A long-term temporal evaluation of environmental flow regimes in southern Victoria

Mark Stacey[1], Ying Quek[2], Ross Hardie[2] and Dorian Rave[3]

1. Alluvium Consulting, Level 1, 105-115 Dover Street, Cremorne, VIC 3121. mark.stacey@alluvium.com.au

2. Alluvium Consulting, Level 1, 105-115 Dover Street, Cremorne, VIC 3121.

3. DELWP, Level 10, 8 Nicholson Street, East Melbourne, VIC 3002.

Key Points

- The Victorian Government is preparing for their first Long-Term Water Resource Assessment to answer – amongst other questions - has there been any deterioration in waterway health for reasons related to flow?
- This evaluation of the provision of environmental flows is one part of the Long-Term Water Resource Assessment preparations
- This evaluation focused on how levels of provision of environmental flow recommendations have changed since implementation of Victoria's Sustainable Water Strategies, with analysis of almost 100 riverine reaches in southern Victoria
- An industry-standard software platform for this assessment was coupled with unique statistical interpretation and aggregation techniques to explore changes over time, between reaches, across flow components and across geographic areas

Abstract

In the early 2000s Victoria undertook a significant water reform program to address threats to water security and river health over a 50–year planning horizon. This reform included the legislative establishment of Long-Term Water Resource Assessments (LTWRAs) to ensure that water management would be adaptive to future changes in water resources and river health. Fifteen years after this reform, Victoria is preparing for the first round of LTWRAs to answer – amongst other questions - has there been any deterioration in waterway health for reasons related to flow?

This paper describes how an evaluation of the provision of environmental flow recommendations in riverine systems across Victoria is being used to help answer that question. The evaluation examined the degree to which the flow regime met the environmental flow recommendations in each year on record. This evaluation was conducted for almost 100 riverine reaches in southern Victoria, which had their environmental water requirements established through more than 40 existing studies. The project provides insights into how water recovery has addressed deficiencies in the provision of water for the environment and will support further examination of the ecological implications of these flow regime changes.

Keywords

Environmental water; Victoria; Long-Term Water Resource Assessments; FLOWS; evaluation; eFlow Predictor

Introduction

This paper summarises the approach taken in a project to evaluate the degree to which riverine flow regimes met scientifically-derived environmental flow requirements (EFRs) in Victoria over time. The project was commissioned by the Victorian Department of Environment, Land, Water and Planning (DELWP) and examined all rivers in Victoria's southern-flowing catchments that had EFRs established in previous investigations. The EFRs for these rivers were established through 42 different investigations commissioned from 2003 to 2017 (Figure 1).

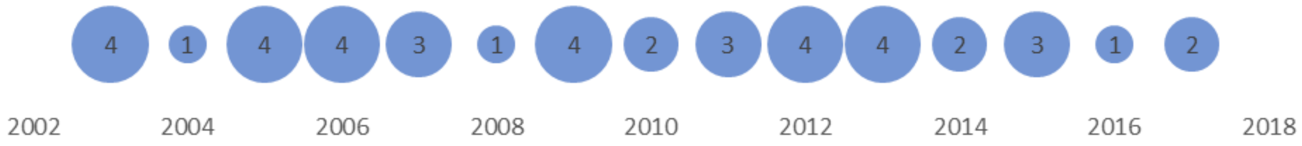

Figure 1. Number of studies per year establishing environmental flow requirements in the study area since 2003

The core driver for the project was the Victorian Government's Long-Term Water Resource Assessments (LTWRAs). The LTWRAs are a key tool to monitor the state of Victoria's water resources. These assessments determine whether long-term water resource availability has changed, and if so, whether there has been a disproportionate impact on water available for consumptive use or the environment. They also assess if there has been a decline in waterway health for flow-related reasons.

Victoria is currently preparing for the first LTWRA, which will test the assumptions upon which water sharing arrangements are based, including if there is sufficient water provided to maintain waterway health. In most riverine systems in Victoria, the current water sharing arrangements were last reviewed in the Sustainable Water Strategies (SWS). The period since the SWSs came into effect across southern Victoria is approximately ten years in the central region and five years in Gippsland and western Victoria. The overall objective of the project was to determine if riverine flow regimes in southern-flowing catchments more frequently achieved their EFRs in the years since implementation of the SWSs than the years preceding the SWSs.

The overall approach involved hydrological analysis of gauged flow records to assess what proportion of the EFRs were achieved in each water year, with subsequent statistical analysis to examine the change from pre-SWS years to post-SWS years. This approach was applied to assess the change for every EFR flow component, in every riverine reach, in each of Victoria's southern-flowing catchments, subject to the availability of suitable gauged data. This paper describes the approach used and provides examples of the findings. At the time of writing the results were still being finalised and so are not detailed in this paper.

Provision assessment technique

At the heart of this project's focus is what is commonly referred to as a 'compliance' assessment in the Victorian environmental water management framework (Department of Environment and Primary Industries 2013). Compliance assessments seek to quantify the level of achievement of each EFR in each season under a given flow regime scenario. They are commonly used during the EFR establishment process (e.g. to identify if the proposed EFRs are practically achievable) and as an input for those managing water for the environment (e.g. to understand whether a riverine system is likely to be under stress due to prolonged low levels of compliance). This project involved a *post-hoc* evaluation of flow regimes, so avoids the 'compliance' terminology, as for most years on record in most systems there was no management obligation to provide the recommended EFRs – this is especially the case for the years preceding the establishment of the EFRs. The project is therefore better described as an assessment of the 'provision' of EFRs over time.

The project used two analytical platforms to assess the level of provision of EFRs over time:

- The primary platform was the eFlow Predictor software (Marsh et al 2009) which was purpose-built to examine compliance and shortfalls for EFRs in riverine systems. In this project eFlow Predictor was used to report on 'under-achievement' of the EFRs i.e. periods when the observed flow rate is lower than that stipulated in the EFRs.

- The secondary platform was a custom spreadsheet which was created to report on 'over-achievement' of EFRs i.e. periods when the observed flow rate is higher than the maximum recommended bounds for the EFRs.

Across southern-flowing catchments study area, EFR studies have placed much greater focus on establishing the critical flow rate thresholds to be exceeded than establishing maximum critical flow rate thresholds. For example, in this region almost all FLOWS studies have recommended a minimum 'low flow' magnitude to be provided continuously throughout the summer period, whereas only a handful of studies recommended a maximum magnitude for the 'low flow'. Most of the analysis for this project therefore focused on assessing and reporting on 'under-achievement' of EFRs.

For both 'over-achievement' and 'under-achievement', the application of the analytical platforms provided an EFR provision score between 0% and 100% for each EFR flow component, in each reach, for each water year on record. For baseflow EFRS, these EFRs provision scores represent the number of days above the recommended threshold, relative to the number of days required to meet the EFR in full. For event-based peak flows EFRs, these EFR provision scores represent the number of successful events, relative to the number of successful events that would have occurred had the EFRs been met in full. An EFR provision score of 0% indicates that the EFR was never achieved in that year, whereas 100% indicates that the EFRs were achieved in full during that year.

Identifying suitable sites

As outlined above, the scope of this project was to assess the change in EFR provision for every EFR flow component, in every riverine reach, in each of Victoria's southern-flowing catchments, subject to the availability of suitable gauged data. The first step of the project therefore involved cataloguing all EFRs previously established in the study area and identifying those that were suitable for analysis in this project. The criteria for inclusion in the analysis were that the EFR:

- was stipulated as a flow rate (e.g. ML/d), rather than as a water level (this enabled it to be analysed in the eFlow Predictor platform, but excluded most estuarine reaches and wetlands in the study area)
- had accompanying streamflow gauge data with a relatively continuous record spanning the pre-SWS and post-SWS periods
- is the most recently scientifically-derived EFR for the reach (to account for the fact that many reaches have had their EFRs developed and reviewed over several cycles).

This cataloguing and gauged data availability review found that across the study area there were:

- 42 separate studies which had established EFRs
- 173 separate reaches that had been delineated (and numbered) through these 42 EFR studies
- 127 separate reaches (i.e. 73% of the 173) had EFRs specified, while the remaining 46 had no EFRs developed during their respecting EFR studies
- 86 separate reaches (i.e. 68% of the 127) had EFRs specified as a flow rate and accompanying gauge data with a relatively continuous record spanning the pre SWS and post SWS periods.

These 86 reaches encompassed all the sites analysed during this project. Their spatial distribution is shown in Figure 2.

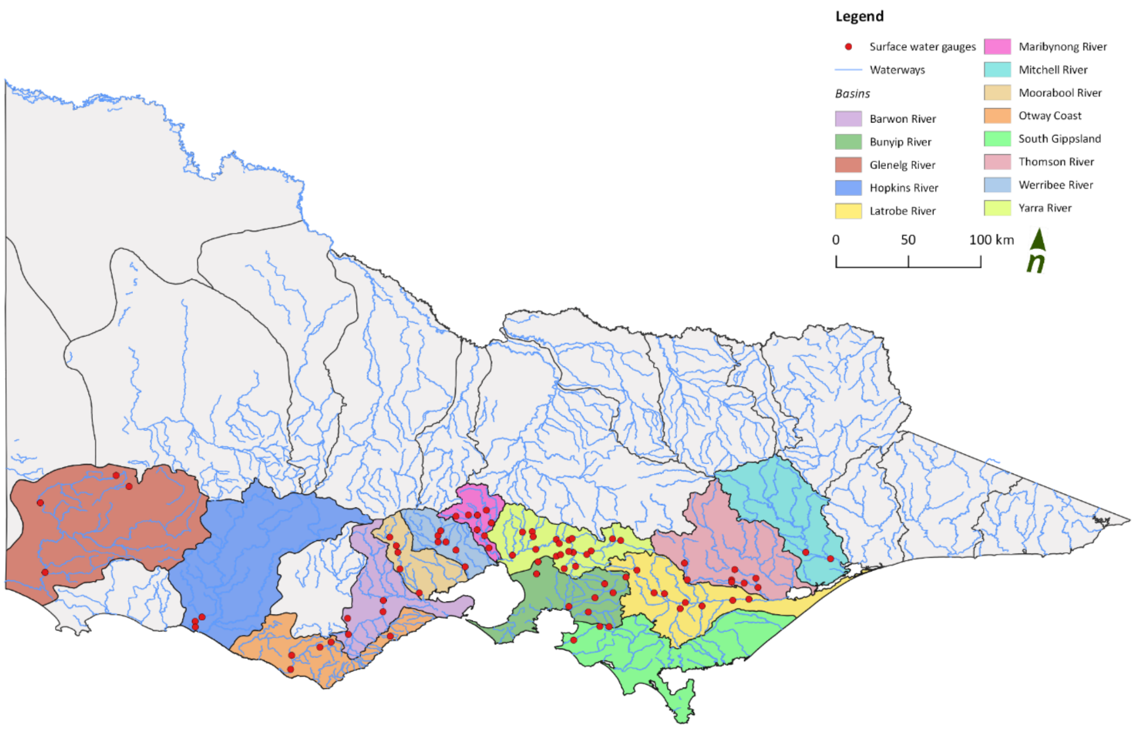

Figure 2. The spatial distribution of assessed surface water gauges (the grey area has no EFRs relevant to this project)

Statistical interpretation and aggregation

Across the 86 analysis reaches there was an average (mean) of approximately 6.5 flow component recommendations per reach, meaning that there were more than 550 EFRs timeseries generated of EFR provision. There was a high level of variability in the number of years of gauged data in the pre-SWS period, with the length of the post-SWS gauged data record being typically considerably shorter (**Figure 3**).

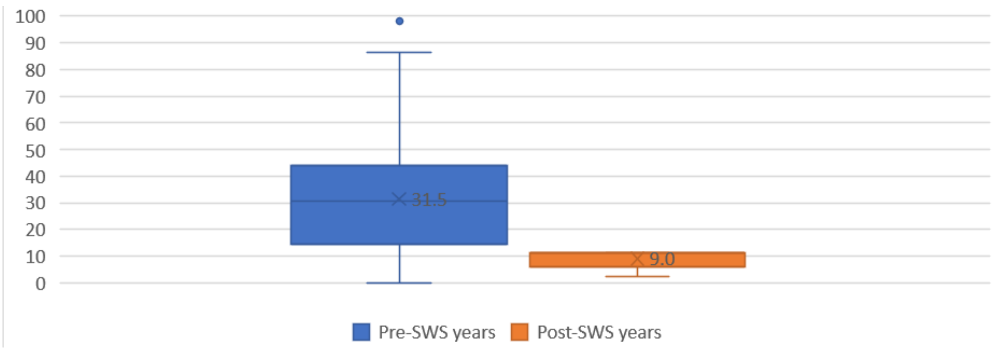

Figure 3. Box plots showing the distribution in the number of years of pre-SWS and post-SWS gauged data across the 86 reaches

Given the depth and breadth of the analysis, considerable statistical interpretation and aggregation was needed to examine trends over time, across catchments, and between flow components. The following sections describe the statistical interpretation and aggregation, which involved three general approaches of timeseries analysis on:

- individual EFRs
- reach-aggregated EFRs
- generalised EFRs

Individual EFRs

The first step in the analysis was to examine how each EFR performed on an individual basis, by comparing the pre-SWS EFR provision to post-SWS EFR provision. Due to considerable variability in the length of pre- and post-SWS gauged data (**Figure 3**), a rolling-average approach was adopted that examined the average (mean) EFR provision during the post-SWS period, comparing this to all historical sequences in the pre-SWS record of equivalent duration. For example, if there were 5 years of post-SWS gauged data then the mean EFR provision in the 5-year post-SWS sequence was compared to the mean EFR provision in all historical 5-year sequences in the pre-SWS data. Fortran-based code was developed within DELWP to undertake this computation and provide the following outputs for each EFR:

- timeseries plot showing EFR provision in each year
- timeseries plot showing the x-year rolling-average EFR provision (where x is the number of years of post-SWS data available)
- box and whisker plot summarising the distribution of the x-year rolling-averages of EFR provision, relative to the post-SWS mean EFR provision
- exceedance curve showing the number of years that a given x-year rolling-average EFR-provision was exceeded prior to the SWS, relative to the post-SWS record.

Figure 4 shows examples of these outputs, and suggests that in this instance, the EFR provision of the example winter baseflow EFR has been very similar in the post-SWS and pre-SWS periods.

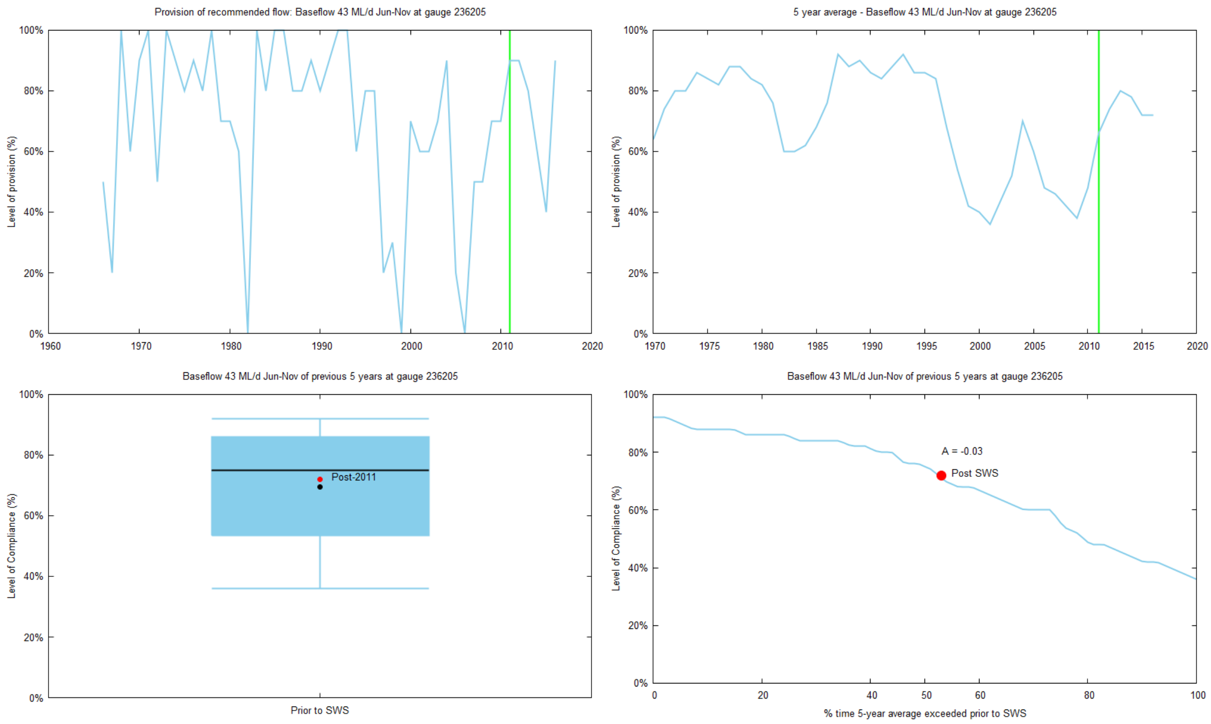

Figure 4. Example of the individual EFR analyses plots from the Upper Merri River

In addition to the plot outputs, the Fortran-based code was also tailored to develop a single, consistent metric which can be used across all EFRs to report on the degree of change in EFR provision. The adopted metric is a value based on the plot position of the post-SWS average on the flow exceedance curve, compared to the pre-SWS period i.e. how far is the post-SWS result from the pre-SWS distribution?

The metric's equation is $A = 0.5 - P_{ile}(Q_{postSWS})$, where $Q_{postSWS}$ is the mean EFR provision in the post-SWS record and $P_{ile}(Q_{postSWS})$ is the proportion of years that $Q_{postSWS}$ was exceeded in periods of the same length in the pre-SWS record. An 'A value' result approaching zero represents minimal change in the EFR provision (i.e. the post-SWS mean was exceeded exactly 50% of the time during the pre-SWS period), but the further that the metric result is from 0.0 (to an upper limit of ±0.5), the greater the change in EFR provision in the post-SWS period. Reaches with an 'A value' further from 0.0 (especially those with a negative 'A value') have experienced greater changes in EFR provision, which suggests further investigation would be warranted to examine the implications on ecological health.

Reach-aggregated EFRs

The approach described above provided a powerful way of examining changes in provision of individual EFRs over time but was not suited to examining trends across reaches. To address this, and help compare EFR provision across reaches, a simple normalisation approach was developed, where the individual EFR provision scores were summed and normalised (by dividing by the number of flow components with EFRs) to provide a total EFR provision score for the reach between 0 and 1. Reaches with all EFRs being fully achieved in a single water year would achieve a normalised score of 1, with scores less than 1 demonstrating some deficiencies in the EFR provision. Figure 5 provides an example of this approach, demonstrating that in this case, the level of provision across all EFRs for this reach varied between 0.14 (in 2006/07) and 0.98 (in 1975/76). These normalised scores can be used to examine trends over time and across catchments.

The contribution of each EFR to the normalised score is also visually apparent in the resultant chart, and in this case, highlights that the winter baseflow and winter fresh recommendations often have relatively low levels of provision (though note the example in Figure 4 indicated that the level of provision of winter baseflow was similar in the pre- and post-SWS periods).

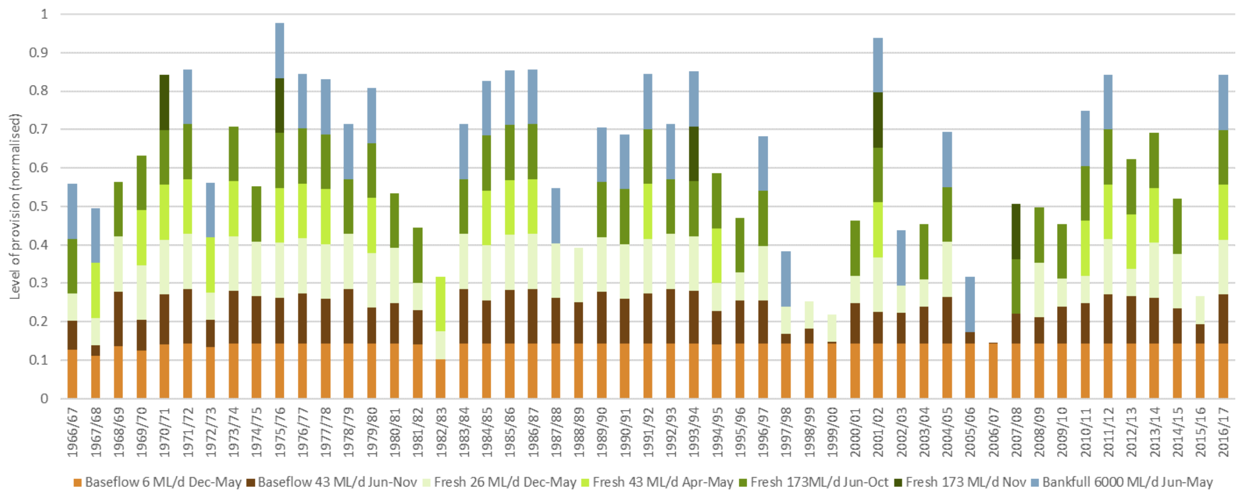

Figure 5. Example of the reach-aggregated EFR timeseries plot from the Upper Merri River

Generalised EFRs

While the two approaches above provided detailed statistics on individual EFRs and enabled comparison across reaches, they are not well suited to examining whether changes in EFR provision were more apparent for some types of flow components than others, and/or, whether changes were more apparent for some months of the year than others.

To enable this, an aggregation process was used to convert the EFR provision timeseries for individual flow components into a series of five generalised EFRs, which were based on and broadly align with those used in Victoria's relatively standardised EFR establishment approach. This approach generally involves establishing recommendations for the following six generalised flow components: cease to flow, low flow, freshes, high flow, bankfull flow and overbank flow (DEPI 2013). However, in their implementation the EFR studies in the study area often adopted variants on these generalized flow components, developing EFRs that often do not neatly align with these six generalized flow components. These discrepancies arise due to variations in the number of flow components, differences in the seasonality of flow components, and nomenclature used to describe them.

An aggregation process was therefore used to convert the EFR provision timeseries for individual flow components into a series of five generalised EFR provision timeseries. This allowed differentiation of flow component types and seasonality:

- Summer baseflow: Duration-based EFRs that typically require several months of continuous minimum flow during summer – autumn months
- Winter baseflow: Duration-based EFRs that typically require several months of continuous minimum flow during winter – spring months
- Summer fresh: Event-based EFRs that typically require several days above a peak flow threshold, and are required to occur during the summer – autumn months
- Winter fresh: Event-based EFRs that typically require several days above a peak flow threshold, and are required to occur during the winter – spring months
- Any period event-flows: Other event-based EFRs that either have more specific timing requirements (e.g. can only occur in September) or non-specific timing requirements (i.e. can occur in any month).

This aggregation approach involved assigning each individual EFR into one of the above five categories and then developing an EFR provision timeseries for each of the generalized EFRs, by taking the average (mean) provision result from the relevant flow components. An example of this is shown in Figure 6, using the same reach that was highlighted in Figure 5. Figure 6 demonstrates that rather than having a normalised score between 0 and 1, this approach produces a normalised score between 0 and 5 where each of the five generalised flow components are scored between 0 and 1. This approach enables a direct comparison of EFR provision for each of the generalised flow components across space and over time.

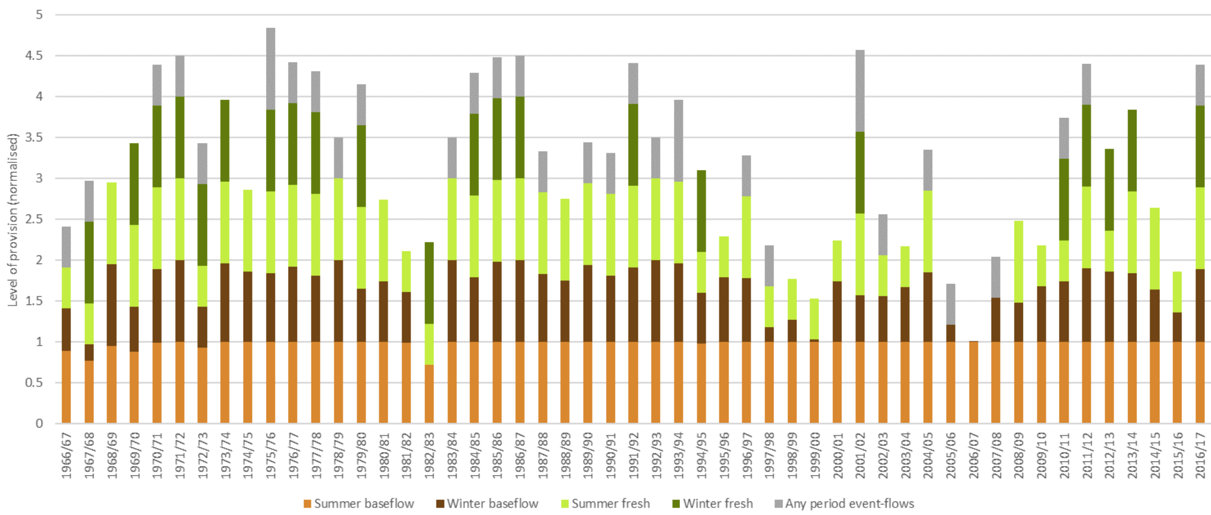

Figure 6. Example of the generalised EFR timeseries plot from the Upper Merri River

Finally, the generalised EFR approach was coupled with the Fortran-based code to enable broad comparisons in the change in EFR provision across all reaches and basins. Across all reaches and all generalised flow components, this demonstrated that EFR provision has increased substantially in some reaches since the SWS but has declined substantially in other reaches (**Figure 7**).

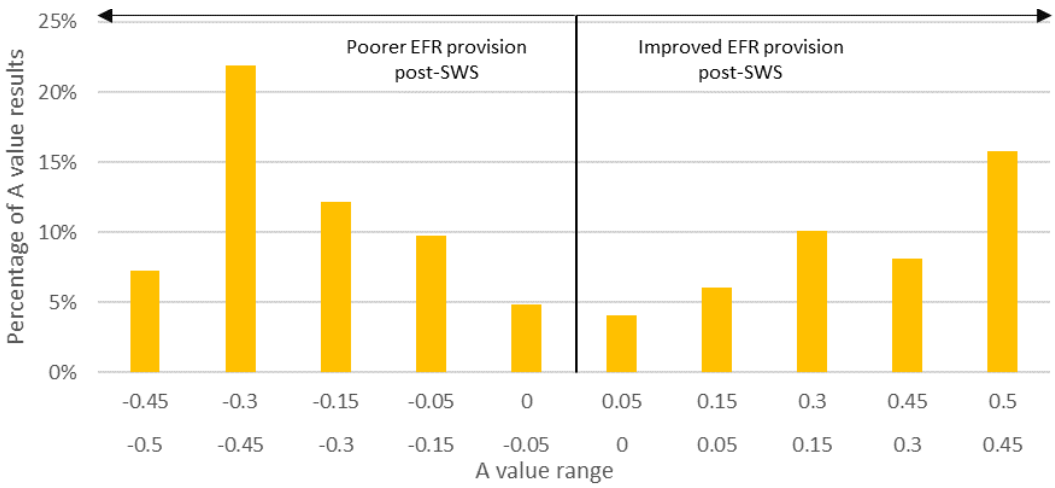

Figure 7. Histogram showing the distribution in 'A value' results across all generalised flow components

Conclusion

The approach outlined in this paper has been developed to enable a regional comparison of the degree to which riverine flow regimes in southern Victoria have met the scientifically-derived EFRs over time. The focus was on comparing EFR provision during the pre- and post-SWS periods, to inform Victoria's first Long-Term Water Resource Assessment. The provision analysis conducted for over 550 individual EFRs involved the application of eFlow Predictor and development of customized spreadsheets and Fortran-based code. This enabled statistically interpretation of the impacts on individual EFRs, reach-aggregated EFRs and generalised EFRs. While the results were still being finalised at the time of writing, the high-level preliminary results suggest there has been considerable variability in levels of improved EFR provision since the SWS. Across the board there appears to have been slightly more decline in EFR provision since the SWSs than there has been improvement.

Acknowledgments

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