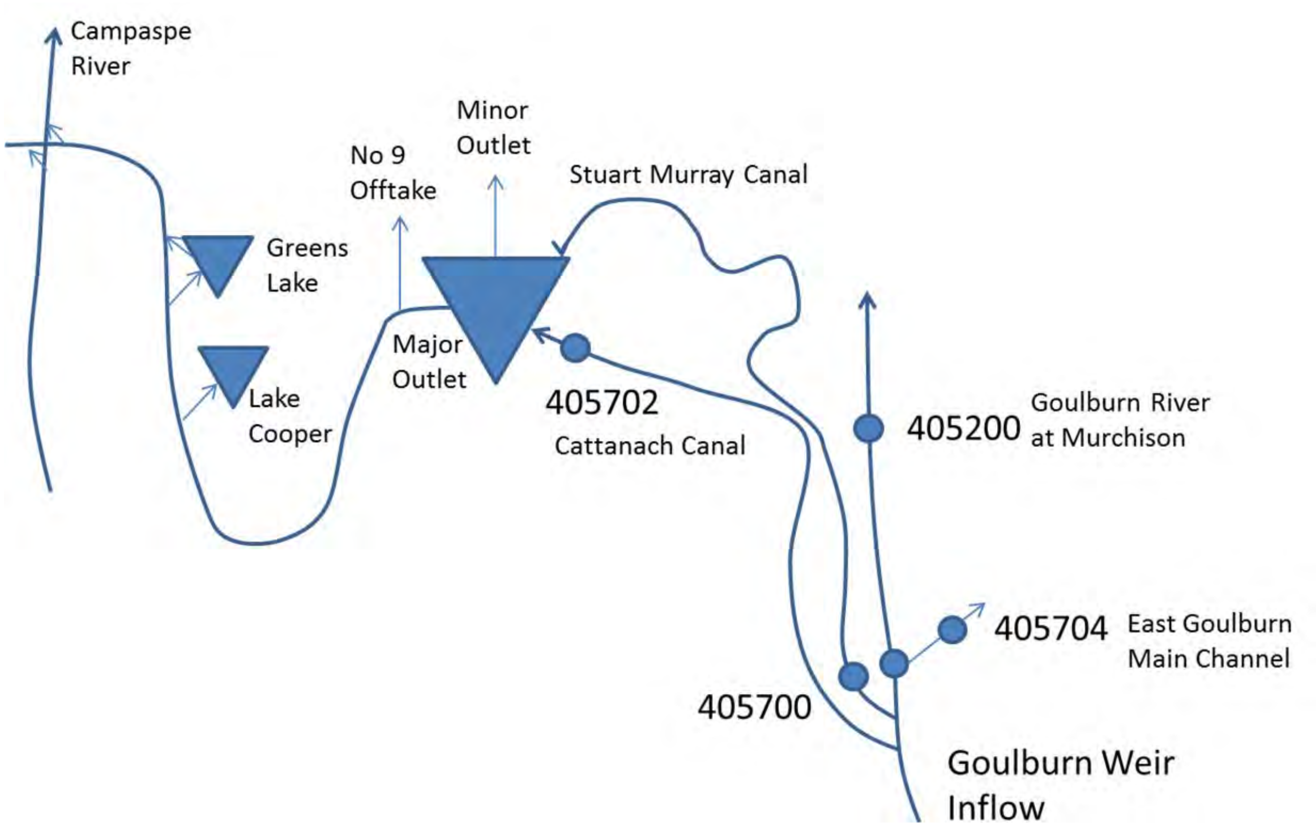

Figure 6.19 : Waranga Basin Schematic

The maximum capacity of Waranga Basin is 432 GL. Waranga Basin is operated to be filled as early as possible in (or prior to) the irrigation season by diverting flow at Goulburn Weir to provide resource for the Goulburn system. Therefore in many years with a number of high flow events in the Goulburn River, Waranga Basin may be expected to be quite full by the August to October period. In these years there may be little available air space to use to store water that was released from Eildon if it is not expected to meet an appropriate environmental flow downstream or may exacerbate downstream flooding.

Alternative management arrangements may be possible for Waranga Basin, for the Basin to be held lower to retain some airspace. If this were done, the Waranga Basin could be refilled by subsequent water harvesting opportunities with no impact on overall water resource availability. If the Waranga Basin didn't refill, environmental water entitlements could be debited for the water not harvested. Further study would be required to assess if such an operating scenario was possible to ensure that impacts on allocations could be avoided through use of environmental allocations. The further study would also need to evaluate the benefits and risk of such an arrangement.

Another possibility may be to store only some of the diverted water from Goulburn Weir and pass some of the water directly out of the basin using the Waranga Western Channel Major Outlet. The capacity of the Waranga Western Channel at the Major Outlet is 4,200 ML/day, and this reduces to around 3,300 ML/day downstream of the Number 9 channel offtake. Flow could potentially be:

- passed to Greens Lake at a rate up to 1,200 ML/day where the water could be held as a resource for the Goulburn system if there was available airspace, or
- passed to Campaspe River at a rate up to 2,300 ML/day where it would flow in the lower reach of the Campaspe River to the River Murray [The capacity of the outfall from the Waranga Western Main Chanel is documented as 1,470 ML/d, but is thought to be actually up to 2,300 ML/d under free fall

conditions when there is no flow in the Campaspe River (Peter Cottingham & Associates and SKM, 2011)], or

- released into Lake Cooper at a rate up to 1,000 ML/day where it is not likely to be able to be used as a resource for the Goulburn system unless it could be subsequently passed to Greens Lake and pumped into the Waranga Western Channel. This is not considered likely as Lake Cooper is not an operational Goulburn-Murray Water storage, and there may be potential water quality issues or hydraulic limitations to gravitate the water from Lake Cooper into Greens Lake. Local flooding issues would also need to be considered.

As the inflow to Waranga Basin via Stuart Murray and Cattanach Canals is around 7,000 ML/day, assuming environmental releases were made over the period of seven days, potential diversion to Waranga Basin would be up to 49,000 ML, and less if only picking up Eildon releases made over 2 to 4 days as Eildon flows were reduced. If releases from Waranga Basin could be made up to 3,300 ML/day, airspace in Waranga Basin could be around half the volume at 25,900 ML.

The benefits and risks of such operating practices would need to be further investigated before making any of these releases in practice.

7. Uncertainty

There are a number of sources of uncertainty with regard to the data used in this study and the assumptions made. These are discussed below.

7.1 Losses

The estimation of catchment inflows in the flood characterisation section noted that no losses have been explicitly included in the analysis, rather they are implicitly included in the ungauged area contributions in each of the Goulburn River reaches.

Also, for the assessment of the impact of additional releases on the flow at Shepparton, it has been assumed that there is zero loss. Depending on the conditions into which the releases are made, it is expected that there will be additional losses and that they will be variable. They will come from filling wetlands and wetting up floodplains as well as the usual transmission losses from the river channel. If releases are made into existing high flow conditions, losses may be lower than if the release was made into low flow conditions. If the release is made into lower flow conditions prior to high inflow due to tributary inflows, although the loss of the release may be high, the loss of the tributary inflows may be lower due to the initial loss of filling the channel from the additional release.

Losses are important as they can both reduce the increase in peak flow and duration achievable at Shepparton, as well as consume water that is then not available for reuse further downstream.

In the interim there may be potential to adopt loss rates already assumed by GMW operators when transferring water for irrigation. However further work will be required in future to quantify the changes in losses associated with overbank environmental releases and for these to be incorporated into release planning and management. This may include developing models to simulate the losses of overbank flows in various reaches of the river.

7.2 Streamflow Data Availability

Streamflow data availability for the period from 1960 to 2015 was variable. Many of the streamflow gauges on the Goulburn River itself had records for the entire period, although some had missing data and were infilled. Stream gauges in the tributaries often did not start until part way through the period of analysis. These tributary inflows were not infilled as part of this project, rather at times of missing data the flow from these tributaries was included in the ungauged catchment inflow and flagged as missing data. For example, in 1984 there was an extended period of missing data for the flow record of the Goulburn River at Murchison (405200). At the same time there was missing data at the now inactive streamflow gauging station downstream of Goulburn Weir (405253) which was available at other times to infill the Murchison streamflow record as there is limited tributary inflow between the two sites.

In some events, particularly earlier in the period of record when there was more periods of missing or unreliable data, there are some spikes and negative inflows. In future, the streamflow records could be examined in detail to review the quality of available data to identify the causes of these if required.

It was noted in the flood characterisation section that the ungauged catchment upstream of Trawool generates significant flow in most events. Approaches need to be further considered to reduce the uncertainty regarding where in the ungauged area these flows originate from. This could include additional flow gauging. The ungauged catchment downstream of Trawool generally generates comparatively little runoff, indicating adequate flow measurement of tributaries in this reach.

The stream gauging on the tributaries are often quite high up in the catchment, so there is substantial catchment area downstream of the current gauged locations. If tributary inflow could be gauged further downstream, assuming suitable flow gauging sites exist, this would add to the information available to input to the management of environmental releases. Additional rainfall monitoring may also be needed to better predict streamflows in selected catchments.

Similarly, additional flow gauging on the Goulburn River itself would provide more information to enable better forecasting of downstream flows and to aid management of environmental releases. More gauging information would also help to better define losses in various reaches of the river.

Telemetry is available on most of the stream gauging sites used for the data analysis as part of this project. This provides remote real time data available to river operators.

The ongoing availability of streamflow data for managing environmental releases may need to be considered. There may be potential risk if important stream gauging stations are missing data at times prior to or during an environmental release.

7.3 Daily timestep data

The analysis undertaken for this study has involved using daily timestep data. In terms of assessing peak flow rates, there is a limitation that only the total daily flow is considered. The instantaneous flow may be much greater at some times during the day. Analysis of shorter timestep data would provide additional accuracy to better define travel time and attenuation.

Also, the rate of rise and fall of flow in the Goulburn and Broken rivers and in particular their tributaries can be much less than one day. An example of the difference on the tributaries can be seen in the flow hydrograph of Home Creek (405274) during the event in June 1995 (Event 102). This shows the peak flow based on hourly data as over 9,000 ML/day compared to the daily average flow of 3,600 ML/day.

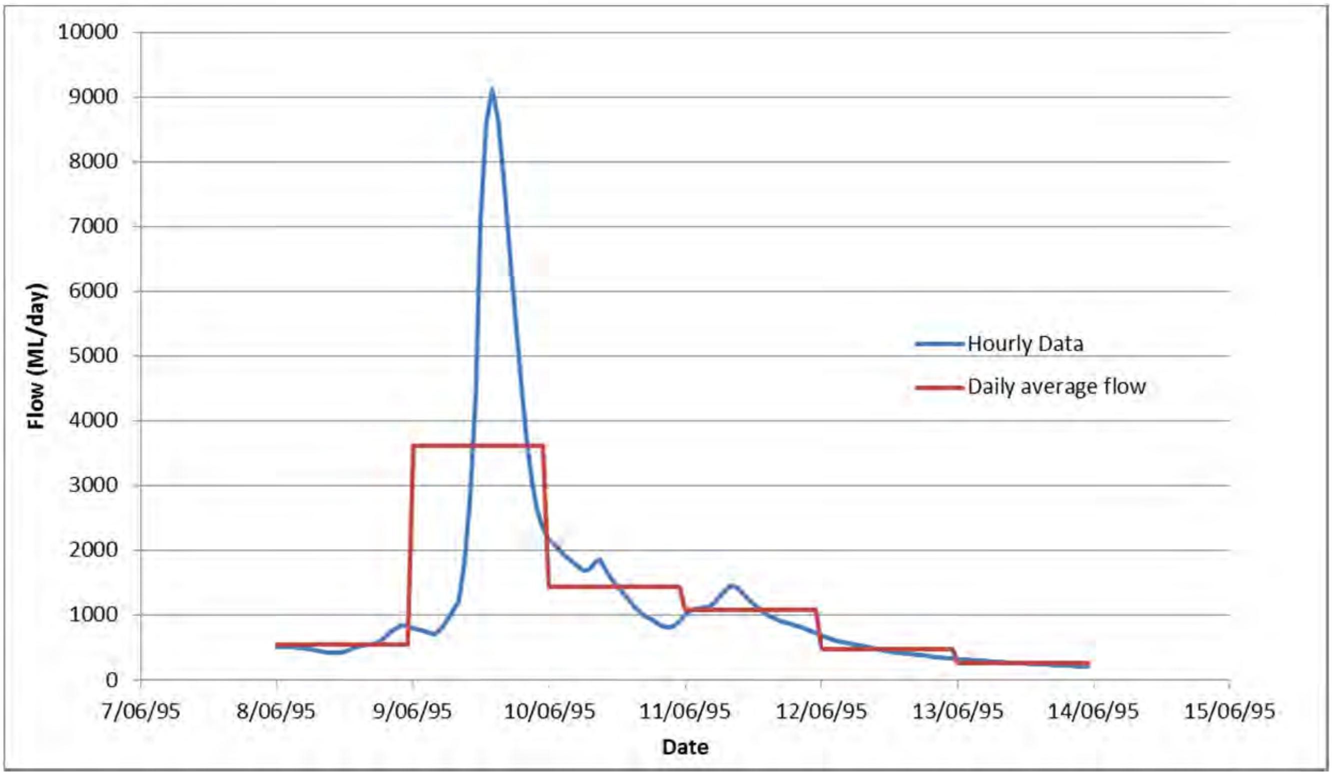

Figure 7.1 : Home Creek gauged flow from 8/6/1995 to 14/6/1995

The difference on the Goulburn River itself during this event is far less. This can be seen in Figure 7.2.

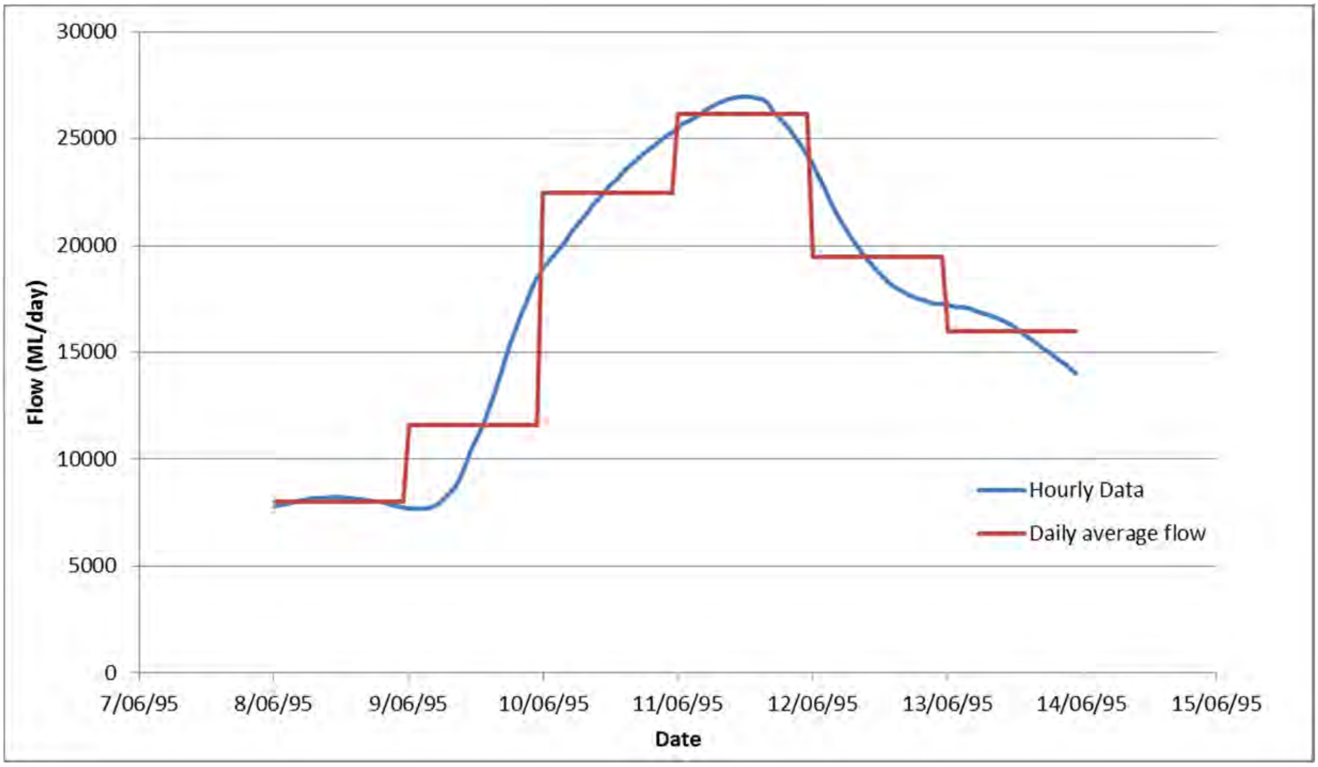

Figure 7.2 : Goulburn River at Trawool gauged flow from 8/6/1995 to 14/6/1995

This significant difference will impact on the routing and attenuation of flows. The current analysis has assumed the same routing parameters for tributary inflows as for the Goulburn River main stem where they are close together. The routing parameters for tributaries in particular could be refined using sub-daily timestep data.

The significant difference in the flow rates for tributaries means that additional work will be required to evaluate peak flow rates at a sub daily timestep. This information would allow the assessment of additional variability and how to manage it, particularly upstream of the Alexandra/Molesworth area where river channel capacity is limited. In critical areas, additional stream gauging may be required to characterise flow responses and provide warning more time in advance for operational response to be made.

The within day rise and fall on the Goulburn River can be quite significant in some events. For example in October 1979 the peak mean daily flow at Seymour was 44,000 ML/day. As discussed above in Section 6.3, this event was driven by 31,000 ML/day from the combined inflow from Sunday and Sugarloaf Creek. This is the highest daily flow for these two creeks on record. The hourly flow is compared with the daily flow in Figure 7.3. It shows that the peak flow rate at Seymour was around 54,000 ML/day compared to the mean daily flow of 44,000 ML/day.

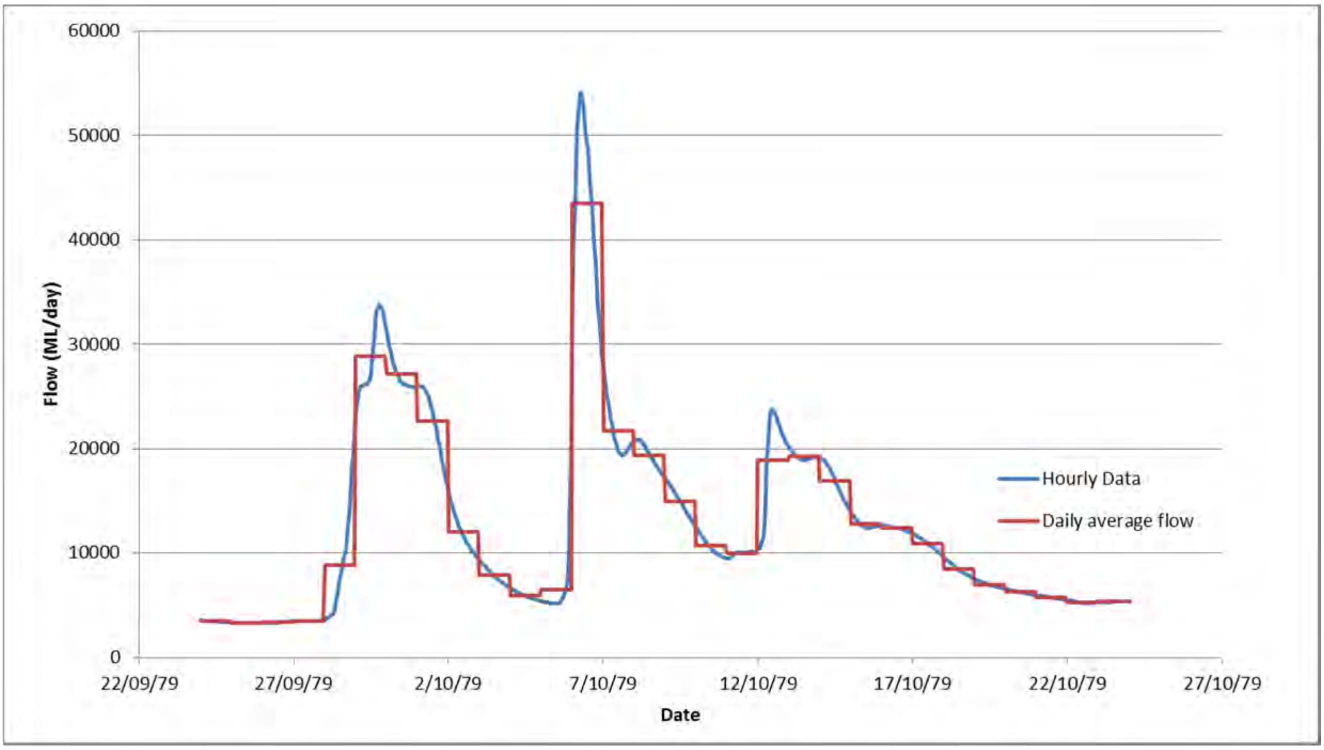

Figure 7.3 : Flow at Seymour in October 1979

It is also noted that in this highest event on record for Sunday and Sugarloaf Creek that the travel time to Murchison in the Goulburn River took longer than the calibrated travel time in this reach which is around 1 day.

Another limitation is the differences in the definition of the daily data. Daily streamflow data is reported from midnight to midnight, while rainfall data is reported as the rainfall to 9 am each day. To refine this estimate it is recommended that this analysis be undertaken at a sub-daily timestep.

7.4 Forecasting

The uncertainty of forecast rainfall is considerable in terms of total rainfall depth and the spatial and temporal variability over an area as large as the Goulburn and Broken catchments during a rainfall event and potentially for multiple rainfall events over a period of days. The risk associated with an event being more intense or at a larger scale than forecast would need further investigation. There is also risk that a rainfall event may be smaller and runoff not sufficient to enable release flows together with catchment runoff to meet a flow rate of over 25,000 ML/day at Shepparton. In addition to the uncertainty of the rainfall forecast itself, there is also uncertainty of the volume and rate of runoff generated from a rainfall event.

As discussed in Section 5.2.3, flow at Shepparton can be forecast using a number of approaches. River Regulation Operators make estimates of flow in the system into the future for the purposes of managing flows in the system. Typically operators use information on flow already in transit in the system, together with estimates (or scenarios) of future inflows. Such scenarios may be based on no further rainfall, in which case future inflow may be based on the rate of recession from the current flow rate into the future. Alternatively, it could be based on historically similar events or rainfall runoff modelling techniques.

Using streamflow data available on a real time basis, it is possible to estimate the total tributary inflow in various parts of the Goulburn and Broken valleys (assuming no additional rainfall). This can be done using the existing network of streamflow gauges. For example, in order to forecast flow at Shepparton in one days' time, hydrologic routing of flow already passing (or passed) streamflow gauging stations could potentially be used which would capture most of the flow which will arrive at Shepparton (assuming it is not just a local inflow event close to Shepparton from for example Seven Creeks).

Forecast of flow at Shepparton further days in advance can be made using a combination of flow already in the river and a projection of future flow from those catchments which are closer to Shepparton. This could be made using forecast streamflow conditions based on a recession factor assuming no further rainfall, or potentially a rainfall-runoff model with forecast rainfall.

It is understood that the Bureau of Meteorology and CSIRO are undertaking current research into short term streamflow forecasting. Techniques include using conceptual rainfall runoff modelling approach for sub-daily/daily flow forecasting out to 7 days using rainfall inputs with modelling outputs adjusted using a site specific correction scheme. Another approach is based on Bayesian Joint-probability methods. Outcomes from such research can potentially be incorporated into a process to forecast flow at Shepparton.

Given the travel time in the Goulburn River from Eildon to Shepparton, and the uncertainty of rainfall conditions and catchment response during that time discussed above, there is a risk that initiated events may fail to achieve the target flow rate or may exceed the maximum flow rate at Shepparton. Approaches to manage this risk need further consideration.

7.5 Future events

The flood event characterisation has shown that all flood events are quite different, therefore future events will be different to past events due to this variability.

In addition to the variability seen in the historical record from 1960 to 2015, impacts of climate change may also influence the characteristics of flood events. A key message of climate change modelling by CSIRO and the Bureau of Meteorology of Southern Murray Basin area which includes the Goulburn and Broken catchments Victorian climate (Timbal, B. et al. (2015)) is:

“Even though mean annual rainfall is projected to decline, heavy rainfall intensity is projected to increase, with high confidence.”

Therefore the consideration of more intense rainfall and catchment response to that rainfall will need to be considered.

7.6 Duration of events

This work has focussed on how to increase the peak river flow at Shepparton. It has shown that current flow peaks tend to be relatively short with sharp recessions, making it difficult to achieve 4 to 5 day durations, unless there is follow up rainfall. It may be that peak flows need to target a higher flow, to provide the desirable duration at a lower flow (eg target 40,000 ML/day to provide 4 days at 35,000 ML/day).

Further, duration of releases from Eildon may be longer than 4 to 5 days to help deliver flows at Shepparton. Further work to investigate different duration of releases is recommended.

8. Discussion and Conclusions

8.1 Discussion

An objective of this study was to assess whether environmental releases from Lake Eildon can be added to tributary flows to create desirable environmental events in the range of 25,000 ML/day to 40,000 ML/day in the lower Goulburn River. Undesirable outcomes include a release being made and not increasing either the flow rate or duration above 25,000 ML/day or for a release to be made to cause an increase in flow above this range which may cause additional flood damage.

8.1.1 Travel time

The assessment of travel time shows a four day travel time from Eildon to Shepparton on average. The limits on the allowable rate of rise on releases from Eildon result in another 2-4 days from the event being started to reaching a target rate. Therefore from the time an event is initiated the peak of the release from Eildon will begin to arrive 6-8 days later.

8.1.2 Event contribution

The flood event characterisation showed many events where a large proportion of the peak flow originated from the ungauged catchment area upstream of Trawool. This catchment area has a travel time of between 2.5 to 4 days to Shepparton.

Many of the events had inflow from the Broken River. Analysis of the Broken River flow at Orrvale showed that in most events a large proportion of the flow originated from upstream of the gauged sites of the Broken River at Moorngag, Holland Creek at Kelfeera and Moonee Creek at Lima. All these sites are approximately three days travel time to Shepparton. Using the gauged flow upstream allows more notice time than relying on flow at Orrvale (however, it introduces more uncertainty due to local catchment contribution downstream of these sites).

The contribution from other areas in the Goulburn Broken catchment can also be very high in certain events.

8.1.3 Impact of rainfall/days/duration/rate of rise and fall

Analysis of events at Shepparton with adjusted flow peaks in the range of 20,000-40,000 ML/day show that they fall typically at a rate in the order of 5000 ML/day/day once the peak has passed if there is no subsequent rainfall in the days following the rainfall event which caused the peak flow. Events at Shepparton in the range 15,000 ML/day to 20,000 ML/day typically fall at the rate in the order of 3,000 ML/day/day.

Therefore if releases are made from Eildon based on observed streamflow and if there is no further rainfall to increase the peak flow at Shepparton, the rate of rise would need to be greater than 3000-5000 ML/day (before routing and losses are considered which limits the rate of rise at Shepparton for a given rise at Eildon). Current operational rate of rise is 3,500 ML/day.

Therefore it is not possible to increase the peak flow at Shepparton on the basis of initiating a release using gauged streamflow where no further subsequent rainfall occurs to supplement the peak. Where releases are initiated based on observed streamflow, increases to the peak flow at Shepparton are possible but only if subsequent rainfall occurs.

A comparatively low risk release strategy could be to wait until streamflow is measured and there is no forecast rainfall then initiate a release. On the basis of this investigation, it has been found that it is not possible to increase the peak flow at Shepparton by waiting until the rainfall event has finished to initiate the release. However, it may be possible to extend the duration of the event if the rate of rise from Eildon is high enough.

Therefore to manage the risk of an undesirable outcome, forecast rainfall and streamflow would need to be utilised to initiate and manage an Eildon release.

Methods to increase the amount of time in advance of the event are required. Using observed rainfall to estimate future streamflow potentially provides up to an additional day, but involves additional uncertainty of forecasting the catchment runoff response from the observed rainfall.

Therefore methods that involve forecasting of rainfall, runoff and river flow are required.

8.1.4 Forecasting

A forecast of streamflow one day in advance can be based largely on gauged streamflow on the Goulburn and Broken Rivers and nearby tributaries such as Sevens Creek. As more days in advance are forecast, the more the forecast streamflow would rely on forecast rainfall and forecast runoff (and hence be more uncertain).

If releases are being managed with the aim to increase flow at Shepparton, then a forecast flow at Shepparton without any environmental release is required. If a perfect forecast of streamflow at Shepparton was possible, it has been shown that if a release is initiated 7 days before the peak flow (allowing for 2 to 3 days for the release to be increased and 4 days travel to Shepparton), then peak flow rates at Shepparton can be increased.

8.1.5 Management of releases using forecast information

In practice this could potentially be achieved by initiating a release based on forecast streamflow (which incorporates the effect on streamflow of forecast rainfall). As the rate of release at Eildon increases, there would be opportunity to reduce the flow rate (subject to the rate of fall constraints at Eildon) to then cease the release if forecast conditions change. Some of the release up to approximately 7,000 ML/day could be harvested into Waranga Basin via Stuart Murray Canal and Cattanach Canal.

Scenarios assuming a maximum constraint in the total flow of Eildon release + Rubicon + Acheron in the range of 10,000 ML/day to 15,000 ML/day has shown it is possible to increase the peak flow at Shepparton in a number of events by initiating the release prior to the event. If forecast flow at Shepparton in four days' time is expected to exceed 40,000 ML/day (assuming a perfect forecast) and the release is reduced, then the number of events which are increased above 40,000 ML/day are reduced.

If a forecast of flow at Shepparton is used to manage releases, the target may still be exceeded or not achieved due to limits on the maximum rate of rise and fall of Eildon release. It has been seen that if a release is initiated from Eildon and a subsequent rainfall event occurs, peak flow in the Goulburn River at locations such as Trawool, Seymour and Murchison can be increased in flow rates in the range up to 40,000 ML/day and potentially higher depending on the tributary inflows during an environmental release.

These scenarios only adjusted flow based on the total Eildon Rubicon and Acheron flow and the forecast Shepparton flow. Further work would be required to examine potential management of releases also including the potential flow rates at other locations in the river.

For all of the work discussed here perfect forecasting of streamflows is assumed. In future a streamflow forecasting technique should be developed and adopted and the success of these scenarios re-tested.

8.2 Conclusions

Historical stream gauging information from July 1960 to December 2014 has been evaluated to characterise flood events at Shepparton, adjusting it for the flow diverted at Goulburn Weir. This was done on the basis that when catchment runoff occurs, water is often diverted at Goulburn Weir to Waranga Basin to store for later use. It is relatively easy to not divert that water and so to increase flow peaks downstream. This option is available in the majority of flow peaks and can add up to 7,200 ML/day (although it usually doesn't divert at the maximum rate). This work assumed that this option was used whenever available.

The adjusted flow at Shepparton was then analysed to find events with a peak greater than 15,000 ML/day; 132 events were identified. Of these, 17 had peak flow rates above 50,000 ML/day and . nine had peak flow rates between 40,000 and 50,000 ML/day. There were 33 events with peak flows in the range of 25,000 to 40,000 ML/day (occurring in 20 years) There are 73 events with peak flows in the range of 15,000 to 25,000 ML/day (occurring in 26 years).

It was found that:

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

In the 55 years examined 11 have no flow events greater than 15,000 ML/day at Shepparton and therefore would not be considered for environmental releases. Of the remaining 44 years there are seven years with only one event. Most years (37) have 2 or more events. There were 13 years in which an event occurred in May or June and in each of these years one or more events occurred later in that year. Similarly, there are 24 years with events in July, where 17 have similar or bigger events in later months. Therefore, not releasing environmental water before August would allow better use of environmental water, targeting potentially larger and later flow events. It is also preferable not to water after October. Therefore the target watering months can be reduced from winter/spring to August to October.

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

The first objective of this project was to assess whether environmental releases from Lake Eildon can be added to tributary flows to create desirable environmental events in the range of 25,000 ML/day to 40,000 ML/day in the lower Goulburn River. It has been found that it could be possible, but given travel time in the river system and constraints on the rate of rise of release, that environmental releases will need to rely on good forecasting of future streamflow and rainfall of up to 7 days to get peak rates of release added to peak flows in the Lower Goulburn River.

It has been shown that making releases based only on observed streamflow or rainfall results in the peak of the released flow generally arriving after the peak flow at Shepparton, resulting in many events peak flow being less than a target flow threshold. Sometimes releases which were initiated based on streamflows then increase further due to subsequent rainfall, resulting in increases to flood peaks above 40,000 ML/day which may exceed a maximum flow threshold target.

If forecast information of both streamflow and rainfall is included into the release initiation process and management of release rate once it has commenced, the number of events failing to reach a target threshold or exceeding a maximum flow rate is reduced. The more accurate the forecast is, the better the outcome in numbers of events achieving the desired flow target without exceeding a maximum flow rate at Shepparton. The development of streamflow forecasting techniques in future is an important aspect to the ability to reduce the risk of adverse outcomes from the release of water from Eildon to achieve environmental flow targets in the Goulburn River at Shepparton.

Some initial strategies investigated made an assumption that the streamflow forecast could be perfect (ie used the recorded streamflow at Shepparton adjusted for diversions at Waranga Basin) up to seven days in advance. In these scenarios assuming perfect foresight of up to seven days there is still a risk that the target flow and duration may not be achieved due to the time needed for the rate of increase from Eildon, the travel time for the event and the event duration exceeding more than seven days. Perfect foresight for longer than this would be needed to ensure no risk to the achievement of the environmental objective.

The flow rates in various reaches of the mid-Goulburn River for a number of scenarios have been presented. The results showed that assuming a release constraint downstream of the Acheron River in the range from 10,000 to 15,000 ML/day results in increased flows up to around 35,000 ML/day at Trawool, 40,000 ML/day at Seymour, and 40,000 ML/day at Murchison. These flow rates appear high given the peak flow rate at Shepparton is 40,000 ML/day and there is usually considerably more inflow to the Goulburn River from downstream of these locations. However the reason is that shorter higher peak flows can occur in the Goulburn River due to tributary inflow which is then attenuated as it passes downstream. There is also the issue of timing, in that the peak flow rates from different parts of the catchment do not coincide at Shepparton, rather they arrive at timing based on their travel time from Shepparton. Another issue is that a flow event may have secondary flow peaks.

The rate of rise and fall of flow in the Goulburn and Broken Rivers and in particular their tributaries can be much less than one day. The significant difference in the instantaneous and daily flow rates for tributaries means that additional work is required to evaluate peak flow rates at a sub daily timestep. This information would allow the assessment of additional variability and how to manage it, particularly upstream of the limiting Alexandra/Molesworth area. In critical areas, additional stream and rainfall gauging may be required to characterise flow responses and provide warning more time in advance for operational response to be made.

Methods to limit the occurrence of undesirable outcomes such as the target flow rate not being achieved or the maximum target rate being exceeded include development of streamflow forecasting techniques, operational management of releases at Eildon and at Goulburn Weir and review of rate of rise and fall of releases from Lake Eildon.

A number of limitations and uncertainty in this analysis has been discussed. Further work is required to address many aspects of uncertainty.

An important assumption in this analysis is that losses for additional releases are zero. In reality there will be losses which will be variable depending on the conditions into which the release is made. Further work will be required in future to quantify losses of environmental releases and be incorporated into release planning and management. This may include developing models to simulate the losses of overbank flows in various reaches of the river.

All the analysis for this project has been undertaken on a daily timestep. In future further work on shorter timestep is required to analyse the available data and refine methods.

Given the limitations and uncertainty noted, the outcomes of this study are not intended to be used for operational releases. Further work would be needed to investigate potential risks and operational management requirements before such approaches could be implemented in practice.

9. Further Work

This study has identified a number of aspects that require further work. These include:

9.1 Sub daily timestep modelling

Observed rainfall and streamflow have been used on a daily timestep. This has an issue that streamflow data is reported on a day from midnight to midnight, while rainfall is reported from 9am to 9am. Observed rainfall could be used as a trigger for events which could potentially provide additional time before the peak flow at Shepparton occurs. This could potentially be explored further using rainfall and streamflow data at a timestep of less than one day.

Also, it has been observed that sub-daily data may give a better representation of peak flows and time lag, particularly for some tributary catchments. It is recommended that sub-daily data be used to improve these estimates in future as well as provide better information for triggering or adjusting releases.

9.2 Forecasting rainfall and streamflow

Much of the analysis undertaken in this report assumes perfect knowledge of future streamflow and rainfall, however in practice forecast data is required.

It is understood that the Bureau of Meteorology and CSIRO are undertaking current research into short term streamflow forecasting. Techniques include using a conceptual rainfall runoff modelling approach for sub-daily/daily flow forecasting out to 7 days using rainfall inputs with modelling outputs adjusted using a site specific correction scheme. Another approach is based on Bayesian Joint-probability methods. Outcomes from such research can potentially be incorporated into a process to forecast flow from the tributaries and also combining it with gauged streamflow data to quantify the flow already in transit in the rivers to forecast flow in the Goulburn River in various reaches.

Forecast rainfall products from the Bureau of Meteorology are available in different forms. A gridded form of forecast rainfall across the catchment could potentially be used to be input to a rainfall runoff catchment model to simulate future streamflow events. This is not within the scope of this project, however, this could be evaluated in future as a decision support tool for managing environmental releases. There is considerable uncertainty in the forecast rainfall in terms of total rainfall depth and the spatial and temporal variability over an area as large as the Goulburn and Broken catchments during a rainfall event and potentially for multiple rainfall events over a period of days. The flood risk associated with an event being more intense or at a larger scale than forecast would need further investigation. There is also risk that a rainfall event may be smaller and runoff not sufficient to enable release flows together with catchment runoff to meet a flow rate of over 25,000 ML/day at Shepparton.

Once a forecast data set is established, trigger scenarios should be re-evaluated using the data.

9.3 Losses

Further work will be required in future to quantify changes in losses associated with overbank environmental releases and be incorporated into release planning and management. This may include developing models to simulate the losses of overbank flows in various reaches of the river.

9.4 Duration of event releases

This work has focussed on how to increase the peak river flow at Shepparton. It has shown that current flow peaks tend to be relatively short with sharp recessions, making it difficult to achieve the desired 4 to 5 day durations, unless there is follow up rainfall event. It may be that peak flows need to target a higher flow, to provide the desirable duration at a lower flow (eg target 40,000 ML/day to provide 4 days at 35,000 ML/day). Alternatively the possibility of a shorter event duration could be explored.

9.5 Operational Management at Goulburn Weir

Alternative management arrangements may be possible for Waranga Basin, for the Basin to be held lower to retain some airspace. If this were done, the Waranga Basin could be refilled by subsequent water harvesting opportunities with no impact on overall water resource availability. If the Waranga Basin didn't refill, environmental water entitlements could be debited for the water not harvested. Further study would be required to assess if such an operating scenario was possible to ensure that impacts on allocations could be avoided through use of environmental allocations. The further study would also need to evaluate the benefits and risks of such an arrangement.

9.6 Evaluation of stream gauge and rainfall gauge network

It was noted in the flood characterisation section that the ungauged catchment upstream of Trawool generates significant flow in most events. Approaches to reduce the uncertainty of where in the ungauged area these flows originate from (such as additional flow gauging) need to be further considered.

9.7 Constraints to rate of rise and fall in releases

Given the potential impact that the rate of rise constraint has on the amount of time required to deliver an environmental flow event to Shepparton, further investigation into the maximum rate of rise downstream of Eildon is recommended.

The rate of fall also impacts on the ability to reduce a release in response to downstream flow conditions or potentially to forecast conditions.

It is recommended that the allowable rates of rise and fall for Eildon releases is investigated.

9.8 Other Assessments

It has been noted in this study that there are offtakes from Stuart Murray Canal which provide water for irrigation demands. In times when high flow events occur in the Goulburn, this may coincide with low or no irrigation demand. However at other times there may be demand which would still need to be supplied. The analysis to date has not evaluated the significance of this which could be explored further.

Also, due to data availability the historical diversions to Lake Mokoan were not added back to Broken River flows. The impact of this assumption could also be further examined.

It was found that in some events, particularly earlier in the period of record when there were more periods of missing or unreliable data, there are some spikes and negative inflows. In future, the streamflow records could be examined in detail to review the quality of available data to identify the causes of these if required.

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