



Adapting to Climate Change

Stage 2

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Authors	Simon Lang, Leah Traill, Andrew John (University of Melbourne)
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Executive Summary

The objectives for Stage 2 of the Victorian Environmental Water Holder's (VEWH's) adapting to climate change project were to:

1. Assess the current and potential future reliability of supply for held environmental entitlements in Victoria
2. Identify where environmental watering objectives are at most risk now and in the future

For Objective 1, the current and future impacts of climate change on reliability of supply were assessed for VEWH, Commonwealth Environmental Water Holder (CEWH) and The Living Murray (TLM) holdings¹. For Objective 2, hydrological indicators were used to assess where in Victoria environmental watering objectives are at most risk. For both objectives, seven climate scenarios were considered: post-1975 conditions, year 2040/45 conditions with low, medium, and high climate change, and year 2065/70 conditions with low, medium, and high climate change. The 2040/45 and 2065/70 scenarios were based on a high emissions scenario (Representative Concentration Pathway (RCP) 8.5).

With regards to environmental entitlement reliability:

- In the southern and western part of the state, the potential for climate change to reduce the volume of allocations to environmental entitlements is greatest in the Wimmera system. That is, average allocations of more than 30,000 ML/year under post-1975 conditions are projected to reduce to less than 15,000 ML/year under year 2065 conditions with high climate change. Allocations to the CEWH's 28,000 ML of low reliability water shares in the Wimmera system are particularly vulnerable to climate change.
- In the southern and western part of the state, the percentage change in average annual allocations under potential future climate change falls within two distinct groups. The Latrobe, Tarago, Barwon, Moorabool, Wimmera and Glenelg systems have reductions of more than 40% for the most severe climate case simulated, whereas for the Thomson, Macalister and Werribee systems the reduction is less than 20%. The exception is the Yarra system, where the environment receives the first 17 GL of inflows each year regardless of climate conditions.
- In northern Victoria, the range of percentage change in average annual allocations under potential future climate change is greater. For the most severe climate case modelled in each system (year 2070 conditions with high climate change), the percentage reduction in average annual allocations is more than 40% for the Goulburn, Campaspe and Loddon systems, approximately 25% for the Victorian Murray system, and less than 20% for the Broken system. However, the environmental entitlement holdings in the Broken are small compared to the other northern Victoria systems.
- In northern Victoria, the size of the environmental entitlements in the Victorian Murray and Goulburn are very large compared to all other systems in Victoria. Consequently, the potential for climate change to reduce the volume of allocations to environmental entitlements is greatest in these two systems.

¹ Only high reliability water shares, low reliability water shares and shares of inflows were considered. Other types of environmental entitlements, such as the Barmah-Millewa Forest environmental entitlement in the Victorian Murray system, were not considered.

The hydrological indicators show that the potential impacts of climate change on achieving environmental watering objectives and ecological outcomes are more significant in the Wimmera, Glenelg, Barwon, Moorabool, Werribee, Tarago, Campaspe and Loddon systems – which are in the west and central parts of Victoria – compared with the other systems. In the other systems, the impacts are generally greater in winter and spring compared with summer and autumn, and for high flows (e.g. freshes) compared with low flows.

For the Glenelg, Goulburn, Campaspe, Loddon and Victorian Murray systems, the outcomes of this top-down scenario modelling were also compared with bottom-up approaches to assessing potential climate change impacts on environmental entitlement reliability and hydrological indicators of ecological outcomes. This showed that the conclusions made from top-down and bottom-up modelling were relatively similar, but that the bottom-up modelling provided additional insights into how modelled environmental entitlement reliability and hydrological indicators behave outside of and in-between the climate conditions represented in the top-down scenarios. Differences between the top-down and bottom-up assessment of how sensitive Victorian Murray and Goulburn allocations are to changes in rainfall-runoff may also warrant further investigation, given the size of environmental water holdings in these two systems.

The scope of this Stage 2 project did not include the development of adaptation options to mitigate potential climate change impacts on environmental entitlement reliability or environmental watering objectives. The design and prioritisation of response options is anticipated to be the focus of future stages of the VEWH's adapting to climate change project.

1. Introduction

1.1 Background

The Victorian Environmental Water Holder (VEWH) was established on 1 July 2011 through an amendment to the *Victorian Water Act 1989*. The VEWH is an independent statutory body responsible for managing Victoria's environmental water entitlements (also known as environmental water holdings). The entitlements are used for environmental watering of Victoria's rivers, wetlands and floodplains.

As per Victoria's *Climate Change Act 2017*, the VEWH is required to consider the potential impacts of climate change on the use of environmental water holdings. Therefore, 'adapting to climate change' is one of the VEWH's priorities in their 10-year strategy². Consistent with this priority, the VEWH began an adapting to climate change project in March 2024. This report summarises the outcomes from Stage 2 of the project.

1.2 Project objectives

The objectives for Stage 2 of the adapting to climate change project were to:

1. Assess the current and potential future reliability of supply for held environmental entitlements in Victoria
2. Identify where environmental watering objectives are at most risk now and in the future

For Objective 1, the current and future impact of climate change on reliability of supply were assessed for VEWH, Commonwealth Environmental Water Holder (CEWH) and The Living Murray (TLM) holdings. For Objective 2, hydrological indicators were used to assess where in Victoria environmental watering objectives are at most risk.

1.3 Stage 1 outcomes

Stage 1 of the adapting to climate change project was completed by HARC in 2024 and:

- Produced an options paper that described different methods that could be used to meet the project objectives.
- Developed – in conjunction with the VEWH and a project steering committee – a recommended method for Stage 2.

The HARC (2024) report describes the outcomes of Stage 1 in detail, and the Stage 2 project scope and method are described below in Section 1.4 and Section 2 respectively.

² <https://www.vewh.vic.gov.au/news-and-publications/>.

1.4 Stage 2 scope

The project scope for Stage 2 was to:

- Collate the latest versions of the daily Source water resource models for each of Victoria's regulated river systems with environmental entitlements, and available Source model results for runs representing post-1975 climate conditions, and potential future climate conditions.
- Complete additional Source model runs (referred to as top-down scenarios in Stage 1) so that long-term modelling results representing post-1975 climate conditions, 2040 or 2045 climate conditions and 2065 or 2070 climate conditions were available for each system³.
- Use the Source model results to assess how the reliability of allocations to environmental water holdings – either via a percentage of inflows to storage or seasonal determinations for water shares – change under potential future climate conditions.
- Use the Source model predictions of total streamflow at selected locations within each system to assess hydrological indicators of ecological outcomes for post-1975 and potential future climate conditions.
- Compare the outcomes from the top-down modelling approach described above with bottom-up assessments of entitlement reliability and hydrological indicators of ecological outcomes for selected systems. These bottom-up assessments were completed by the University of Melbourne.
- Summarise the project outcomes in this report.

The Stage 2 project was overseen by a steering committee comprised of:

- The VEWH: Nicholas Longden, Andrew Sharpe⁴ and Keith Chalmers
- The Department of Energy, Environment and Climate Action (DEECA): Sandra Dharmadi, Xue Hou and Fiona Spruzen

1.5 Systems investigated

The river systems considered in this project were:

- **Gippsland region:** Latrobe, Thomson and Macalister
- **Central region:** Yarra, Tarago, Werribee, Barwon and Moorabool
- **Western region:** Wimmera-Glenelg
- **Northern region:** Victorian Murray, Goulburn, Broken, Campaspe and Loddon

These systems are all regulated to some degree. This project does not consider climate change impacts or potential management responses in unregulated catchments.

³ The future climate conditions were modelled as per the DEECA (2020) *Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria*, assuming a Representative Concentration Pathway (RCP) 8.5 emissions scenario, and low, medium and high degrees of climate change

⁴ For approximately the first half of the project

In some sections of the report, results for the Central region systems were further divided into eastern (Yarra, Tarago) and western (Werribee, Barwon and Moorabool) parts.

There are environmental water holdings in the Ovens River system and for Wimmera-Mallee wetlands. However, these were not included in the project scope because of the relatively small size of environmental entitlements in both systems.

1.6 This report

The remainder of this report includes:

- Section 2: A description of the method used for Stage 2
- Section 3: Findings about the reliability of supply for held environmental entitlements in Victoria
- Section 4: Findings about where hydrological indicators of ecological outcomes are expected to change most under potential future climate conditions
- Section 5: A comparison of these findings with bottom-up assessments of environmental entitlement reliability and hydrological indicators of ecological outcomes for the Glenelg, Goulburn, Campaspe, Loddon and Victorian Murray systems
- Section 6: A summary of the project outcomes.

The appendices to the report are:

- Appendix A to Appendix C: Additional detail on aspects of the project method
- Appendix D to Appendix R: System-specific plots of the modelled allocations to environmental entitlements, the streamflow at selected locations, and the hydrologic indicators of ecological outcomes
- Appendix S: Plots showing the similarities and differences between modelled and observed data for historic allocations and streamflow.

2. Stage 2 method

The method for Stage 2 of the VEWH adapting to climate change project was a three-step process. The steps are summarised in Figure 1.

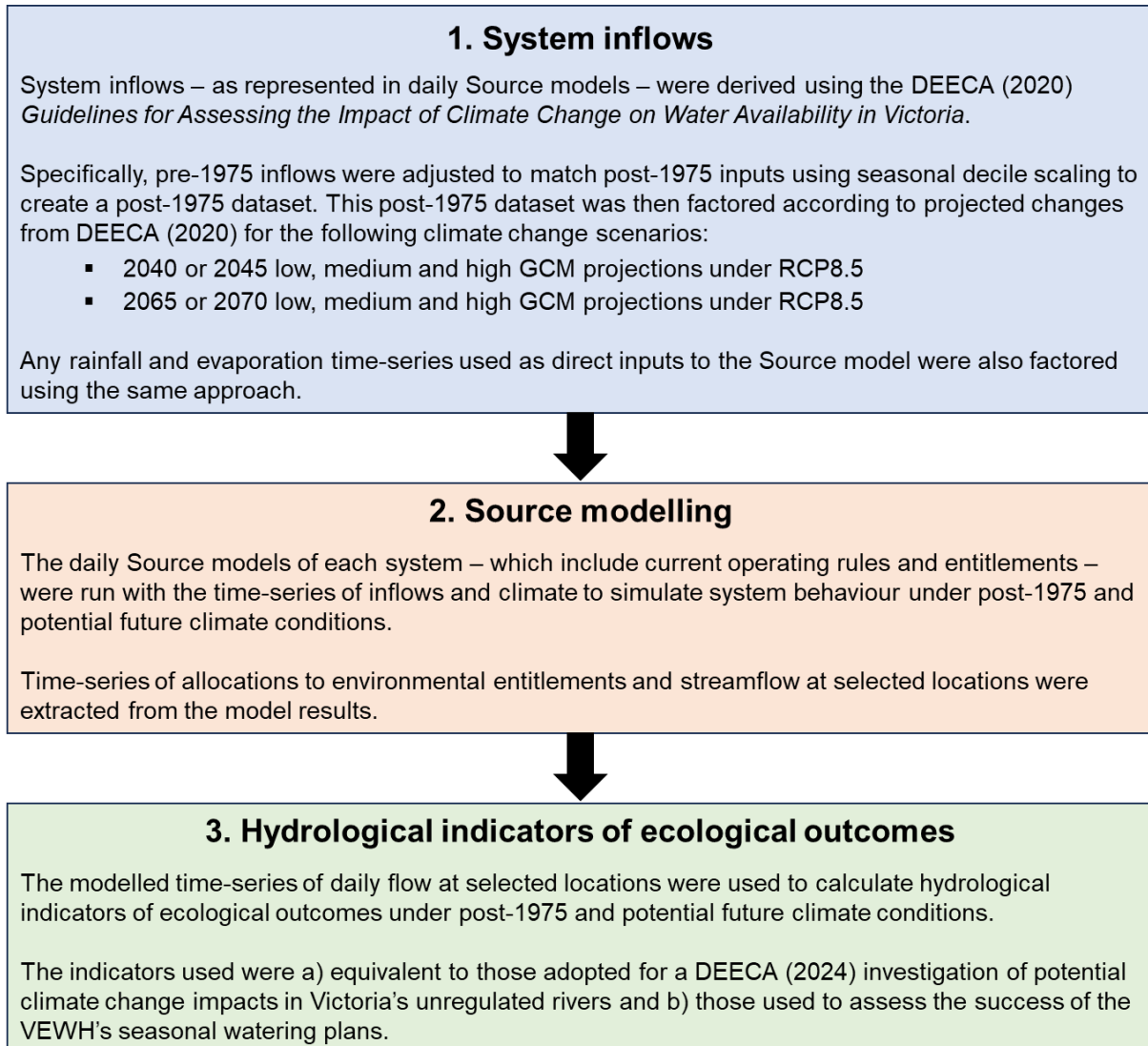


Figure 1: Overview of the method used for Stage 2 of the VEWH adapting to climate change project

Figure 2 and Figure 3 given an example of how Source model inputs were derived for the climate cases considered. Time-series that represent post-1975 conditions were created by scaling pre-1975 inputs to match post-1975 seasonal deciles (e.g. Figure 2). Time-series that represented potential future climate conditions were then derived by factoring the post-1975 scenario using the average projected changes in rainfall-runoff from DEECA (2020) (e.g. Figure 3). The projected changes from DEECA (2020) were based on an RCP 8.5 emissions scenario.

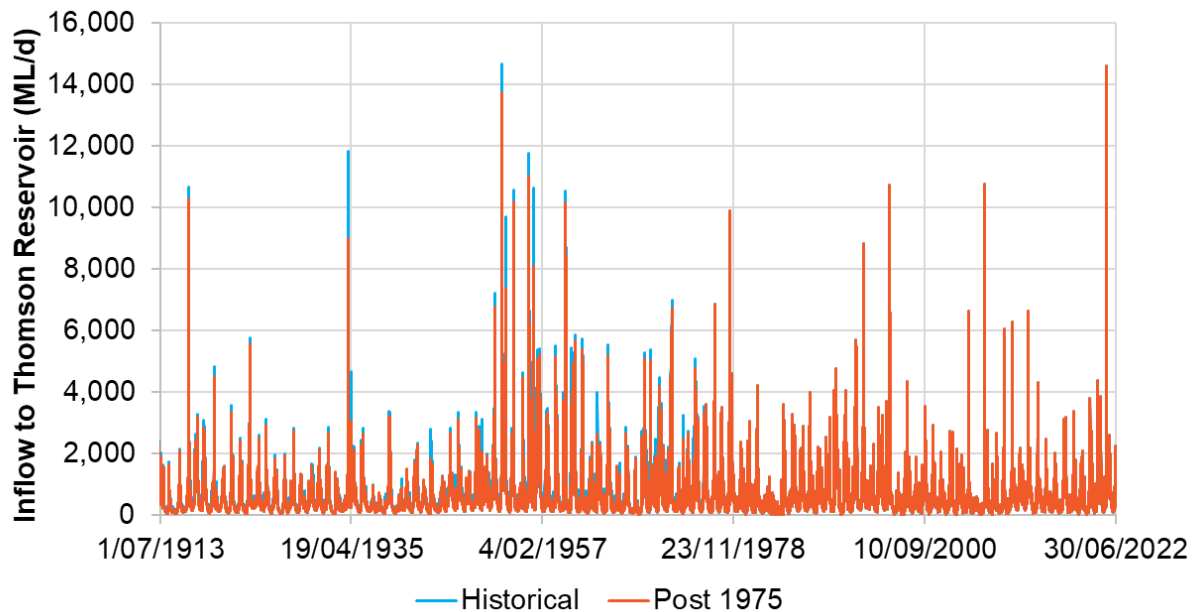


Figure 2: An example of the effect of adjusting a Thomson-Macalister Source model input to represent post-1975 conditions.

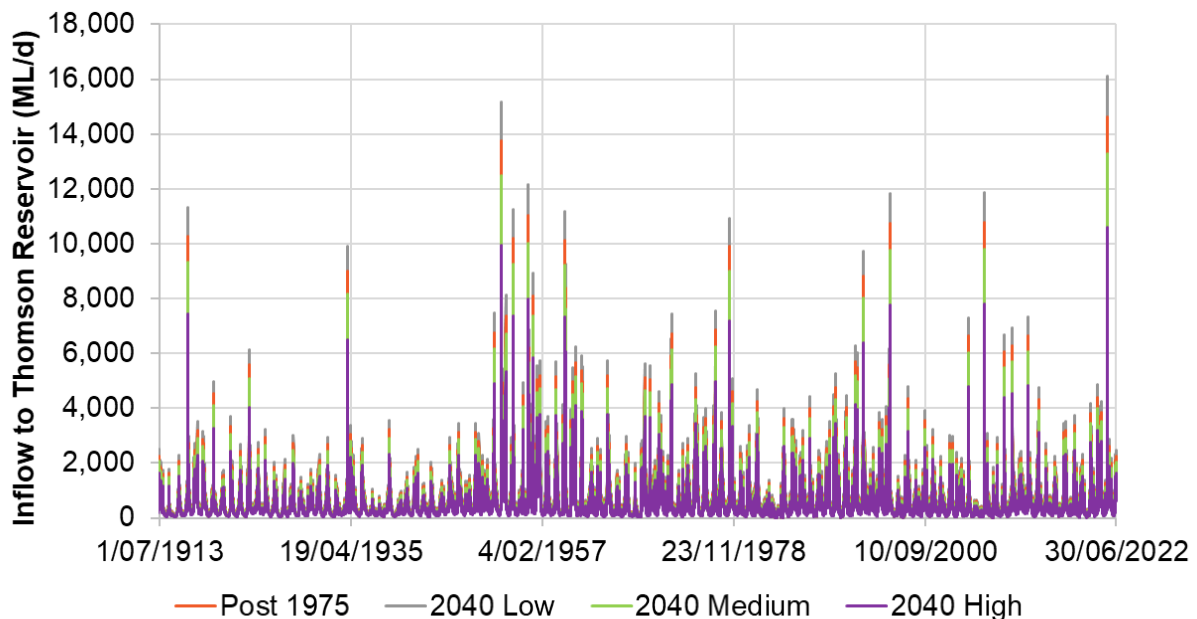


Figure 3: An example of factoring post-1975 data to represent potential conditions in 2040 for low (10.3%), medium (-9.1%) and high (-27.6%) climate change projections.

This method of factoring time-series to represent potential future climate conditions is reasonably simplistic. It does not account for potential changes in streamflow sequencing, seasonality, or the characteristics of droughts and floods. Current trends show that some catchments are experiencing rarer floods more commonly, and frequent floods less often (Wasko and Nathan, 2019). This means the impact of climate change on bankfull and overbank flows may be overestimated in this report. However, the report focuses on potential changes to average allocations for environmental entitlements, and how often low flow and fresh targets are met in regulated river systems downstream of storages. Therefore, the approach is fit-for-purpose.

Table 1 to Table 4 list the Source models used to simulate the regulated river systems in the four regions of Victoria. These tables also show:

- The owner of the Source models. These owners provided the base case model used for Stage 2 of the VEWB adapting to climate change project. The base case represents current system infrastructure (e.g. dams, weirs), demands (e.g. urban, rural, environmental) and management rules (e.g. entitlements, allocations).
- The most recent known application of the base case Source models prior to the start of the Stage 2 project (August 2024).
- Climate conditions (i.e. system inflows) previously simulated with the base case models.
- Climate conditions derived in the Stage 2 project, to also be used with the base case models.

Some assumptions in the Source models to be aware of are:

- Wimmera-Glenelg:
The share of the VEWB Wimmera-Glenelg entitlement was split 60% for the Wimmera and 40% for the Glenelg. Other splits were tested (i.e. 50% : 50% and 40% : 60%) and found to have no impact on model results for post-1975 climate conditions. However, the model results for the most severe climate case were more sensitive to the assumed split.
- Latrobe:
Representation of the environmental share of Blue Rock Reservoir and its use was approximated (see Appendix B for more detail).
- Thomson-Macalister:
Melbourne Water provided modelled time-series of monthly Thomson Reservoir to Upper Yarra Reservoir transfers for all climate scenarios. These transfers were uniformly disaggregated to daily volumes.

Appendix A includes further detail on how system inflows in the Source models – and in some cases other input time-series of rainfall, evaporation and demands – were factored to represent post-1975 and potential future climate conditions.

Table 1: Source models in Gippsland region

System(s)	Water resources model	Owner	Most recent known application(s)	Climate conditions (i.e. system inflows) modelled with base case	
				Previous application(s)	For Stage 2 of VEWH project
Latrobe	Latrobe Source model	DEECA	Latrobe Valley Regional Rehabilitation Strategy (Alluvium and HARC, 2023) Latrobe 3-4 Bench Entitlement water resource modelling (HARC, 2024b)	Post-1975 for both RCP8.5 2065, with high, medium and low climate change for LVRRS	RCP8.5 2040 with high, medium and low climate change
Thomson, Macalister	Thomson-Macalister Source model	DEECA	Thomson Macalister Source Model Update (HARC, 2023) MID Operational Model Review (HARC, 2024c)	Post-1975 Post-1997	RCP8.5 2040 with high, medium and low climate change RCP8.5 2065, with high, medium and low climate change

Table 2: Source models in Central region

System(s)	Water resources model	Owner	Most recent known application(s)	Climate conditions (i.e. system inflows) modelled with base case	
				Previous application(s)	For Stage 2 of VEWH project
Yarra, Tarago	Melbourne Water Source headworks model	MWC	None for recently developed daily time-step version of Source model	n/a	Post-1975 RCP8.5 2040 with high, medium and low climate change RCP8.5 2065, with high, medium and low climate change
Werribee	Werribee Source model	DEECA	Werribee Source Model Development Report (HARC, 2021) Quantifying the hydrological and hydraulic impact of environmental flows in Victoria (Streamology, 2024)	Post-1975 Post-1997 RCP8.5 2020 with high, medium and low climate change RCP8.5 2045 with high, medium and low climate change RCP8.5 2070 with high, medium and low climate change	
Barwon, Moorabool	Barwon-Moorabool Source model	DEECA	Development of the Barwon Moorabool Source model (GHD, 2022)	Historic	Post-1975 RCP8.5 2040 with high, medium and low climate change RCP8.5 2065, with high, medium and low climate change

Table 3: Source model in Western region

System(s)	Water resources model	Owner	Most recent known application(s)	Climate conditions (i.e. system inflows) modelled with base case	
				Previous application(s)	For Stage 2 of VEWH project
Wimmera, Glenelg	Wimmera-Glenelg Source model	DEECA	Update of Glenelg River environmental flow targets (Streamology, 2023) Quantifying the hydrological and hydraulic impact of environmental flows in Victoria (Streamology, 2024)	Post-1975 Post-1997 RCP8.5 2020 with high, medium and low climate change RCP8.5 2040 with high, medium and low climate change RCP8.5 2065 with high, medium and low climate change	

Table 4: Source models in Northern region

System(s)	Water resources model	Owner	Most recent known application(s)	Climate conditions (i.e. system inflows) modelled with base case	
				Previous application(s)	For Stage 2 of VEWH project
Victorian Murray	Source Murray Model (SMM)	MDBA	Murray constraints modelling to inform Victorian Constraints Measures Program (MDBA, 2022)	Post-1975 RCP8.5 2070 with high and medium climate change	RCP8.5 2040 with high, medium and low climate change RCP8.5 2070 with low climate change
Goulburn, Broken, Campaspe, Loddon	GBCCCL Source model	DEECA	GBBCL Source Model Modelling for Constraints Measures Program (DEECA, 2023)	Post-1975 RCP8.5 2070 with high and medium climate change	RCP8.5 2040 with high, medium and low climate change RCP8.5 2070 with low climate change

HARC was responsible for the Source modelling of each system, with three exceptions:

- Melbourne Water modelled the Yarra and Tarago systems. This was the first application of the daily time-step version of the Melbourne Water Source headworks model.
- DEECA modelled the Goulburn, Broken, Campaspe and Loddon systems using the GBBCL Source model.
- The MDBA modelled the Victorian Murray system using the Source Murray Model. The interactions between the Victorian tributaries and River Murray were simulated using the same two-step iteration procedure applied for Stage 1A of the Victorian Constraints Measures Program (MDBA, 2022).

Time-series of allocations to environmental entitlements and streamflow at selected locations were extracted from the Source model results. Allocations considered were shares of system inflows, and / or seasonal determinations for high and low reliability water shares within the VEWH, CEWH and TLM holdings. The reliability of other environmental entitlements products, such as the Barmah-Millewa Forest Environmental Allocation in the Murray system, were not assessed. Further details about the environmental entitlements represented in the Source models are available in Appendix B.

The hydrologic indicators calculated from the streamflow modelled at selected locations are shown in Table 5. The first six of these are equivalent to indicators used in the DEECA (2024) investigation of potential climate change impacts in Victoria's unregulated river systems – which was based on monthly time-step modelling – and are a subset of the indicators developed by USGS (2006) for their hydrological integrity assessment process.

For the MH26 and DL16 indicators, the median daily flow and 75th percentile flow was calculated using model results for the post-1975 scenario. The last two indicators (Avg0Dur and Max0Dur) were included based on advice from the project steering committee.

Table 5: Hydrologic indicators calculated from Source model simulations of daily streamflow

Hydrologic indicator	Units	Abbreviation
Mean daily flow	ML/d	MA1
Mean February flow	ML/d	MA13
Mean August flow	ML/d	MA19
Mean high peak flow (>7 x median daily flow), divided by median daily flow	Unitless	MH26
Median low flow (<75 th percentile flow) spell duration	Days	DL16
Mean number of zero flow (<0.1 ML/d) days per year	Days	DL18
Average duration of zero flow (<0.1 ML/d) spells	Days	Avg0Dur
Maximum duration of zero flow (<0.1 ML/d) spells	Days	Max0Dur

The streamflow modelled at selected locations was also used to assess how often environmental flow targets were being met under each of the simulated climate conditions. This 'success' metric was calculated using the VEWH's licenced version of eFlow Projector.

Appendix C lists the environmental flow targets in each river system, and which of these are included as environmental water demands in the Source models (i.e. are supplied partially or wholly by stored environmental water). Where the environmental flow demand in the Source model contained an 'or natural' clause (e.g. a low flow of 10 ML/d or natural), the 'or natural' aspect was assessed using the post-1975 scenario, and then applied to all climate conditions.

The method described above is a top-down approach. That is, a discrete number of scenarios representing different potential future climate conditions were used to model environmental entitlement reliability and hydrological indicators of ecological outcomes. A bottom-up assessment was also completed for the Glenelg, Goulburn, Campaspe and Loddon systems. A bottom-up approach involves modelling a wider range of potential future climate conditions using smaller increments of change (e.g. to rainfall-runoff). This was done so that the outcomes from both approaches could be compared. The method used for the bottom-up approach is described in Section 5.

3. Environmental entitlement reliability

The time-series of simulated allocations⁵ to environmental entitlements were extracted from the Source model results and post-processed in a range of ways to assess how potential future climate change may affect the reliability of these entitlements. The time-series of the simulated allocations within each system for post-1975 and potential future climate conditions are shown in Appendix D to Appendix R.

Figure 4 summarises the outcomes within the Gippsland, Central and Western regions of Victoria by plotting average end-of-water-year allocations to environmental entitlements in each river system, versus potential future changes in average rainfall-runoff relative to post-1975 conditions. The left side shows average allocations in ML per year, and the right side shows the percentage change in average allocations compared with post-1975 conditions. Figure 5 is the same but for the river systems in Northern region of Victoria. The change in average allocation between scenarios is assumed to be linear, but this may not be the case in practice.

These two figures demonstrate that:

- In the southern and western part of the state, the potential for climate change to reduce the volume of allocations to environmental entitlements is greatest in the Wimmera system. That is, average allocations of more than 30,000 ML/year under post-1975 conditions are projected to reduce to less than 15,000 ML/year under year 2065 conditions with high climate change. Allocations to the CEWH's 28,000 ML of low reliability water shares in the Wimmera system are particularly vulnerable to climate change (average annual allocations decrease from 12,200 ML under post-1975 climate conditions to 200 ML in the year 2065 high climate change scenario).
- In the southern and western part of the state, the percentage change in average annual allocations under potential future climate change falls within two distinct groups. The Latrobe, Tarago, Barwon, Moorabool, Wimmera and Glenelg systems have reductions of more than 40% for the most severe climate case simulated, whereas for the Thomson, Macalister and Werribee systems the reduction is less than 20%. The exception is the Yarra system, where the environment receives the first 17 GL of inflows each year regardless of climate conditions.
- In northern Victoria, the range of percentage change in average annual allocations under potential future climate change is greater. For the most severe climate case modelled in each system (year 2070 conditions with high climate change), the percentage reduction in average annual allocations is more than 40% for the Goulburn, Campaspe and Loddon systems, approximately 25% for the Victorian Murray system, and less than 20% for the Broken system. However, the environmental entitlement holdings in the Broken are small compared to the other northern Victoria systems.
- In northern Victoria, the size of the environmental entitlements in the Victorian Murray and Goulburn are very large compared to all other systems in Victoria. Consequently, the potential for climate change to reduce the volume of allocations to environmental entitlements is greatest in these two systems.

⁵ The allocations assessed were shares of system inflows, and seasonal determinations for high and low reliability water shares

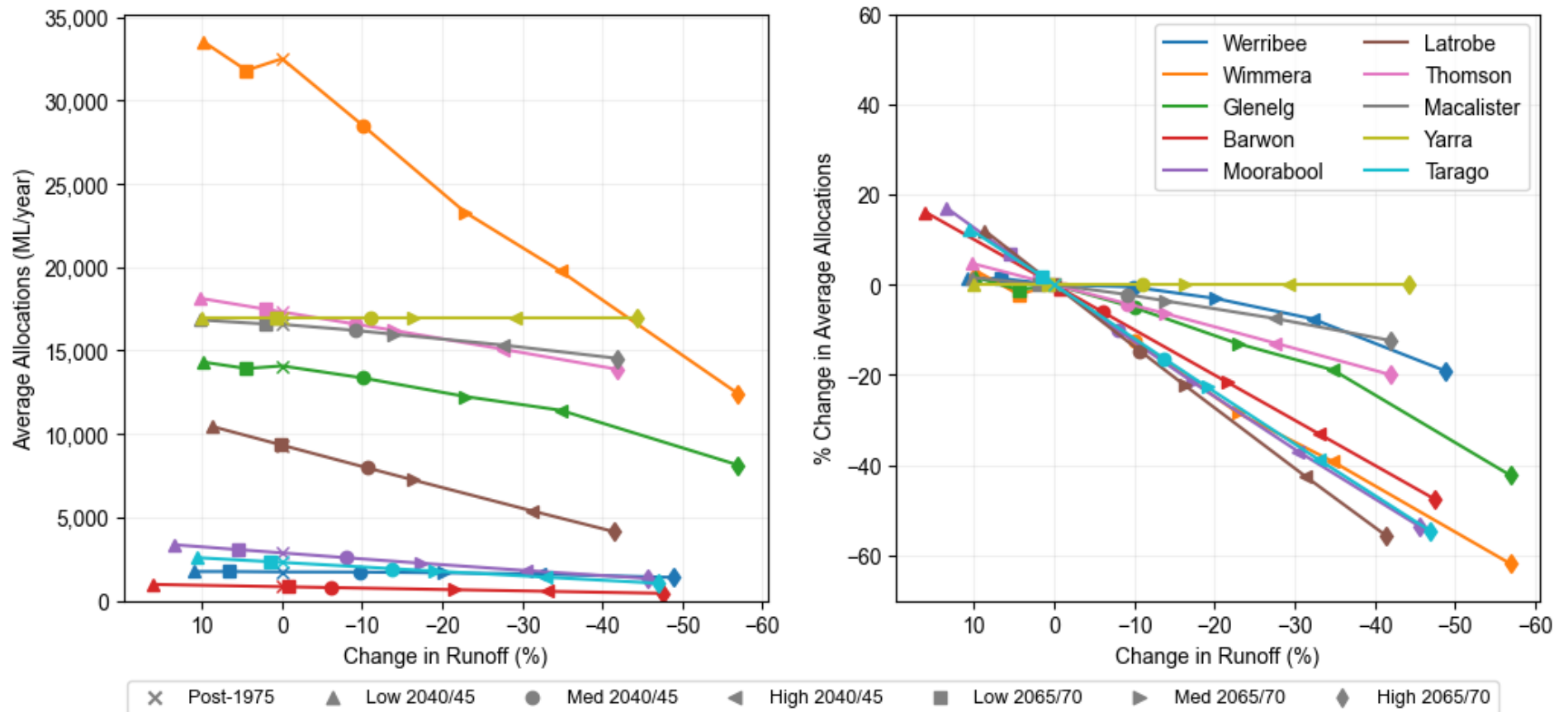


Figure 4: Average allocations to environmental entitlements in river systems within the Gippsland, Central and Western regions of Victoria, versus potential future changes in average rainfall-runoff relative to post-1975 conditions. The left side shows average allocations in ML per year, and the right side shows the percentage change in average allocations compared with post-1975 conditions.

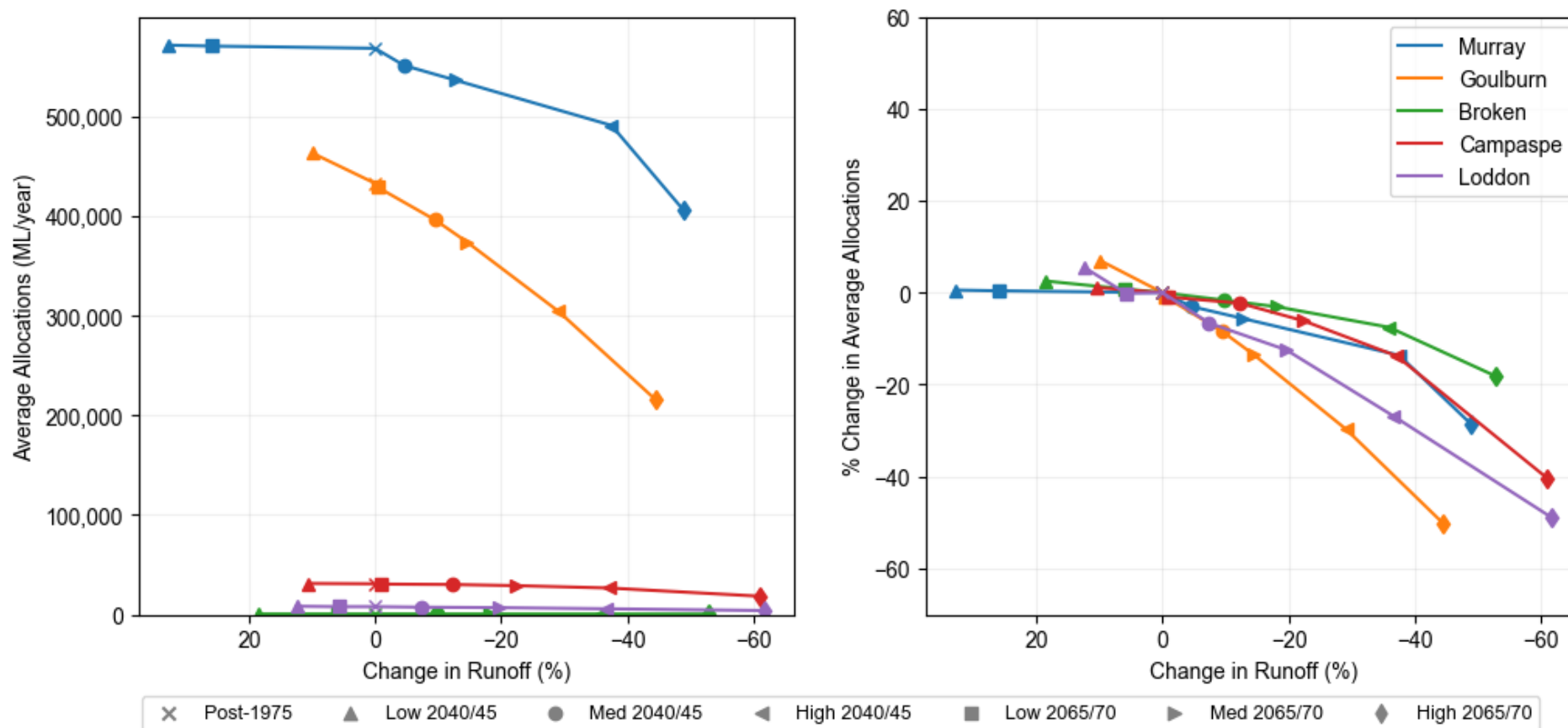


Figure 5: Average allocations to environmental entitlements in river systems within the Northern region of Victoria, versus potential future changes in average rainfall-runoff relative to post-1975 conditions. The left side shows average allocations in ML per year, and the right side shows the percentage change in average allocations compared with post-1975 conditions.

Figure 6 summarises the percentage change in end-of-water-year average annual allocations to environmental entitlements across the state, and compares this to percentage changes in October and February. This shows that for systems where allocations are comprised mainly or solely of seasonal determinations to water shares, the percentage changes are greater earlier in the season (October) compared to later in the season.

There are two reasons for this. Firstly, early season allocations are typically smaller than mid-season and late-season allocations, and therefore a change compared with post-1975 conditions will typically be larger. For example, in the Broken system the average environmental entitlement allocation under post-1975 conditions is 510 ML in October, 570 ML in February and 580 ML by the end of the water year (June). If climate change reduces this by 100 ML on average at each point in the season, the reduction is 20% in October, 18% in February and 17% in June. Secondly, allocations to water shares can only be made after other commitments are met (e.g. storage and river losses, reserves for future years, etc). Reducing runoff and hence inflows to storages therefore delays the time at which allocations are first made. The degree to which changes are greater earlier in the season compared to later in the season therefore also depends on the system characteristics (e.g. size of storages, rules for allocations, type and number of water shares, etc).

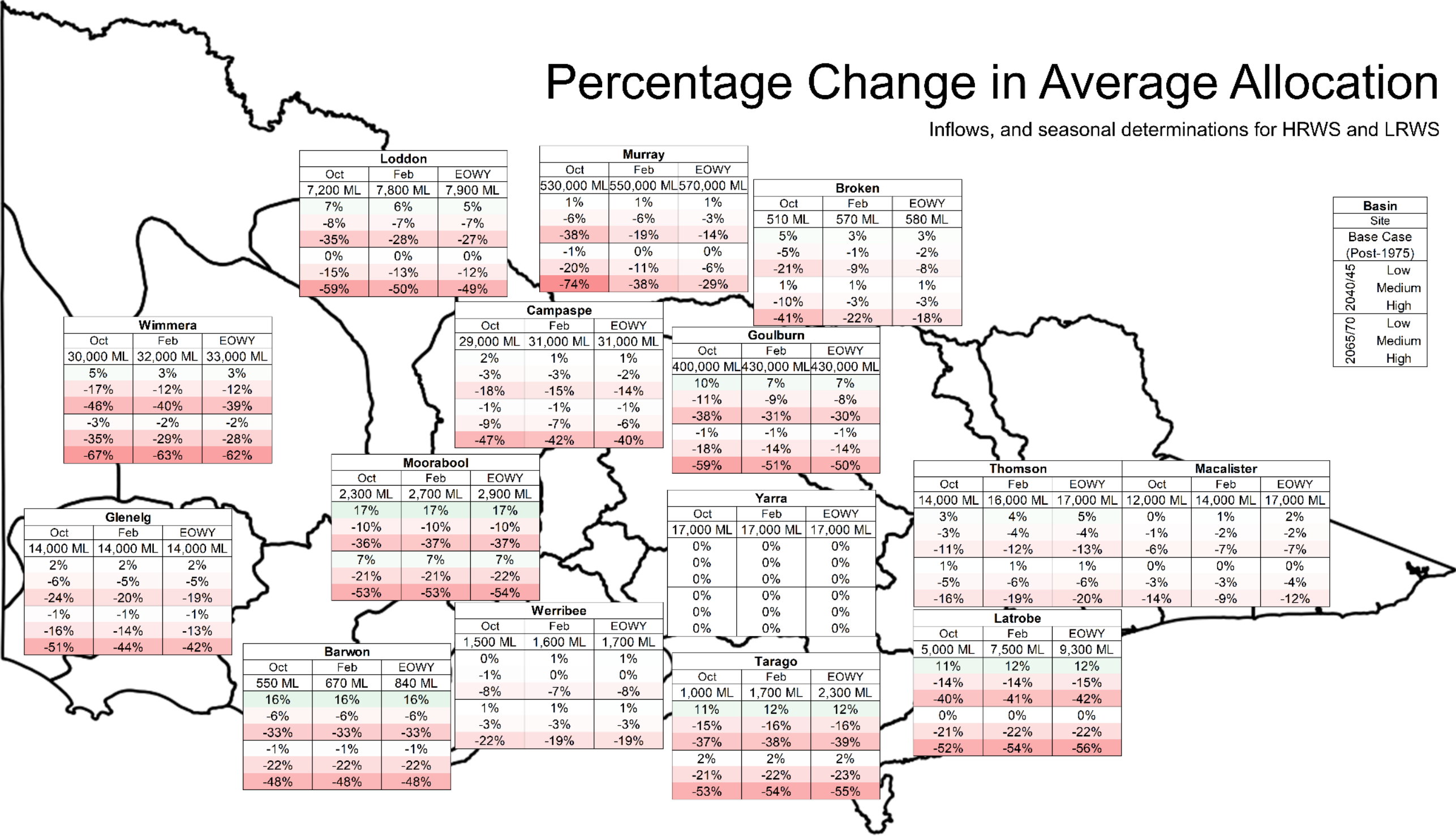


Figure 6: The percentage change in average allocations compared with post-1975 conditions, for October, February and end-of-water-year (EOWY).

Figure 7 to Figure 21 include more detail on the modelled allocations to environmental entitlements in each of the river systems. In these figures, the 5th, 25th, median, 75th and 95th percentile allocation at the end of October, February and June across the period of record modelled is shown for each of the climate conditions simulated. The location on the x-axis for each of the climate cases corresponds with the projected change in average annual rainfall-runoff. Again, the change in allocation percentiles in between scenarios has been assumed to be linear.

Observations that can be made from these figures include:

- For systems where environmental entitlements are a share of system inflows (e.g. the Thomson, Latrobe, Tarago, Barwon and Moorabool), the change in allocations is a linear response to the change in average rainfall-runoff.
- In the systems where allocations to environmental entitlements are wholly or partially dependent on seasonal determinations for high and low reliability water shares, the change in allocations across the climate cases is non-linear for the percentiles assessed when compared with the change in rainfall-runoff. In particular:
 - Allocations to environmental entitlements in the Macalister and Werribee system are relatively robust, although the change in the 5th percentile allocation compared with post-1975 conditions is noticeable when the reduction in average annual rainfall-runoff is >10%. In other words, if runoff reduces by >10% allocations in the driest 5% of years will be much reduced compared to what they are under post-1975 conditions.
 - In the Wimmera system, the changes in 75th percentile allocations for reductions in runoff of approximately 10-20% compared with post-1975 conditions are significant. That is, allocations in the wettest 25% of years will be much reduced because of reduced allocations to the low-reliability water shares held by the CEWH. For reductions in runoff >20%, the change in allocations compared with post-1975 conditions is apparent for all percentiles.
 - In the Glenelg system, allocations to environmental entitlements are relatively unchanged until the reduction in average annual rainfall-runoff exceeds approximately 10%. To the right of this point, the reduction in allocations across the percentiles plotted is relatively linear. The 60%:40% split of the VEWH entitlement between Wimmera and Glenelg was held constant across all scenarios, but the sensitivity of the results to this assumption was tested using a 50%:50% and 40%:60% options. This showed that the 60%:40% versus other splits had no impact on the post-1975 scenario results, but did begin to change outcomes for the most severe case modelled (year 2065 with high climate change).
 - In the Murray system, the potential impact of climate change on allocations to environmental entitlements is much larger in the early months of the water year (i.e. October) compared with the end of the water year (i.e. June). A similar pattern is apparent for the Broken system.
 - In the Goulburn system, the median and 95th percentile allocations to environmental entitlements are relatively unchanged until the reduction in average annual rainfall-runoff is more than approximately 15%. However, the 5th, 25th and 75th percentile allocations reduce compared to post-1975 conditions as soon as runoff reduces.

- The variable nature of allocations to environmental entitlements in the Campaspe and Loddon systems is demonstrated by the width of the 5th – 95th and 25th – 75th percentile ranges across the climate cases modelled. The potential impact of climate change is apparent though in the reduction of the median allocations as average annual rainfall-runoff reduces, particularly for runoff reductions >10 – 20%.

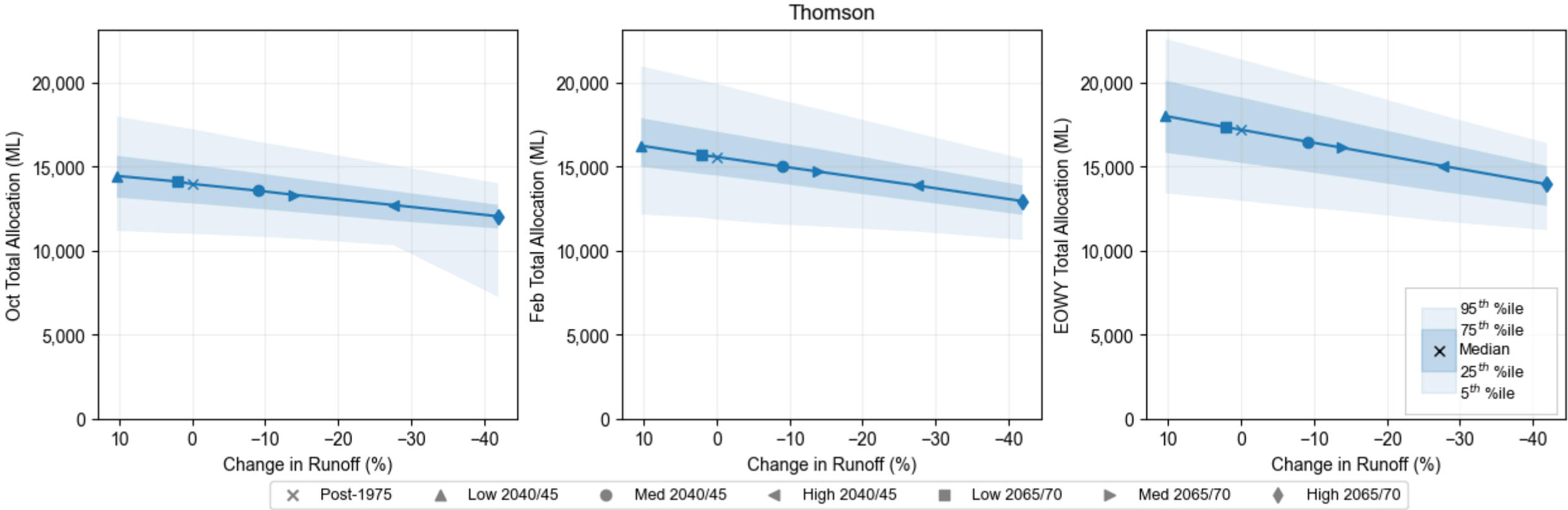


Figure 7: Modelled environmental allocations in the Thomson system

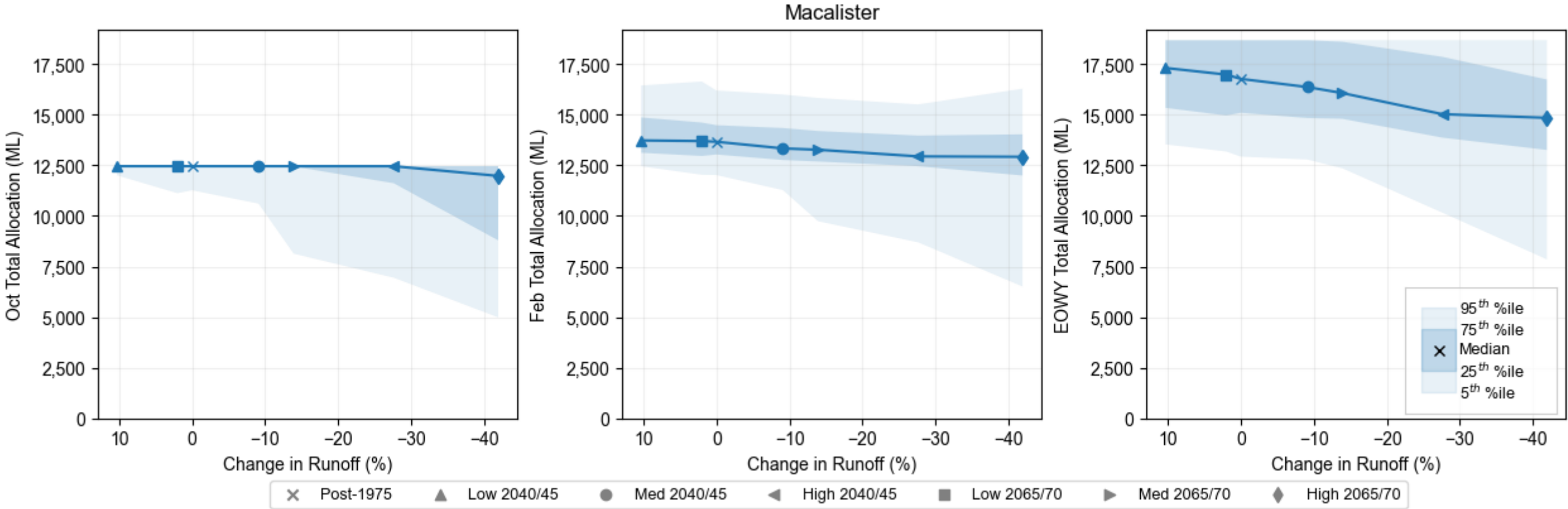


Figure 8: Modelled environmental allocations in the Macalister system

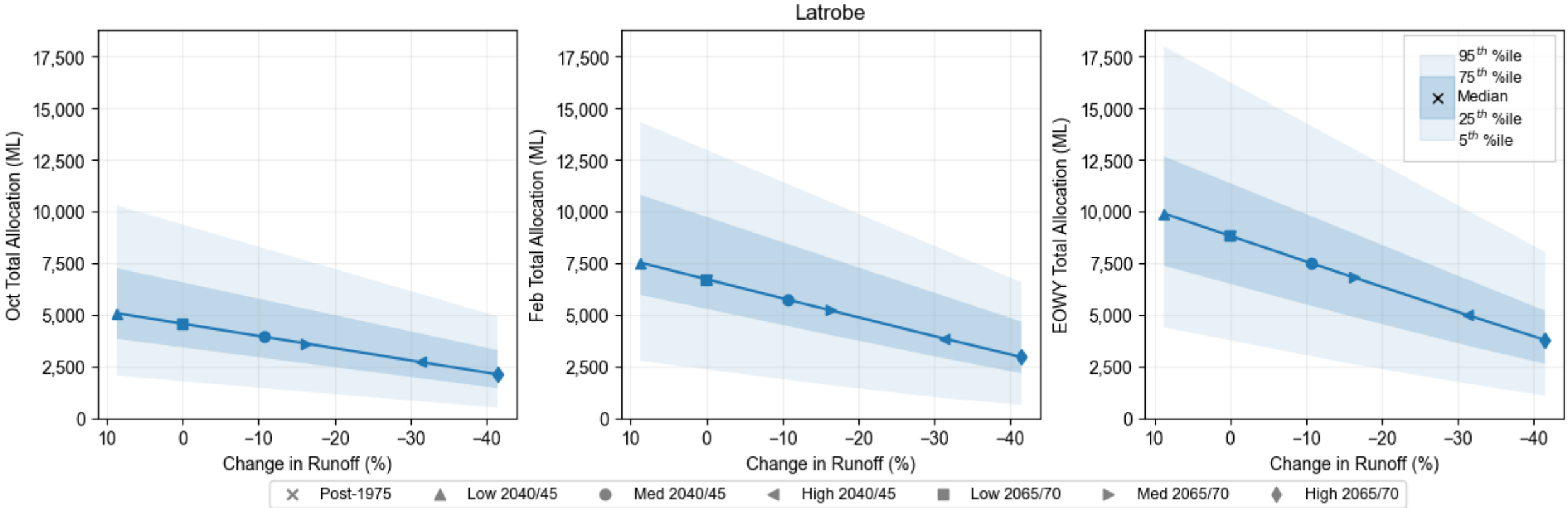


Figure 9: Modelled environmental allocations in the Latrobe system

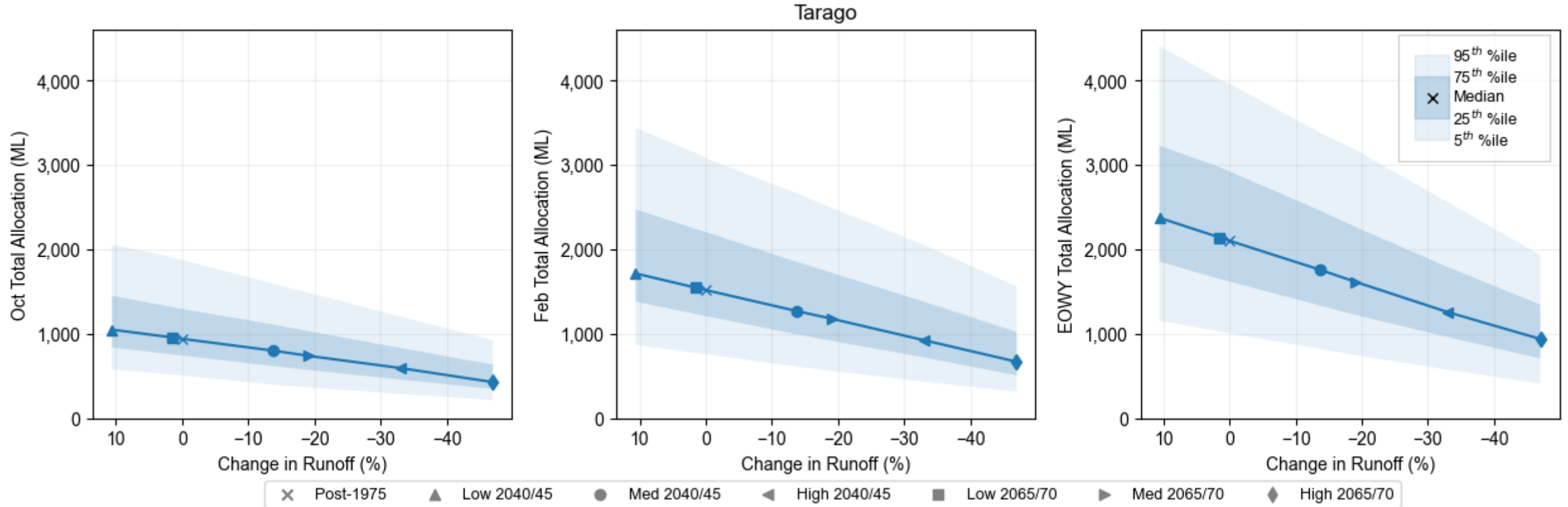


Figure 10: Modelled environmental allocations in the Tarago system

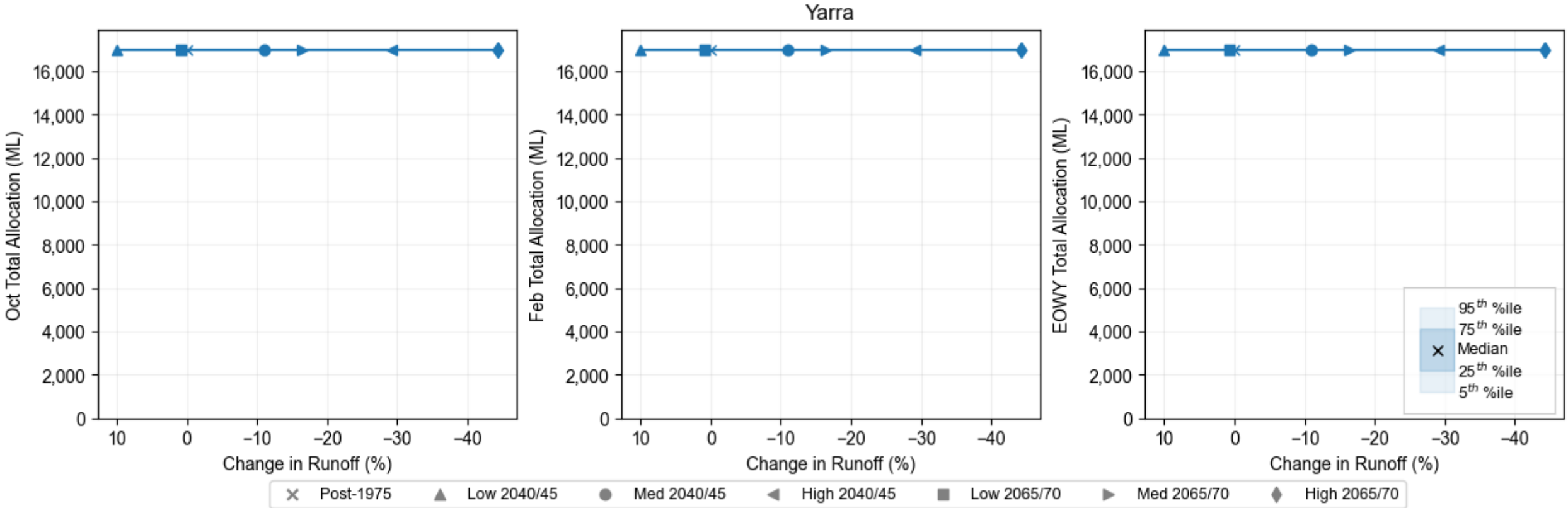


Figure 11: Modelled environmental allocations in the Yarra system

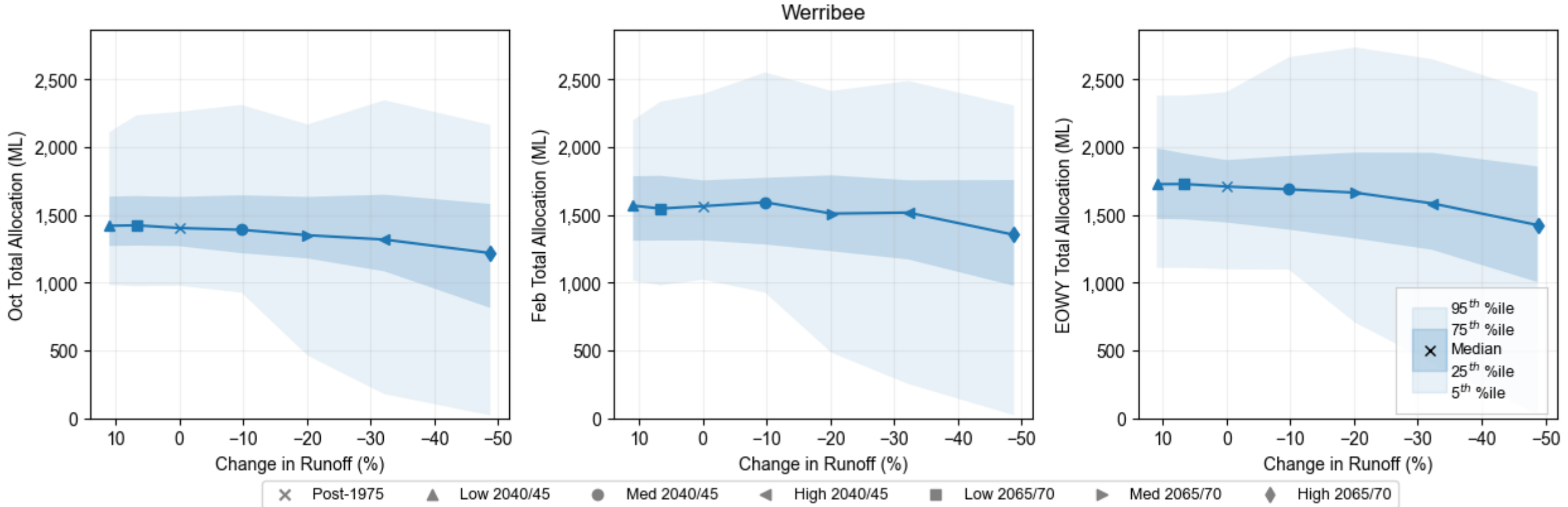


Figure 12: Modelled environmental allocations in the Werribee system

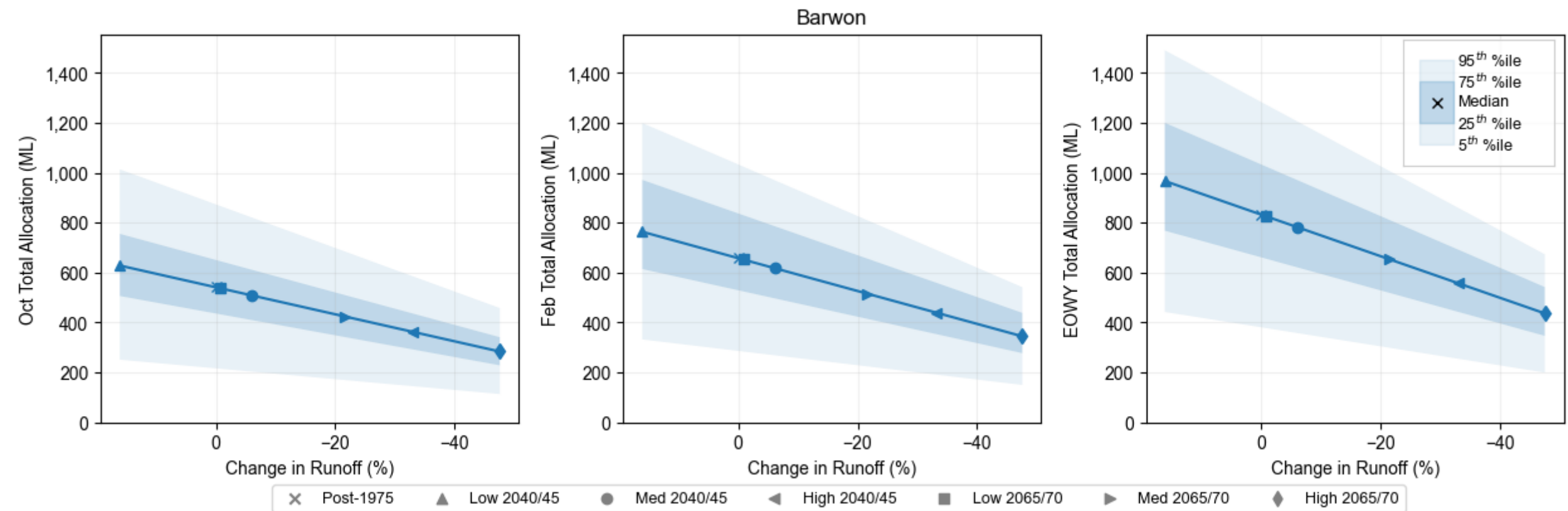


Figure 13: Modelled environmental allocations in the Barwon system

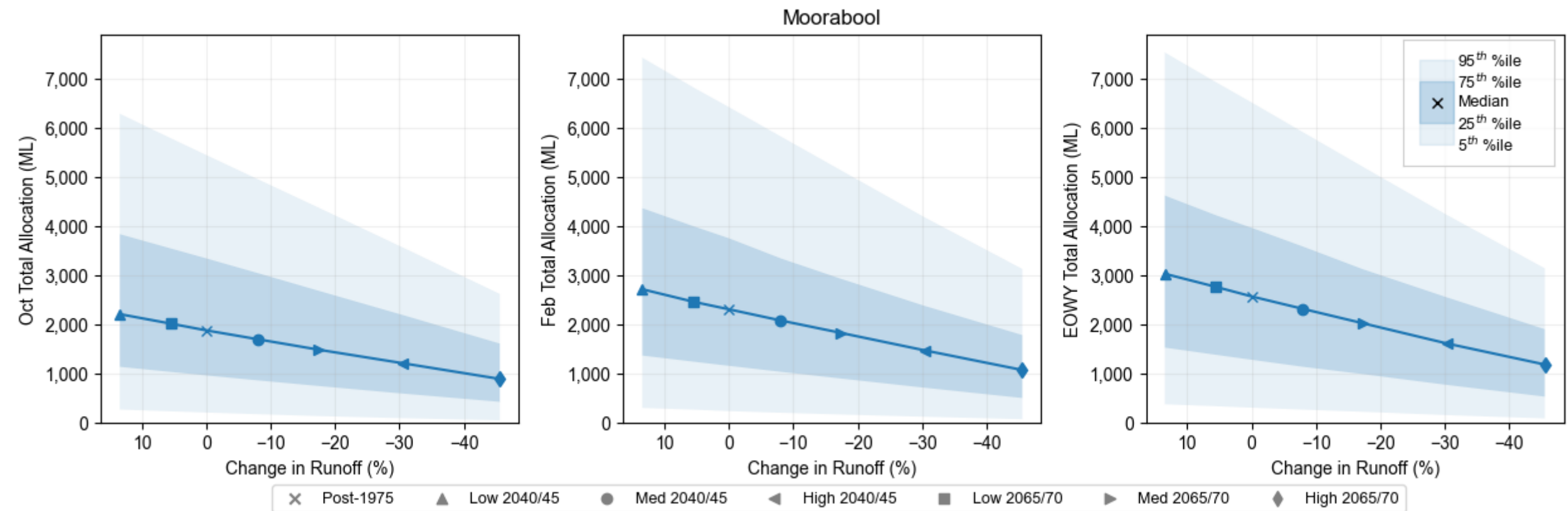


Figure 14: Modelled environmental allocations in the Moorabool system

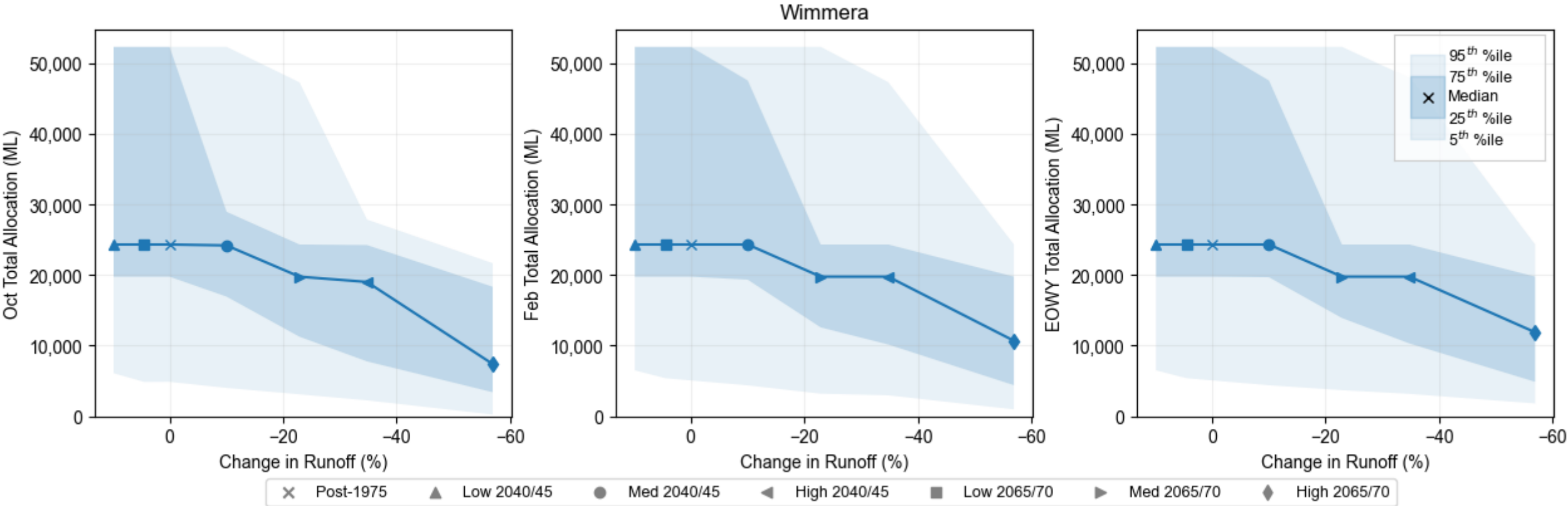


Figure 15: Modelled environmental allocations in the Wimmera system

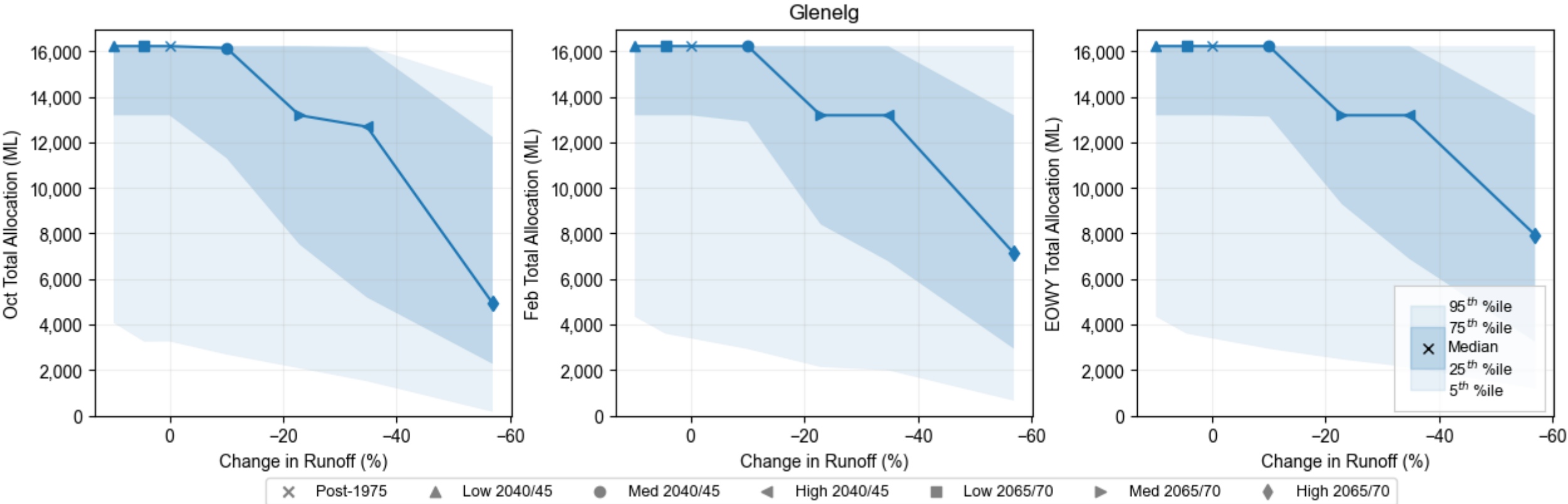


Figure 16: Modelled environmental allocations in the Glenelg system

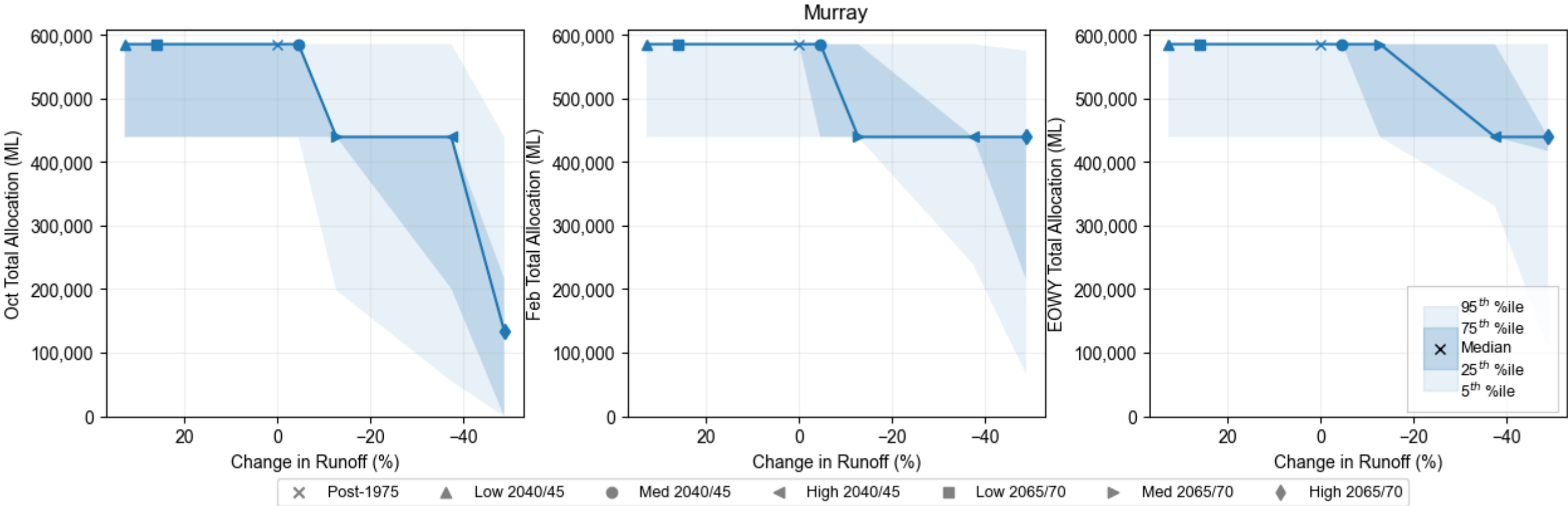


Figure 17: Modelled environmental allocations in the Victorian Murray system

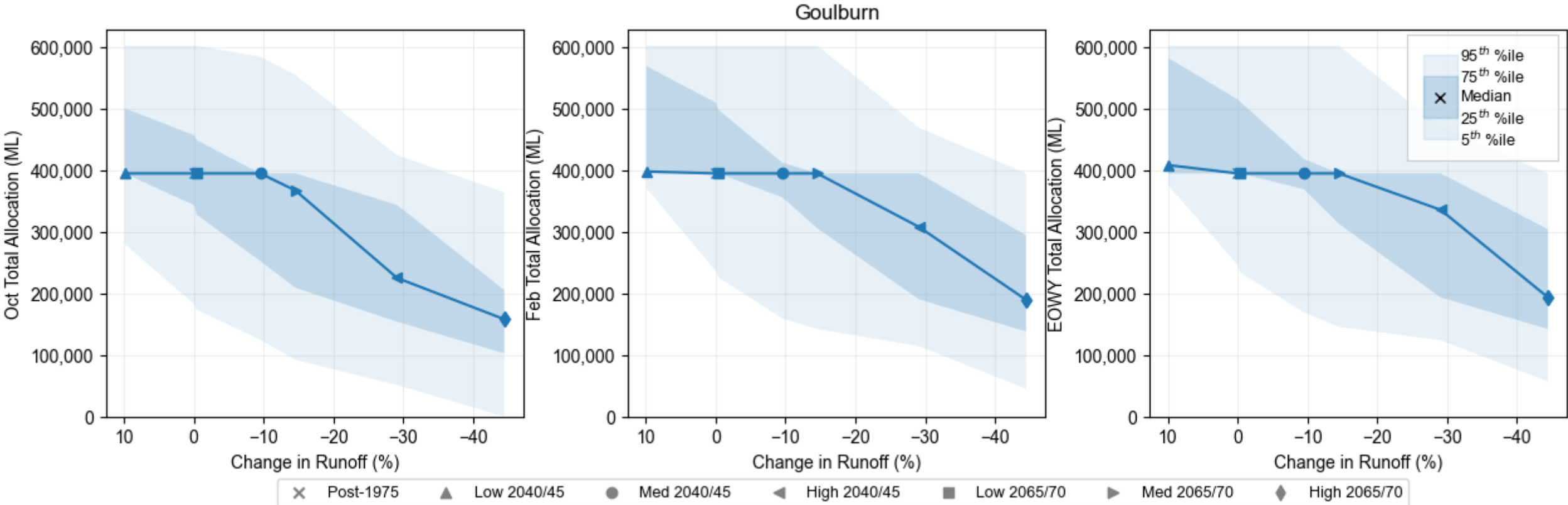


Figure 18: Modelled environmental allocations in the Goulburn system

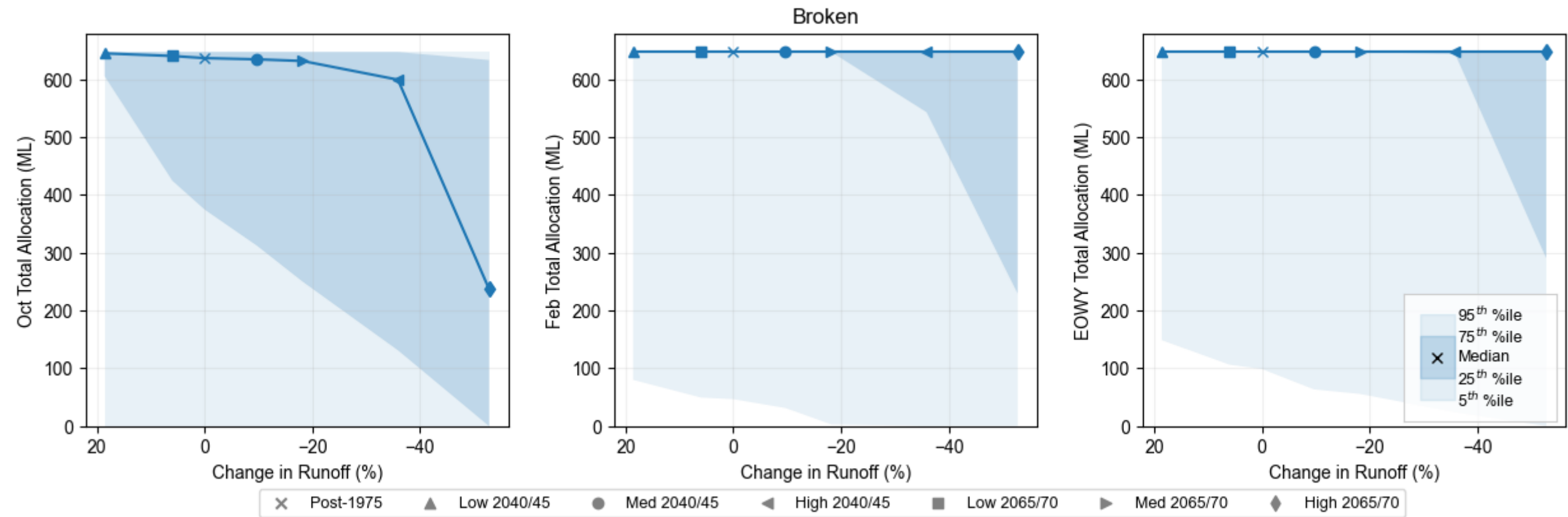


Figure 19: Modelled environmental allocations in the Broken system

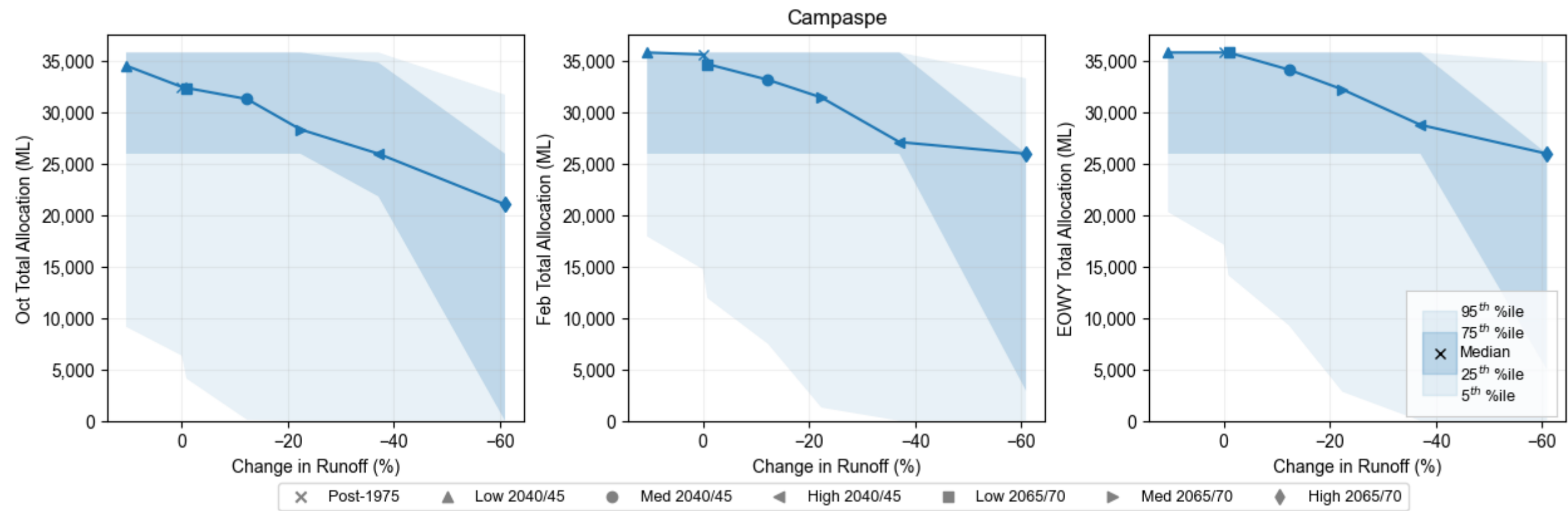


Figure 20: Modelled environmental allocations in the Campaspe system

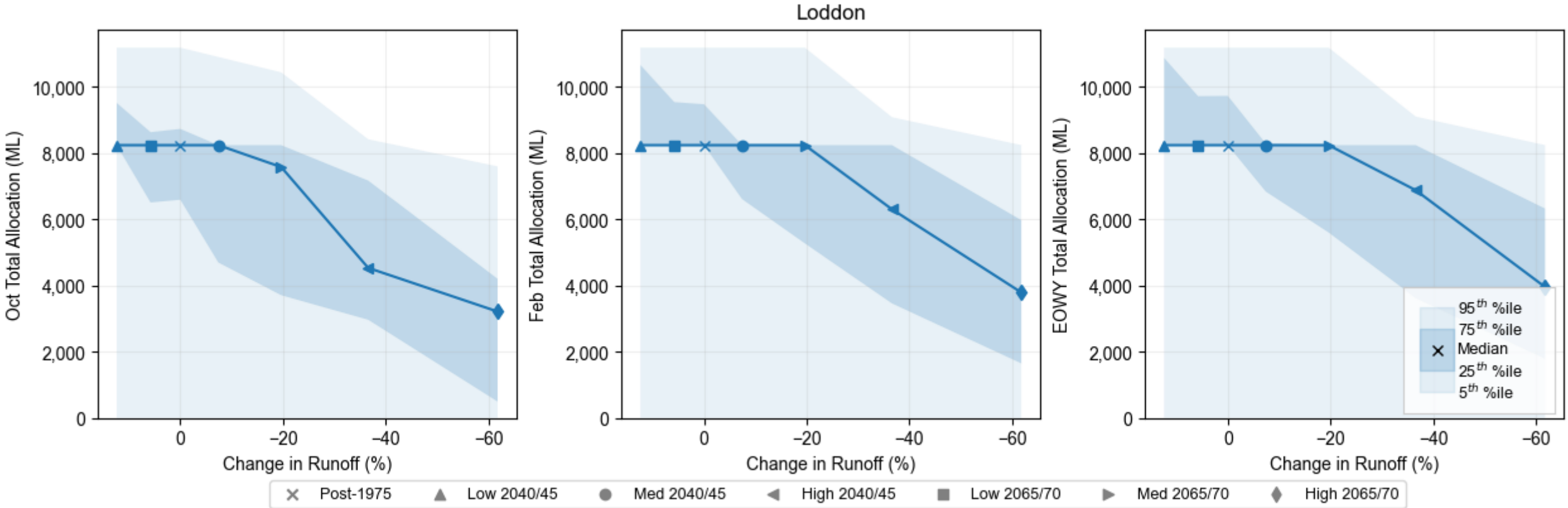


Figure 21: Modelled environmental allocations in the Loddon system

4. Hydrological indicators

4.1 Based on total streamflow at selected locations

Time-series, flow duration curves and monthly averages of the streamflow simulated at selected locations in each river system under post-1975 and potential future climate conditions are shown in Appendix D to Appendix R. These locations were selected by the VEWH.

Based on the modelled streamflow, the change in hydrological indicators (Table 5) under potential future climate conditions was calculated – i.e. compared with post-1975 conditions. A selection of these results are shown on maps of Victoria (Figure 22 to Figure 26). Specifically:

- Figure 22 and Figure 23 show the percentage change in mean February (MA13) and mean August flow (MA19) respectively.
- Figure 24 shows the percentage change in the median duration of low flow spells, where low flow is defined by the 75th percentile daily flow in the post-1975 scenario (DL16).
- Figure 25 and Figure 26 show the change in the average number of zero flow days per year (DL18), and the maximum zero flow spell duration respectively (Max0Dur). Zero flow is defined as flow < 0.1 ML/d.

The changes have been colour-coded in each figure, with green indicating an increase in flow or reduction in low or zero flow periods, red indicating a decrease in flow or increase in low or zero flow periods, and white indicating there is minimal change. All hydrological indicators calculated in this project are included in Appendix D to Appendix R.

From these plots, it can be observed that:

- The reduction in mean February flow under potential future climate conditions is most apparent in the west and central parts of Victoria (Wimmera, Glenelg, Barwon, Moorabool, Werribee, Tarago, Campaspe, Loddon). The Murray, Goulburn, Yarra, Latrobe, Thomson and Macalister systems are less affected.
- The reduction in mean August flow under medium and high climate change projections is significant state-wide.
- The median duration of low flow spells is significantly increased in most systems under the most severe climate case modelled (year 2065 or 2070 with high climate change). The results for the Loddon system are counter-intuitive for the 2040 climate case (i.e. there is a decrease in the median duration of low spells). This occurs because there are more low flow spells compared to post-1975 conditions, and these additional low flow periods have shorter durations than the post-1975 median. Outcomes like this highlight why it is important to consider multiple rather than single hydrologic indicators of ecological outcomes.
- Changes to the annual average and maximum duration of zero flow days are apparent in the west and central parts of Victoria, whereas the other systems – which are generally perennial rivers – are relatively unaffected. The notable exception though is that periods of zero flow begin to occur in the Macalister and Murray systems for the most severe climate case modelled. Based on visual inspection of the time-series of streamflow, the zero flow results for the Goulburn River at Murchison appear to be an artefact of the Source modelling, rather than a true reflection of expected changes under climate change.

It is also worth noting that the change to average and maximum duration of zero flow days for Dartmoor (Glenelg system), when using a threshold of 0.1 ML/d, showed improvement under some climate change scenarios (Table 6). The post-1975 scenario has consistently higher flow than the medium and high climate change scenarios (Appendix L), however appears to experience greater extractions during some low flow periods. This is likely an artefact of how restrictions on diversions have been configured in the Source model. Using a slightly higher zero flow threshold of 1 ML/d results in more intuitive results (Table 6), which were adopted instead. This highlights that the results presented in this report are intended to be high-level. Only outcomes that stood out have been interrogated in detail.

Table 6: The average and maximum duration of zero flow days in Dartmoor, calculated using different thresholds for zero flow. The change from post-1975 conditions is shown in brackets.

Scenario	Avg0Dur		Max0Dur	
	0.1 ML/d Threshold	1 ML/d Threshold	0.1 ML/d Threshold	1 ML/d Threshold
Post 1975	13	17	42	65
2040 Low	14 (+1)	17 (0)	40 (-2)	65 (0)
2040 Medium	15 (+2)	19 (+2)	41 (-1)	84 (+19)
2040 High	7 (-6)	20 (+3)	33 (-9)	90 (+25)
2065 Low	14 (+1)	18 (+1)	41 (-1)	136 (+71)
2065 Medium	8 (-5)	19 (+2)	31 (-11)	140 (+75)
2065 High	12 (-1)	20 (+3)	85 (+43)	142 (+77)

In summary, in the hydrological indicators shown below, the potential impacts of climate change on ecological outcomes are most significant in the Wimmera, Glenelg, Barwon, Moorabool, Werribee, Tarago, Campaspe and Loddon systems. These systems are in the west and central parts of Victoria, and generally have more ephemeral rivers and / or smaller storages compared with the Goulburn-Broken, Murray, Yarra, Latrobe and Thomson-Macalister systems. In these other systems, the potential impacts of climate change on the hydrological indicators of ecological outcomes are generally greater in winter compared with summer.

Percentage Change in MA13

Mean February flow (ML/d)

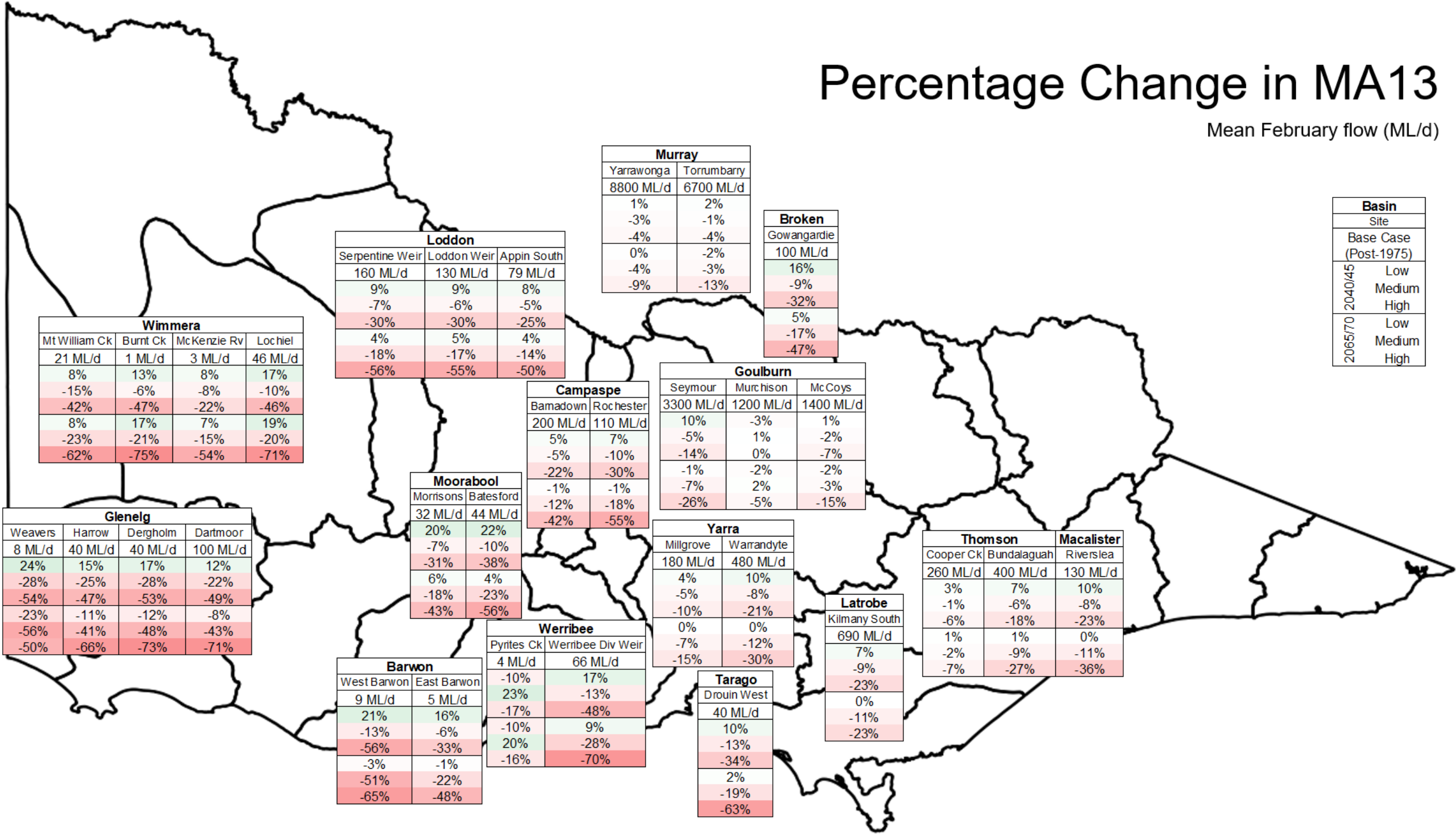


Figure 22: Percentage change compared with post-1975 conditions – mean February flow

Percentage Change in MA19

Mean August flow (ML/d)

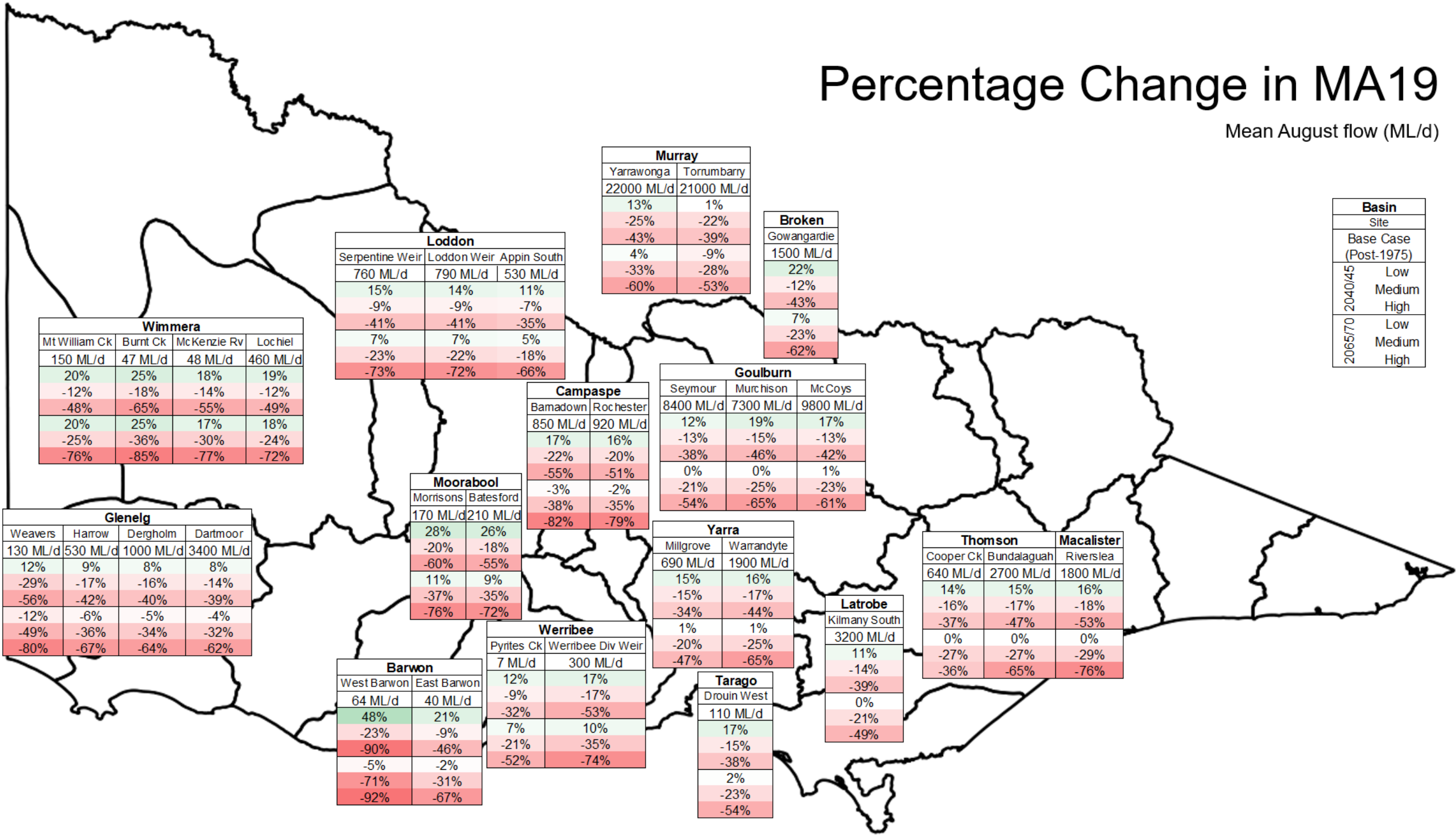


Figure 23: Percentage change compared with post-1975 conditions – mean August flow

Percentage Change in DL16

Median low flow (< 25th percentile) duration (days)

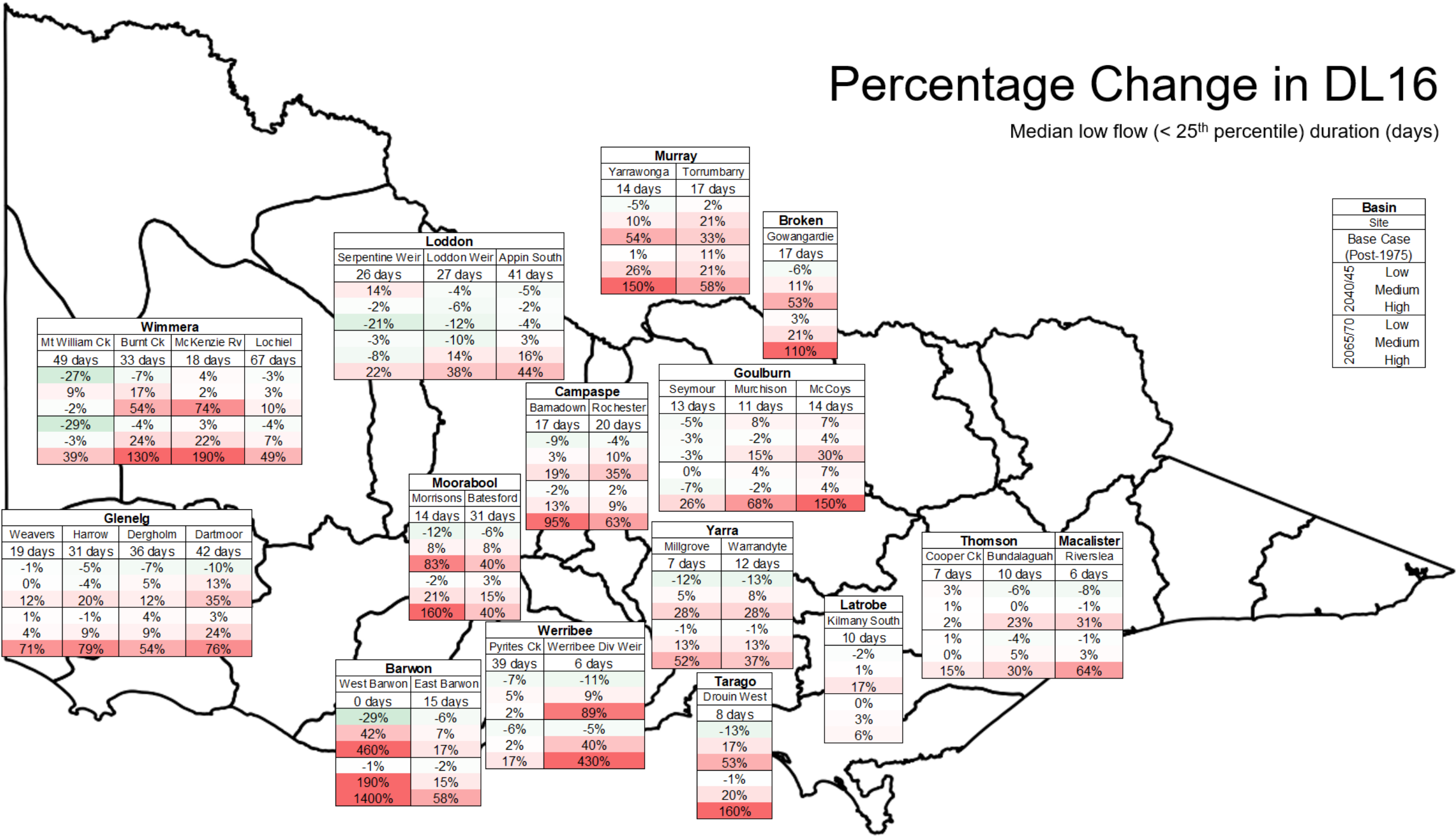


Figure 24: Percentage change compared with post-1975 conditions – median low flow duration

Absolute Change in DL18

Average number of zero (< 0.1 ML) flow days in a year (days)

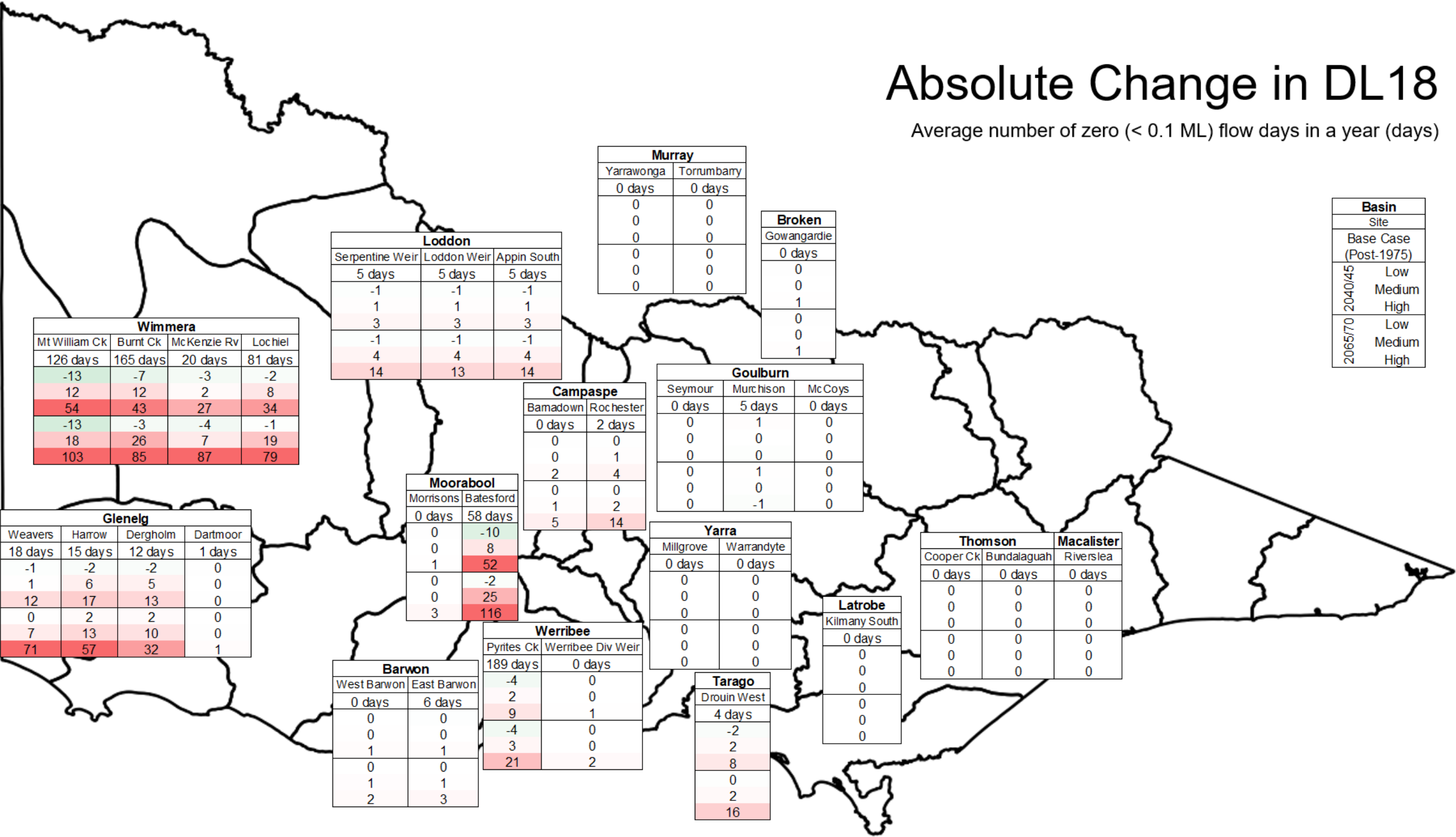


Figure 25: Percentage change compared with post-1975 conditions – average number of zero flow days per year

Absolute Change in Max0Dur

Maximum duration of zero (< 0.1 ML) flow spells (days)

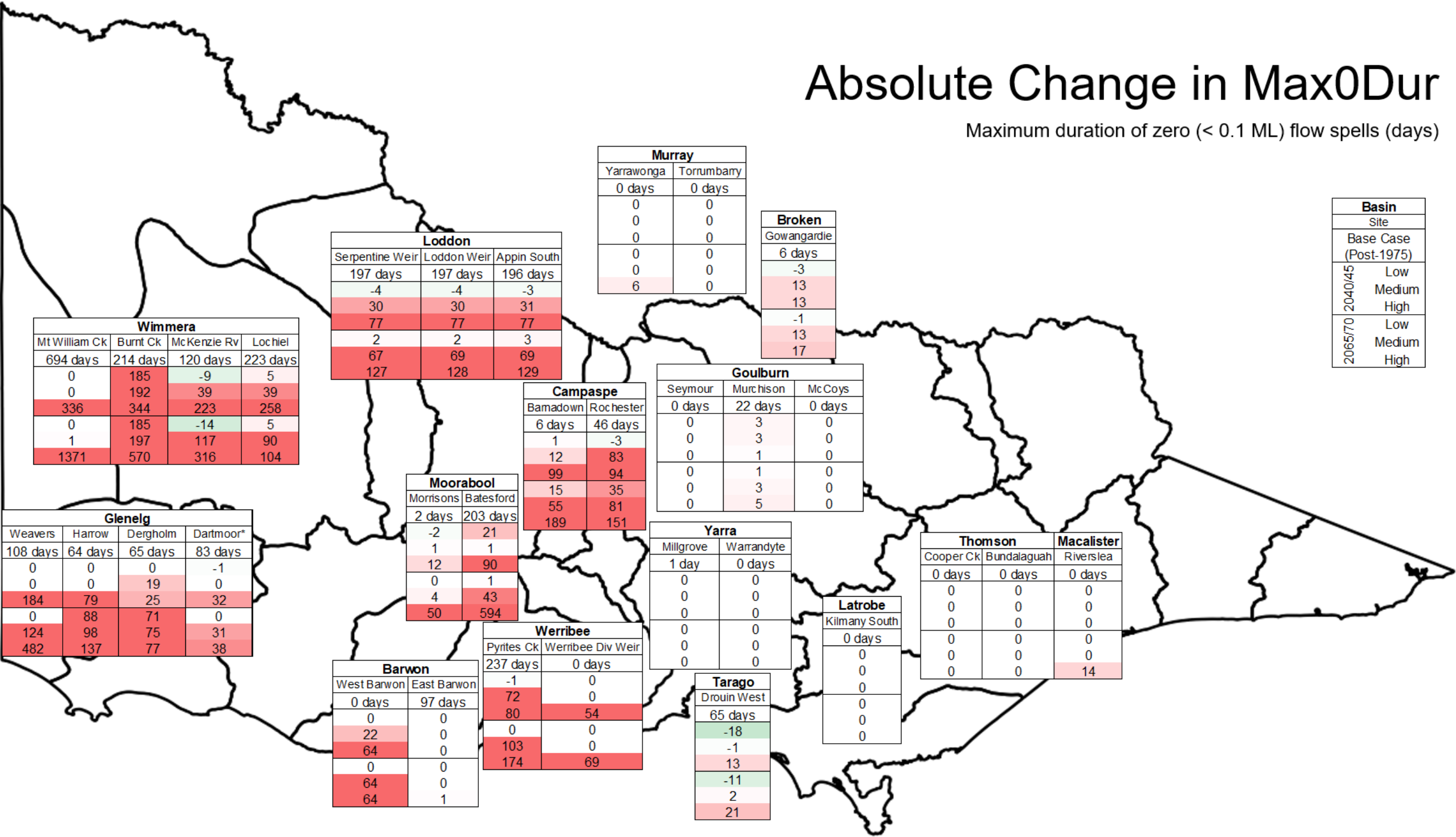


Figure 26: Percentage change compared with post-1975 conditions – maximum duration of zero flow spell. For Dartmoor in the Glenelg system, a threshold of 1 ML/d was used instead of 0.1 ML/d.

4.2 Based on eFlow Projector measures of success

To complement the hydrologic indicator results presented in Section 4.1, this section summarises how often environmental flow targets are met within each river system under the post-1975 and potential future climate conditions simulated in the Source models. The environmental flow targets considered here are low flows in summer and autumn, low flows in winter and spring, freshes in summer and autumn, and freshes in winter and spring, and are therefore a subset of all environmental flow targets for Victoria’s regulated river systems.

It is also important to note that only some environmental flow targets are represented as demands in Source models (i.e. the model attempts to deliver the flow target using stored environmental water). For the Source models that HARC had access to, Appendix C shows which components were ordered. In general, low flow targets are ordered more commonly than freshes. Low flow targets are separate to, but may be partially or wholly met by, passing flow rules in Bulk Entitlements. The sensitivity of how often environmental flow targets are met to whether they are included as a demand in Source or not has not been tested as part of this project.

The assessment of how often environmental flow targets are met was done using the success metric in eFlow Projector (<https://eflowprojector.net.au/>). The two figures below summarise how success is measured by comparing the modelled time-series of streamflow to environmental flow targets for low flows (Figure 27) and freshes (Figure 28). Success was calculated separately for each year of the modelled period of record using this approach. The eFlow Projector results – in terms of average success over the modelled period of record – are tabled in Appendix D to Appendix R.

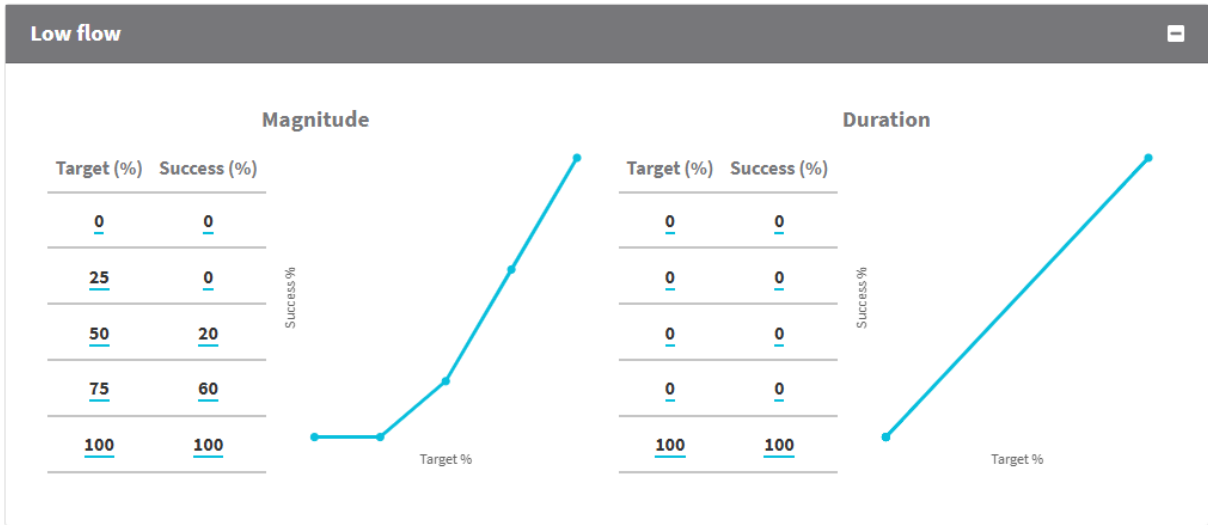


Figure 27: A screenshot from eFlow Projector showing how modelled flow as compared to the target flow (i.e. flow target) is converted to a measure of success for low flow targets



Figure 28: A screenshot from eFlow Projector showing how modelled flow as compared to the target flow (i.e. flow target) is converted to a measure of success for freshes

The three figures below show the 25th, median and 75th percentile measures of annual success in meeting summer and autumn low flow targets across the river systems in the Western and Western-Central regions (Figure 29), the Eastern-Central and Gippsland regions (Figure 30), and the Northern region (Figure 31). As per the approach in Section 3, the potential future climate conditions are located on the x-axis of plots using the projected change in average rainfall-runoff relative to post-1975 conditions.

These figures show that for most systems in the Western and Central regions, the frequency with which summer and autumn low flow targets will be met are a) vulnerable to potential future climate change or b) already low. In contrast, in the Yarra system and the Northern and Gippsland regions, there is a high degree of success in meeting summer and autumn low flow targets across all the climate cases considered (except in the lower reaches of the Loddon (Loddon Weir; Appin South) and at Riverslea in the Macalister system).

This outcome resembles what was observed in Figure 22, albeit that Figure 22 showed more change in mean February flow across more sites in the Northern and Gippsland regions. Figure 31 and Figure 30 suggest however, that even though summer flows are projected to reduce in these systems, they are likely to remain above targeted summer and autumn low flows.

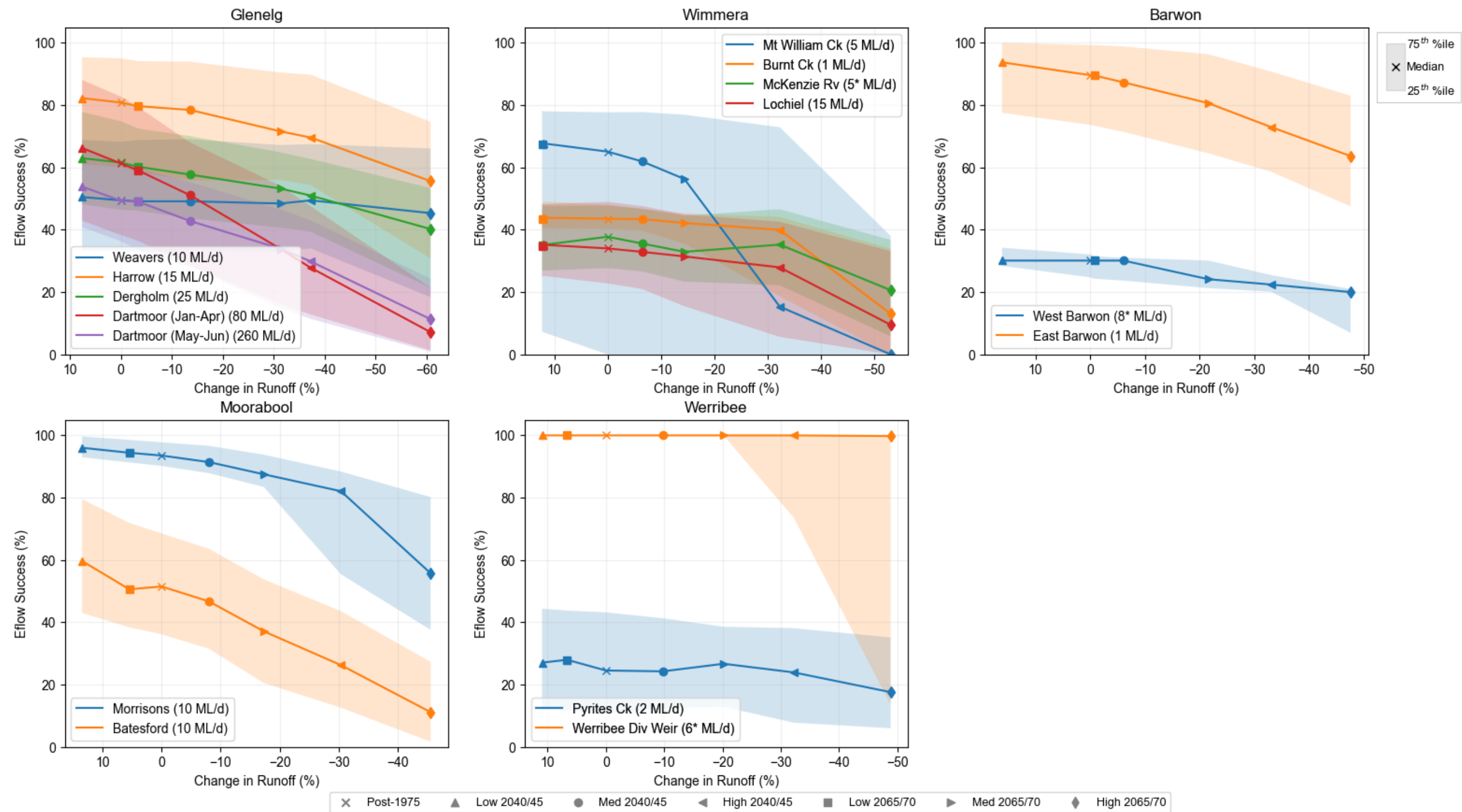


Figure 29: 25th, median and 75th percentile measures of annual success in meeting summer and autumn low flow targets under different climate conditions in river systems across the Western and Western-Central regions. The asterisk indicates that the magnitude of the flow target differed per climate season (see Appendix C for further detail).

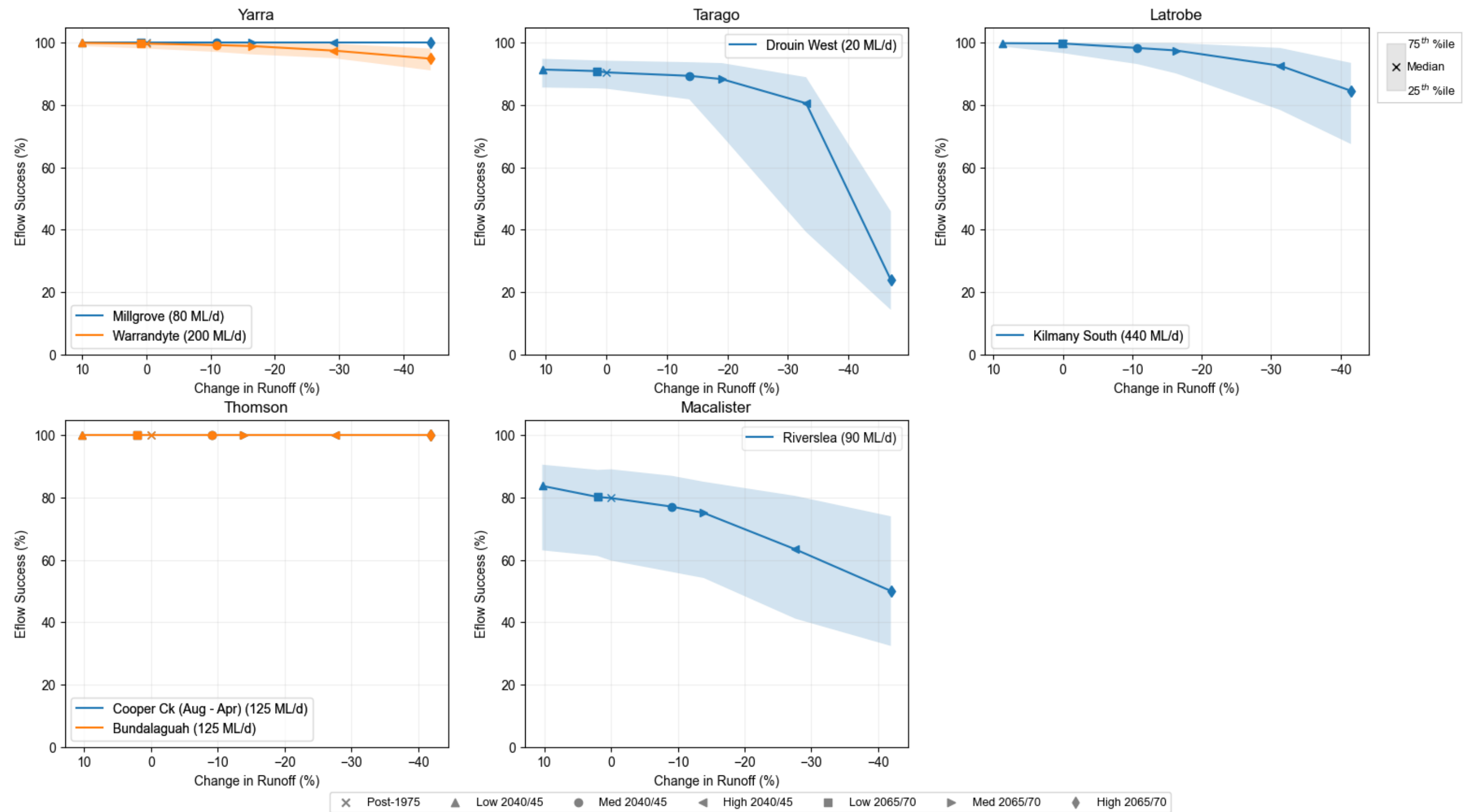


Figure 30: 25th, median and 75th percentile measures of annual success in meeting summer and autumn low flow targets under different climate conditions in river systems across the Eastern-Central and Gippsland regions

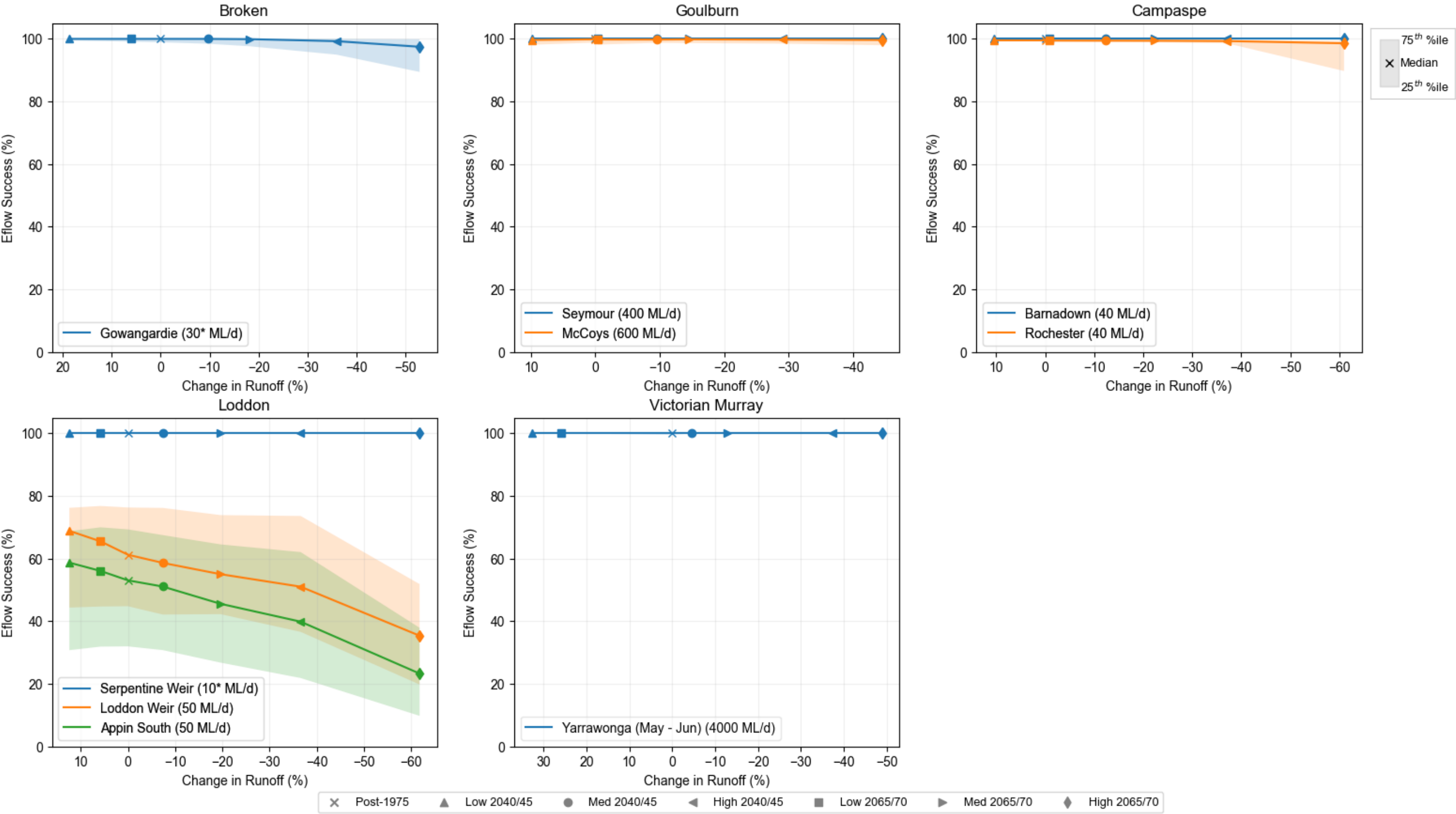


Figure 31: 25th, median and 75th percentile measures of annual success in meeting summer and autumn low flow targets under different climate conditions in river systems across the Northern regions. The asterisk indicates that the magnitude of the flow target differed per climate season (see Appendix C for further detail).

The three figures below show the 25th, median and 75th percentile measures of annual success in meeting winter and spring low flow targets across the river systems in the Western and Western-Central regions (Figure 32), the Eastern-Central and Gippsland regions (Figure 33), and the Northern region (Figure 34). The reduction in how often these flow targets are met as rainfall-runoff reduces is more apparent than in the corresponding figures above for summer and autumn low flows, and this mirrors the difference between Figure 22 and Figure 23 in Section 4.1.

Again, the changes in the Northern and Gippsland regions – and the Yarra system – are less than in the other systems in the Western and Central regions (Figure 32 - Figure 34). This indicates that although mean daily flows are expected to reduce in winter and spring across Victoria under potential future climate change (Figure 23), in the Yarra and regulated river systems of northern Victoria and Gippsland, flows are likely to remain above winter and spring low flow targets most of the time.

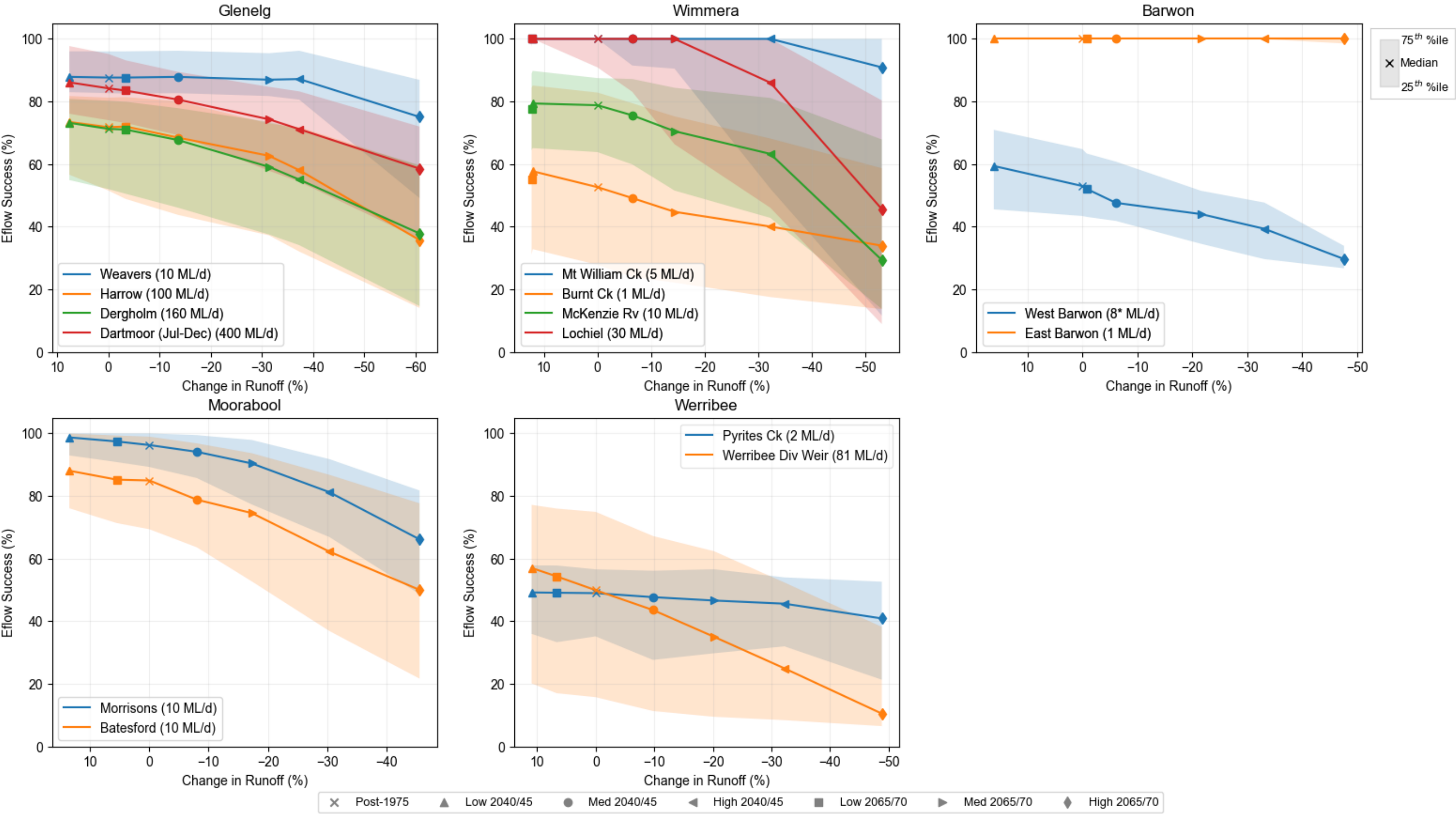


Figure 32: 25th, median and 75th percentile measures of annual success in meeting winter and spring low flow targets under different climate conditions in river systems across the Western and Western-Central regions. The asterisk indicates that the magnitude of the flow target differed per climate season (see Appendix C for further detail).

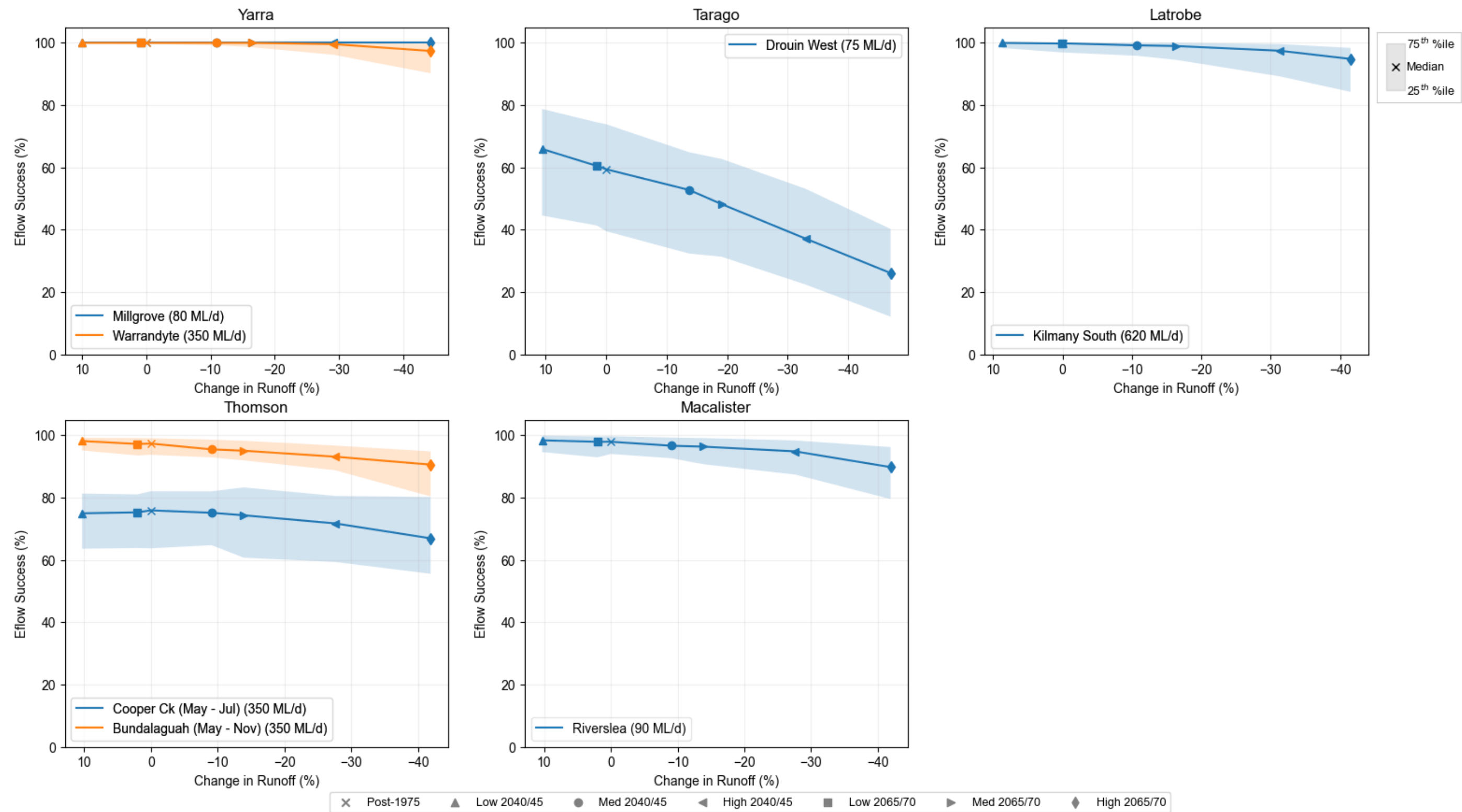


Figure 33: 25th, median and 75th percentile measures of annual success in meeting winter and spring low flow targets under different climate conditions in river systems across the Eastern-Central and Gippsland region

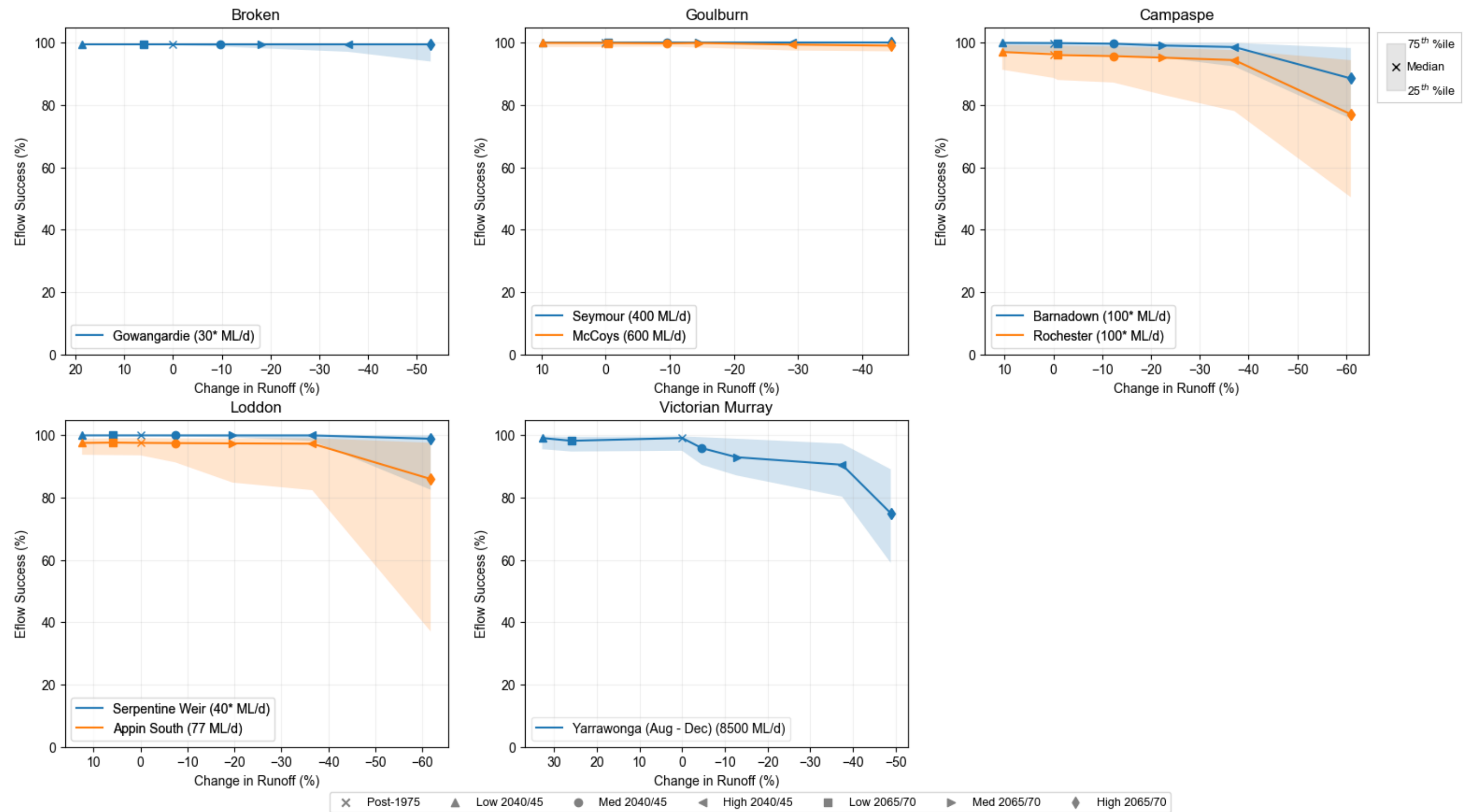


Figure 34: 25th, median and 75th percentile measures of annual success in meeting winter and spring low flow targets under different climate conditions in river systems across the Northern region. The asterisk indicates that the magnitude of the flow target differed per climate season (see Appendix C for further detail).

The three figures below show the 25th, median and 75th percentile measures of annual success in meeting summer and autumn fresh targets across the river systems in the Western and Western-Central regions (Figure 35), the Eastern-Central and Gippsland regions (Figure 33), and the Northern region (Figure 37).

In contrast to what was found for summer and autumn low flows (Figure 29 to Figure 31), the reduction of success in meeting summer and autumn fresh targets as rainfall-runoff reduces is apparent across all systems except for the Yarra, particularly for the two most severe climate cases modelled (2040/45 and 2065/70 with high climate change). However, the reduction in success did vary between sites. In particular:

- Reductions were not as significant where the summer and autumn fresh success rates were already low (i.e., in the post-1975 scenario)
- Success rates for freshes of lower magnitude were generally more resilient to changes in rainfall-runoff, even for freshes not ordered in the Source model (e.g. Batesford 20 ML/d freshes compared to the 60 ML/d freshes, Bundalaguah 230 ML/d freshes compared to the 350 ML/d and 800 ML/d freshes).
- Success rates for downstream sites were generally poorer compared with upstream sites, even if they had the same flow target (e.g. Appin South compared to Loddon Weir in the Loddon system, Barnadown compared to Rochester in the Campaspe system, and Dergholm compared to Dartmoor in the Glenelg system).

In summary, how often summer and autumn fresh targets are met in regulated river systems across Victoria is more vulnerable to potential future climate change than how often summer and autumn low flow targets are met ⁶.

⁶ One site where the success rates do not behave as expected is Cooper Creek in the Thomson system, where they slightly increase for the 800 ML/d April fresh as runoff reduces. This happens because in the drier scenarios, higher release rates are required from Thomson Reservoir to meet downstream demands, and these releases slightly increase how often the environmental flow target is met. Success rates in the wetter scenarios could be increased by modifying the release rules so that the 800 ML/d environmental flow target is met more often.

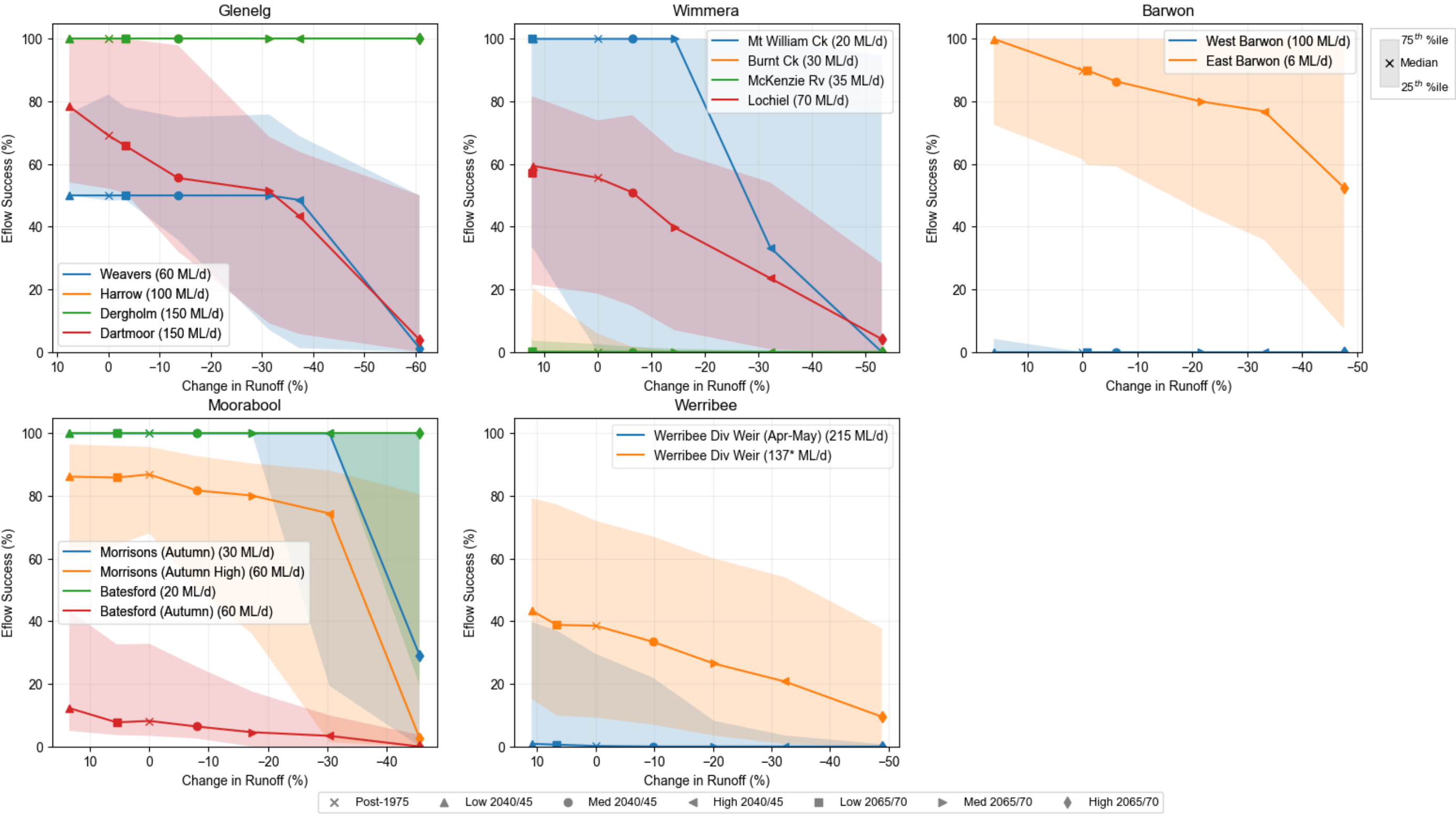


Figure 35: 25th, median and 75th percentile measures of annual success in meeting summer and autumn freshes targets under different climate conditions in river systems across the Western and Western-Central regions. The asterisk indicates that the magnitude of the flow target differed per climate season (see Appendix C for further detail).

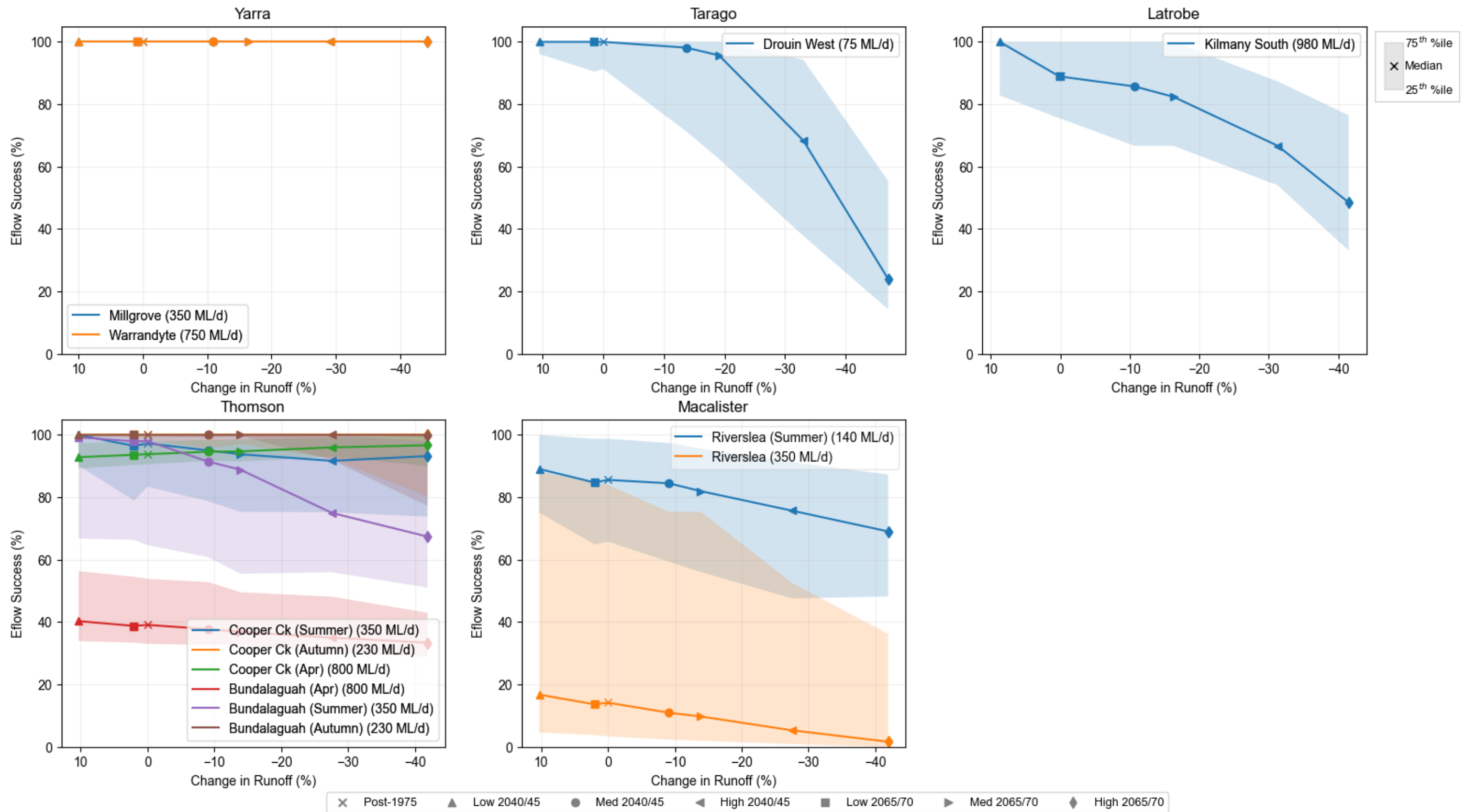


Figure 36: 25th, median and 75th percentile measures of annual success in meeting summer and autumn freshes targets under different climate conditions in river systems across the Eastern-Central and Gippsland region

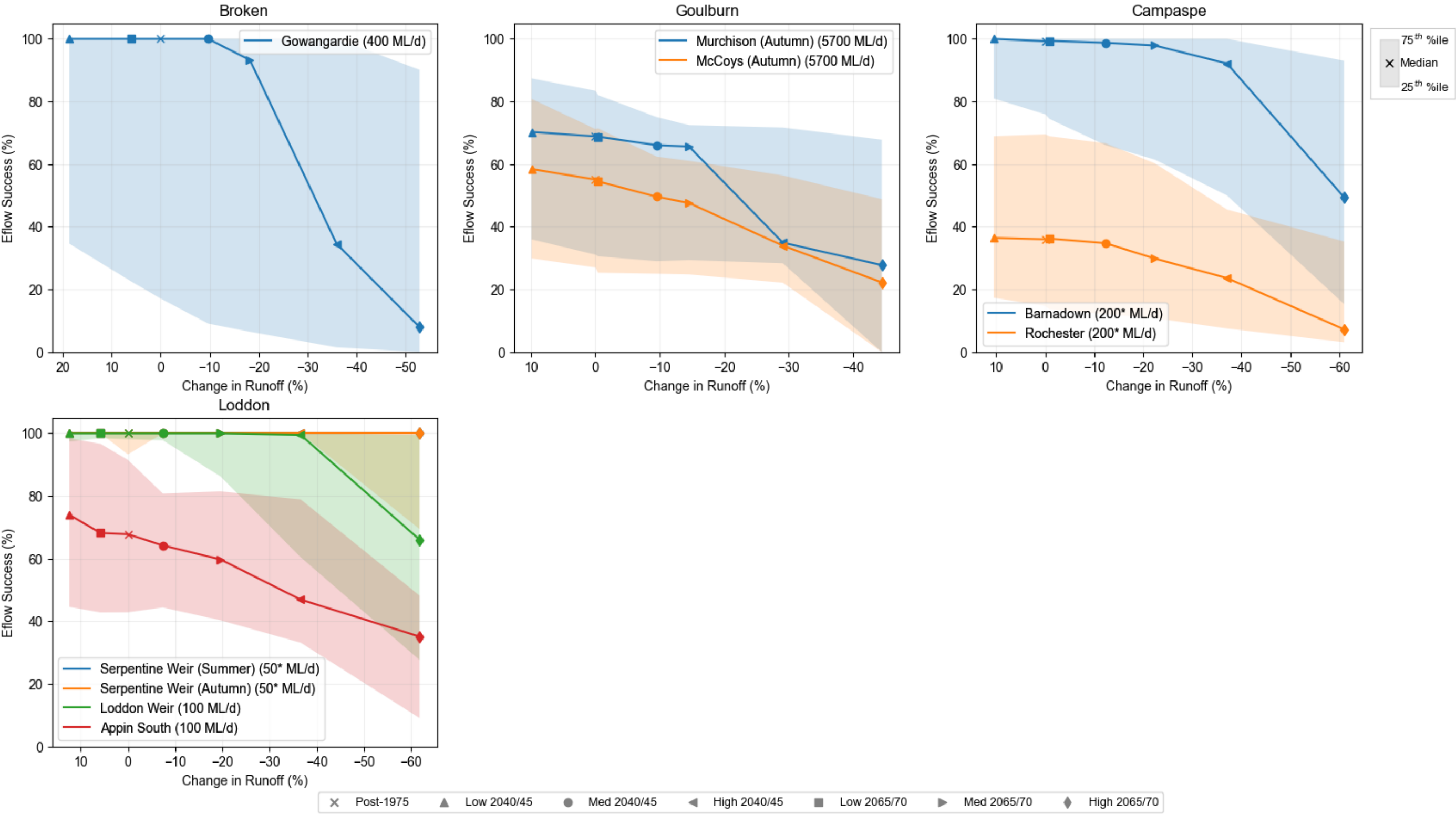


Figure 37: 25th, median and 75th percentile measures of annual success in meeting summer and autumn freshes targets under different climate conditions in river systems across the Northern region. The asterisk indicates that the magnitude of the flow target differed per climate season (see Appendix C for further detail).

The three figures below show the 25th, median and 75th percentile measures of annual success in meeting winter and spring fresh targets across the river systems in the Western and Western-Central regions (Figure 38), the Eastern-Central and Gippsland regions (Figure 39), and the Northern region (Figure 40).

Of the four groups of environmental flow targets assessed (summer and autumn low flow, winter and spring low flow, summer and autumn freshes, winter and spring freshes), the frequency with which winter and spring freshes are met is most vulnerable to post-1975 conditions and potential future climate change. Across most sites in nearly all regions, the measure of success is either already low or significantly reduced by the decline of annual rainfall-runoff expected by 2065/2070 under medium or high climate change. One noticeable exception to this is the Goulburn system, where some of the winter / spring fresh targets are still frequently provided even when reductions in runoff are severe.

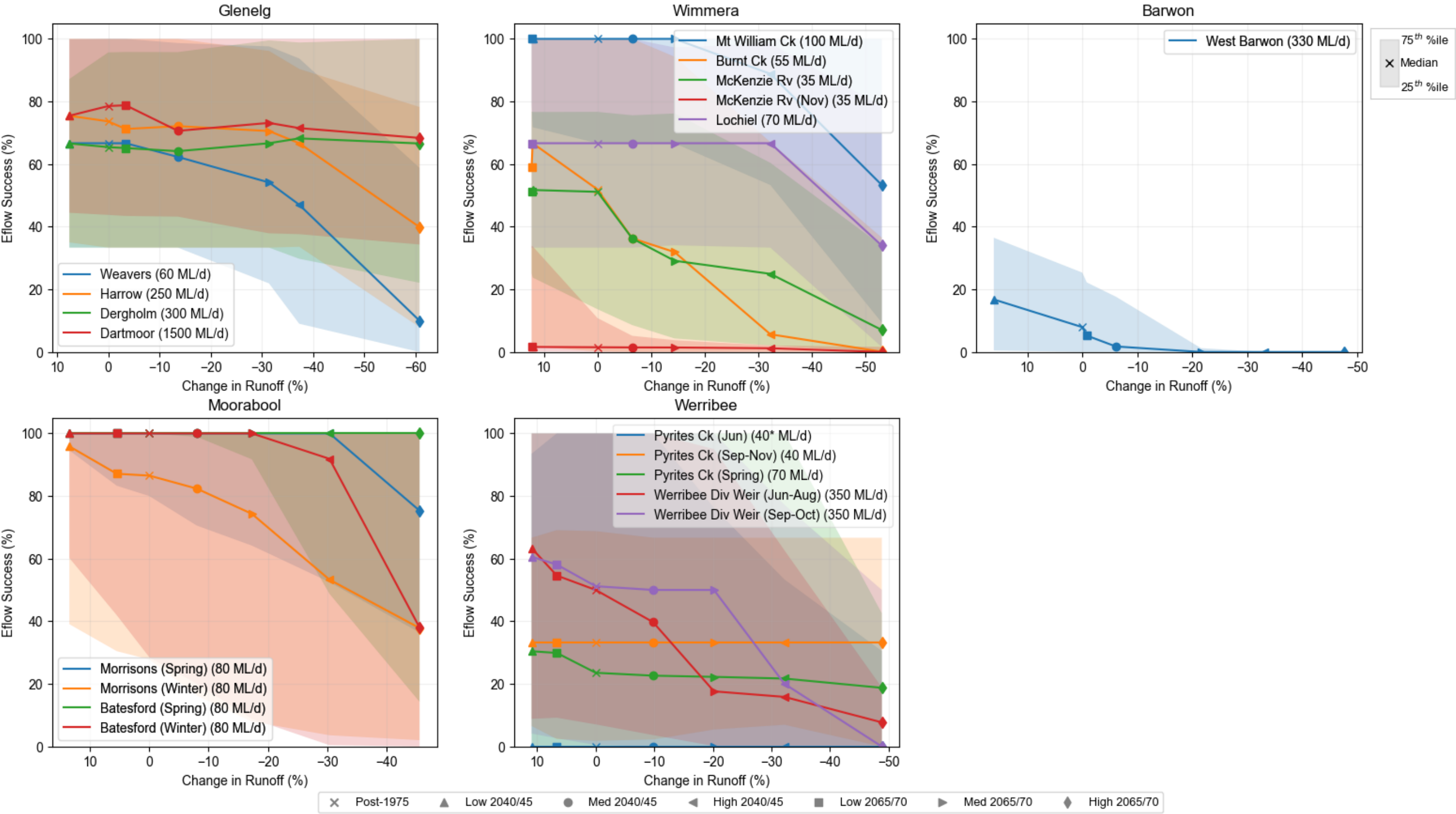


Figure 38: 25th, median and 75th percentile measures of annual success in meeting winter and spring freshes targets under different climate conditions in river systems across the Western and Western-Central regions. The asterisk indicates that the magnitude of the flow target differed per climate season (see Appendix C for further detail).

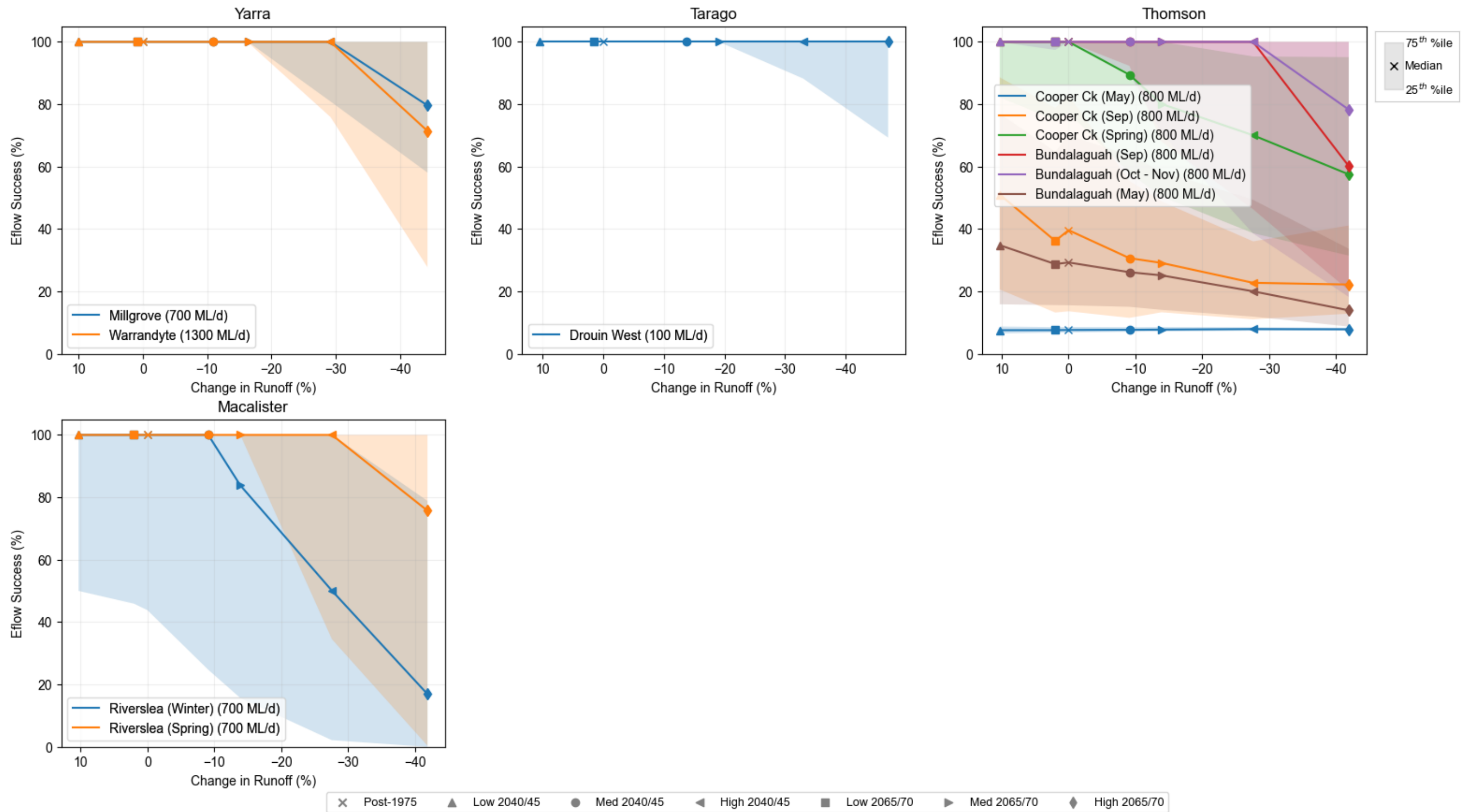


Figure 39: 25th, median and 75th percentile measures of annual success in meeting winter and spring freshes targets under different climate conditions in river systems across the Eastern-Central and Gippsland regions

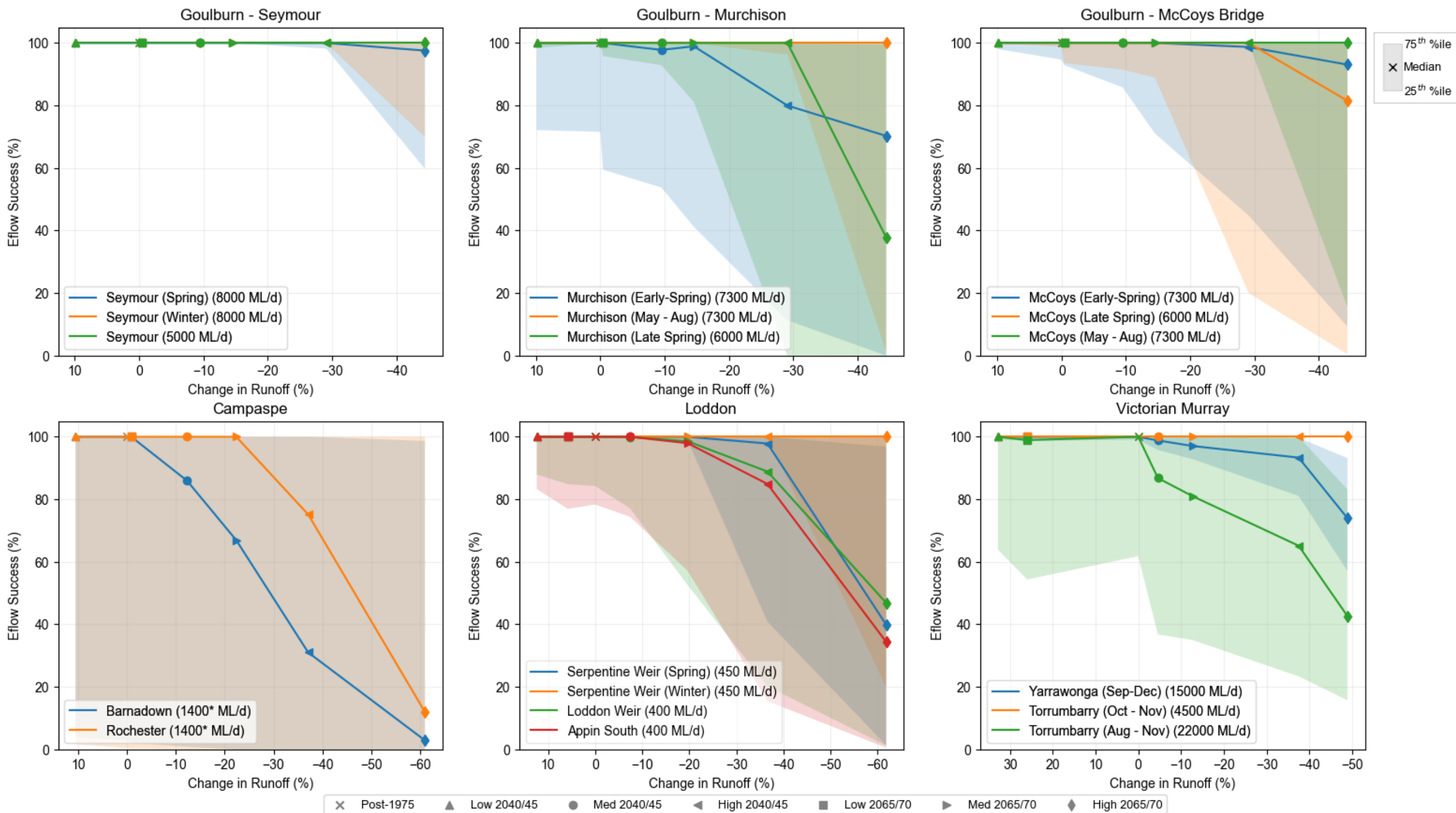


Figure 40: 25th, median and 75th percentile measures of annual success in meeting winter and spring freshes targets under different climate conditions in river systems across the Northern region. The asterisk indicates that the magnitude of the flow target differed per climate season (see Appendix C for further detail).

5. Comparison with bottom-up assessments

5.1 Top-down vs bottom-up assessments

The climate change impact assessments described above follow a top-down (or scenario-centred) approach, where climate projection scenarios are used in combination with river system models to simulate climate change impacts on water availability (Fowler et al., 2024). As per this project, it is common that a range of high, medium and low climate projection scenarios are selected on the assumption that these will represent the full range of potential impacts. However, this approach may not highlight important aspects of system behaviour, such as thresholds of change or non-linearities of system response (Brown et al., 2012).

Bottom-up approaches involve simulating incremental shifts in climate, and using simplified models to assess the system response (John et al., 2022). Both top-down and bottom-up methods can be implemented using either factored historical data or stochastically generated data. However, the run time of detailed water resource models mean it is often difficult to use stochastic data in a top-down approach (Bell et al., 2014; Wheeler et al., 2018). In contrast, the simplified models used in bottom-up approaches are designed to be evaluated for hundreds or thousands of scenarios, using factored historical or stochastically generated data.

A schematic of the steps involved in both top-down and bottom-up assessments is shown in Figure 41. The Stage 1 report for this project (HARC, 2024) includes a more detailed comparison, including the advantages and disadvantages of both approaches.

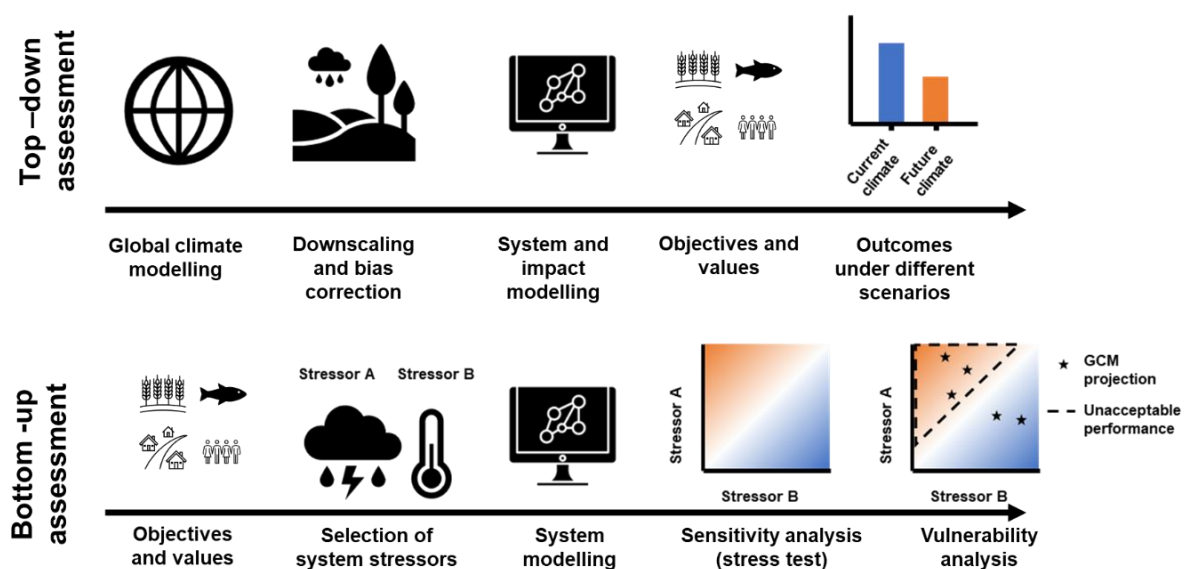


Figure 41: Comparison of top-down (top row) and bottom-up climate vulnerability assessments. Top-down methods are led by information from climate models. Bottom-up methods are led by an appreciation of the important objectives and values within a system, and an understanding of changes that affect these values.

5.2 Bottom-up methods used in this study

As implied by Figure 41, a true bottom-up method begins with a detailed mapping of the important objectives and values within a system, and the selection of future changes that are most impactful to these values. This can be quite a lengthy process, involving systematic exploration of values and sensitivity analysis which is outside of the scope of this study. In contrast, this study adopts a stress-testing approach to look for vulnerabilities in pre-identified objectives (and corresponding indicators), including thresholds where performance degrades rapidly for increasing levels of climate change.

Here, top-down results from this project are compared with three different bottom-up methods that overcome the computational challenges of complex water resource models. The first approach (Section 5.3) uses emulator models based on machine learning to model the daily timeseries of Glenelg River flows at Dergholm and Dartmoor, and allocations to environmental entitlements. Emulator models are trained on the output of more complex model scenarios, so that they can quickly produce outputs, either without a detailed system representation or with a significantly simplified one (Castelletti et al., 2012). Emulator models have found traction other related fields such as climate modelling (Meinshausen et al., 2011), rainfall-runoff modelling (Gladish et al., 2018) and hydraulic modelling (Fraehr et al., 2023).

The second method (Section 5.4) uses a simplified water resource model built specifically for bottom-up assessments. This work was already available from the ARC *Linkage Project Vulnerabilities for Environmental Water Outcomes in a Changing Climate* (Horne et al., 2023). The results presented here focus on the Goulburn River, Campaspe River and Loddon River, and compare the vulnerability of specific environmental flow components to changes in climate.

The third method (also in Section 5.4) uses statistical regression-based models that predict end of year allocations based on annual inflows. This work was completed as part of the OneBasin CRC *Stress testing water availability in the Southern Murray-Darling Basin* and involved stress-testing water allocations in the Goulburn and Murray systems to changes in climate.

Each approach has advantages and disadvantages. An emulator approach using machine learning can be applied rapidly to understand system vulnerabilities across large spatial areas (John et al, in review). However, emulators may not extrapolate well, are opaque, and do not explicitly account for physical constraints. Statistical models are relatively simple to understand and can also be used to rapidly understand system vulnerabilities. However, strong statistical relationships may not exist for the inputs and outputs of interest. A simplified water resource model is more resource intensive to construct, however lends itself to exploring adaptation options.

Note that in the first example (Glenelg River), the bottom-up outputs use the same set of metrics as the top-down outputs in Section 4.1. In the second example (Goulburn River, Campaspe River, Loddon River), the bottom-up outputs are more akin to – but not the same as – the measures of success in Section 4.2, and other statistics are included (e.g. duration of low allocation periods). This is because the bottom-up outputs in the second example were based on previous work.

In addition, one of the benefits of the bottom-up approach, that of testing and identifying adaptation options that deliver benefits despite climate change uncertainty, is not investigated here. For details on how this can be implemented refer to John et al. (2021b, 2024).

5.3 Glenelg system

5.3.1 Method

For the Glenelg River system, changes to daily flow metrics and monthly water allocations in response to perturbed climate inputs were assessed using an emulator model – specifically, a machine learning Long-Short Term Memory (LSTM) model. LSTM models are a variation of recurrent neural networks that allow for long-term dependencies. The model determines the relative importance of each input, and of previous inputs, in determining the output.

The LSTM model was calibrated to Source model outputs from the top-down scenario modelling. Using these existing climate scenarios allows the LSTM model to respond to a wider range of climate variability and better project into a drier or wetter future climate. Separate models were calibrated for monthly flow at Dergholm, Dartmoor, and Glenelg monthly allocations. The model was calibrated using the same methods as in John et al. (In review), briefly summarised here:

- The rainfall-runoff models developed as part of DEECA's unregulated rivers project (Fowler et al., 2024) were used to generate inputs (Figure 42). The benefit of this approach is that potential climate change impacts can be modelled using climate perturbations (e.g. changes in rainfall and temperature), rather than factoring runoff directly. This method better captures seasonal dynamics in the rainfall-runoff response to climate change.
- A square root transformation was applied to input data to better calibrate across the distribution of the flow regime (rather than focusing on high or low flows).
- The 2065 high, medium and low climate change top-down scenario modelling results were used for calibration, while the post-1975 scenario modelling results were used for validation.
- 50 separate gradient-based local optimisation runs were used for calibration. The selected parameter set for the model was the one that performed best (measured by Kling-Gupta Efficiency) across all calibration and validation scenarios.

The calibration and validation performance of flows and allocations is shown in Figure 43. The LSTM model calibrates well, with KGE scores near or above 0.95 for all scenarios and outputs. Performance was slightly lower in the high climate change scenario (drier conditions), and slightly higher overall for flows at Dartmoor compared to Dergholm and the Glenelg system allocations.

The validation performance for three outputs is shown in more detail in Figure 44. These plots compare outcomes from the LSTM model and Source model for the post-1975 scenario. The differences are small, especially for the flow outputs, although there is a tendency to overestimate very low flows (above 95th exceedance percentile), and underestimate very high flows (at about the typical annual maxima).

The low flow performance may have implications for the estimation of zero-flow related hydrological metrics. To address this, a calibration objective function that is deliberately targeted at zero flow performance could be used, but this may reduce performance across other parts of the flow regime. Different calibration objective functions have not been tested as part of this study.

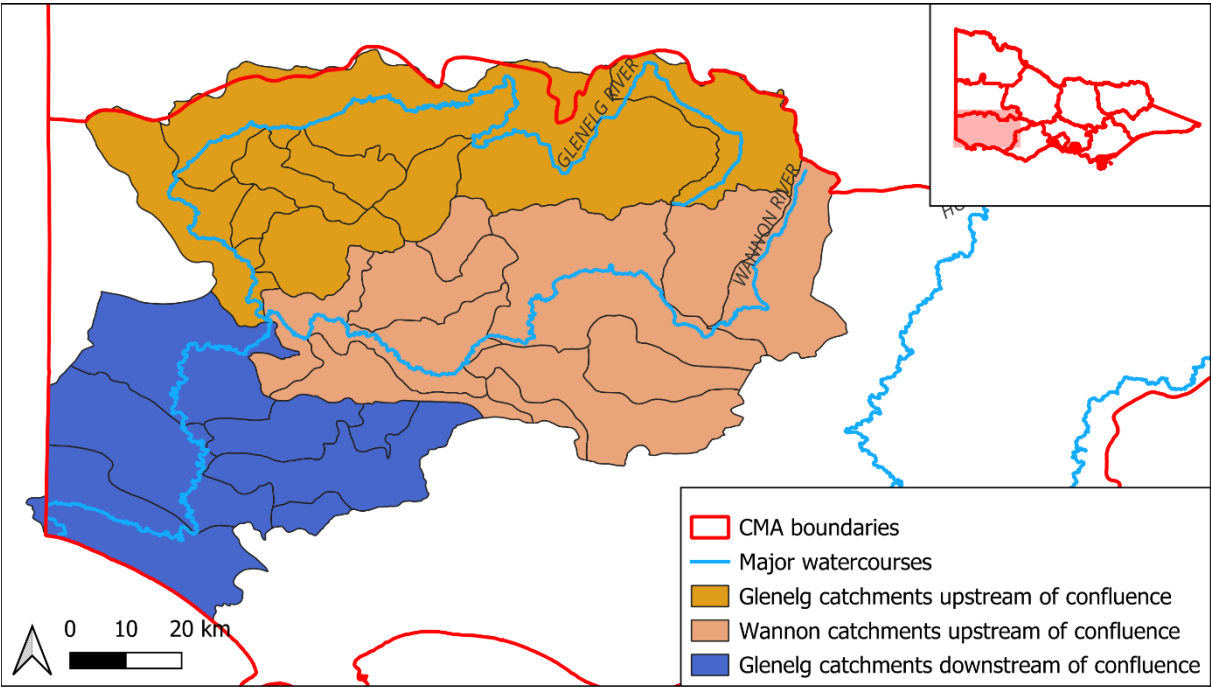


Figure 42: Unregulated catchments in the Glenelg River system used for modelling in this study. Input data for the Dartmoor flow model uses inflows to all catchments, whereas input data for the Dergholm flow model and the Glenelg allocation model only uses inflows to catchments upstream of the confluence of the Glenelg and Wannon rivers (brown and beige catchments).

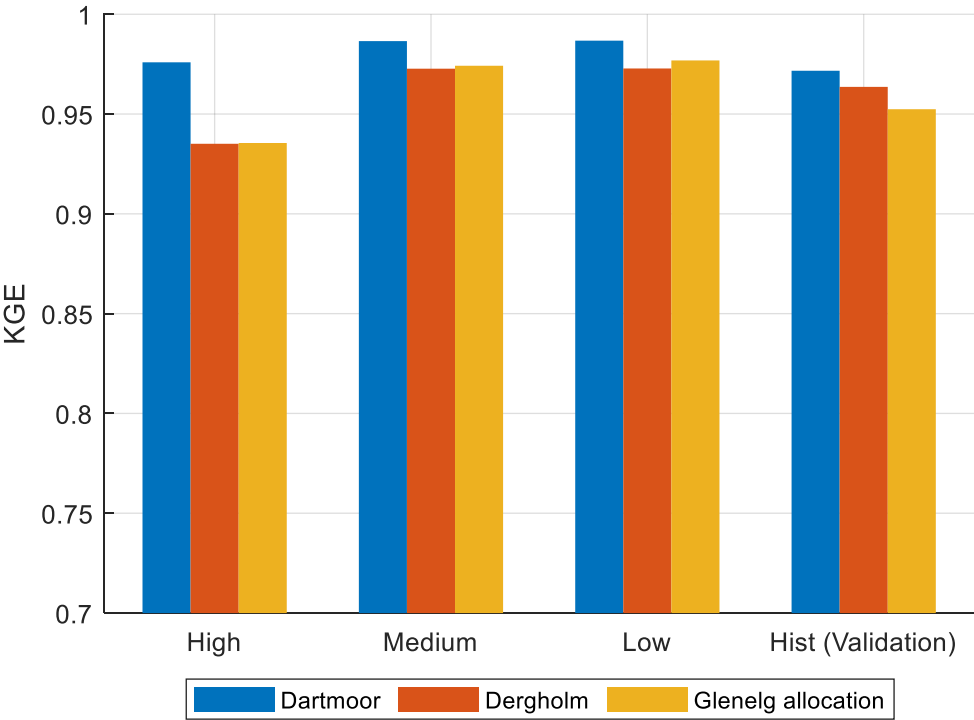


Figure 43: Calibration and validation performance of the LSTM emulator model in representing flows at Dartmoor, Dergholm, and allocations to the Glenelg entitlement. The model is calibrated over the 2065 high, medium, and low climate scenarios, and validated over the post-1975 (Hist) scenario.

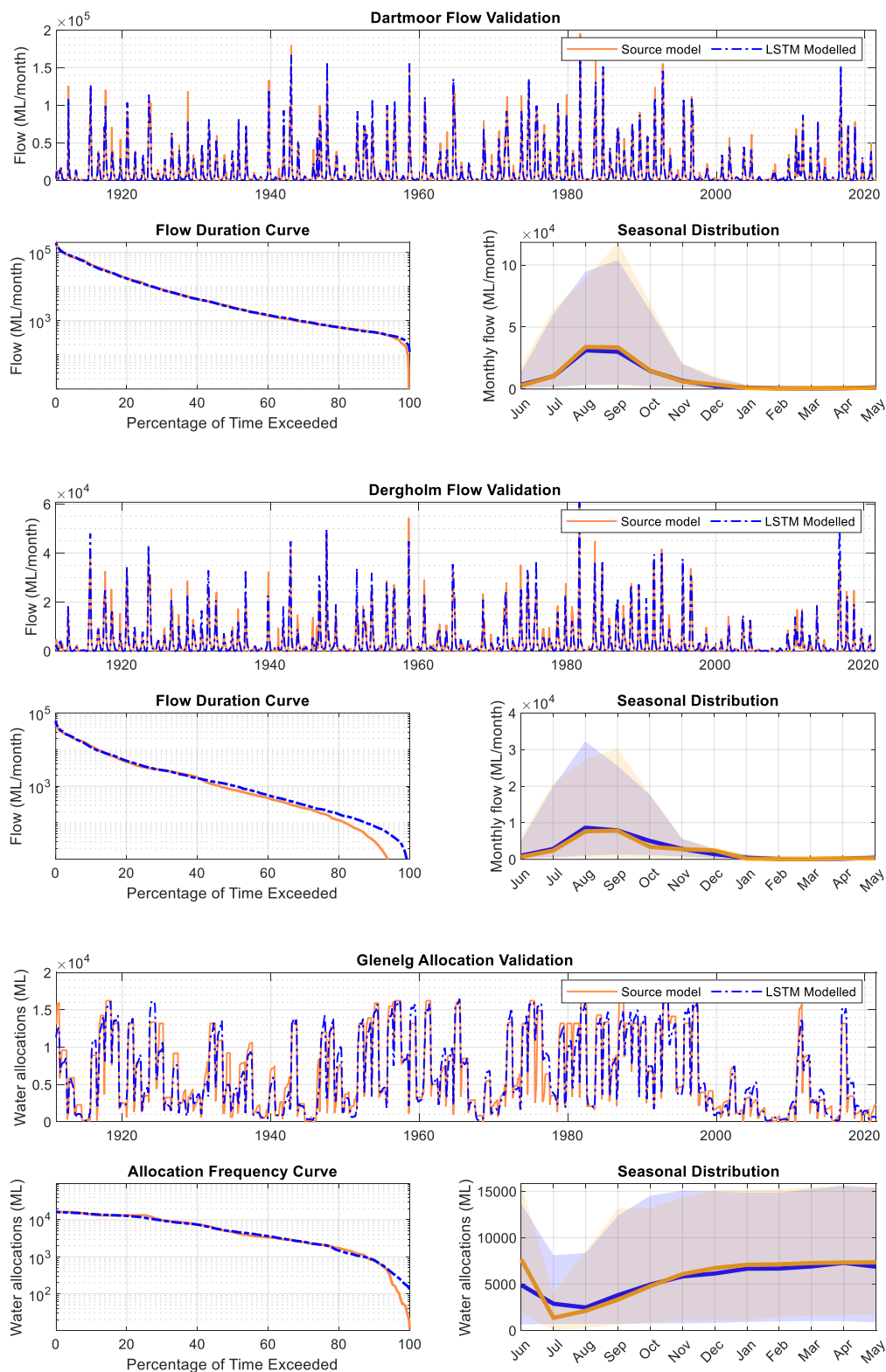


Figure 44: Validation performance of the three LSTM models. The top panel in each shows the time-series, the bottom left the flow duration curves, and the bottom right the seasonal distribution of outputs.

The LSTM modelled allocations do not always increase throughout the water year as expected. For example, June average allocations are lower than May average allocations, which is not realistic. This illustrates that the LSTM model does not have physical constraints, which can lead to outputs that differ from how the system is operated. While post-processing, such as specifying that monthly allocations cannot decrease in a water year, can be used to ‘correct’ outputs, this is better done in the model calibration phase. Often referred to as physics-informed machine learning, this is a relatively advanced approach that is outside of the scope of this project, and unnecessary when only assessing mean allocation results at a monthly or seasonal level (as is the case in this work).

A monthly-to-daily disaggregation technique was used to transform the monthly LSTM flow outputs to daily flows (John et al, 2021a). This involves using a method of fragments and estimates of catchment soil moisture to select daily patterns from the observed record for disaggregating the monthly flows. The method is well suited to environmental indicators. In this case, the ‘observed’ record is the Source model output. Thus, whilst the disaggregation technique preserves many of the statistical characteristics from the Source model, it cannot be better or more realistic, and will introduce some uncertainty in daily sequence outputs.

Table 7 shows – for post-1975 conditions – the results of the daily hydrologic metrics from 1) the Source model; 2) using monthly Source model outputs and then disaggregating to daily, thus isolating the effect of the disaggregation algorithm; and 3) using the LSTM disaggregated outputs. There is little variation between the LSTM model and the Source model results in the mean daily flow metrics (MA1, MA13, and MA19), mean high peak daily flow ratio (MH26), and the October and February allocations. However, there is more variation between the approaches for the low flow metrics (DL16 and DL18). Variation in the mean low flow spell duration (DL16) seems to be more driven by the disaggregation approach rather than the LSTM model. On the other hand, variation in the mean number of zero flow days per year (DL18) seems to be more driven by the LSTM performance rather than disaggregation, given the similar performance between the daily Source outputs and monthly-to-daily disaggregated Source outputs.

Table 7: Summary of outputs - for post-1975 conditions - from the original daily Source model, monthly Source model outputs disaggregated, and the disaggregated LSTM model. The bottom two rows also show the proportional difference between the daily Source model and the other two approaches.

Metric	Glenelg Dartmoor						Glenelg Dergholm						Allocations	
	MA1	MH26	DL16	DL18	MA13	MA19	MA1	MH26	DL16	DL18	MA13	MA19	Oct	Feb
Daily Source model	1200	29.1	37.5	0.9	113	3497	365	26.9	29.5	12.1	45.4	1077	13600	13990
Disaggregated Source model	1200	26.0	27.4	1.0	113	3497	365	23.3	20.3	11.6	45.4	1077	n/a	n/a
Disaggregated LSTM model	1159	27.5	25.0	0.5	115	3465	355	23.7	16.3	7.7	40.4	1066	13471	13796
Difference (disag Source model)	0%	-11%	-27%	10%	0%	0%	0%	-13%	-31%	-4%	0%	0%	n/a	n/a
Difference (disag LSTM model)	-3%	-6%	-33%	-47%	2%	-1%	-3%	-12%	-45%	-36%	-11%	-1%	-1%	-1%

Note that metric values differ to those presented in Section 4.1 because they are calculated over a different period (1911 – 2021 rather than 1891 – 2021).

Because of the uncertainty in some metrics, the stress testing outputs that follow are based on the relative change in the metrics compared with post-1975 conditions, rather than their absolute output, as this is generally more robust. For example, a reduction in precipitation of 10% and increase of

temperature of 2°C might yield an increase in the number of zero flow days by five (from two to seven), and this is reported as + five days in the results, rather than seven days.

5.3.2 Bottom-up results

Figure 45, Figure 46 and Figure 47 show the stress testing results of each flow metric (Table 8) at Dergholm and Dartmoor, and October and February allocations in the Glenelg River system. Each figure shows the outcomes of each metric, the spread of 2040 and 2065 climate model projections from a downscaled and bias corrected 37 member CMIP5 ensemble, and DEECA's (2020) climate change guidelines scenarios (H, M and L).

Table 8: Hydrological indicators assessed using bottom-up modelling results for the Glenelg system

Hydrologic indicator	Units	Abbreviation
Mean daily flow	ML/d	MA1
Mean February flow	ML/d	MA13
Mean August flow	ML/d	MA19
Mean high peak flow (>7 x median daily flow), divided by median daily flow	Unitless	MH26
Median low flow (<75 th percentile flow) spell duration	Days	DL16
Mean number of zero flow (<0.1 ML/d) days per year	Days	DL18

Unsurprisingly, all metrics are more sensitive to changes in precipitation compared to temperature. However, the results at Dartmoor (Figure 46) show some interesting differences in the sensitivity of different metrics. Average metrics (MA1, MA13 and MA19) respond relatively linearly to changes in climate. High and low flow metrics (MH26, DL16, and DL18) show less linear responses, and vary more based on crossing certain regions in precipitation and temperature change. For example, the mean low flow spell duration (DL16) at Dartmoor does not respond greatly until about a 10% reduction in precipitation (modulated by temperature increases), beyond which the duration of low flow spells starts to increase more rapidly. Similarly, the mean number of zero flow days per year (DL18) barely responds until quite significant reductions in precipitation in the order of 20%, which does demonstrate some robustness of perennial conditions at Dartmoor. Beyond this point, the mean number of zero flow days can increase from the very low baseline of ~1 day up to an extra 10 days.

The outputs at Dergholm (Figure 45) tell a similar story to those at Dartmoor. There are regions within the climate space where the mean number of zero flow days per year (DL18) and the mean high peak flow ratio (MH26) begin to change more rapidly. These are commonly around a 10% reduction in precipitation. Changes to DL18 begin at lower values of precipitation reductions compared to Dartmoor. Note, that the fluctuations in the mean low flow spell duration (DL16) – i.e. where more severe decreases in precipitation sometimes result in lower changes compared to less severe decreases in precipitation – are likely an artefact of the modelling.

As per the average flow metrics at the two sites, the October and February allocations (Figure 47) respond relatively linearly to changes in climate. However, the February allocations are more resilient to smaller reductions in precipitation compared to the October allocations, suggesting impacts could be more severe for earlier season allocations and the flow components and irrigation outcomes that rely on them. Both monthly allocations can be reduced by ~50% from their baseline values for about a 20% reduction in precipitation. Any increases in precipitation generally have a greater impact on the October allocations compared to February allocations.

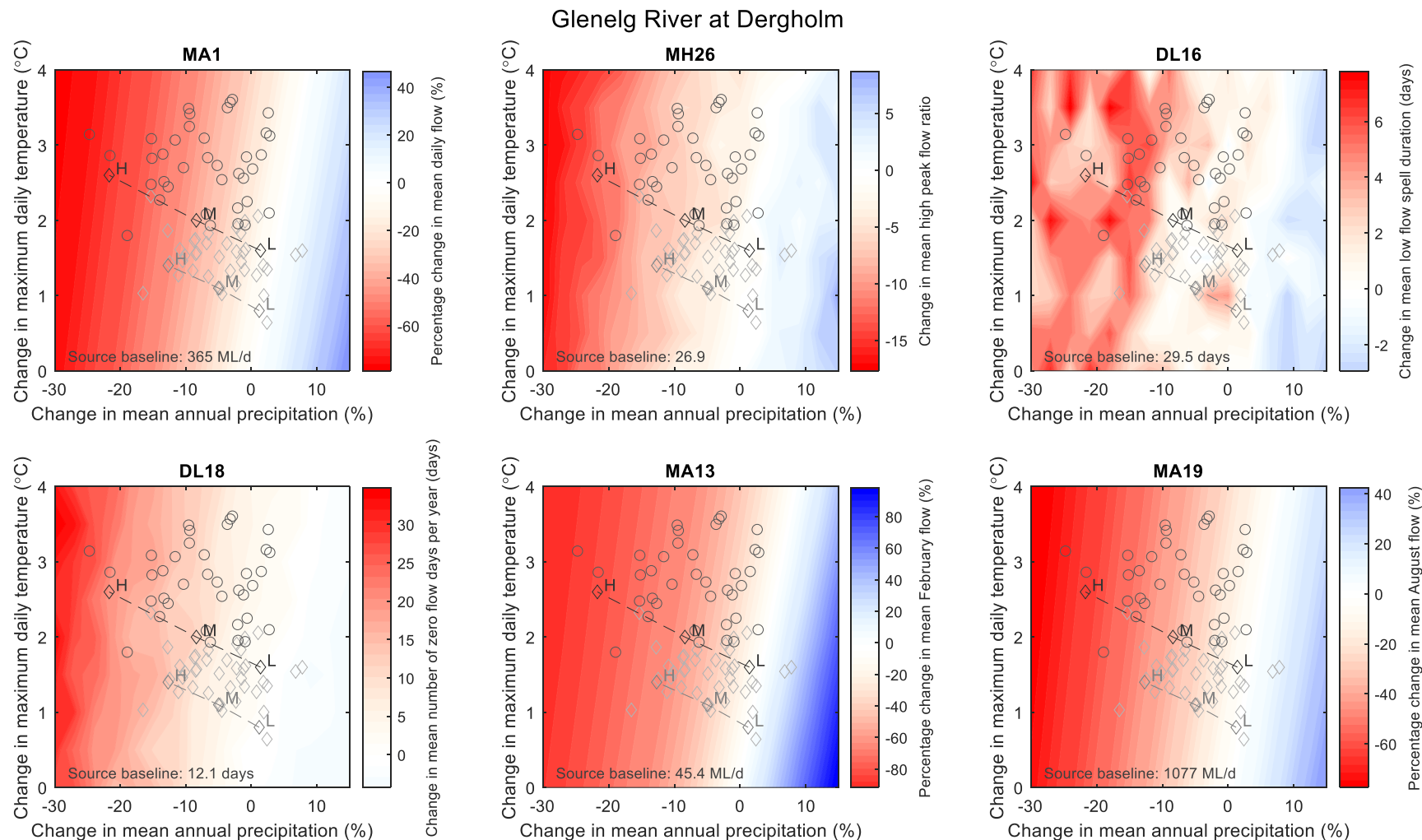


Figure 45: Stress testing results for the Glenelg River at Dergholm. Each panel shows how a different hydrologic metric responds to change in precipitation and temperature, relative to post-1975 conditions. The scatter points show climate model projections for RCP8.5 2040 (grey diamonds) and RCP8.5 2065 (black circles). The L, M and H icons show DEECA's climate change guidelines scenarios. The text in the bottom left of each panel shows the baseline for each metric (i.e., the results from the post-1975 daily Source model outputs). In all panels, post-1975 conditions are coloured white, with red representing a decrease and blue an increase in the metric.

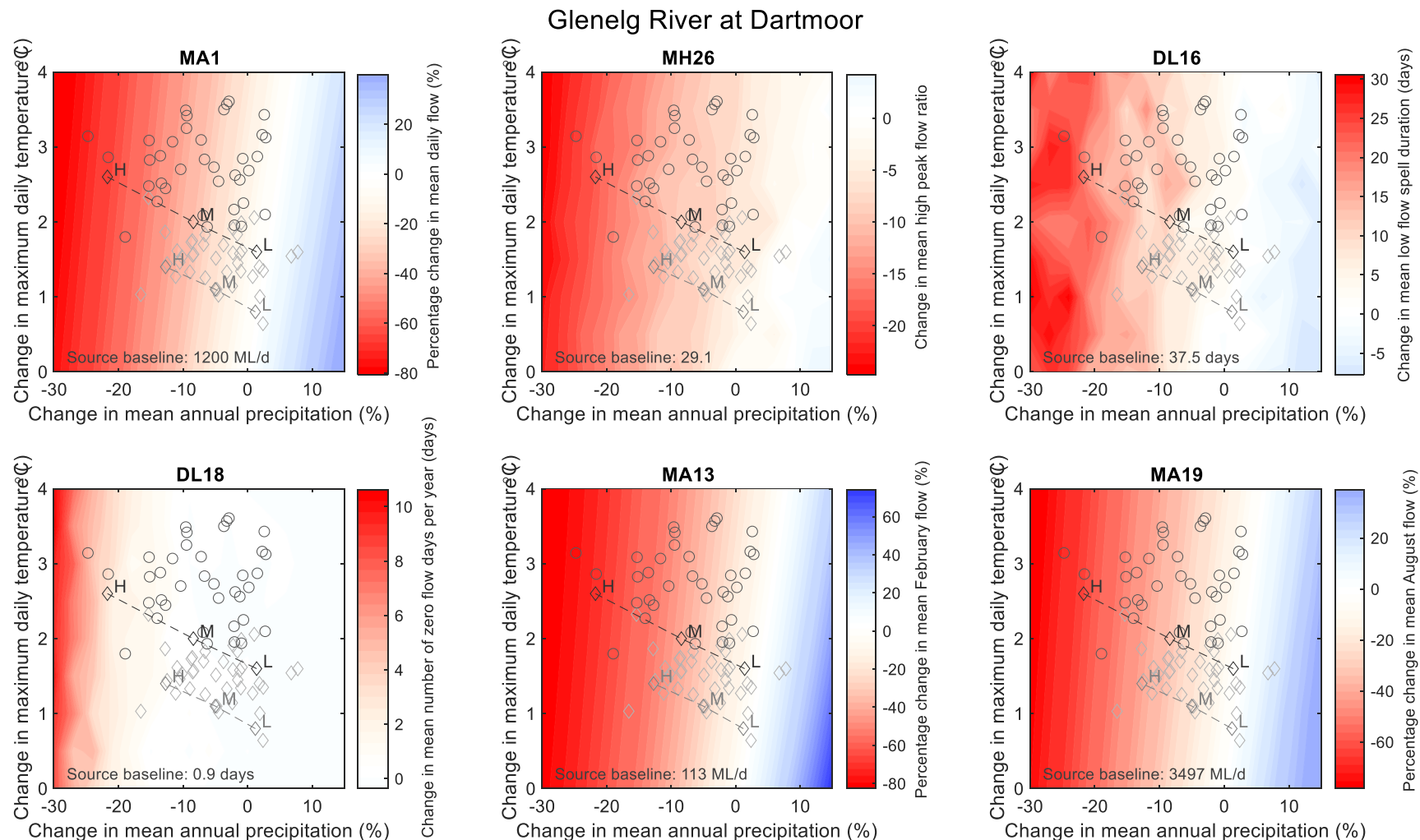


Figure 46: Stress testing results for the Glenelg River at Dartmoor. Each panel shows how a different hydrologic metric responds to change in precipitation and temperature, relative to post-1975 conditions. The scatter points show climate model projections for RCP8.5 2040 (grey diamonds) and RCP8.5 2065 (black circles). The L, M and H icons show DEECA's climate change guidelines scenarios. The text in the bottom left of each panel shows the baseline for each metric (i.e., the results from the post-1975 daily Source model outputs). In all panels, post-1975 conditions are coloured white, with red representing a decrease and blue an increase in the metric.

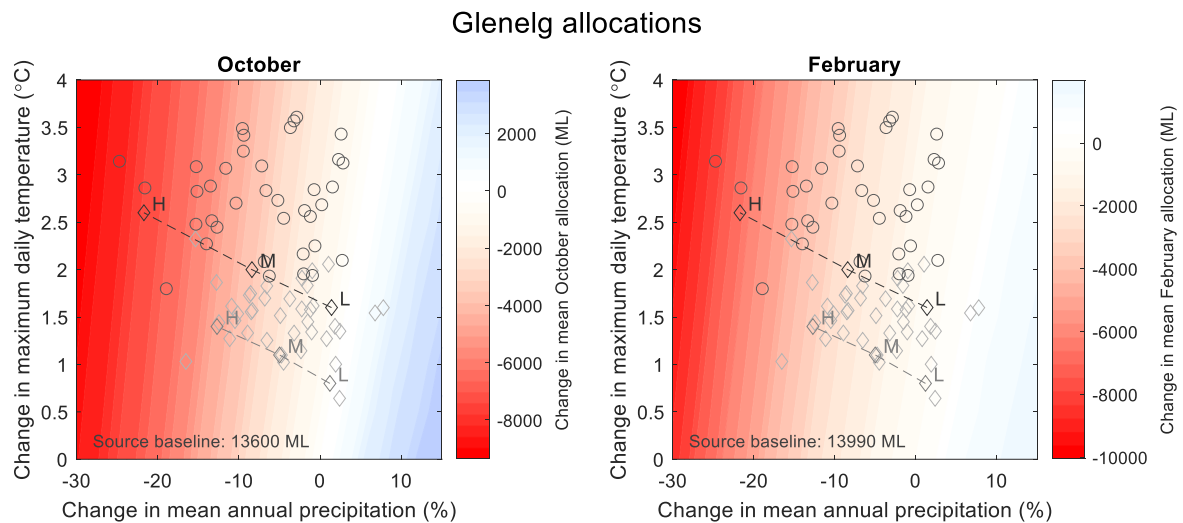


Figure 47: Stress testing results for Glenelg system allocations, for October (left) and February (right). The scatter points show climate model projections for RCP8.5 2040 (grey diamonds) and RCP8.5 2065 (black circles). The L, M and H icons show DEECA's climate change guidelines scenarios. The text in the bottom left of each panel shows the baseline allocation (i.e., the results from the post-1975 daily Source model). Post-1975 conditions are coloured white, with red representing a decrease and blue an increase in the metric.

The DEECA (2020) climate change guidelines scenarios generally span the range of precipitation impacts quite well, although there are a few GCM members that project more severe changes outside of the bounds of the high and low climate change scenarios. This is as expected, since the DEECA scenarios are designed to represent the 90th and 10th percentile range in GCM outputs. There are some greater differences in the temperature change factors. For example, DEECA's 'medium' scenarios typically sit towards the bottom of the GCM ensemble projections in Figure 45 to Figure 47. The key reason for this is that the data generation framework from DEECA's unregulated rivers project (which is the basis of the GCM ensemble) uses maximum daily temperature as the temperature-related variable. In contrast, the DEECA (2020) climate change guidelines use average annual temperature, which may be impacted by climate change in a different way.

5.4 Northern Victoria

5.4.1 Method

The University of Melbourne previously developed the Stochastic Goulburn Environmental Flow Model (SGEFM) to support the ARC Linkage Project *Vulnerabilities for Environmental Water Outcomes in a Changing Climate*. This model was designed to be fast and flexible, and represent contemporary water policy and management in the rivers.

The model uses a monthly time-step to calculate water allocations and environmental and irrigation demands, and a custom disaggregation algorithm to simulate daily river flows (John et al., 2021a). The model can either be run using historic river inflows or the stochastic data generation framework of Fowler et al., (2022), which enables statistical downscaling of climate change projections and assessment of the significance of climate variability on model outcomes. The model is also compatible with twelve ecological models representing the fundamental and means objectives for environmental flows identified in the Goulburn River (Horne et al., 2022).

The SGEFM has been previously used to support the update of environmental flow targets in the lower Goulburn (Kaiela) River (Horne et al., 2020), understand interacting stressors on freshwater ecosystem outcomes (John et al., 2022), assess the effectiveness of different climate adaptation options in the Goulburn River, and set constraints relaxation targets (John et al., 2024). It has also been used to assess the vulnerability of environmental flow components in the Goulburn, Broken, Campaspe and Loddon rivers under climate change – work that is summarised in this report (Section 5.4.2).

The simplified hydrologic representation of the Goulburn system is shown in Figure 48. This includes a level of detail sufficient to capture the major regulation infrastructure, tributary inflows, and demands within the system.

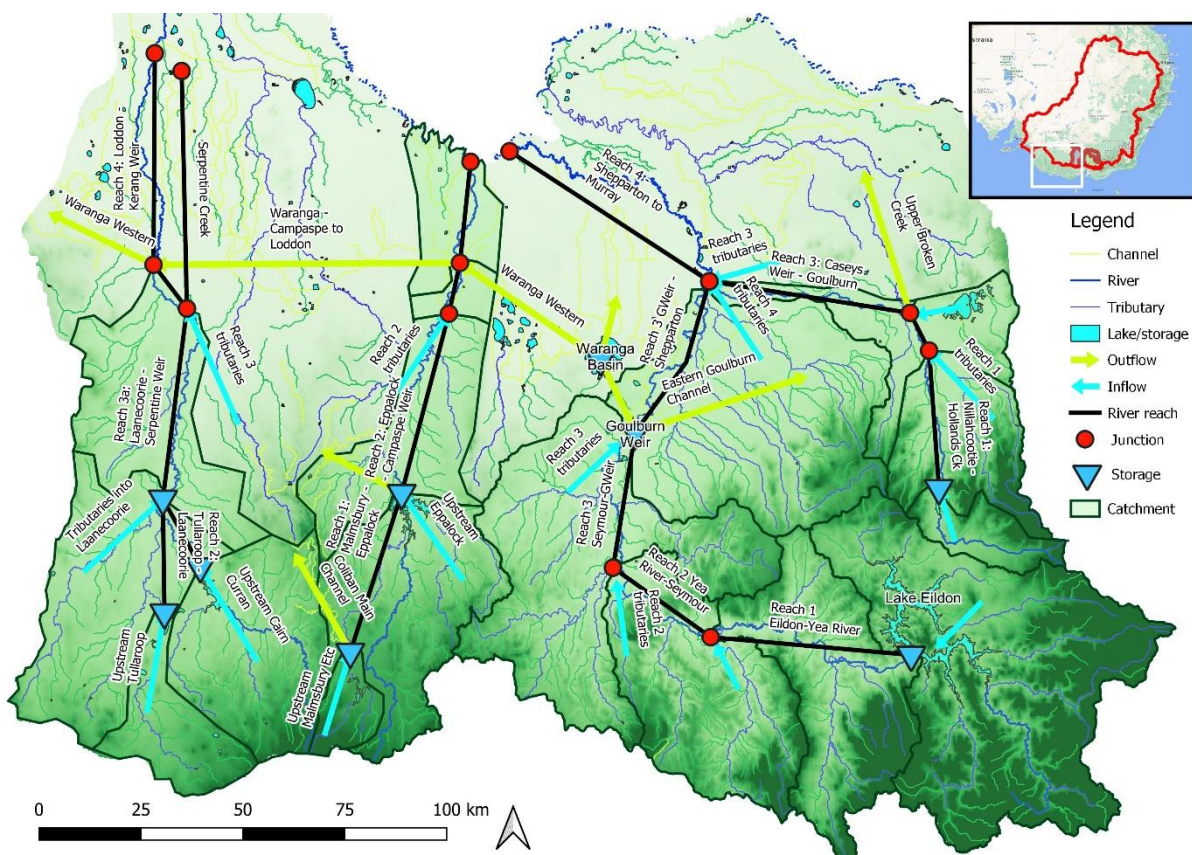


Figure 48: Simplified representation of the Goulburn, Broken, Campaspe and Loddon river system.

5.4.2 Bottom-up results

Figure 49 shows how often five key flow components across the Goulburn River, Campaspe River and Loddon River are met under different climate conditions (relative to current conditions). These flow components have been amalgamated from various flow recommendation reports to have a consistent set across the three rivers, but do not represent the full diversity in flow targets.

Based on Figure 49, it is observed that:

- **Overbank flows** – Overbank flows do not occur often compared with the frequency of the other flow components, and are sensitive to changes in climate for all three rivers. Moderate drying can dramatically reduce overbank flow frequency. For example, how often an overbank flow occurs falls to ~10% of years for a 10% reduction in precipitation, and to ~0% for a 20% reduction. This observation needs to be tempered by ongoing research that suggests large floods will become more frequent as the climate changes (Wasko and Nathan, 2019).
- **Winter low flows** – Conditions in all three rivers are generally good, however both the Loddon and Campaspe will be more affected than the Goulburn, and challenged by reductions of 20% rainfall or more.
- **Summer low flows** – Both the Goulburn and Campaspe are generally protected by high inter-valley trade (IVT) (that may also provide too much water in summer), and deliveries for environmental and consumptive purposes. In contrast, the frequency with which Loddon summer low flow targets are met is lower. Climate change impacts are apparent for summer low flows for any reduction in rainfall >5-10%. This relatively small size of storages and environmental entitlements in the Loddon system contributes to these differences compared with the Goulburn and Campaspe.
- **Summer/autumn fresh** – The targets for summer-autumn freshes are generally met less often compared with summer low flows, and the sensitivity to changes in precipitation is also more apparent. The frequency with which freshes are met will be influenced by both changes in rainfall-runoff from tributaries, and the priorities for using environmental water in storage.
- **Winter/spring fresh** – For the Campaspe and Loddon, this flow component is most sensitive (i.e. greatest range of blue to red) to the simulated range of change in annual precipitation. In the Goulburn, the outcomes are less sensitive, but there is a decrease in how often the flow targets are met when the reduction in annual precipitation is more than ~10%.

Differences in how often some flow components are achieved also represent different frequency targets. For example, it is generally not desired to deliver a summer/autumn fresh in the lower Goulburn River each year, and this behaviour is reflected in the water resource model used in this analysis. Further, the results here are very sensitive to flow component priorities and planning procedures represented in the model. For example, the typical climate based (dry/average/wet etc.) flow scenario planning that is currently used to manage environmental water means that under a drying climate, dry conditions are more likely to occur for consecutive years. Thus, the further conditions move away from the “baseline” climate, the less variability there will be in flow component delivery and prioritisation, and some lower priority flow components may be ceased to be delivered altogether.

Overall, the results here are consistent with analysis presented in Section 4.2, despite the significant differences between the top-down and bottom-up approaches. Specifically, it was found that winter / spring and summer / autumn low flows could still be achieved under a range of climate conditions, especially in the Goulburn. In contrast, summer / autumn and winter / spring freshes are more vulnerable to climate change.

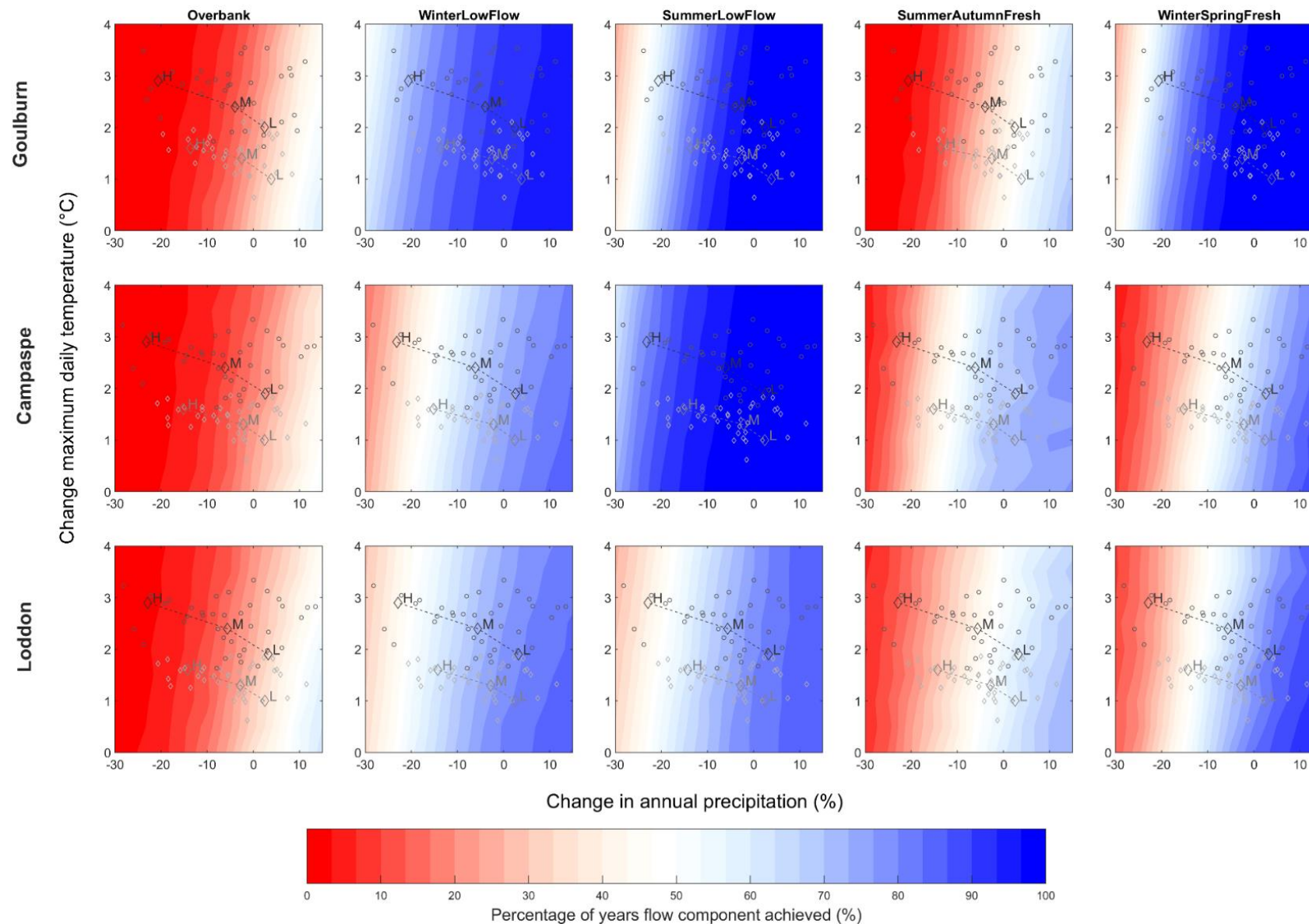


Figure 49: Vulnerability in achieving flow components across the Goulburn, Campaspe and Loddon rivers. Flow components are split into five dominant functional flows for transferability across rivers but may differ slightly from flow components in environmental flow targets. These results show the percentage of years a component is achieved, but some flow components do not need to be delivered every year. The scatter points show climate model projections for RCP8.5 2040 (grey diamonds) and RCP8.5 2065 (black circles). The L, M and H icons show DEECA's climate change guidelines scenarios

5.4.3 Additional analysis of Goulburn and Murray allocations

Method

In addition to the SGEFM, the University of Melbourne has also developed statistical models of allocations to HRWS as part of the OneBasin CRC project *Stress testing water availability in the Southern Murray-Darling Basin*. These statistical models use annual inflows to major storages (Lake Dartmouth and Lake Hume for the Murray system, Lake Eildon and Goulburn Weir for the Goulburn system) to predict end-of-season allocations. The models were calibrated to results from the Source Murray Model (Murray) and SGEFM (Goulburn) for historical climate conditions and a dry climate scenario. More details can be found in Horne et al. (In review).

To apply the models a stochastic framework was used to generate 3000 years of monthly rainfall and temperature data, based on historical characteristics or changes to average rainfall, temperature, and rainfall seasonality (the distribution of rainfall). The generated climate data was then run through rainfall-runoff models to simulate inflows, which were aggregated to an annual time-step. Annual inflows were used with the statistical models to obtain end-of-season HRWS allocations.

Results

Based on results from the statistical models described above, Figure 50 shows the sensitivity of allocations to HRWS in the Victorian Murray and Goulburn systems to changes in rainfall-runoff. The left-panel shows average end-of-season allocations, and the right-panel shows allocation reliability (i.e. percentage of years with 100% allocation). This demonstrates that allocations to HRWS in the Victorian Murray and Goulburn systems are not very sensitive to small changes in runoff (i.e. $\pm 10\%$), but there is a sudden drop in allocations for reductions in runoff greater than $\sim 25\%$.

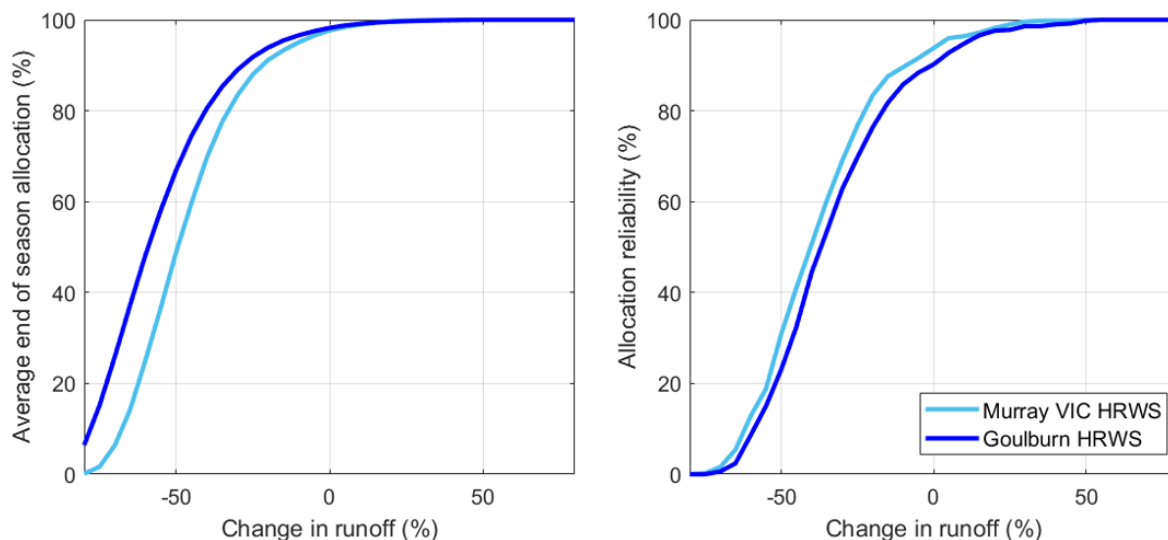


Figure 50: End of season allocations (left panel) and allocation reliability (right panel) vs. change in average annual runoff, for high reliability water shares in the Goulburn and Murray systems.

Figure 51 shows the relative vulnerability of average end-of-season HRWS allocations for the Victorian Murray and Goulburn systems to shifts in seasonality (-6% to +15%) and annual precipitation (-40% to +25%). To keep these results consistent with an expectation of continued climate change, each panel in Figure 51 has a temperature increase modelled as 2°C above the baseline scenario. Note these differ compared to other plots produced in this work, where the focus was only on changes in precipitation and temperature.

This figure again demonstrates that both the Victorian Murray and Goulburn HRWS allocations are reasonably robust to small changes in runoff, but decline rapidly in very dry conditions (precipitation reductions >20%). The overlay of 2060 global climate model projections show that there are several projections that can lead to average end of season allocations as low as 60% in the Goulburn River, and 50% in the Victorian Murray system.

Using the same statistical models, Figure 52 shows how the maximum duration of periods with low allocations (defined as < 50%) vary with changes in runoff. Again, the durations are relatively insensitive to small changes in runoff, but increase significantly to generally >10 years within the 3000-year simulation period if the decrease in runoff exceeds ~20%.

Interestingly, the top-down results (Section 3) showed that the Goulburn system allocations were more vulnerable to runoff changes than the Murray, while Figure 50 and Figure 51 reversed the pattern. For example, for the Goulburn, a change in runoff of -45% resulted in a decrease in average allocation of ~50% in Figure 5, but only ~25% in Figure 50. For the Murray, a change in runoff of -50% resulted in a decrease in average allocation of ~25% in Figure 5, but ~50% in Figure 50.

These differences could be because:

- For the top-down approach, model inputs were based on historical data (factored to match post-1975 conditions, and scaled to account for climate change) (~100 years), whereas for the statistical models, inputs were based on stochastic data (3000 years).
- The statistical models are only for HRWS, whereas the Source models consider both HRWS and LRWS.
- The statistical models consider only inflows to major storages, whereas the Source models simulate the whole system (inflows, carryover, and spills).

Given the size of the environmental entitlement holdings in the Goulburn and Murray systems, further investigation of these differences in predictions between the top-down and bottom-up approaches may be warranted.

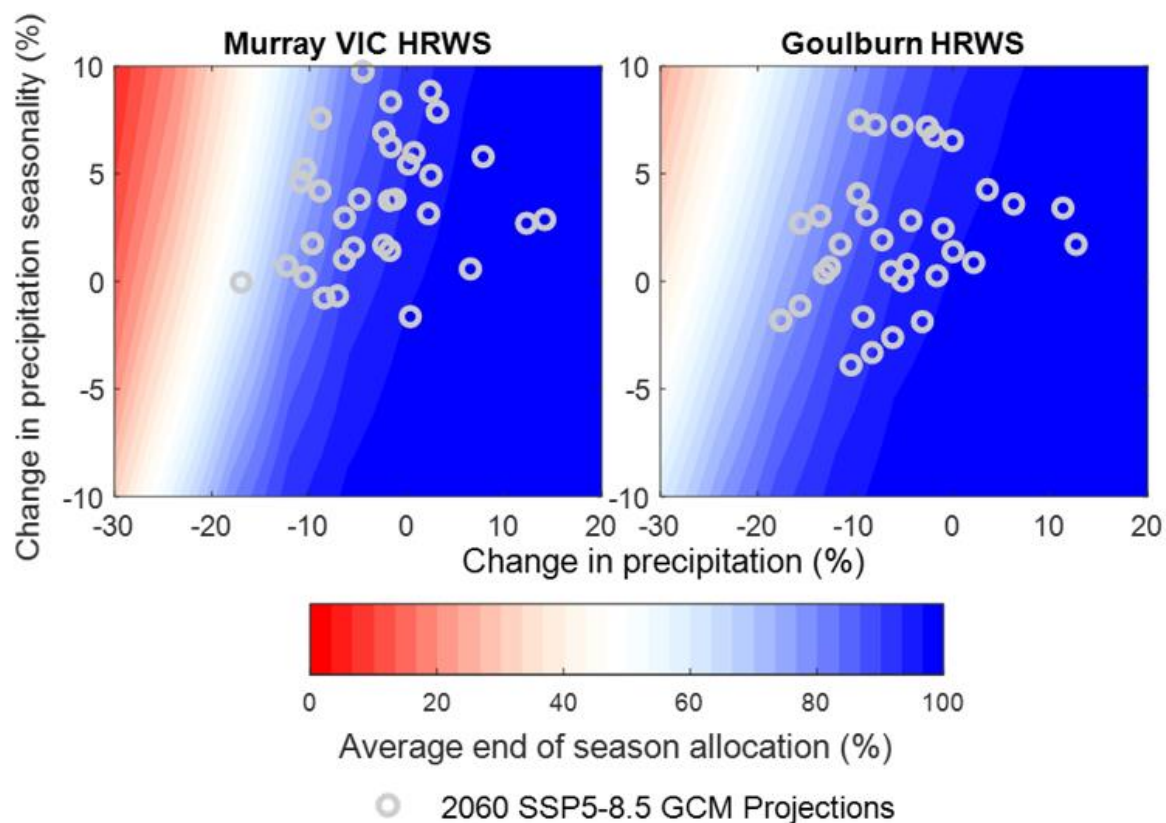


Figure 51: Vulnerability of average end-of-season allocations to changes in seasonality and annual precipitation (for a temperature increase of 2°C)

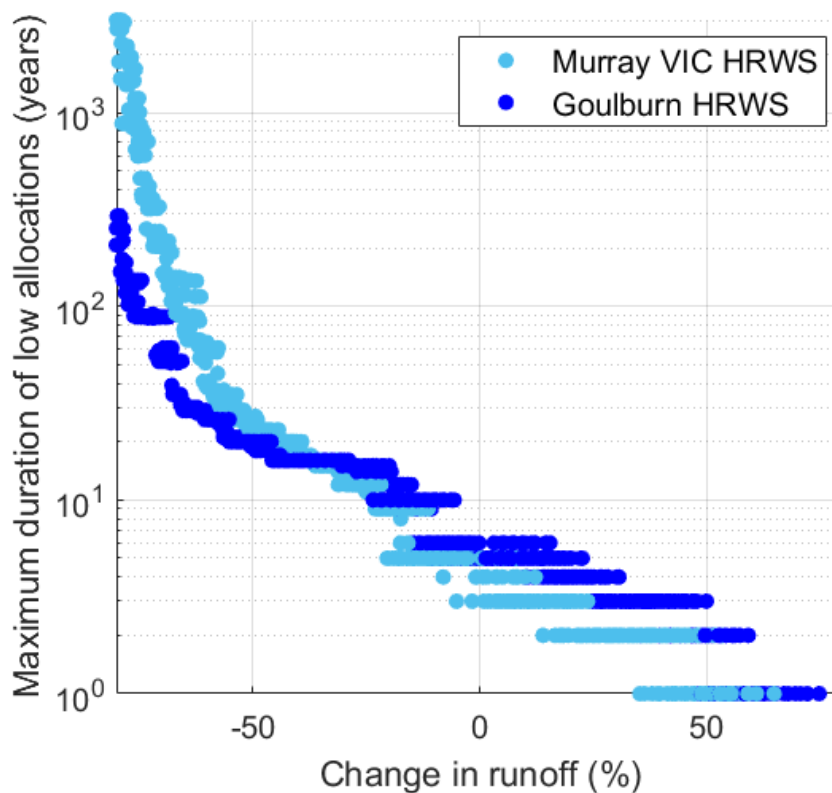


Figure 52: The maximum duration of low allocation periods, defined as less than 50%, vs. change in average annual runoff, for high reliability water shares in the Goulburn and Murray systems.

5.5 Findings

This report section describes the application of three different bottom-up methods to assess entitlement reliability and hydrological indicators. The case study systems used to demonstrate the applications of the bottom-up methods were the Glenelg and Northern Victoria (comprised of the Goulburn, Campaspe, Loddon and Murray). The findings were generally consistent with what was observed via the top-down scenario modelling, including that:

- Early season (October) allocations are more sensitive to changes in runoff compared with late season (February) allocations (Glenelg).
- The frequency with which summer / autumn and winter / spring freshes are met is more vulnerable to changes in runoff compared with summer / autumn and winter / spring low flows (Goulburn, Campaspe and Loddon).
- End-of-season allocations to high reliability water shares in the Victorian Murray and Goulburn systems are not very sensitive to small changes in runoff (i.e. $\pm 10\%$), but drop significantly if the reduction in runoff is more than $\sim 25\%$.
- Low flow spell durations and the number of zero flow days are less likely to respond linearly to changes in climate compared with changes in the averages of daily or monthly flow (i.e., after a certain point, low flow spells will increase rapidly).

Notably, there is a difference in the relative sensitivity of the Victorian Murray and Goulburn system allocations to potential climate change depending on whether a top-down or bottom-up approach (statistical model using stochastic data) is used to assess how end-of-season allocations change as rainfall-runoff reduces. This demonstrates that modelling outcomes can differ depending on the approach used.

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Appendix A Derivation of system inflows

The input derivation approaches used for different climate cases are summarised in Table 9. Note that when future demands have been derived under future climate, consistent with the DEECA 2020 *Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria*, only the medium climate change factors have been applied to the climate inputs used to derived demands.

Also note that:

- A two-season decile scaling method is used in the Werribee system, and in all other systems the decile scaling is based on four seasons (spring, summer, autumn, winter).
- The length of the post-1975 / post-1997 period used for decile scaling is reasonably consistent between models.

Table 9: Input derivation for different climate cases

System	Inflow and climate adjustment to create reference climate series (type of scaling)	Post 1975 period of record used to derive decile scaling	Future irrigation demands derived under future climate?	Future urban demands derived under future climate?	Future farm dam impacts derived using future inflows?
Latrobe	Seasonal decile scaling (four seasons)	30/06/20	N	N	N
Thomson-Macalister*	Seasonal decile scaling (four seasons)	30/06/22	Y	N	N
Werribee	Seasonal decile scaling (warm season: Nov-Mar, cool season: Apr-Oct)	31/12/20	N	N	N, pre-1975 baseline STEDI outputs adopted for future climate
Wimmera-Glenelg	Seasonal decile scaling (four seasons)	30/06/21	N	N	N
Barwon-Moorabool	Seasonal decile scaling (four seasons)	31/12/22	N (except for the Barwon R, which has built in irrigation demand models)	N	N
GBCCCL	Seasonal decile scaling (four seasons)	30/06/22	N	N	N
Murray	Seasonal decile scaling (four seasons)	30/06/19	N	N	N
Yarra	Seasonal decile scaling (four seasons)	30/06/21	N	N	N
Tarago	Seasonal decile scaling (four seasons)	30/06/21	N	N	N

* Modelled monthly Thomson – Upper Yarra transfer volumes were provided by MW for all climate scenarios assuming a Melbourne system demand of 454 GL/yr. These transfers were disaggregated uniformly to a daily time-step.

Appendix B Environmental entitlements in Source

The environmental entitlements and water shares included in the Source models available to HARC are summarised in Table 10.

Note that:

- Latrobe: representation of the Blue Rock environmental share and its use is only approximated. Environmental flow nodes are not set up in the Latrobe Source model. Instead, a repeating daily time series forcing 17 GL each year out of Blue Rock is configured to represent environmental demand (see Figure 53). Carryover of environmental entitlement is also not represented.
- Latrobe: Blue Rock outlet capacity could constrain delivery of Reach 8 freshes and at times winter low flows when the storage is drawn down under climate change.
- Thomson-Macalister: MID2030 mitigation water held by VEWH not represented in the model.
- Werribee: Melton outlet capacity constrains delivery of summer freshes to Reach 8.
- Wimmera-Glenelg: Delivery of freshes may be constrained by storage outlets. The impact of the assumed 60% : 40% split of the VEWH entitlement between Wimmera and Glenelg was tested using 50% : 50% and 40% : 60% options. This showed that the 60% : 40% versus other splits had no impact on the post-1975 scenario results, but did begin to change outcomes for the most severe case modelled (year 2065 with high climate change).

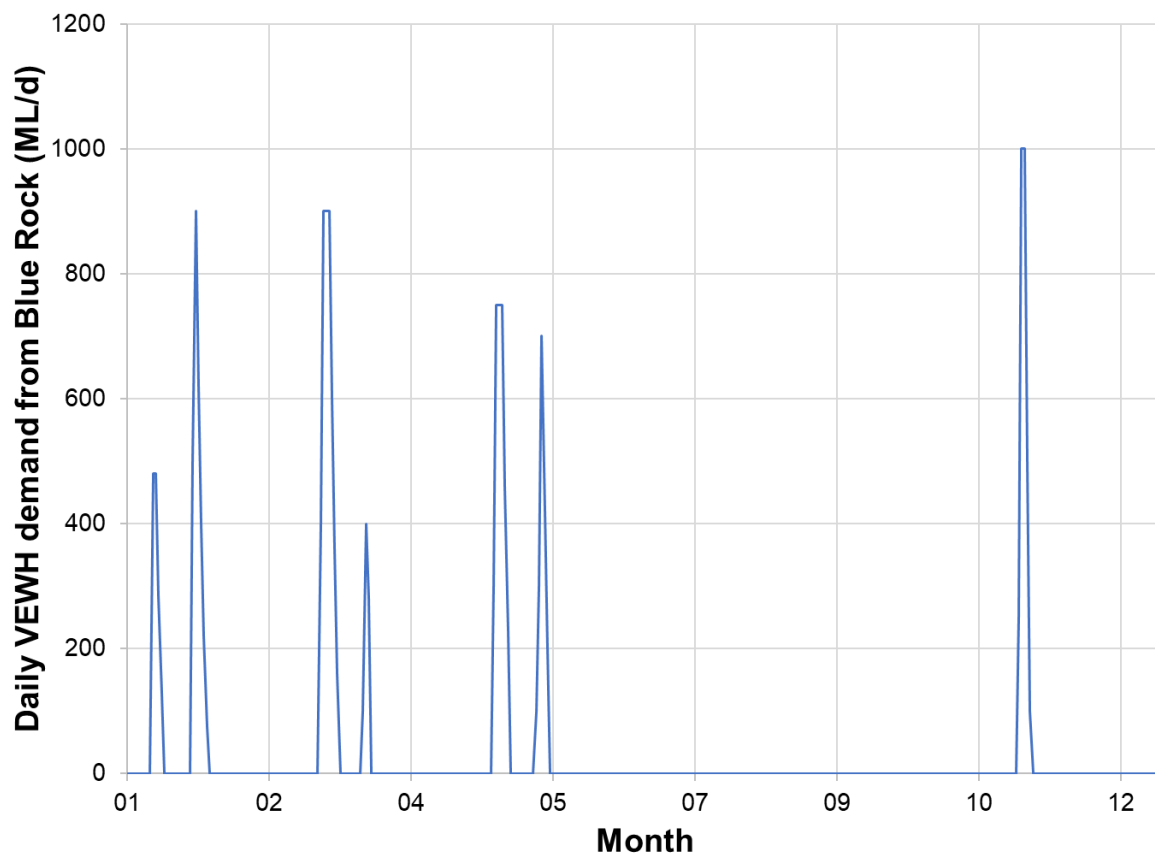


Figure 53: VEWH demand from Blue Rock (repeating series over the model run period)

For the Victorian Murray, Goulburn, Broken, Campaspe, and Loddon systems, HARC received modelling results from the MDBA (using the Source Murray Model) and DEECA (using the GBCCL Source model). These modelling results included allocations in percentages. To convert these results to volumes, HARC estimated environmental HRWS and LRWS using VEWH (2024)'s Annual Report and information on the CEWH website⁷:

- Victorian Murray: 439,441 ML HRWS, 145,981 ML LRWS
- Goulburn: 394,681 ML HRWS, 207,082 ML LRWS
- Broken: 624 ML HRWS, 23 ML LRWS
- Campaspe: 25,939 ML HRWS, 9,837 ML LRWS
- Loddon: 8,238 ML HRWS, 3,271 ML LRWS

Other types of environmental entitlements – e.g. the Barmah-Millewa Forest environmental entitlement in the Murray system – are represented in the Source models, but were not considered in the assessment of environmental entitlement reliability.

For the Tarago and Yarra systems, HARC received modelling results from Melbourne Water. In the Yarra system, the environment receives the first 17 GL of inflows from July 1st (and any carryover, subject to spills). In the Tarago system, the environment receives 10.3% of inflows to Tarago Dam (and any carryover, subject to spills).

⁷ <https://www.dcceew.gov.au/cewh/manage-water/basin/water-holdings>

Table 10: Representation of environmental entitlements, water shares and management in Source

System	Storage	Environments share of inflow	Environments share of storage	Carryover?	Water shares (HRWS/LRWS)	Representation in Environmental Flow Manager	Delivery constraints	Comments
Latrobe	Blue Rock	9.45%	9.45%	Not represented		Not represented	Outlet capacity 151-268 ML/d when storage is low would constrain delivery of Reach 8 freshes and at times winter low flows when storage is drawn down	Use of VEWH share of Blue Rock represented as a timeseries demand extracting 17 GL/yr (see Figure 53).
Thomson-Macalister	Lake Glenmaggie	0%	Entitled to unused share of storage to hold carryover until spill	Yes	12,460.9 ML HRWS 6,229.5 ML LRWS	Macalister EFNs linked under MacEE Portfolio	Maximum storage discharge of 1,200 ML/d	MID2030 mitigation water not represented 856.9 ML HRWS 377.9 ML LRWS
	Thomson Reservoir	first 10,000 ML of inflow then 3.9%	1.685% (18,000 ML) and airspace	Yes		Thomson EFNs linked under ThomsonEE portfolio	Maximum storage discharge of 900 ML/d	MID2030 mitigation water not represented 711.9 ML HRWS 313.9 ML LRWS

System	Storage	Environments share of inflow	Environments share of storage	Carryover?	Water shares (HRWS/LRWS)	Representation in Environmental Flow Manager	Delivery constraints	Comments
Werribee	Melton Reservoir	VEWH share of inflows into Melton is considered between May to August (inclusive) and when Melton Reservoir is above target, the lesser of 15ML/d and natural flow less passing flows	Airspace	Yes	734.1 ML HRWS held by VEWH 360.8 ML LRWS held by VEWH.	Linked to WerribeeEE, Merrimu, Lerderberg, 31BR Lower Werribee VEWH portfolios	Maximum storage discharge of 83.5 ML/d constrains delivery of summer freshes	Outlet capacity can only deliver low flows so unable to provide freshes to Reach 8
	Merrimu Reservoir	10%	Airspace	Yes			Maximum storage discharge of 1,728 ML/d	

System	Storage	Environments share of inflow	Environments share of storage	Carryover?	Water shares (HRWS/LRWS)	Representation in Environmental Flow Manager	Delivery constraints	Comments
Wimmera-Glenelg	Rocklands Reservoir	0%	0%	Yes	1,000 ML of wetland product available and 40,560 ML of Wimmera-Mallee Pipeline product to VEWH. 28,000 ML of LRWS held by CEWH. Split of water 40% to Glenelg CMA and 60% to Wimmera CMA	Portfolios for VEWH Glenelg, VEWH Wimmera, CEWH and Glenelg compensation setup	Rocklands max storage discharge 400 ML/d so unable to supply some freshes. 500 ML/d Dist Heads – Burnt Ck / Mackenzie R3 500 ML/d Wartook – Mackenzie R1&2 Lake Lonsdale 600 ML/d – Mt William Ck	Check 60% 40% split. Delivery of freshes constrained by storage outlets
	Lake Wartook	0%	0%	Yes				
	Lake Bellfield	0%	0%	Yes				
	Lake Fyans	0%	0%	Yes				
	Lake Lonsdale	0%	0%	Yes				
	Taylors Lake	0%	0%	Yes				
	Toolondo Reservoir	0%	0%	Yes				
Barwon-Moorabool	Lal Lal Reservoir	11.9%	11.9%	Yes		Portfolios for West Barwon VEWH and Lal Lal VEWH		7,500 ML/3 years limit on e-water delivered
	West Barwon Reservoir	3.8%	9.1%	Yes				

Appendix C Environmental flow targets

This section summarises the environmental flow targets used in the eFlow Projector assessment (Section 4.2). For some systems, targets differ according to seasonal conditions. Where this was the case, seasonal conditions were based on the post-1975 scenario.

For the systems where HARC did the Source modelling, these environmental flow targets matched the flow components defined in the Source environmental demand nodes. The one exception was the Latrobe Source model (see Appendix B).

For the systems where HARC did the Source modelling, Table 11 shows:

- Whether the environmental flow targets were 'ordered' in Source – i.e. the Source model attempts to meet the demand using environmental water in storage.
- Whether the environmental flow target and corresponding demand in Source has an 'or natural' clause. In these cases, 'or natural' was defined using Source modelling results for post-1975 conditions. The 'or natural' clause is not considered when calculating in eFlow Projector how often an environmental flow target is met.

The environmental flow targets assessed in eFlow Projector for the Goulburn, Broken, Campaspe, Loddon, Victorian Murray, Yarra, Tarago and Latrobe systems are shown in Table 12.

For these systems, either:

- The Source model does not include environmental demand nodes (Latrobe)
- The Source modelling was done by other agencies:
 - Goulburn, Broken, Campaspe, Loddon: DEECA, using the GBCCL Source model
 - Murray: MDBA, using the Source Murray model
 - Yarra, Tarago: Melbourne Water, using the Melbourne Water Source headworks model

Note that for the Yarra and Tarago systems, some environmental flow targets vary by climate conditions (i.e., drought, dry, average or wet). But how the climate condition is defined differs according to the flow target and time of year. eFlow Projector does not currently have the functionality to track success using climate condition definitions that vary in this manner, and therefore all seasons were treated as 'average' in the eFlow Projector assessments for the Yarra and Tarago systems.

Table 11: Environmental flow targets for systems where HARC was responsible for the Source modelling (excluding the Latrobe system). Targets shown in red were not ordered in the Source model, while targets shown in black were.

Catchment	Site	Name	Season	When	Magnitude	Duration	# of Events	Ordered (Y/N)	Or natural (Y/N)
Macalister	Riverslea (R2)	Summer/autumn low flow	Drought/Dry/Average/Wet	Dec - May	90			Y	Y
		Winter/spring low flow	Drought/Dry/Average/Wet	Jun - Nov	90			Y	Y
		Summer fresh FR1	Drought/Dry/Average/Wet	Dec - Mar	140	3	3	Y	N
		Autumn fresh FR2	Drought/Dry/Average/Wet	Apr - May	350	5	1	Y	N
		Winter fresh FR3	Drought/Dry/Average/Wet	May - Aug	700	5	1	Y	N
		Spring fresh FR4-5	Drought/Dry/Average/Wet	Sep - Nov	700	5	1	Y	N
		Spring fresh FR6	Drought/Dry/Average/Wet	Sep - Dec	1500	3/5/15/25	2	N	N
		High fresh FR7	Drought/Dry/Average/Wet	Jan - Dec	1500	1	1	N	N
		Bankfull	Drought/Dry/Average/Wet	Jan - Dec	10000	1	1	N	N
Thomson	Cooper Ck (R3)	Spring/summer/autumn low flow	Only one set of recs	Aug - Apr	125			Y	N
		Winter low flow	Only one set of recs	May - Jul	350			Y	N
		Summer fresh (low 1)	Only one set of recs	Dec - Mar	350	7	1	Y	N
		Summer fresh (low 2)	Only one set of recs	Feb - Mar	230	7	1	Y	N
		Apr fresh (low 3)	Only one set of recs	Apr	800	6	1	Y	N
		Spring fresh (high 3)	Only one set of recs	Sep - Nov	800	6	1	Y	N
		May fresh (high 1)	Only one set of recs	May	800	11	1	N	N
		Sep fresh (high 2)	Only one set of recs	Sep	800	11	1	N	N
		Bankfull	Only one set of recs	Jan - Dec	3000	1	1	N	N
	Bundalaguah (R6)	Summer/autumn low flow	Only one set of recs	Dec - Apr	125			N	N
		Winter/spring low flow	Only one set of recs	May - Nov	350			N	N
		Summer fresh (low 1)	Only one set of recs	Dec - Jan	350	13	1	N	N
		Summer fresh (low 2)	Only one set of recs	Feb - Mar	230	11	1	N	N
		Apr fresh (low 3)	Only one set of recs	Apr	800	18	1	N	N
		May fresh (high 1)	Only one set of recs	May	800	12	1	N	N
		Sep fresh (high 2)	Only one set of recs	Sep	800	12	1	N	N

Catchment	Site	Name	Season	When	Magnitude	Duration	# of Events	Ordered (Y/N)	Or natural (Y/N)
Glenelg		Spring fresh (high 3)	Only one set of recs	Oct - Nov	800	12	1	N	N
		Bankfull 1	Only one set of recs	Oct - Nov	9500	2	1	N	N
		Bankfull 2	Only one set of recs	Oct - Nov	18000	2	1	N	N
	Weavers (R1a)	Summer/autumn low flow	Only one set of recs	Nov - Apr	10			Y	Y
		Winter/spring low flow	Only one set of recs	May - Oct	10			Y	Y
		Summer/autumn freshes	Only one set of recs	Nov - Apr	60	3	2	N	N
		Winter/spring fresh	Only one set of recs	May - Oct	60	5	3	N	N
		Bankfull	Only one set of recs	Jul - Jun	1400	3	1	N	N
		Overbank	Only one set of recs	Jul - Oct	4000	2	1	N	N
	Harrow (R1b)	Summer/autumn low flow	Only one set of recs	Nov - Apr	15			Y	Y
		Winter/spring low flow	Only one set of recs	May - Oct	100			N	Y
		Summer/autumn freshes	Only one set of recs	Nov - Apr	100	3	1	N	N
		Winter/spring low fresh	Only one set of recs	May - Oct	250	5	3	N	N
		Winter/spring high fresh	Only one set of recs	May - Oct	550	2	1	N	N
		Bankfull	Only one set of recs	Jul - Jun	1000	3	1	N	N
		Overbank	Only one set of recs	Jul - Oct	6000	2	1	N	N
	Dergholm (R2)	Summer/autumn low flow	Only one set of recs	Nov - Apr	25			Y	Y
		Summer/autumn fresh	Only one set of recs	Nov - Apr	150 ⁸	2 ³	2	Y	N
		Winter/spring low flow	Only one set of recs	May - Oct	160			N	N
		Winter/spring low fresh	Only one set of recs	May - Oct	300	5	3	N	Y
		Winter/spring high fresh	Only one set of recs	May - Oct	1800	2	1	N	N
		Bankfull	Only one set of recs	Jul - Jun	6000	1	1	N	N
		Overbank	Only one set of recs	Jul - Oct	9000	5	1	N	N
	Dartmoor (R3)	Jan - Apr low flow	Only one set of recs	Jan - Apr	80			N	Y
		May - Jun low flow	Only one set of recs	May - Jun	260			N	Y

⁸ Configured as 200 ML/d for 4 days in Source due to routing issues (aimed to achieve 150 ML/d for 2 days).

Catchment	Site	Name	Season	When	Magnitude	Duration	# of Events	Ordered (Y/N)	Or natural (Y/N)
Wimmera		Jul - Dec low flow	Only one set of recs	Jul - Dec	400			N	Y
		Summer/autumn fresh	Only one set of recs	Jan - Apr	150	3	2	N	N
		Winter/spring low fresh	Only one set of recs	Jul - Dec	1500	2	3	N	N
		Winter/spring high fresh	Only one set of recs	Jul - Dec	6000	1	2	N	N
		Bankfull	Only one set of recs	May - Oct	24000	1	1	N	N
	Burnt Ck (Upper)	Summer/autumn low flow	Only Dry recs	Dec - May	1			Y	Y
		Winter/spring low flow	Only Dry recs	Jun - Nov	1			Y	Y
		Summer/autumn freshes	Only Dry recs	Dec - May	30	4	3	N	N
		Winter/spring freshes	Only Dry recs	Jun - Nov	55	3	3	N	N
		Winter/spring high fresh	Only Dry recs	Jun - Nov	160	1	1	N	N
	McKenzie Rv (R3)	Summer/autumn low flow	Only Dry recs	Dec - May	5			Y	Y
		Winter/spring low flow	Only Dry recs	Jun - Nov	10			Y	Y
		Summer/autumn freshes	Only Dry recs	Dec - May	35	3	3	N	N
		Winter/spring freshes	Only Dry recs	Jun - Nov	35	4	4	N	N
		Nov fresh	Only Dry recs	Nov	35	4	1	N	N
	Mt William Ck (Lower)	Summer/autumn low flow	Only Dry recs	Dec - May	5			Y	Y
		Winter/spring low flow	Only Dry recs	Jun - Nov	5			Y	Y
		Summer/autumn freshes	Only Dry recs	Dec - May	20	3	3	Y	N
		Winter/spring freshes	Only Dry recs	Jun - Nov	100	3	3	Y	N
		Winter/spring high fresh	Only Dry recs	Jun - Nov	500	1	1	N	N
	Lochiel (R4)	Summer/autumn low flow	Only Dry recs	Dec - May	15			Y	N
		Winter/spring low flow	Only Dry recs	Jun - Nov	30			Y	N
		Summer/autumn freshes	Only Dry recs	Dec - May	70	2	2	Y	N
		Winter/spring low freshes	Only Dry recs	Jun - Nov	70	2	3	Y	N
		Winter/spring high fresh	Only Dry recs	Jun - Nov	200	1	1	Y	N
Werribee	Pyrites Ck (R6)	Summer/autumn low flow	Only one set of recs	Dec - May	2			Y	Y
		Winter/spring low flow	Only one set of recs	Jun - Nov	2			Y	Y

Catchment	Site	Name	Season	When	Magnitude	Duration	# of Events	Ordered (Y/N)	Or natural (Y/N)
		Jun fresh	Only one set of recs	Jun	40	2	1	Y	N
		Sep - Nov freshes	Only one set of recs	Sep - Nov	40	2	3	Y	N
		Spring high flow	Only one set of recs	Sep - Oct	70	1	1	Y	N
		High flow 1	Only one set of recs	Jul - Jun	70	1	1	N	N
		High flow 2	Only one set of recs	Jul - Jun	130	2	1	N	N
	Werribee Div Weir (R9)	Summer/autumn low flow	Only one set of recs	Dec - May	6			Y	N
		Winter/spring low flow	Only one set of recs	Jun - Nov	81			Y	N
		Summer/autumn freshes	Only one set of recs	Dec - May	137	2	3	Y	N
		Apr - May freshes	Only one set of recs	Apr - May	215	2	2	Y	N
		Jun - Aug freshes	Only one set of recs	Jun - Aug	350	3	2	Y	N
		Sep - Oct freshes	Only one set of recs	Sep - Oct	350	3	2	Y	N
		Bankfull	Only one set of recs	Jun - Nov	3000	2	1	N	N
Moorabool	Morrisons (R3b)	Summer/autumn low flow	Only Dry recs	Dec - May	10			N	N
		Winter/spring low flow	Only Dry recs	Jun - Nov	10			N	N
		Autumn fresh 1	Only Dry recs	Apr - May	60	5	1	N	N
		Autumn fresh 2	Only Dry recs	Apr - May	30	3	1	N	N
		Winter fresh (1)	Only Dry recs	May - Aug	80	5	1	N	N
		Spring fresh (2)	Only Dry recs	Sep - Nov	80	5	1	N	N
	Batesford (R4)	Summer/autumn low flow	Only Dry recs	Dec - May	10			N	N
		Winter/spring low flow	Only Dry recs	Jun - Nov	10			N	N
		Autumn fresh (1)	Only Dry recs	Apr - May	60	5	1	N	N
		Summer/autumn fresh (2)	Only Dry recs	Dec - May	20	2	1	N	N
		Winter fresh (1)	Only Dry recs	May - Aug	80	5	1	N	N
		Spring fresh (2)	Only Dry recs	Sep - Nov	80	5	1	N	N
Barwon	West Barwon (R3)	Summer/autumn low flow	Only Dry recs	Dec - May	8			Y	Y
		Winter/spring low flow	Only Dry recs	Jun - Nov	8			Y	Y
		Summer/autumn fresh	Only Dry recs	Dec - May	100	6	5	N	N

Catchment	Site	Name	Season	When	Magnitude	Duration	# of Events	Ordered (Y/N)	Or natural (Y/N)
		Winter/spring fresh	Only Dry recs	Jun - Nov	330	5	6	N	N
	East Barwon (R4)	Summer/autumn low flow	Only Dry recs	Dec - May	1 ⁹			Y	Y
		Winter/spring low flow	Only Dry recs	Jun - Nov	1			Y	Y
		Summer/autumn freshes	Only Dry recs	Dec - May	6	2	2	Y	N

Table 12: Environmental flow targets for the Yarra, Tarago, GBCCL, Murray, and Latrobe systems.

Catchment	Site	Name	Season	When	Magnitude	Duration	# of Events
Yarra	Millgrove (R2)	Summer/autumn low flow	Dry/Average/Wet	Dec - May	80		
		Winter/spring low flow	Dry/Average/Wet	Jun - Nov	80		
		Summer/autumn freshes	Dry/Average/Wet	Dec - May	350	2	3
		Autumn high flow	Dry/Average/Wet	Apr - May	560	7	1
		Winter/spring freshes	Dry/Average/Wet	Jun - Sep	700	3	2
		Spring high flow	Average/Wet	Sep - Oct	700	14	1
	Warrandyte (R5)	Summer/autumn low flow	Dry/Average/Wet	Dec - May	200		
		Winter/spring low flow	Dry/Average/Wet	Jun - Nov	350		
		Summer/autumn freshes	Dry/Average/Wet	Dec - May	750	2	3
		Autumn high flow	Dry/Average	Apr - May	1300	7	1
		Winter/spring freshes	Dry/Average/Wet	Jun - Sep	1300	3	2
		Spring high flow	Average/Wet	Sep - Oct	2500	14	1
Tarago	Drouin West (R2)	Summer/autumn low flow	Drought/Dry/Average/Wet	Dec - May	20		
		Winter/spring low flow	Drought/Dry/Average/Wet	Jun - Nov	75		
		Summer/autumn freshes	Drought/Dry/Average/Wet	Dec - May	75	2	5/3/5/5
		Autumn high flow	Drought/Dry/Average/Wet	Apr - May	100	2	1
		Winter/spring freshes	Drought/Dry/Average/Wet	Jun - Sep	100	2	1/1/2/2
		Spring high flow	Dry/Average/Wet	Sep - Oct	200	2	1

⁹ 0.5 ML/d but eFlow Projector did not allow decimals, so rounded to 1 ML/d

Catchment	Site	Name	Season	When	Magnitude	Duration	# of Events
Loddon	Loddon Weir (R4)	Summer/autumn low flow	Drought/Dry/Average/Wet	Dec - May	50		
		Winter/spring low flow	Drought/Dry/Average/Wet	Jun - Nov	50/77/77/77		
		Summer/autumn freshes	Drought/Dry/Average/Wet	Dec - May	100	3	3
		Autumn high flow	Drought/Dry/Average/Wet	Mar - May	400	6	1
		Winter/spring high flow	Drought/Dry/Average/Wet	Aug - Nov	400	10	1
	Appin South (R4)	Summer/autumn low flow	Drought/Dry/Average/Wet	Dec - May	50		
		Winter/spring low flow	Drought/Dry/Average/Wet	Jun - Nov	50/77/77/77		
		Summer/autumn freshes	Drought/Dry/Average/Wet	Dec - May	100	3	3
		Autumn high flow	Drought/Dry/Average/Wet	Mar - May	400	6	1
		Winter/spring high flow	Drought/Dry/Average/Wet	Aug - Nov	400	10	1
	Serpentine Weir (R3b)	Summer/autumn low flow	Drought/Dry/Average/Wet	Dec - May	5/5/10/10		
		Winter/spring low flow	Drought/Dry/Average/Wet	Jun - Nov	30/30/40/40		
		Summer fresh	Drought/Dry/Average/Wet	Dec - Feb	30/30/50/50	1	1
		Autumn fresh	Drought/Dry/Average/Wet	Mar - May	30/30/50/50	2	2
		Winter fresh	Average/Wet	Jul - Aug	450	1	1
		Spring fresh	Average/Wet	Sep - Oct	450	14	1
Vic Murray	Yarrawonga	Winter/spring/summer low flow	Dry/Average/Wet	Aug - Dec	8500		
		Autumn/Winter Low Flow in the Murray River	Drought/Dry	May - Jun	4000		
		Spring wetting of floodplain marshes	Drought/Dry/Average/Wet	Sep - Dec	9500	90 ¹⁰	
		Spring wetting of floodplain marshes (full)	Average/wet	Sep - Dec	15000	90	
	Torrumbarry	Nesting support	Average/wet	Oct - Nov	4500	21	
		Bankfull 1	Average/Wet	Aug - Nov	16000	45	
		Bankfull 2	Average/Wet	Aug - Nov	22000	30	
Broken	Gowangardie (R3)	Summer/autumn low flow	Drought/Dry/Average/Wet	Dec - May	15/15/30/30		
		Winter/spring low flow	Drought/Dry/Average/Wet	Jun - Nov	15/15/30/30		

¹⁰ Defined as a low flow, with a magnitude of 9,500 ML/d for 90 days

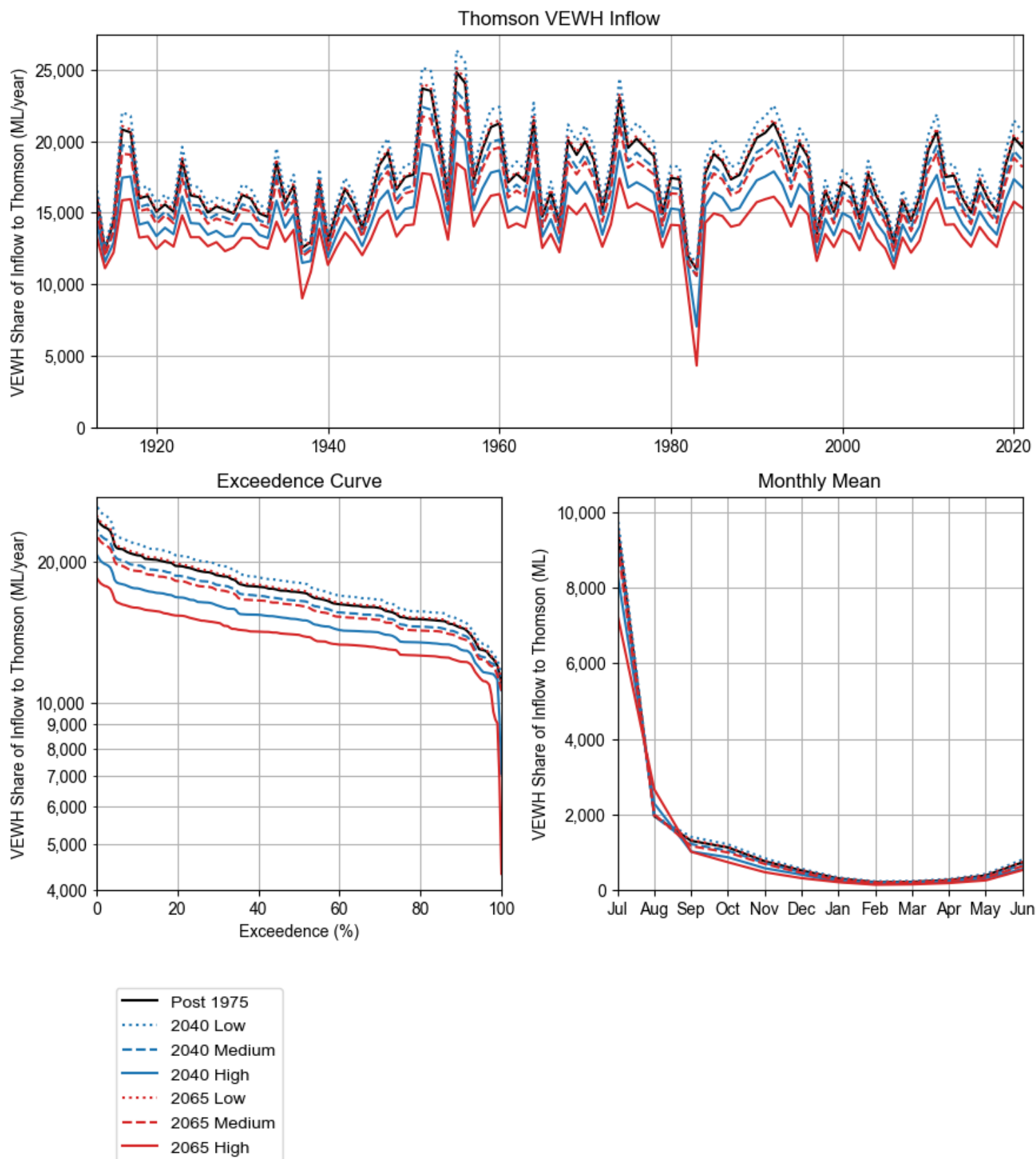
Catchment	Site	Name	Season	When	Magnitude	Duration	# of Events
		Summer/autumn fresh	Average/Wet	Dec - May	400	2	1
Campaspe	Barnadown (R2)	Summer/autumn low flow	Drought/Dry/Average/Wet	Dec - May	40		
		Winter/spring low flow	Drought/Dry/Average/Wet	Jun - Nov	40/70/100/100		
		Summer/autumn freshes	Drought/Dry/Average/Wet	Dec - May	100/150/200/200	2	3
		Winter/spring freshes	Drought/Dry/Average/Wet	Jun - Nov	1000/1200/1400/1400	2	1
	Rochester (R4)	Summer/autumn low flow	Drought/Dry/Average/Wet	Dec - May	40		
		Winter/spring low flow	Drought/Dry/Average/Wet	Jun - Nov	40/70/100/100		
		Summer/autumn freshes	Drought/Dry/Average/Wet	Dec - May	100/150/200/200	2	3
		Winter/spring fresh(es)	Drought/Dry/Average/Wet	Jun - Nov	1000/1200/1400/1400	2	1
Goulburn	Seymour (R3)	Summer/autumn low flow	Drought/Dry/Average/Wet	Dec - May	400		
		Winter/spring low flow	Drought/Dry/Average/Wet	Jun - Nov	400		
		Winter fresh	Drought/Dry/Average/Wet	Jul - Aug	8000	5	1
		Winter/spring freshes	Drought/Dry/Average/Wet	May - Nov	5000	5	1
		Spring fresh	Drought/Dry/Average/Wet	Sep - Nov	8000	5	1
	Murchison (R4)	Summer/autumn low flow	Drought/Dry/Average/Wet	Dec - May	600		
		Winter/spring low flow	Drought/Dry/Average/Wet	Jun - Nov	600		
		Autumn fresh	Drought/Dry/Average/Wet	Mar - May	5700	2	1
		Winter/autumn fresh	Drought/Dry/Average/Wet	May - Aug	7300	4	1
		Early-spring fresh	Drought/Dry/Average/Wet	Sep - Oct	7300	7	1
		Late spring fresh	Drought/Dry/Average/Wet	Oct - Dec	6000	2	1
	McCoys (R5)	Summer/autumn low flow	Drought/Dry/Average/Wet	Dec - May	600		
		Winter/spring low flow	Drought/Dry/Average/Wet	Jun - Nov	600		
		Autumn fresh	Drought/Dry/Average/Wet	Mar - May	5700	2	1
		Winter/autumn fresh	Drought/Dry/Average/Wet	May - Aug	7300	4	1
		Early-spring fresh	Drought/Dry/Average/Wet	Sep - Oct	7300	7	1
		Late-spring fresh	Drought/Dry/Average/Wet	Oct - Dec	6000	2	1
Latrobe	Kilmany South (R5)	Summer/autumn low flow	Drought/Dry/Average/Wet	Dec - May	440		



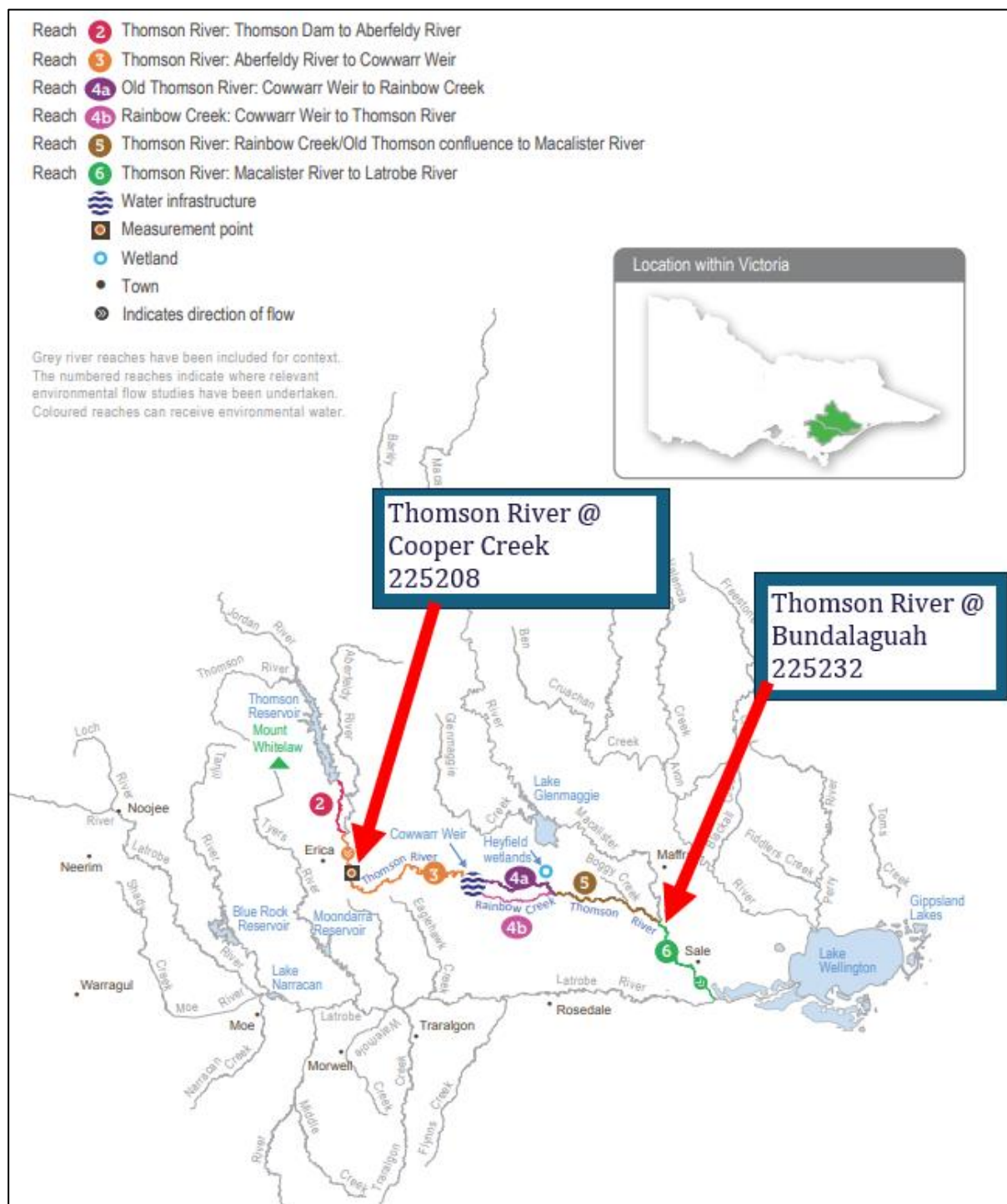
Catchment	Site	Name	Season	When	Magnitude	Duration	# of Events
		Winter/spring low flow	Drought/Dry/Average/Wet	Jun - Nov	620		
		Summer/autumn river freshes	Drought/Dry/Average/Wet	Nov - May	980	1	5/7/9/9

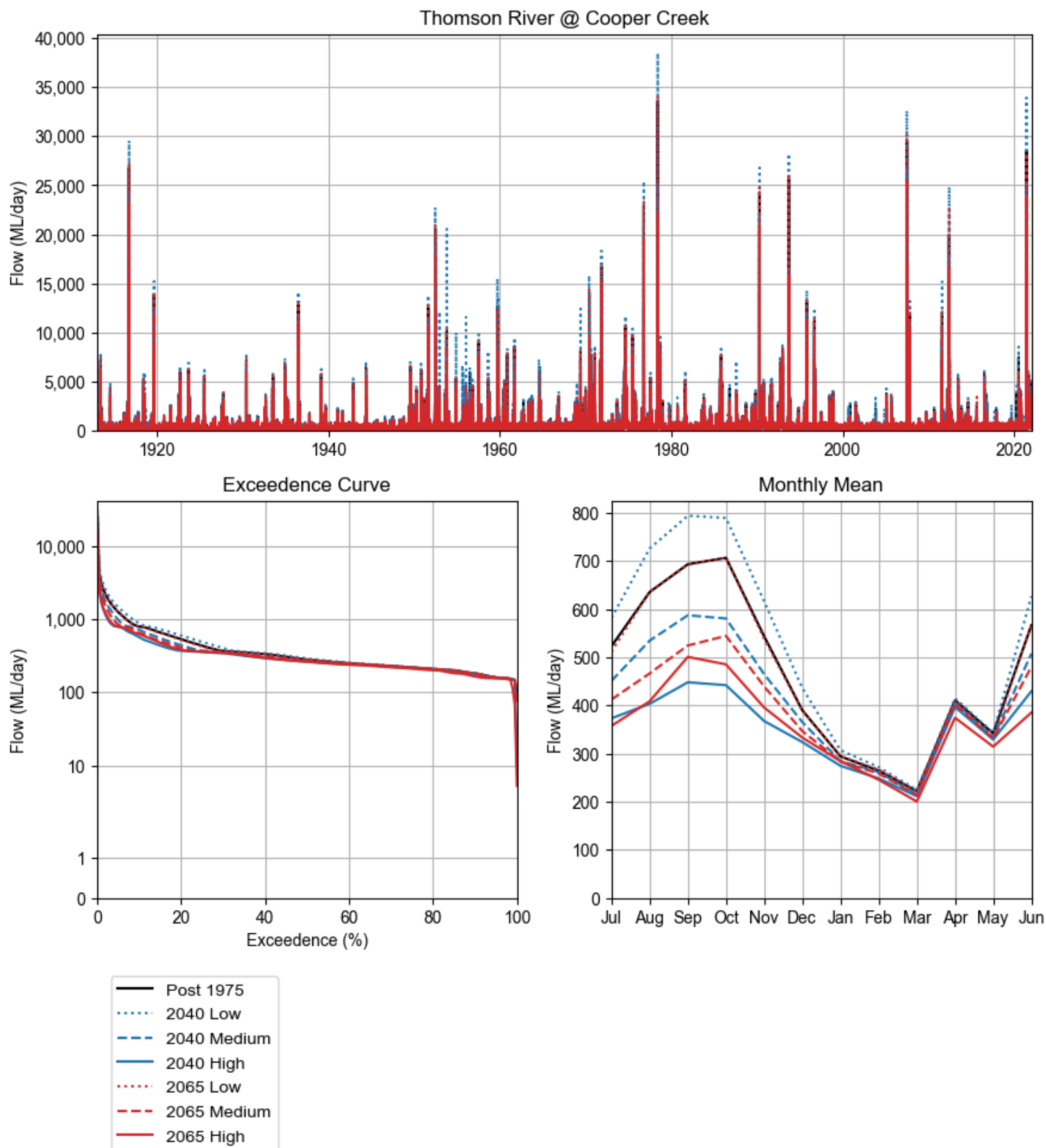
Appendix D Thomson model results

D.1 Environmental entitlement allocations

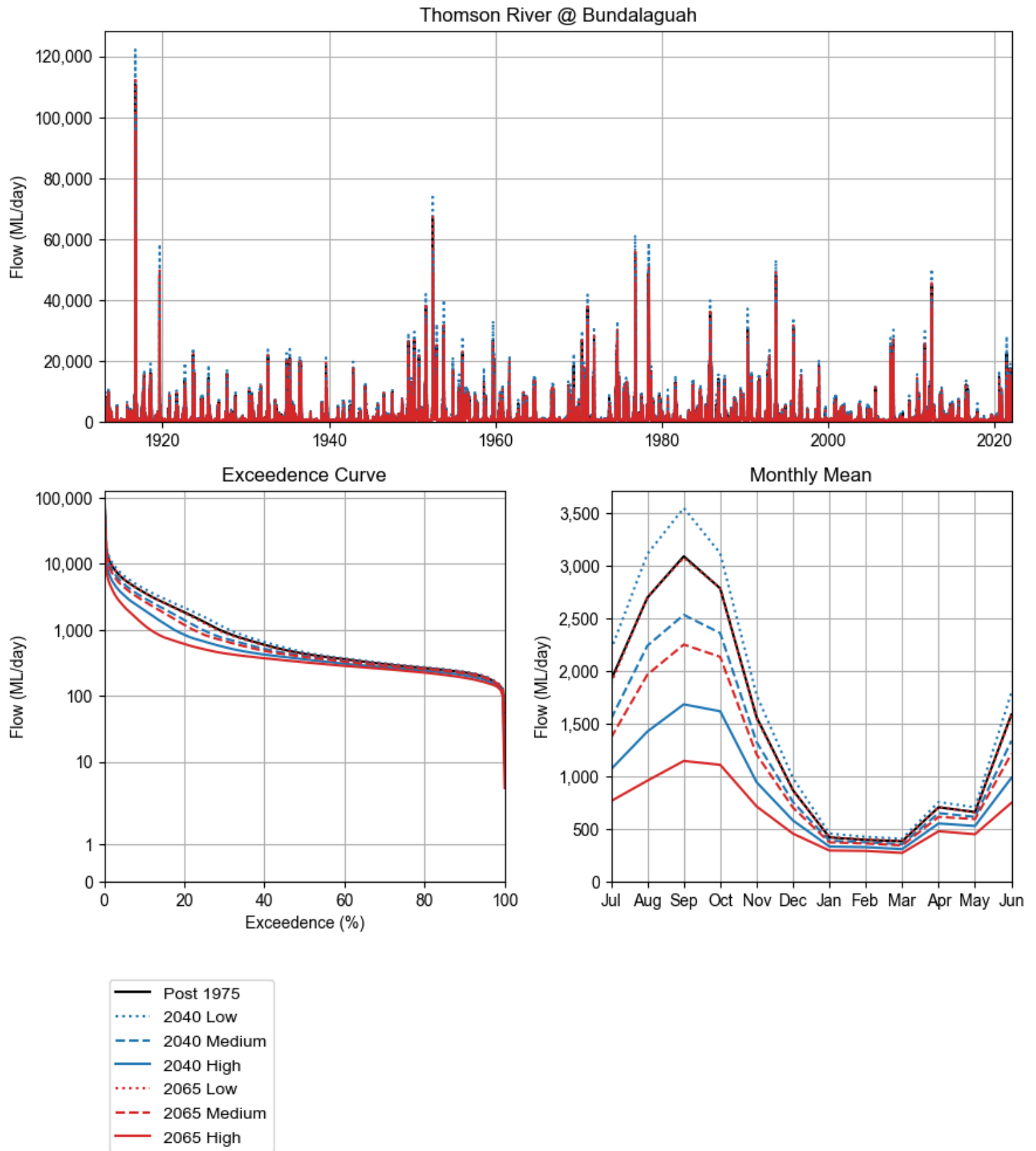


D.2 Streamflow





Note: In the 2065 High climate change scenario, modelled transfers from Thomson Reservoir to Upper Yarra Reservoir are smaller compared with the 2040 High climate change scenario, and therefore flows down the Thomson River are higher. The higher average flows in April compared with March and May in all scenarios are because of the April fresh deliveries.



D.3 Hydrologic indicators

Table 13: Hydrological indicators for the Thomson River @ Cooper Ck

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	466	511	416	354	464	392	357
MA13 (ML/d)	265	272	262	249	268	259	246
MA19 (ML/d)	636	726	535	403	636	467	409
MH26	17	18	18	17	18	17	15
DL16 (days)	6.7	7.0	6.8	6.9	6.8	6.7	7.7
DL18 (days)	0	0	0	0	0	0	0
Avg0Dur (days)	0	0	0	0	0	0	0
Max0Dur (days)	0	0	0	0	0	0	0

Table 14: Hydrological indicators for the Thomson River @ Bundalagwah

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	1,424	1,609	1,207	862	1,419	1,095	639
MA13 (ML/d)	395	425	372	326	400	362	290
MA19 (ML/d)	2,699	3,114	2,241	1,425	2,703	1,966	957
MH26	21	22	20	18	21	19	17
DL16 (days)	10	10	10	13	10	11	14
DL18 (days)	0	0	0	0	0	0	0
Avg0Dur (days)	0	0	0	0	0	0	0
Max0Dur (days)	0	0	0	0	0	0	0

D.4 eFlow Projector results

Table 15: Average success (%) – flow targets for the Thomson River @ Cooper Ck. Targets shown in red were not ordered in the Source model.

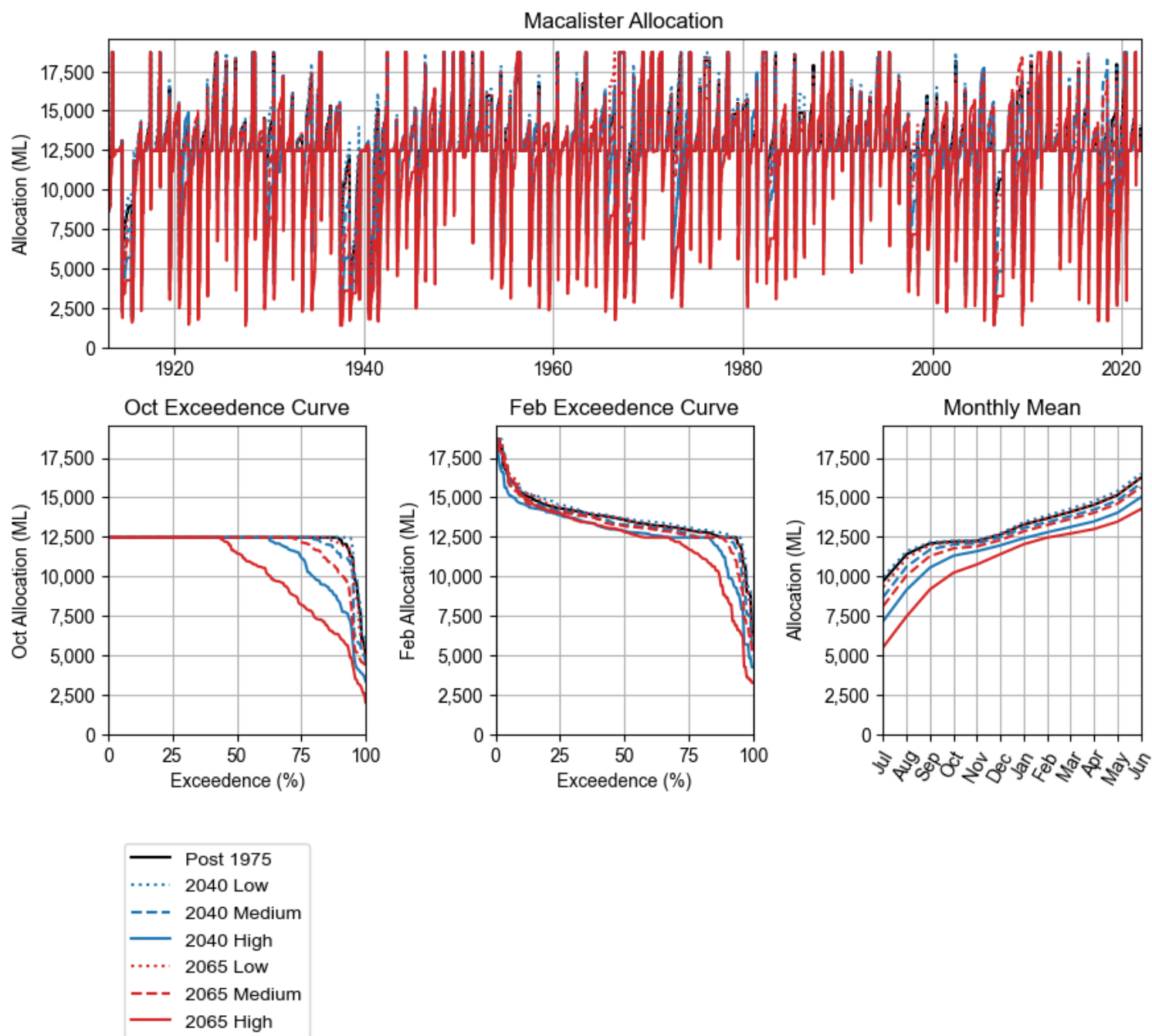
Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Spring to autumn low flow	100	100	100	100	100	100	99
Winter low flow	73	72	73	70	72	72	66
Summer fresh (low 1)	90	92	88	86	89	87	87
Summer fresh (low 2)	97	97	96	95	96	96	90
Apr fresh (low 3)	92	91	93	93	92	92	86
Spring fresh (high 3)	84	85	76	65	84	73	61
May fresh (high 1)	13	13	12	11	12	11	10
Sep fresh (high 2)	47	54	38	28	46	34	31
Bankfull	72	76	63	54	70	60	51

Table 16: Average success (%) – flow targets for the Thomson River @ Bundalaguah. Targets shown in red were not ordered in the Source model.

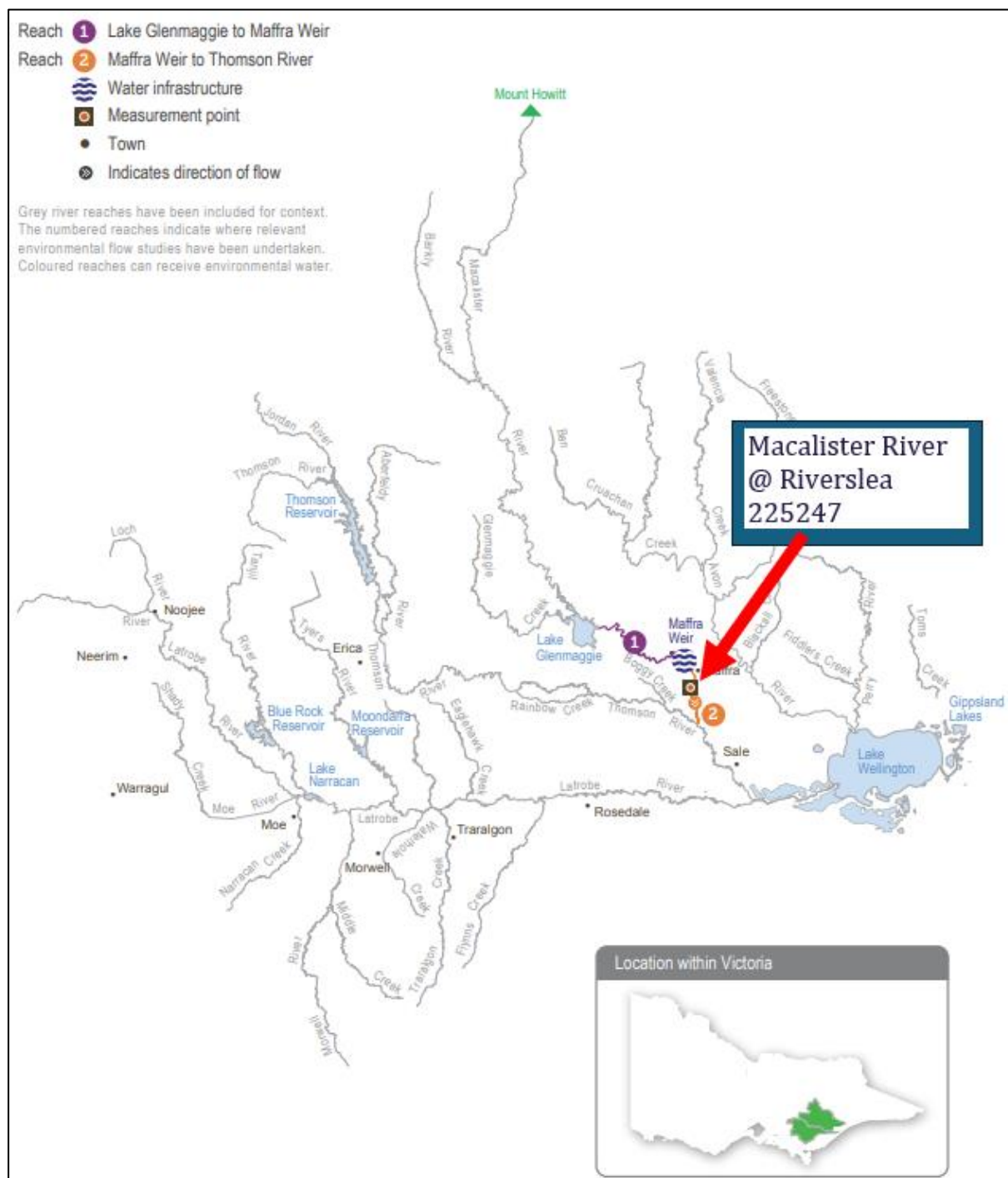
Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	100	100	100	99	100	100	99
Winter/spring low flow	95	96	94	91	95	93	86
Summer fresh (low 1)	82	84	80	74	83	78	69
Summer fresh (low 2)	94	96	95	92	95	95	89
Apr fresh (low 3)	46	47	44	41	46	43	35
May fresh (high 1)	42	45	39	32	42	38	26
Sep fresh (high 2)	90	92	83	73	89	80	57
Spring fresh (high 3)	86	88	83	73	85	81	62
Bankfull 1	43	48	37	26	43	34	18
Bankfull 2	20	24	16	10	21	14	5.8

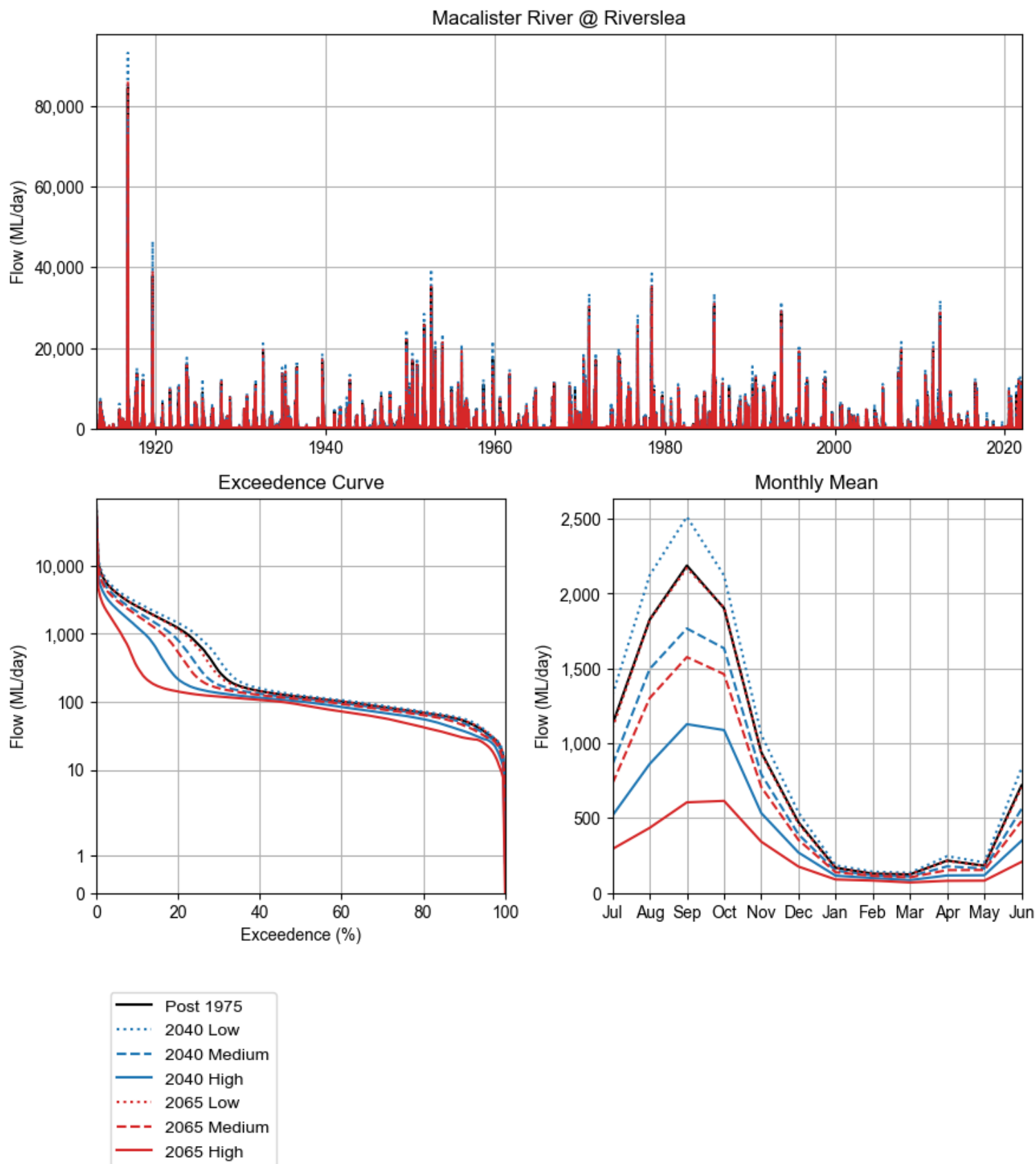
Appendix E Macalister model results

E.1 Environmental entitlement allocations



E.2 Streamflow





E.3 Hydrologic indicators

Table 17: Hydrological indicators for the Macalister River @ Riverslea

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	834	953	686	441	828	607	257
MA13 (ML/d)	129	142	118	100	129	115	83
MA19 (ML/d)	1,827	2,123	1,497	862	1,824	1,303	435
MH26	42	46	39	31	43	36	26
DL16 (days)	6.4	5.9	6.3	8.3	6.3	6.5	10
DL18 (days)	0	0	0	0	0	0	0.1
Avg0Dur (days)	0	0	0	0	0	0	5.3
Max0Dur (days)	0	0	0	0	0	0	14.0

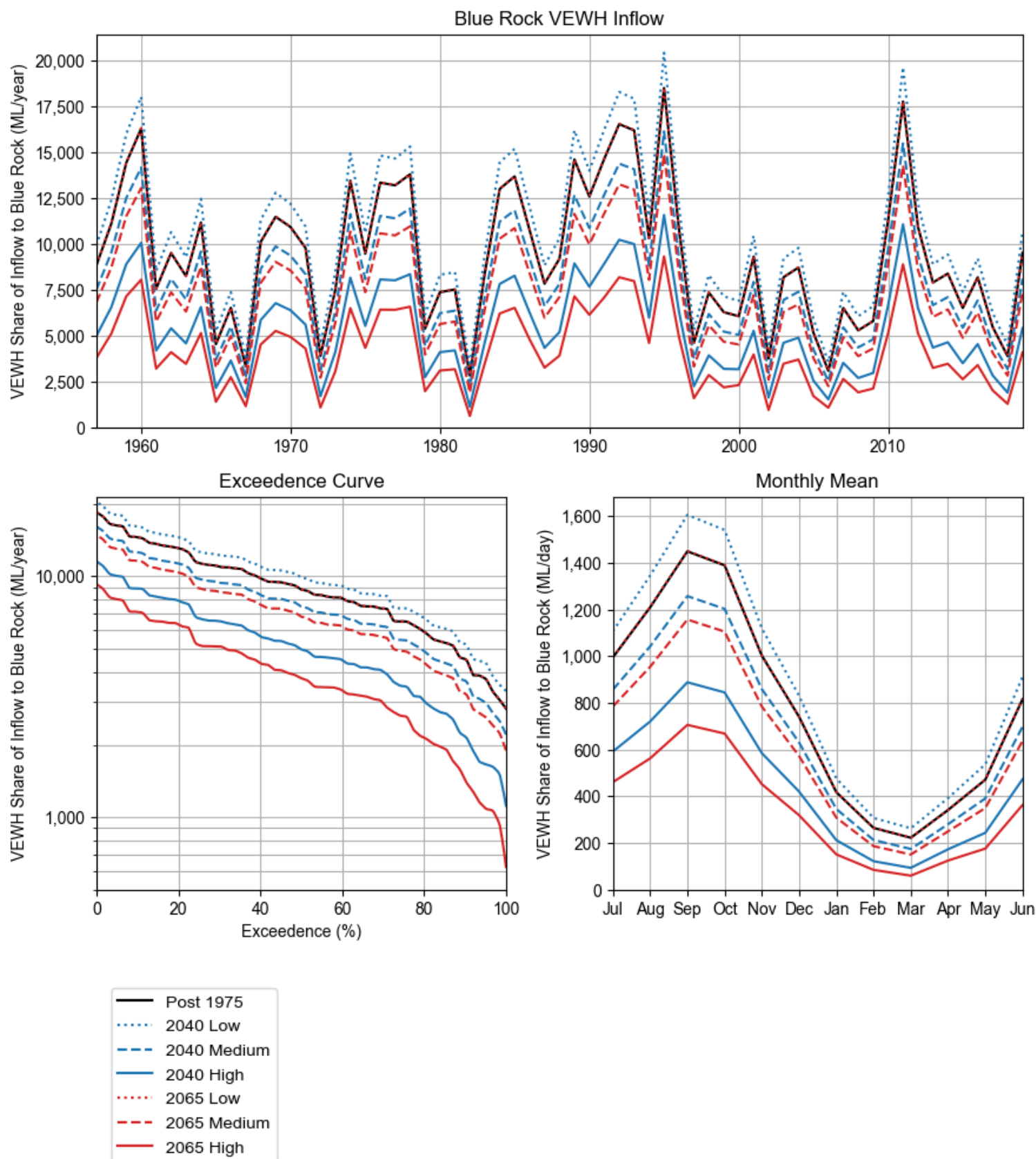
E.4 eFlow Projector results

Table 18: Average success (%) – flow targets for the Macalister River @ Riverslea. Targets shown in red were not ordered in the Source model.

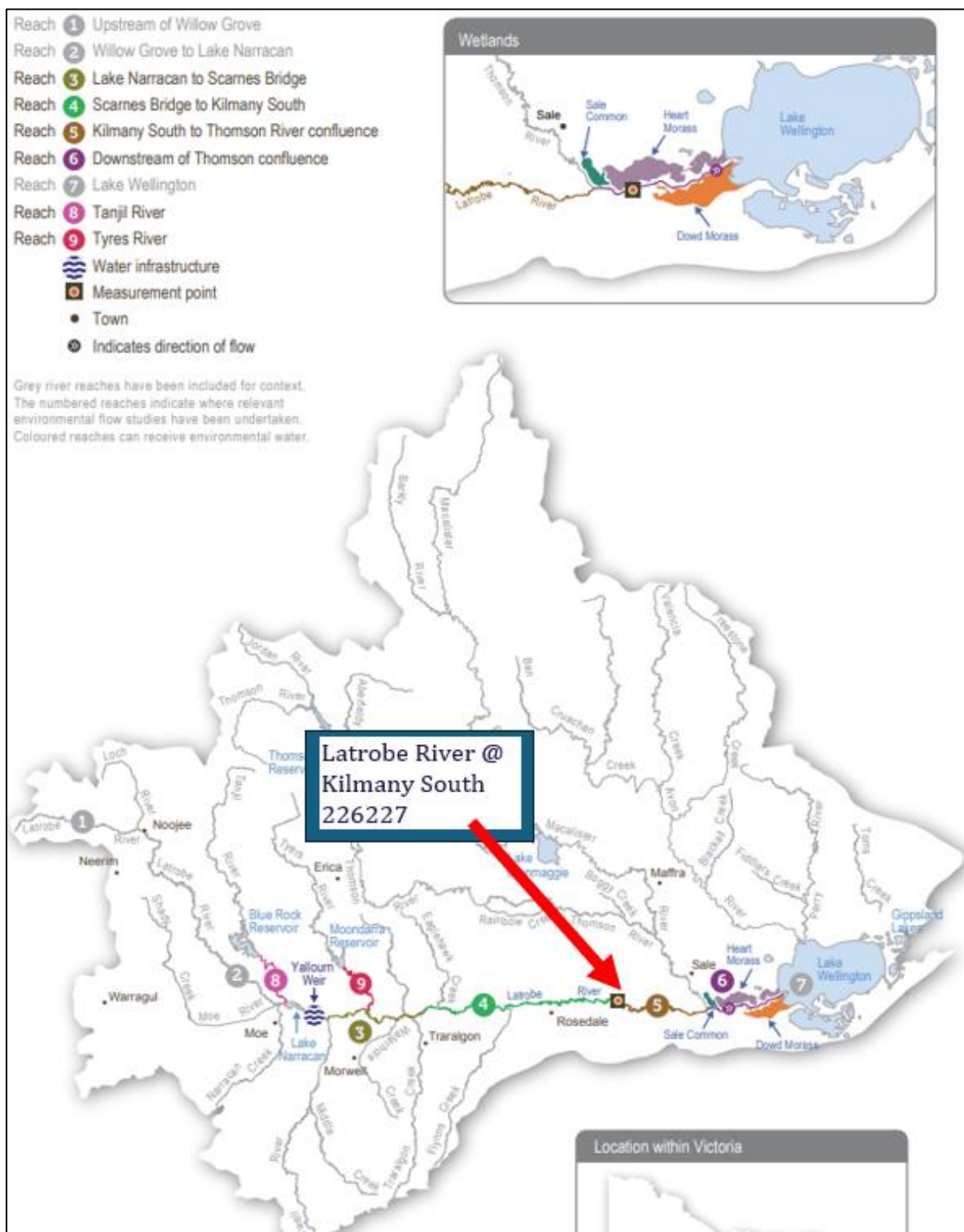
Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	72	75	69	60	73	68	51
Winter/spring low flow	95	95	94	90	95	93	85
Summer fresh FR1	78	82	76	67	79	75	66
Autumn fresh FR2	39	42	36	30	38	35	23
Winter fresh FR3	71	74	66	50	69	63	37
Spring fresh FR4-5	89	91	87	74	88	86	54
Spring fresh FR6	62	64	56	42	61	53	23
High fresh FR7	88	90	86	73	88	84	60
Bankfull	53	57	46	30	52	42	15

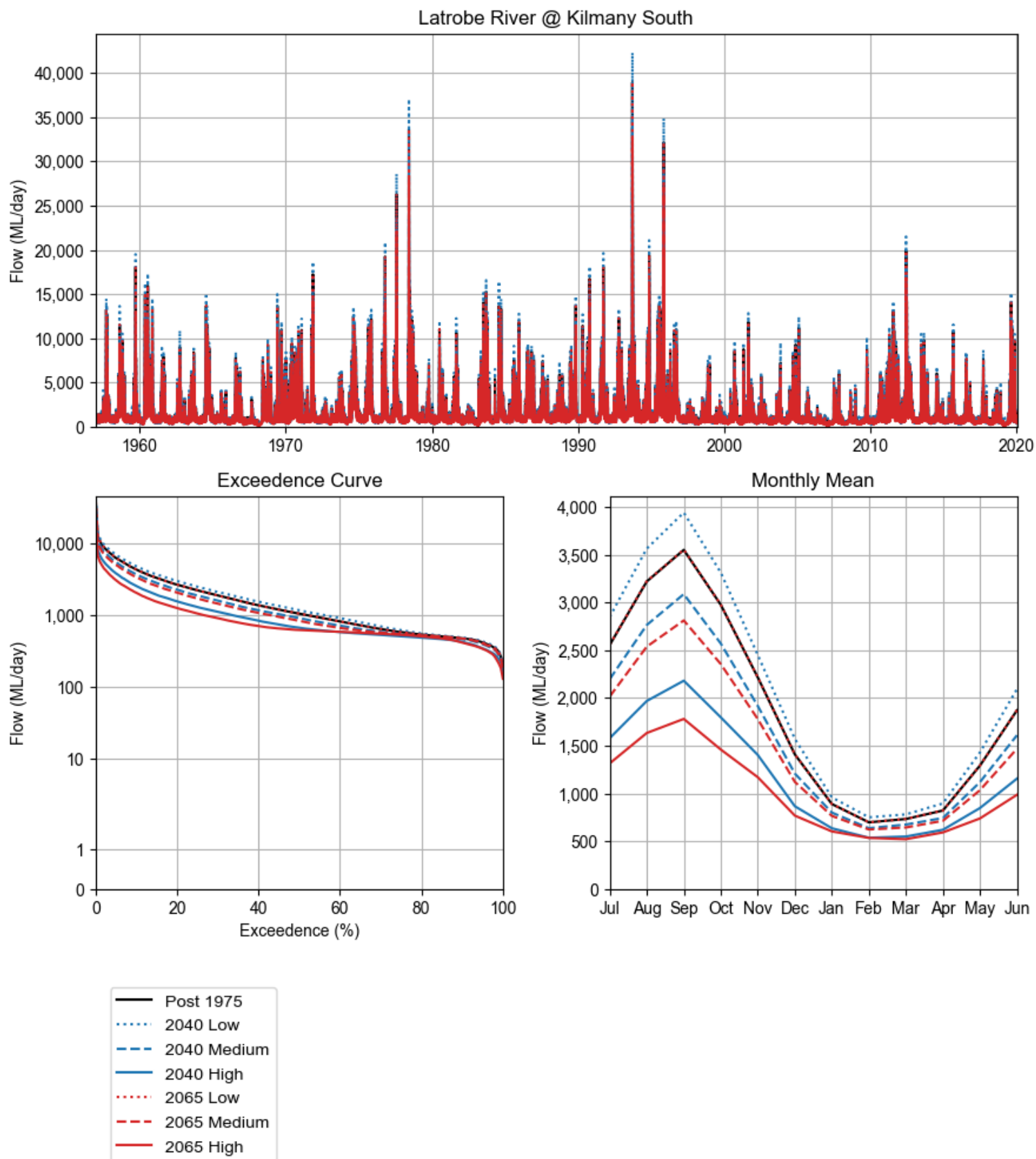
Appendix F Latrobe model results

F.1 Environmental entitlement allocations



F.2 Streamflow





F.3 Hydrologic indicators

Table 19: Hydrological indicators for the Latrobe River @ Kilmany South

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	1,855	2,052	1,613	1,180	1,856	1,491	1,010
MA13 (ML/d)	694	745	635	535	694	621	533
MA19 (ML/d)	3,221	3,565	2,765	1,969	3,223	2,538	1,634
MH26	11	11	10	9.5	11	10	10
DL16 (days)	10	10	10	11	10	10	10
DL18 (days)	0	0	0	0	0	0	0
Avg0Dur (days)	0	0	0	0	0	0	0
Max0Dur (days)	0	0	0	0	0	0	0

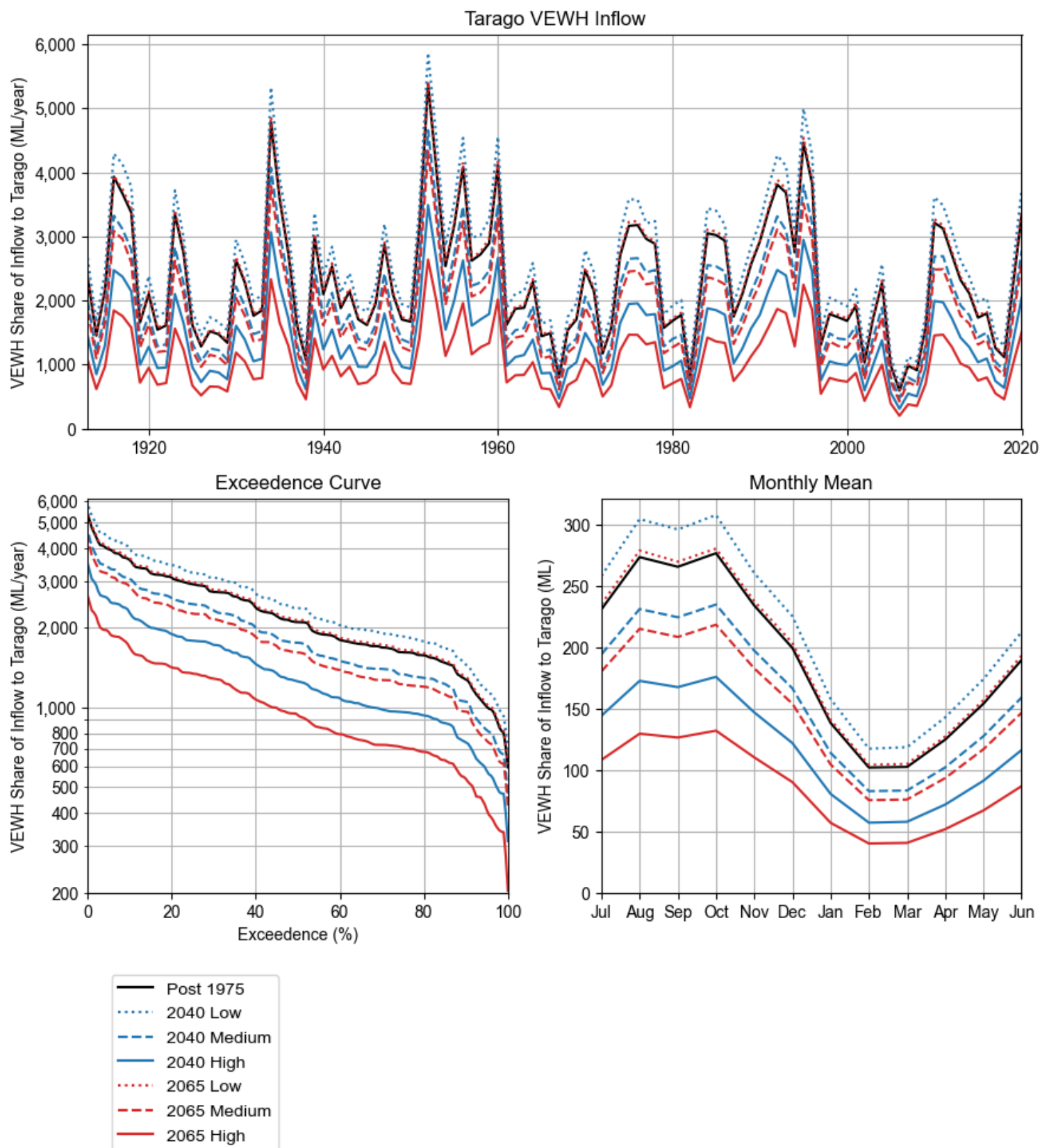
F.4 eFlow Projector results

Table 20: Average success (%) – flow targets for the Latrobe River @ Kilmany South

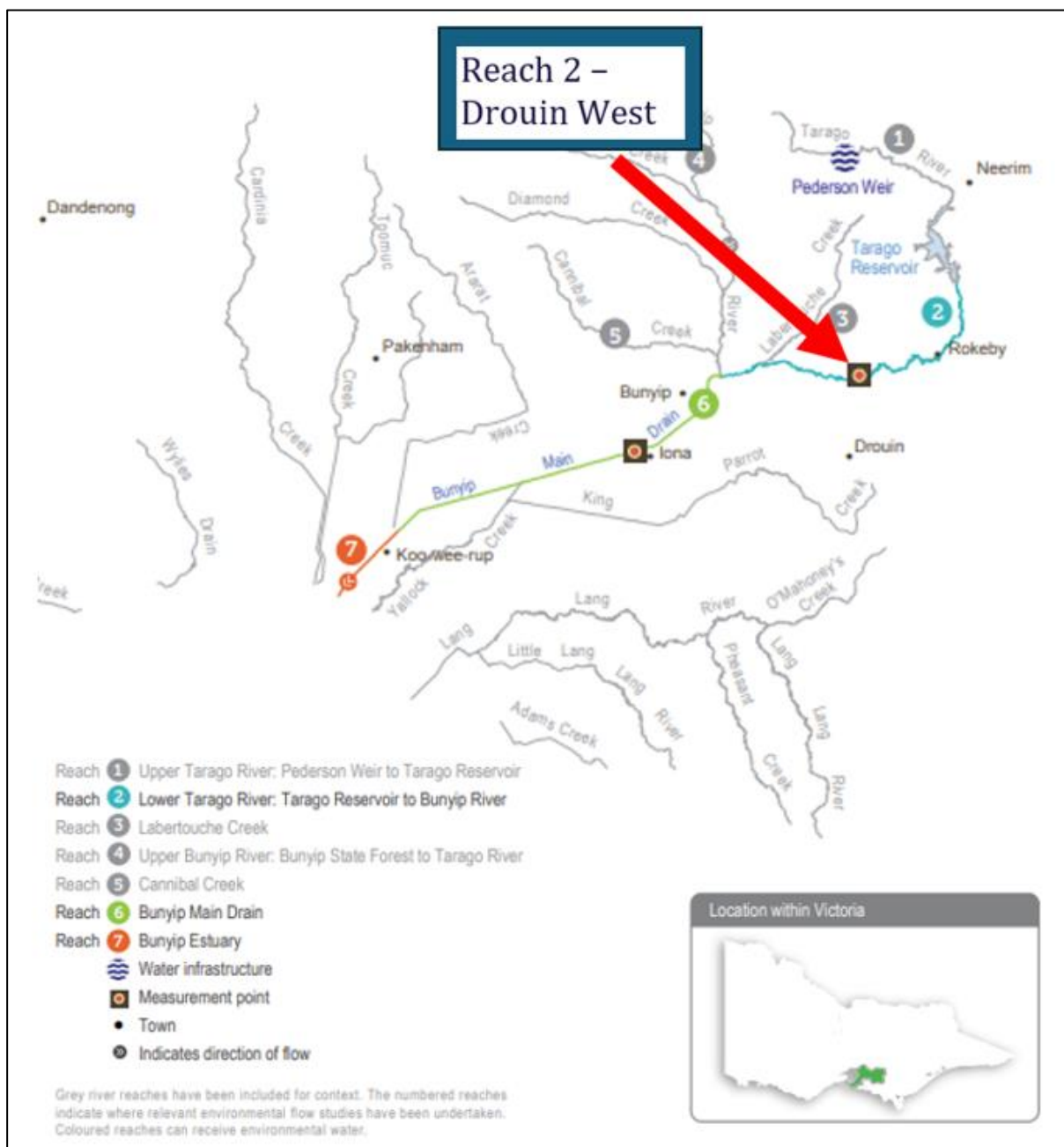
Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	97	98	94	86	97	93	79
Winter/spring low flow	98	98	97	94	98	96	90
Summer/autumn freshes	86	88	82	68	86	78	54

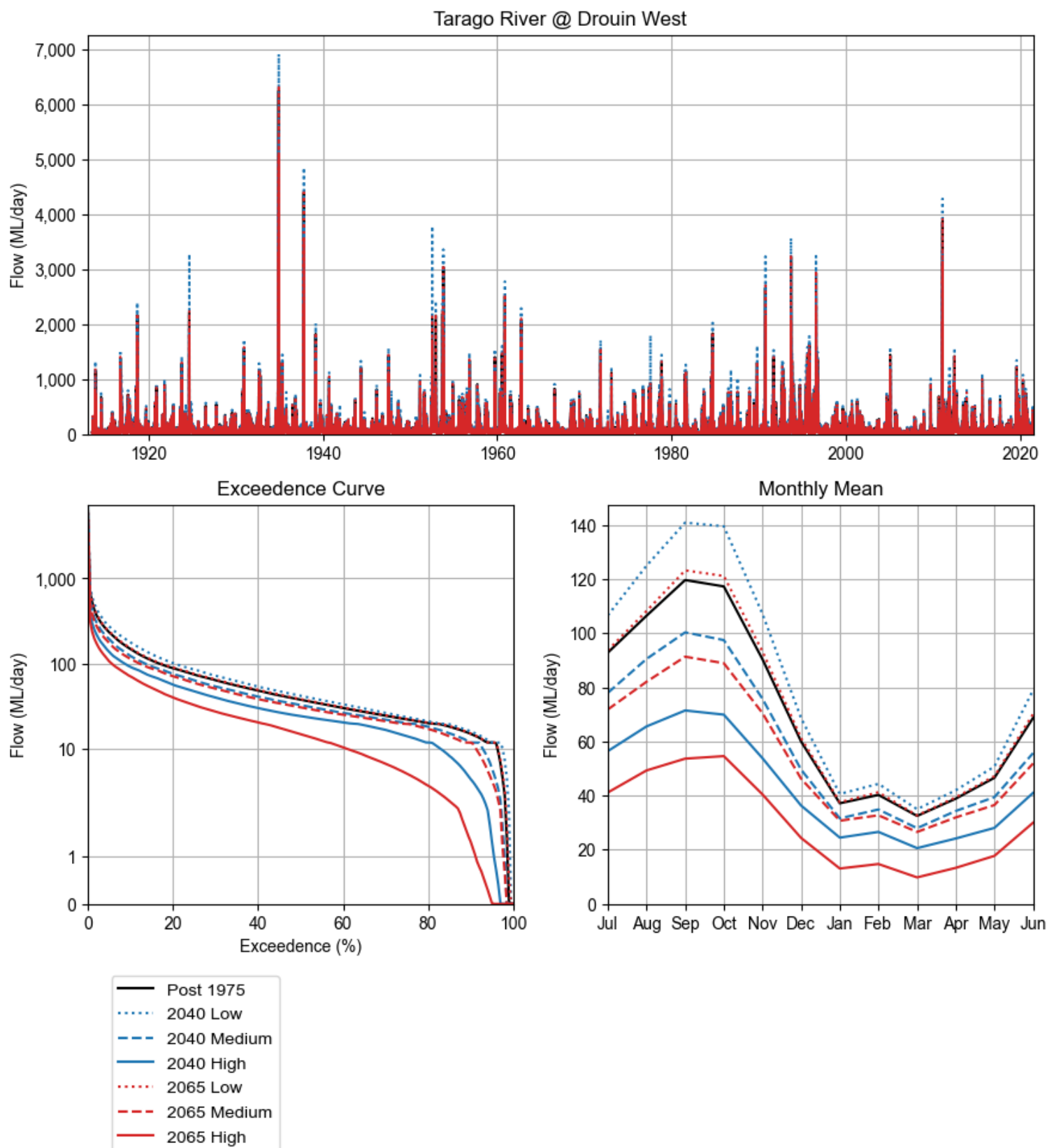
Appendix G Tarago model results

G.1 Environmental entitlement allocations



G.2 Streamflow





G.3 Hydrologic indicators

Table 21: Hydrological indicators for the Tarago River @ Drouin West

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	71	82	60	43	72	55	30
MA13 (ML/d)	40	44	35	27	41	33	15
MA19 (ML/d)	107	125	91	66	108	82	49
MH26	15	16	14	14	15	14	12
DL16 (days)	8.3	7.2	10	13	8.2	10	21
DL18 (days)	3.7	1.9	5.8	11.5	3.3	6.1	20
Avg0Dur (days)	8.9	7.8	8.1	8.5	8.8	7.7	7.7
Max0Dur (days)	65	47	64	78	54	67	86

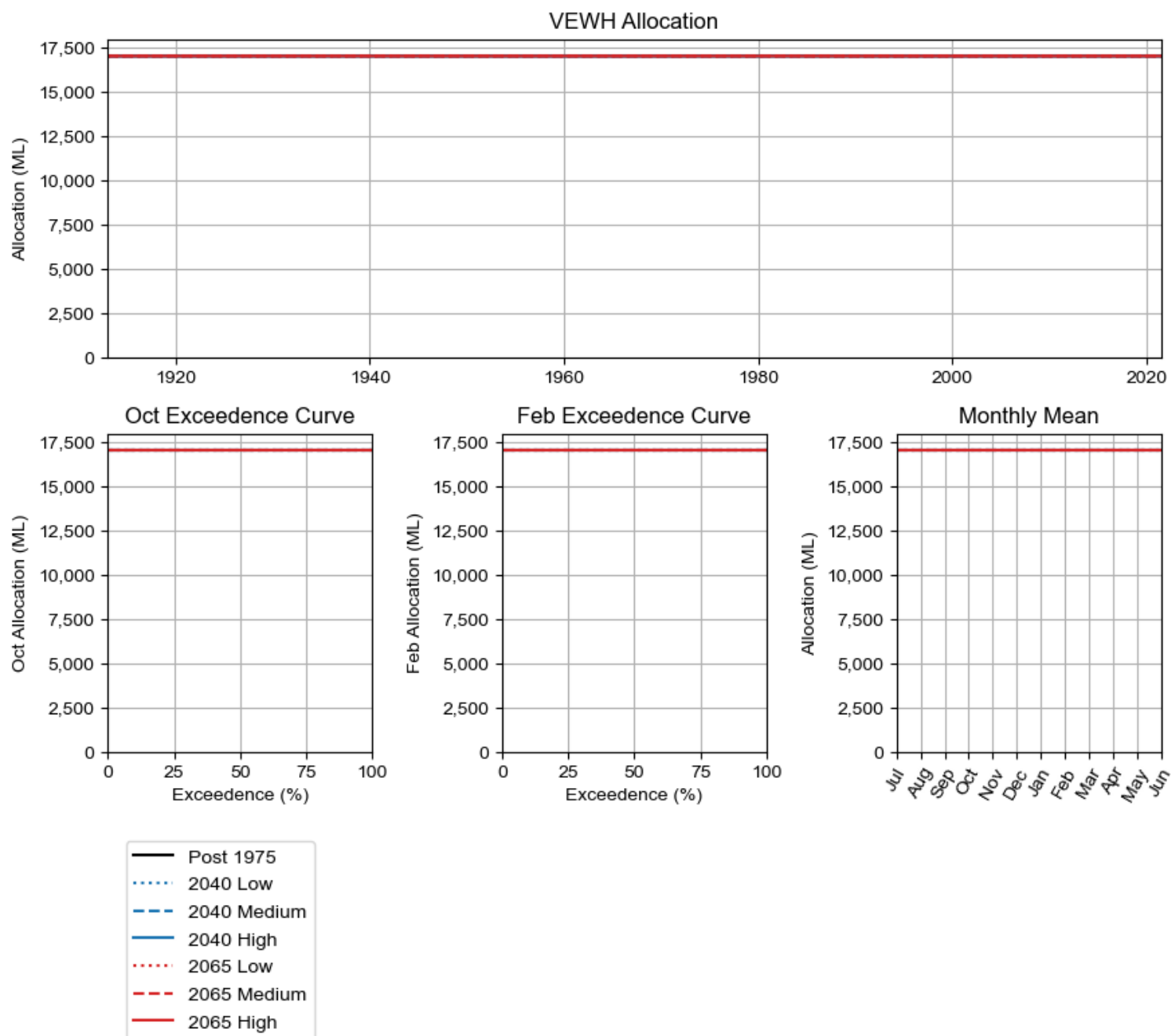
G.4 eFlow Projector results

Table 22: Average success (%) – flow targets for the Tarago River @ Drouin West

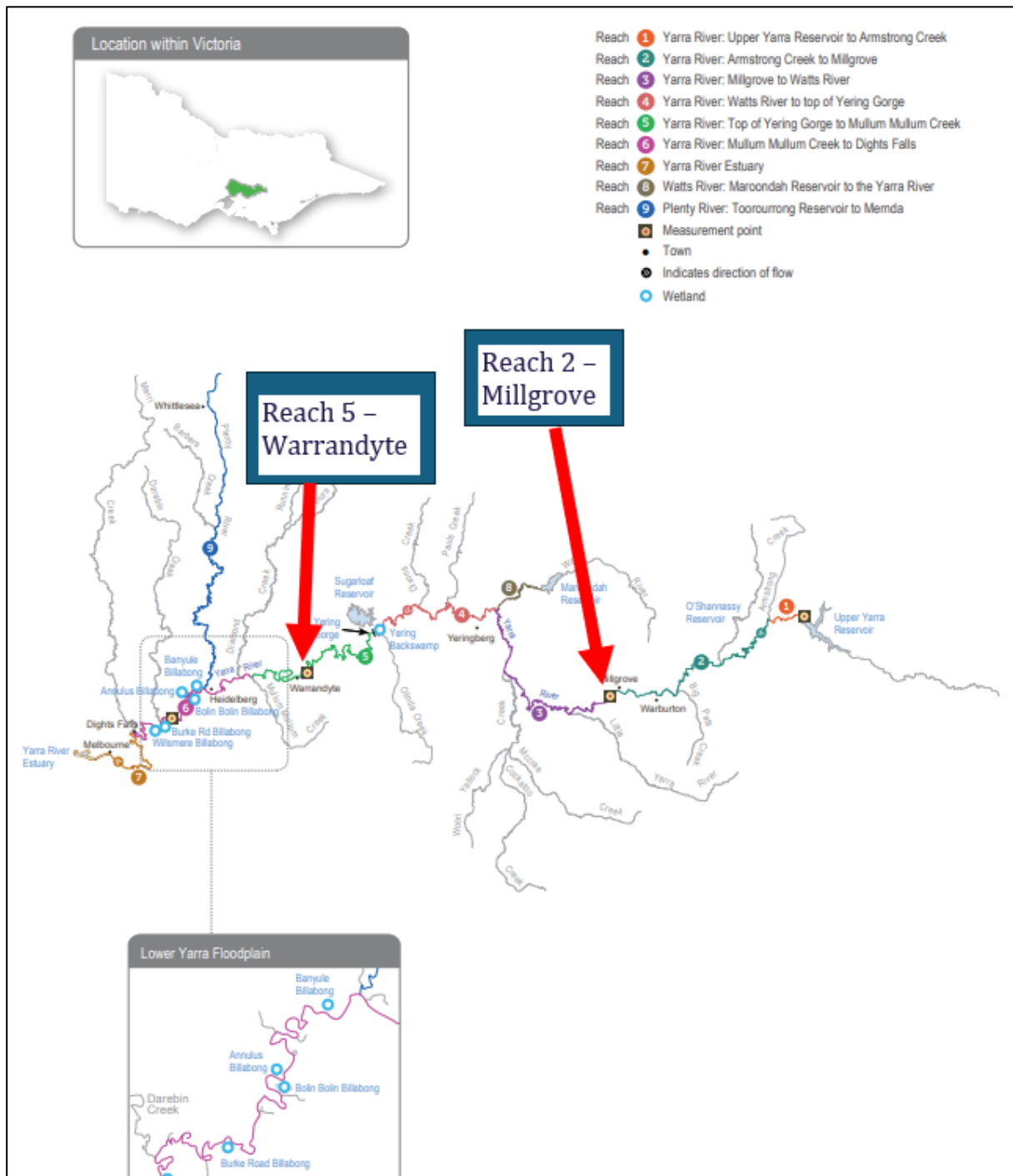
Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	86	89	81	66	87	78	34
Winter/spring low flow	57	62	50	38	58	48	28
Summer/autumn freshes	92	95	83	65	92	80	37
Autumn high flow	85	83	76	55	86	70	32
Winter/spring freshes	96	95	94	89	95	93	82
Spring high flow	88	93	84	74	89	83	61

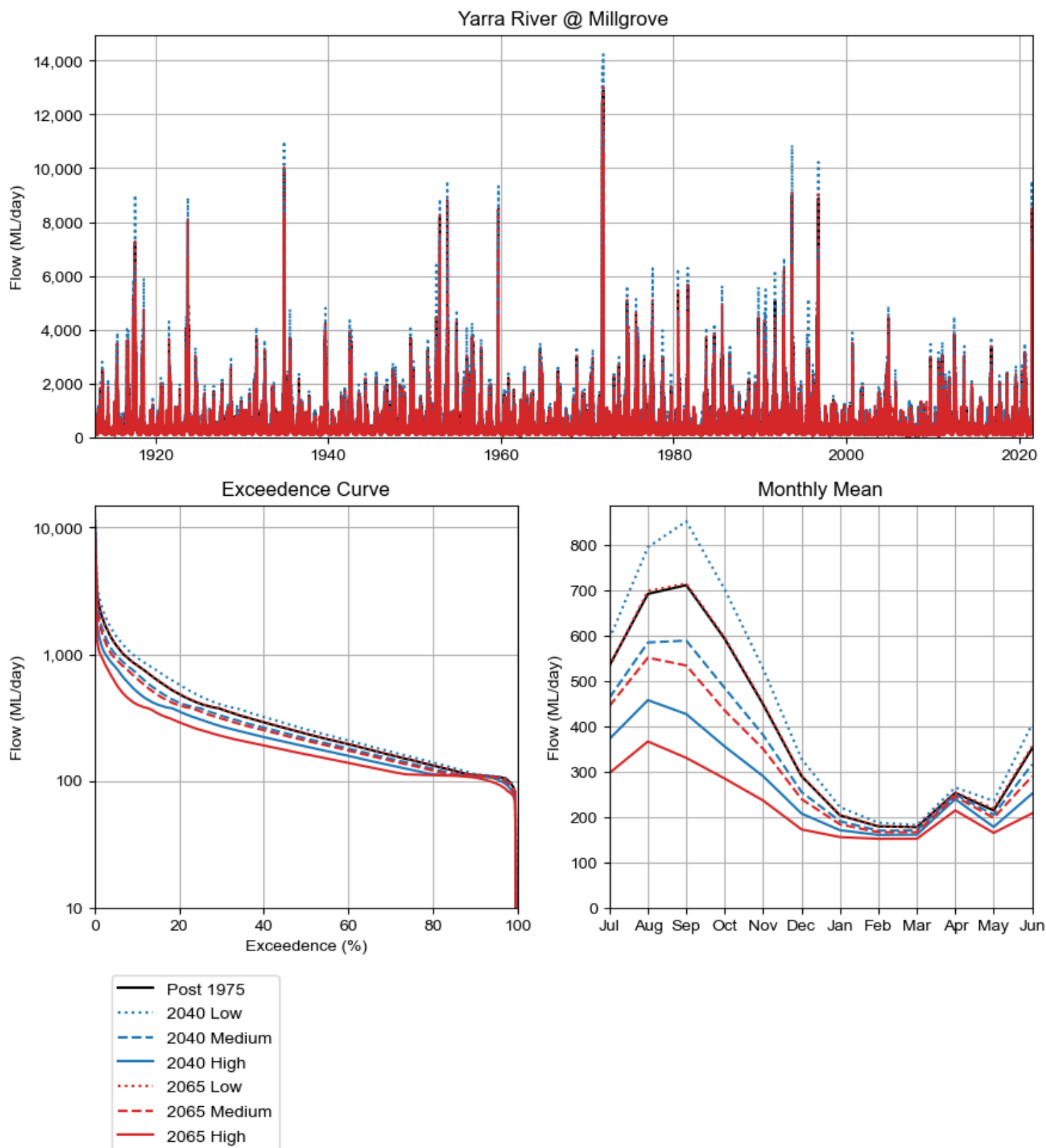
Appendix H Yarra model results

H.1 Environmental entitlement allocations



H.2 Streamflow





H.3 Hydrologic indicators

Table 23: Hydrological indicators for the Yarra River @ Millgrove

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	388	441	338	273	390	317	228
MA13 (ML/d)	179	187	169	160	179	166	152
MA19 (ML/d)	692	795	585	457	698	551	366
MH26	12	12	11	11	12	11	10
DL16 (days)	6.8	6.0	7.1	8.8	6.7	7.7	10
DL18 (days)	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Avg0Dur (days)	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Max0Dur (days)	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Table 24: Hydrological indicators for the Yarra River @ Warrandyte

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	1,085	1,255	918	675	1,091	841	480
MA13 (ML/d)	475	521	435	377	476	416	332
MA19 (ML/d)	1,945	2,260	1,605	1,094	1,959	1,450	687
MH26	12	12	11	11	12	11	11
DL16 (days)	12	11	13	16	12	14	17
DL18 (days)	0	0	0	0	0	0	0
Avg0Dur (days)	0	0	0	0	0	0	0
Max0Dur (days)	0	0	0	0	0	0	0

H.4 eFlow Projector results

Table 25: Average success (%) – flow targets for the Yarra River @ Millgrove

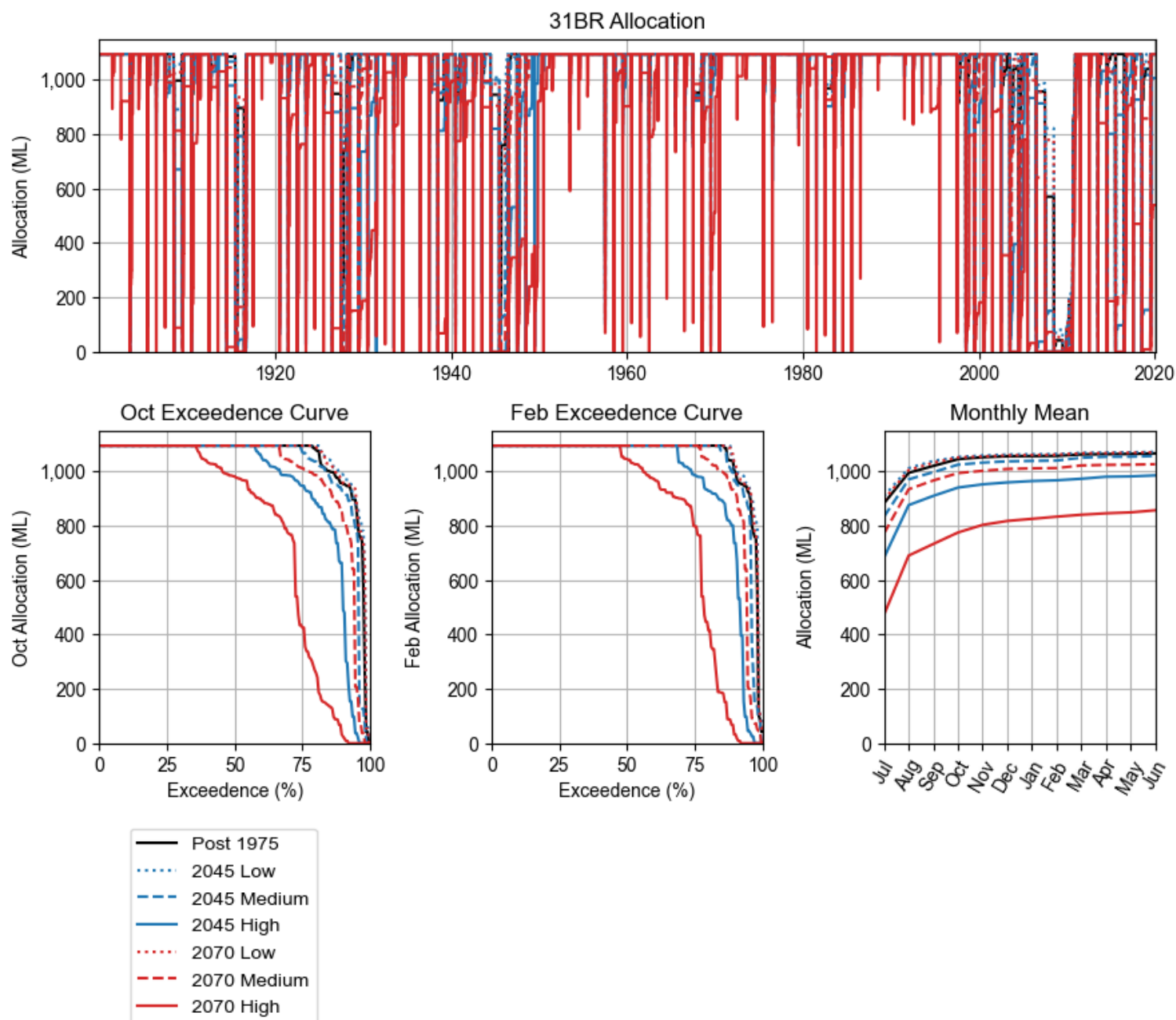
Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	98	99	98	96	98	97	93
Winter/spring low flow	99	99	99	97	99	98	94
Summer/autumn freshes	100	100	100	99	100	99	94
Autumn high flow	65	70	62	57	66	59	49
Winter/spring freshes	93	93	92	83	94	92	62
Spring high flow	58	66	50	34	58	46	17

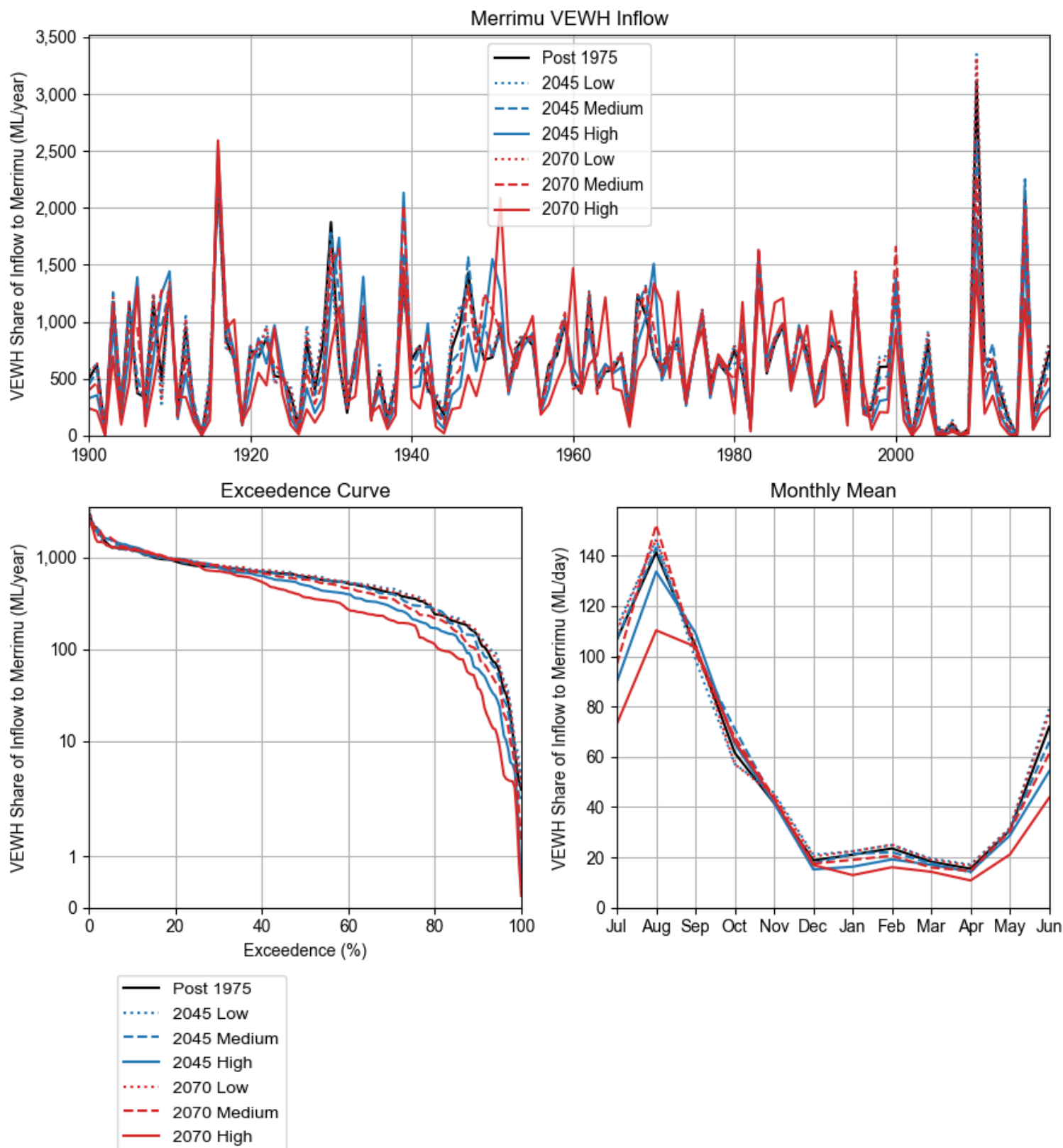
Table 26: Average success (%) – flow targets for the Yarra River @ Warrandyte

Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	100	100	100	100	100	100	100
Winter/spring low flow	100	100	100	100	100	100	100
Summer/autumn freshes	100	100	100	100	100	100	93
Autumn high flow	59	64	58	55	60	57	47
Winter/spring freshes	97	98	95	88	97	95	75
Spring high flow	57	65	49	33	58	44	24

Appendix I Werribee model results

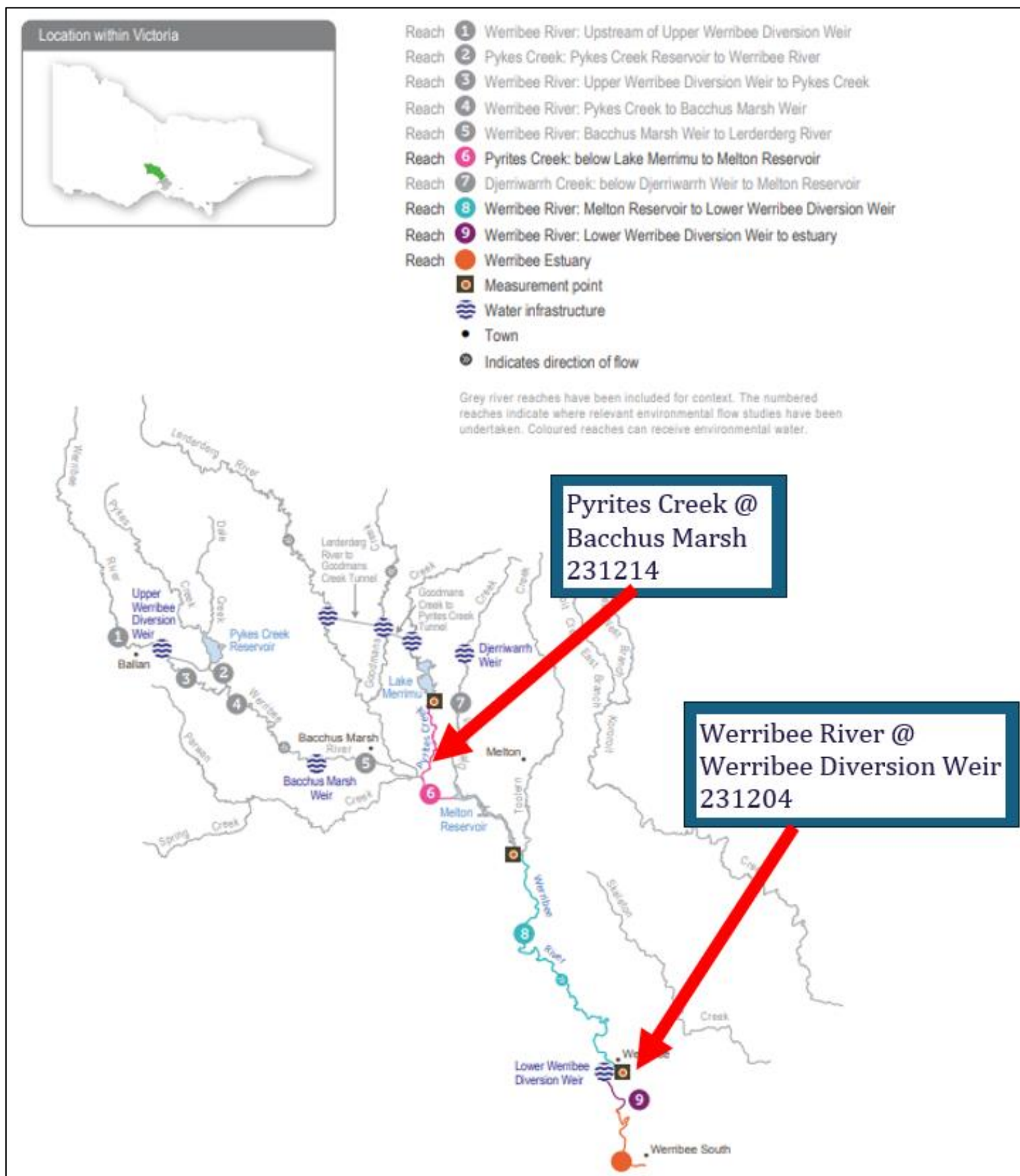
I.1 Environmental entitlement allocations

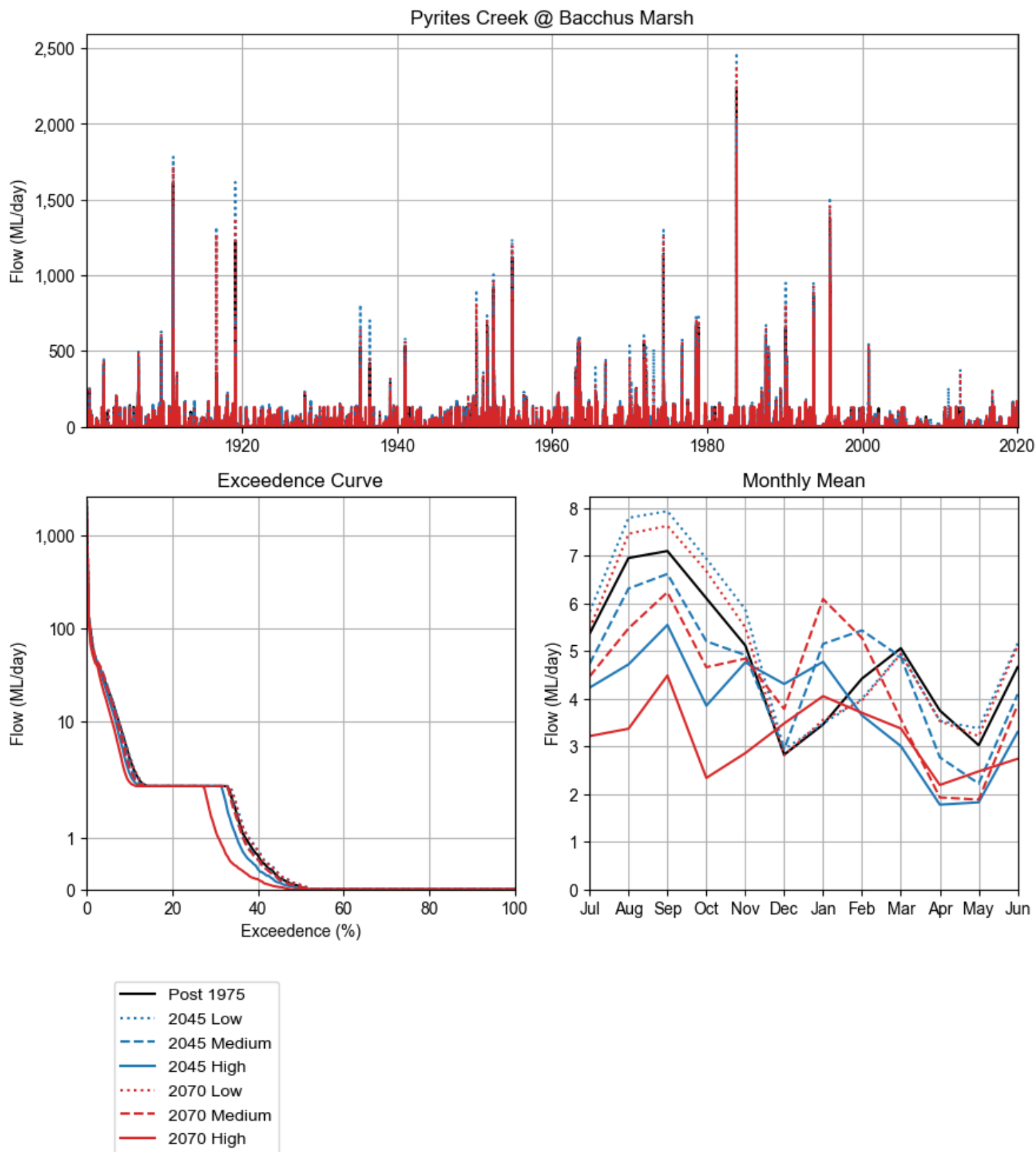




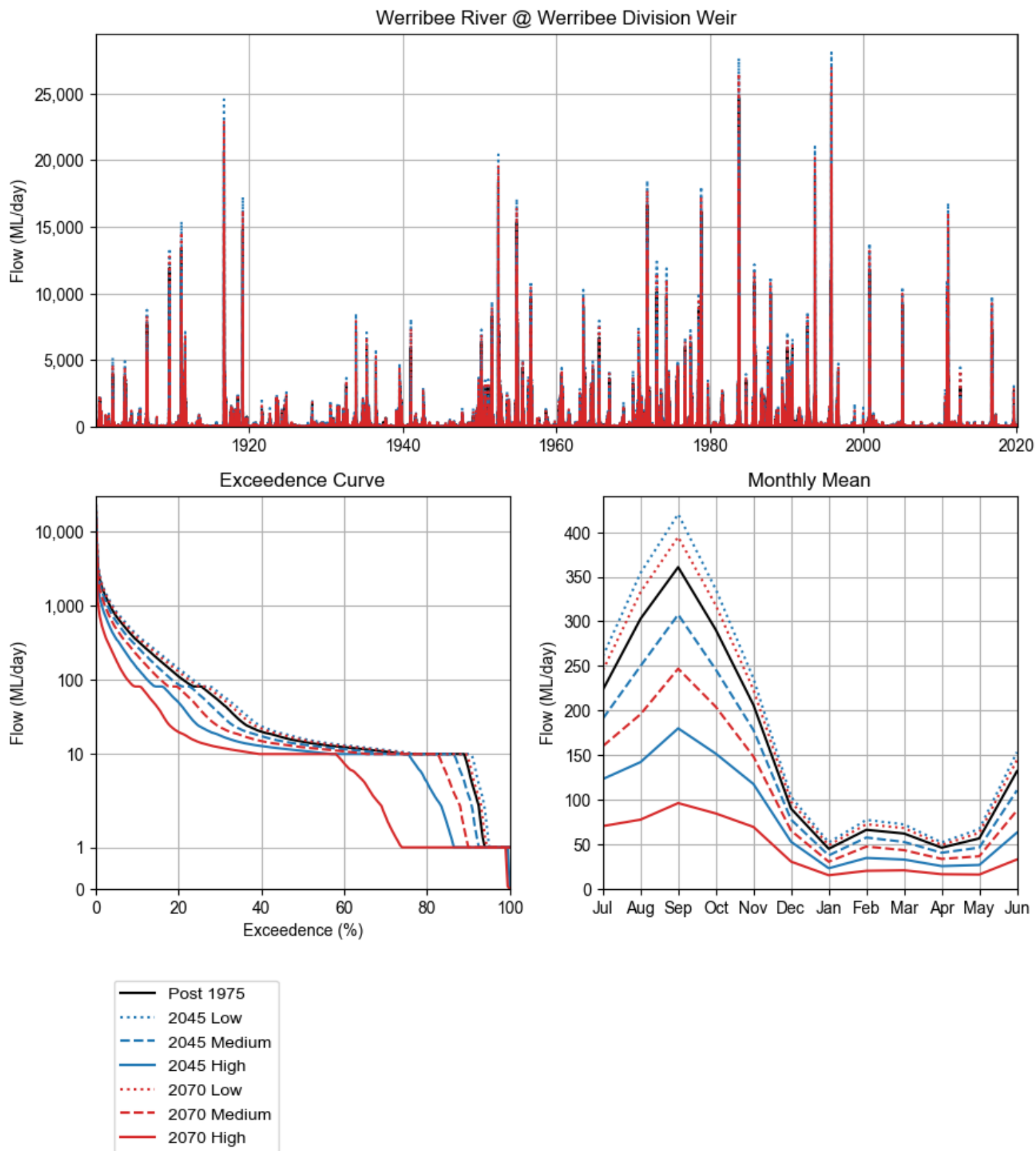
Note: The annual VEWH share of inflow to Merrimu is sometimes larger in the High climate change scenarios compared to the post 1975 scenario because the Source model often increases diversions from the Lerderderg River to Pyrites Creek in dry conditions.

I.2 Streamflow





Note: Under Medium and High climate change scenarios, transfers from the Lerderderg River to Merrimu Reservoir via Pyrites Creek increase, resulting in changes to the seasonal flow pattern downstream of Merrimu.



I.3 Hydrologic indicators

Table 27: Hydrological indicators for the Pyrites Creek @ Bacchus Marsh

Hydrological indicator	Post 1975	2045 Low	2045 Medium	2045 High	2070 Low	2070 Medium	2070 High
MA1 (ML/d)	4.8	5.2	4.6	3.8	5.0	4.3	3.2
MA13 (ML/d)	4.4	4.0	5.4	3.7	4.0	5.3	3.7
MA19 (ML/d)	7.0	7.8	6.3	4.7	7.5	5.5	3.4
MH26	42	44	39	34	43	38	31
DL16 (days)	39	36	40	39	36	39	45
DL18 (days)	189	185	191	198	185	192	210
Avg0Dur (days)	25	24	27	27	25	27	29
Max0Dur (days)	237	236	309	317	237	340	411

Table 28: Hydrological indicators for the Werribee River @ Werribee Diversion Weir

Hydrological indicator	Post 1975	2045 Low	2045 Medium	2045 High	2070 Low	2070 Medium	2070 High
MA1 (ML/d)	157	182	133	81	172	108	46
MA13 (ML/d)	66	78	58	35	73	47	20
MA19 (ML/d)	303	354	250	142	333	196	77
MH26	85	96	76	59	91	70	40
DL16 (days)	6.4	5.7	6.9	12	6.0	8.9	34
DL18 (days)	0	0	0	0.6	0	0	2.0
Avg0Dur (days)	0	0	0	24	0	0	17
Max0Dur (days)	0	0	0	54	0	0	69

I.4 eFlow Projector results

Table 29: Average success (%) – flow targets for the Pyrites Creek @ Bacchus Marsh. Targets shown in red were not ordered in the Source model.

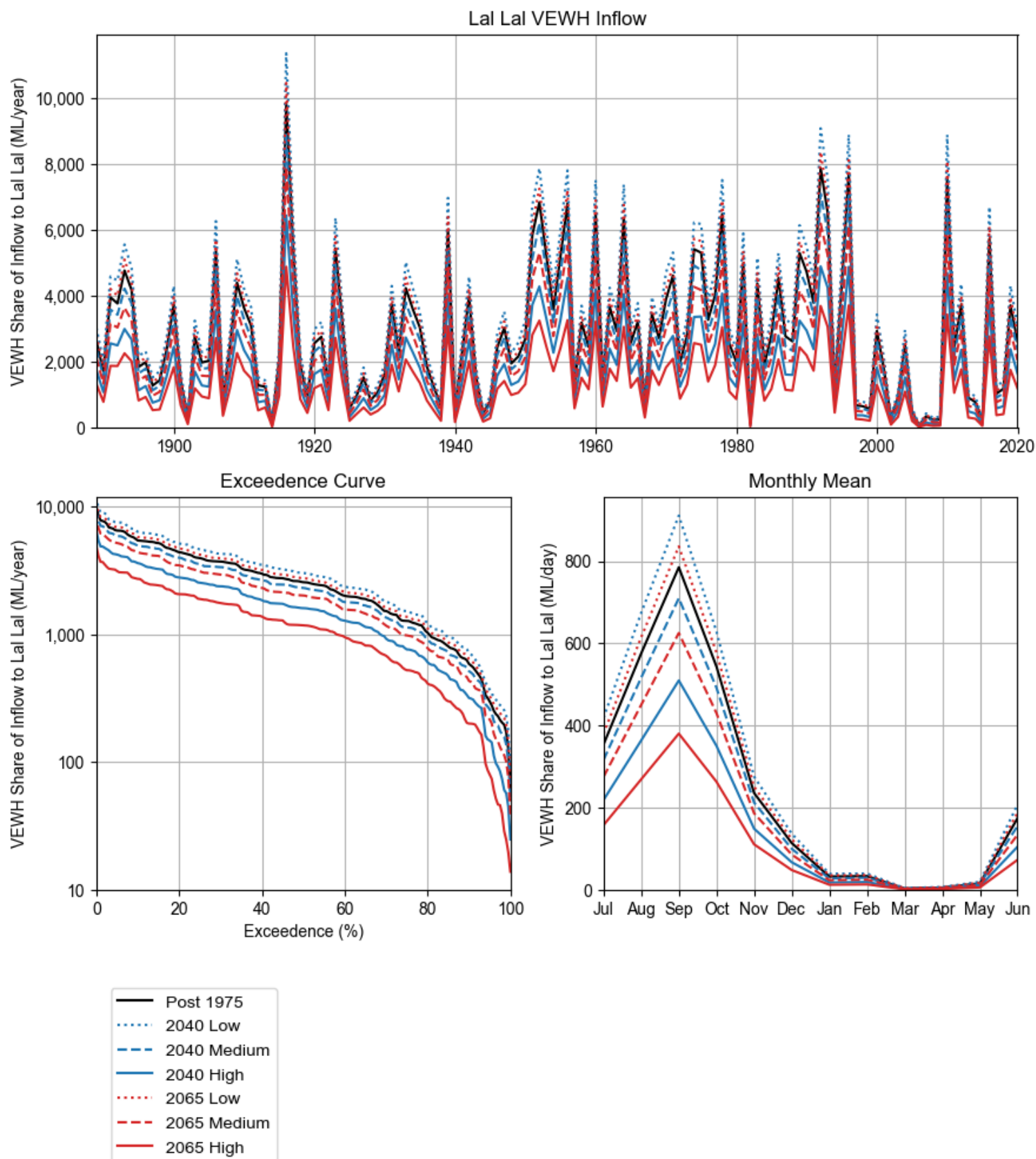
Name	Post 1975	2045 Low	2045 Medium	2045 High	2070 Low	2070 Medium	2070 High
Summer/autumn low flow	28	28	28	26	28	28	23
Winter/spring low flow	43	45	43	42	45	43	37
Jun fresh	32	33	31	26	34	29	22
Sep - Nov freshes	40	41	40	42	41	41	37
Spring high flow	43	46	40	39	45	41	32
High flow 1	85	87	86	84	86	86	77
High flow 2	65	68	65	56	67	60	50

Table 30: Average success (%) – flow targets for the Werribee River @ Werribee Diversion Weir.
Targets shown in red were not ordered in the Source model.

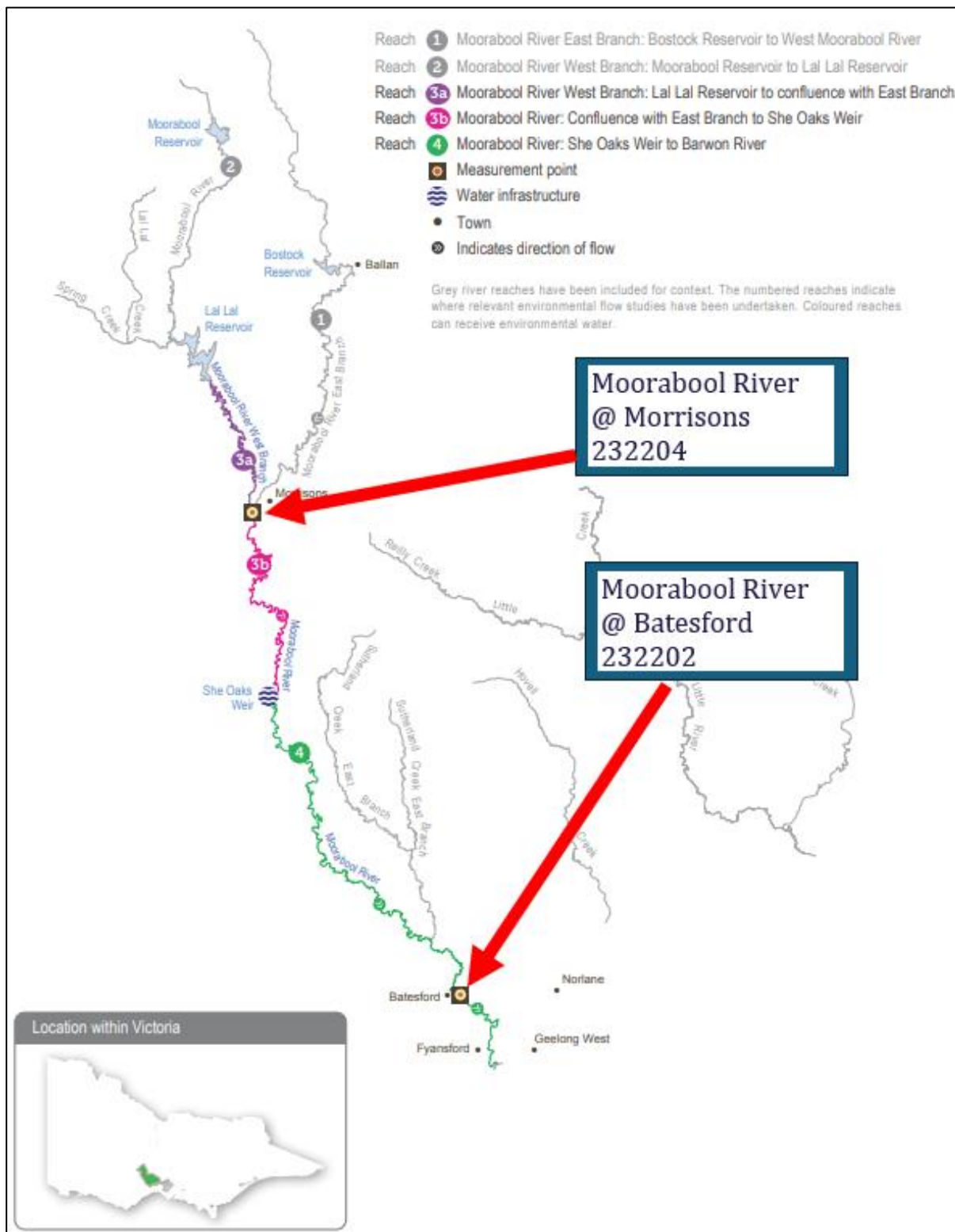
Name	Post 1975	2045 Low	2045 Medium	2045 High	2070 Low	2070 Medium	2070 High
Summer/autumn low flow	91	93	90	80	92	86	63
Winter/spring low flow	48	52	43	32	50	38	22
Summer/autumn freshes	43	47	40	31	45	35	23
Apr - May freshes	17	20	16	10	19	13	5.1
Jun - Aug freshes	50	54	47	33	53	40	23
Sep - Oct freshes	54	58	48	38	57	45	26
Bankfull	38	42	35	24	40	30	13

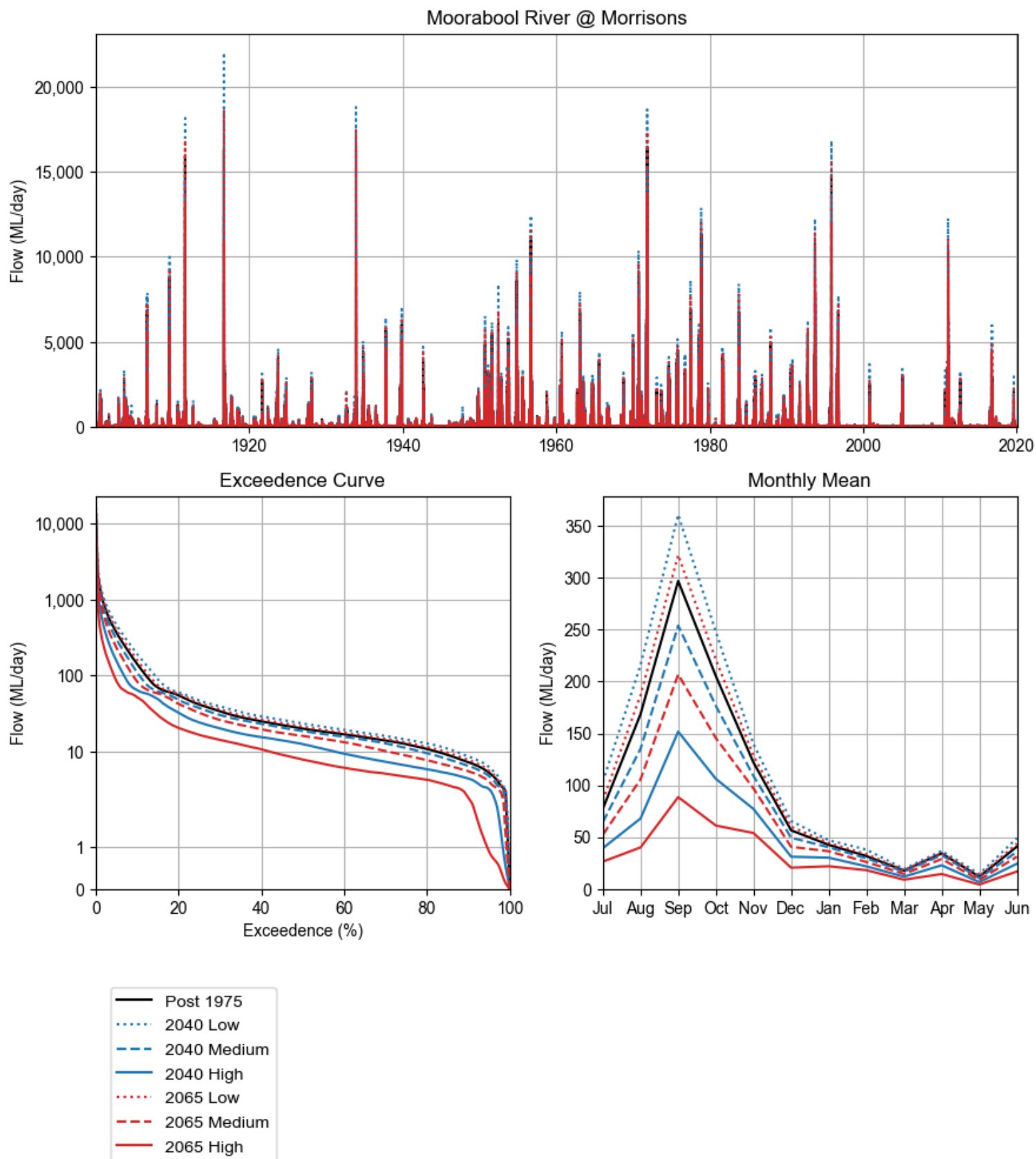
Appendix J Moorabool model results

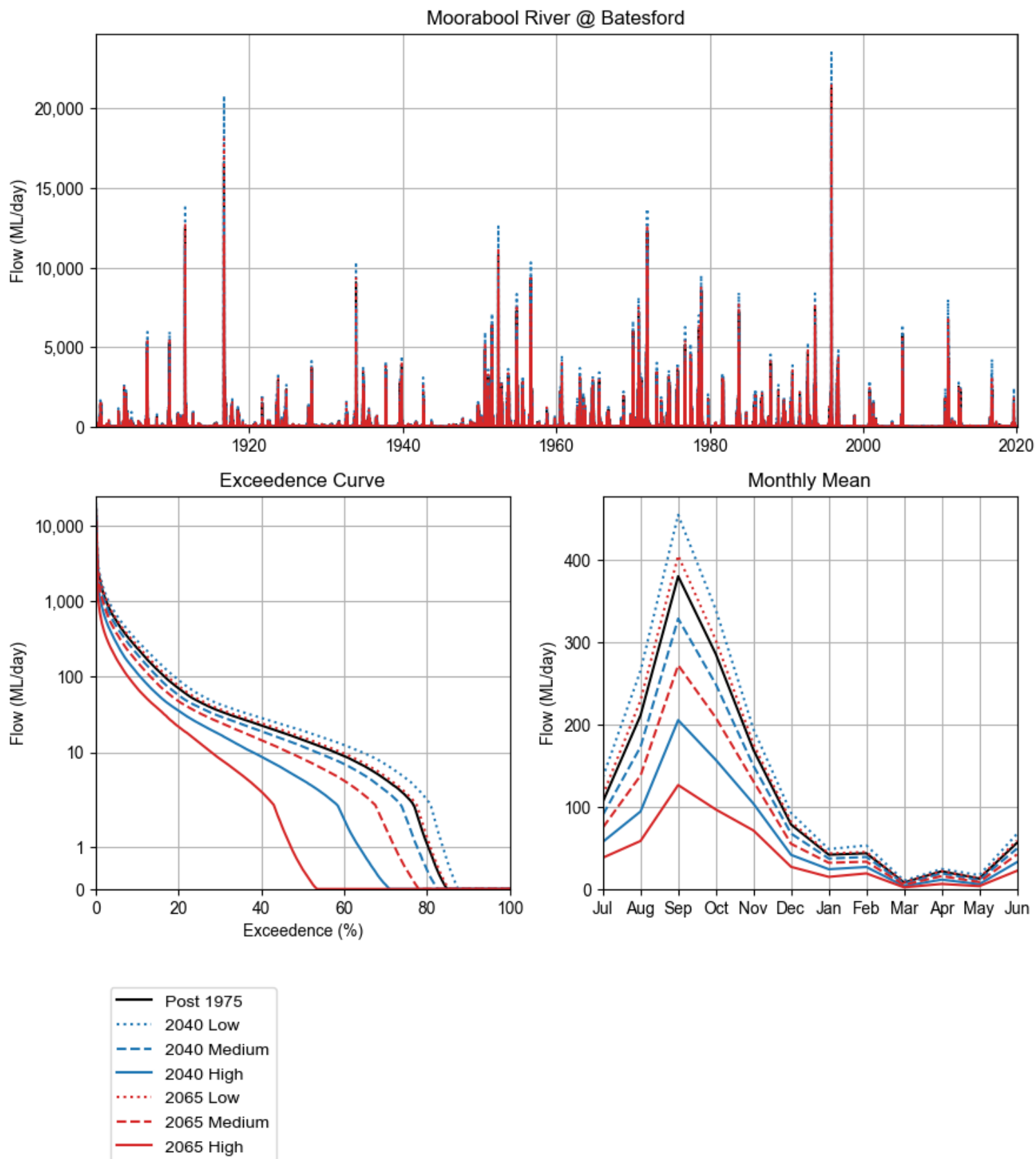
J.1 Environmental entitlement allocations



J.2 Streamflow







J.3 Hydrologic indicators

Table 31: Hydrological indicators for the Moorabool River @ Morrisons

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	92	112	80	49	99	66	31
MA13 (ML/d)	32	38	30	22	34	26	18
MA19 (ML/d)	169	216	135	68	187	106	40
MH26	59	65	54	43	62	48	35
DL16 (days)	14	12	15	25	14	17	35
DL18 (days)	0.02	0	0.1	0.6	0.02	0.2	2.8
Avg0Dur (days)	1.5	0	1.7	3.9	1.5	3.1	6.9
Max0Dur (days)	2.0	0	3.0	14.0	2.0	6.0	52

Table 32: Hydrological indicators for the Moorabool River @ Batesford

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	118	142	102	64	125	85	40
MA13 (ML/d)	44	53	39	27	45	33	19
MA19 (ML/d)	211	265	173	94	229	138	58
MH26	63	70	57	46	65	52	38
DL16 (days)	31	29	33	43	31	35	43
DL18 (days)	58	47	66	110	56	83	174
Avg0Dur (days)	19	19	20	19	20	20	21
Max0Dur (days)	203	224	204	293	204	246	797

J.4 eFlow Projector results

Table 33: Average success (%) – flow targets for the Moorabool River @ Morrisons. Targets shown in red were not ordered in the Source model.

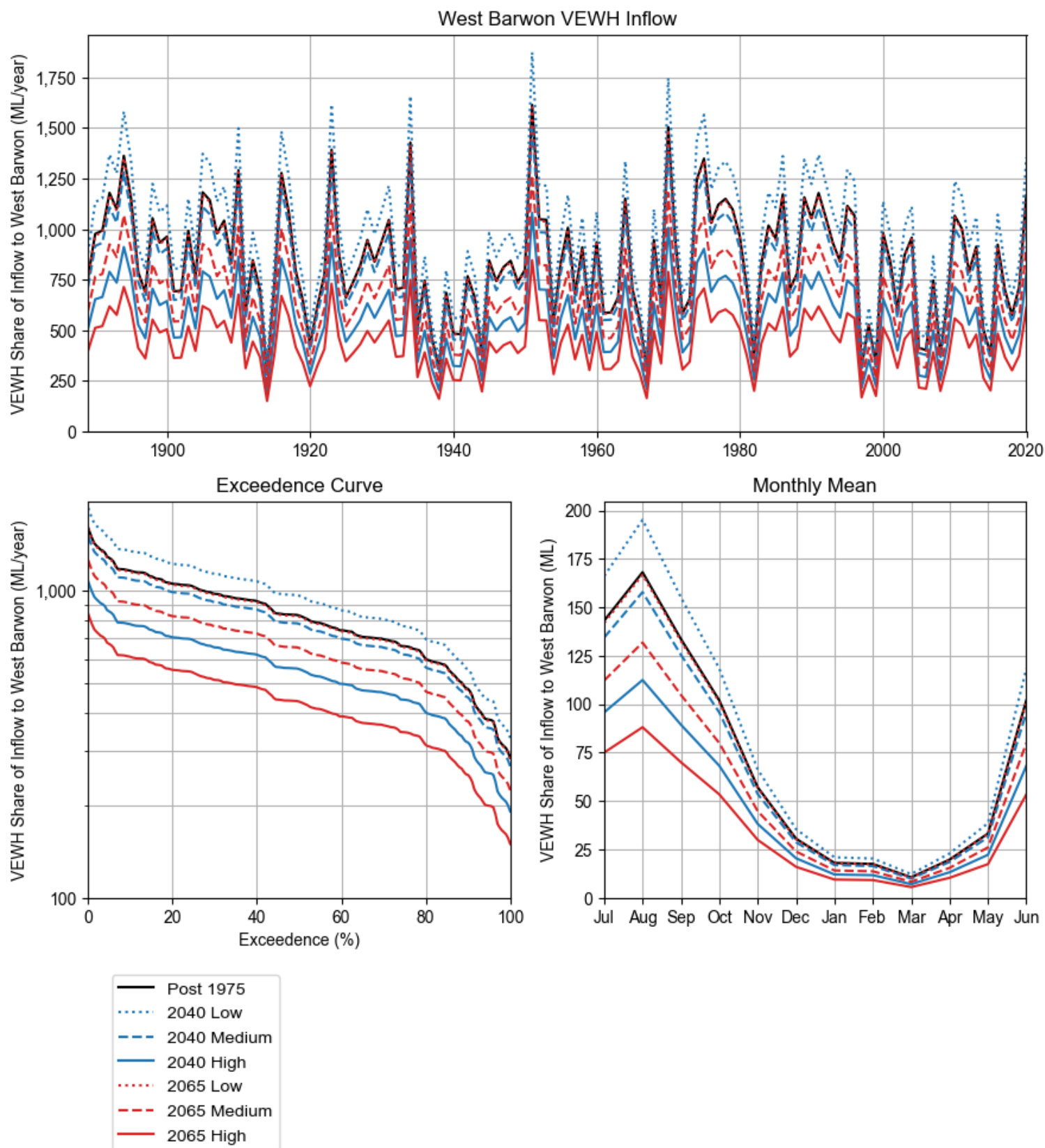
Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	91	94	89	72	92	83	56
Winter/spring low flow	91	93	89	77	92	85	62
Autumn fresh 1	73	74	68	52	73	62	31
Autumn fresh 2	91	94	90	70	92	83	48
Winter fresh (1)	66	69	64	53	67	61	47
Spring fresh (2)	83	85	80	73	84	77	65

Table 34: Average success (%) – flow targets for the Moorabool River @ Batesford. Targets shown in red were not ordered in the Source model.

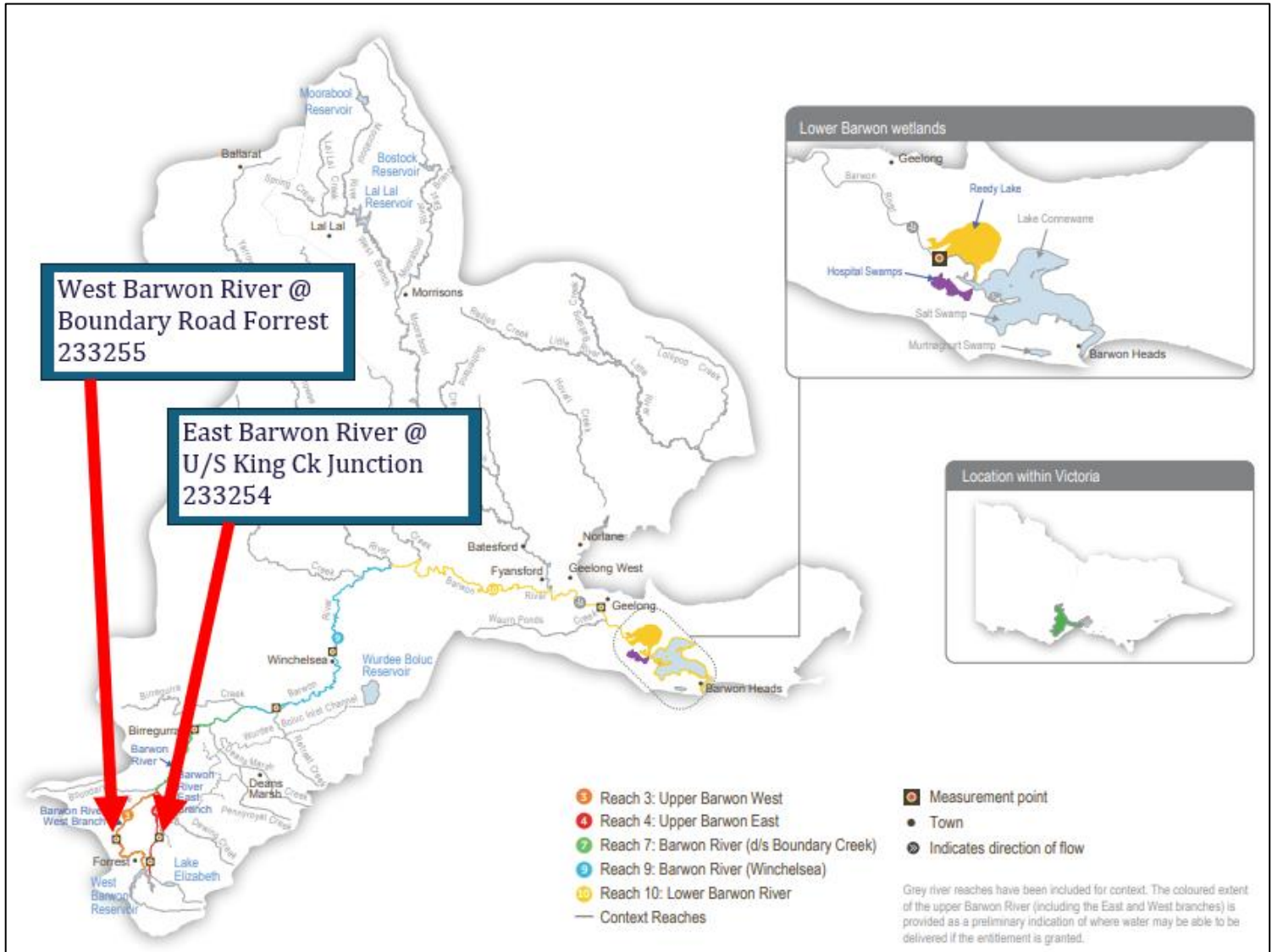
Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	53	61	48	29	54	39	17
Winter/spring low flow	77	81	74	60	78	68	49
Autumn fresh (1)	27	30	24	17	27	21	13
Summer/autumn fresh (2)	97	99	96	85	98	92	69
Winter fresh (1)	74	76	71	60	75	67	50
Spring fresh (2)	84	86	82	76	85	80	67

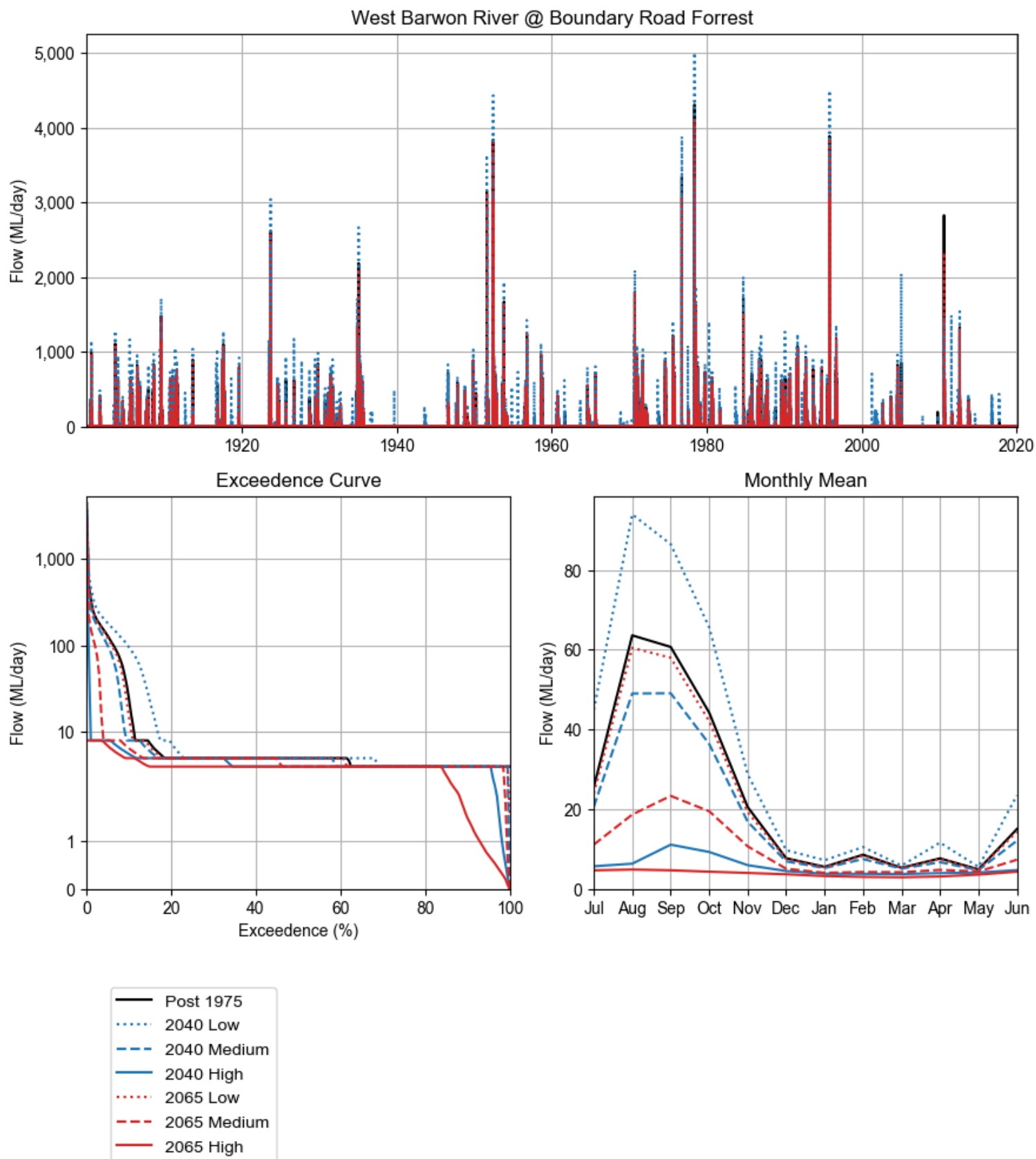
Appendix K Barwon model results

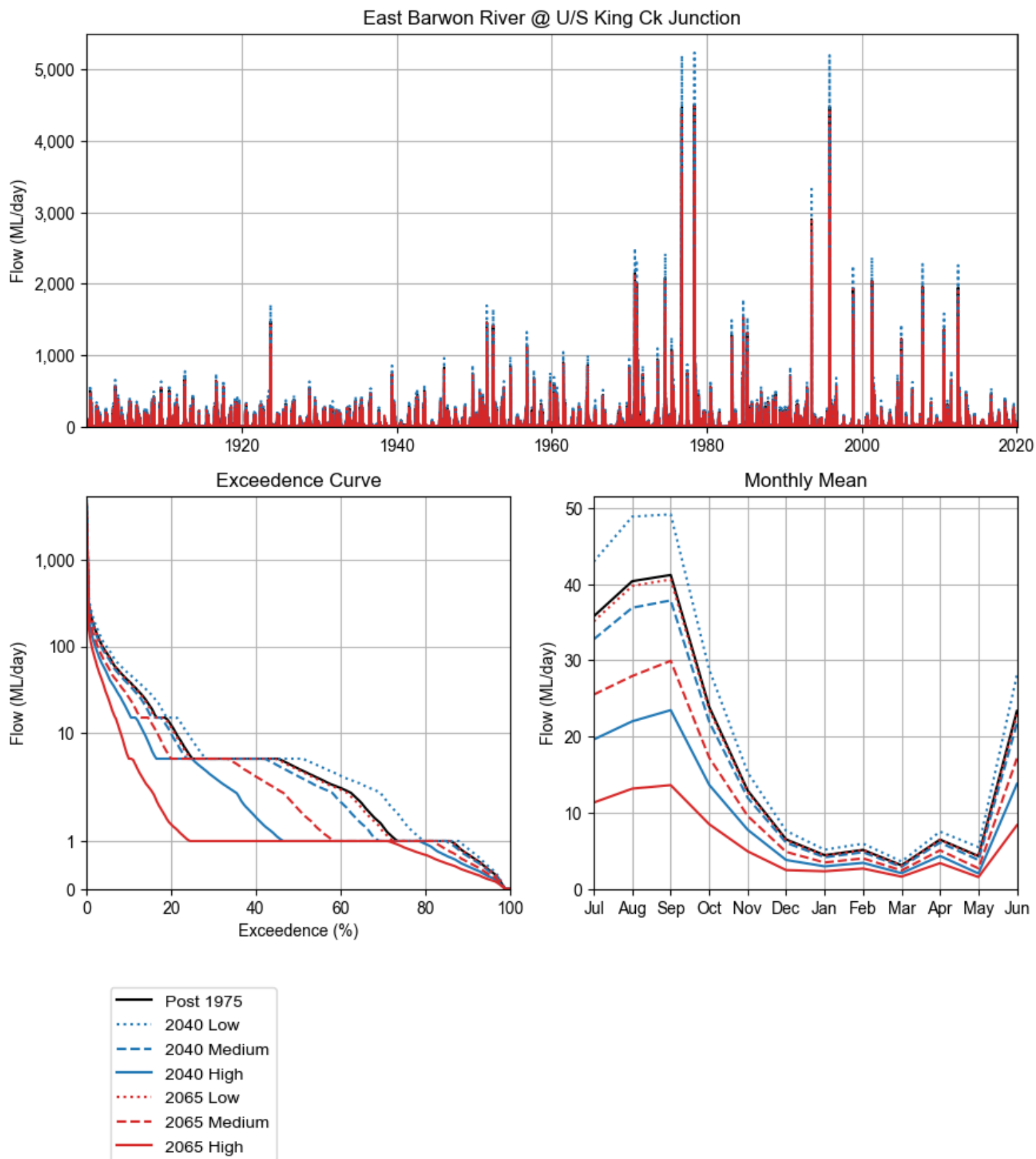
K.1 Environmental entitlement allocations



K.2 Streamflow







K.3 Hydrologic indicators

Table 35: Hydrological indicators for the West Barwon River @ Boundary Road Forrest

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	23	33	18	5.6	21	10	3.9
MA13 (ML/d)	8.6	10	7.5	3.8	8.4	4.3	3.0
MA19 (ML/d)	64	94	49	6	60	19	4.9
MH26	84	90	77	56	85	69	0
DL16 (days)	46	49	42	23	46	31	13
DL18 (days)	0	0	0.4	1.1	0	1.0	2.0
Avg0Dur (days)	0	0	8.5	13	0	15	7.4
Max0Dur (days)	0	0	22	64	0	64	64

Table 36: Hydrological indicators for the East Barwon River @ U/S King Creek Junction

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	17	21	16	10	17	13	6.2
MA13 (ML/d)	5.1	6.0	4.8	3.4	5.1	4.0	2.7
MA19 (ML/d)	40	49	37	22	40	28	13
MH26	45	50	43	34	45	38	31
DL16 (days)	15	14	16	18	15	18	24
DL18 (days)	6.4	6.1	6.7	7.7	6.4	7.0	9.1
Avg0Dur (days)	12	12	13	13	12	12	14
Max0Dur (days)	97	97	97	97	97	97	98

K.4 eFlow Projector results

Table 37: Average success (%) – flow targets for the West Barwon River @ Boundary Road Forrest. Targets shown in red were not ordered in the Source model.

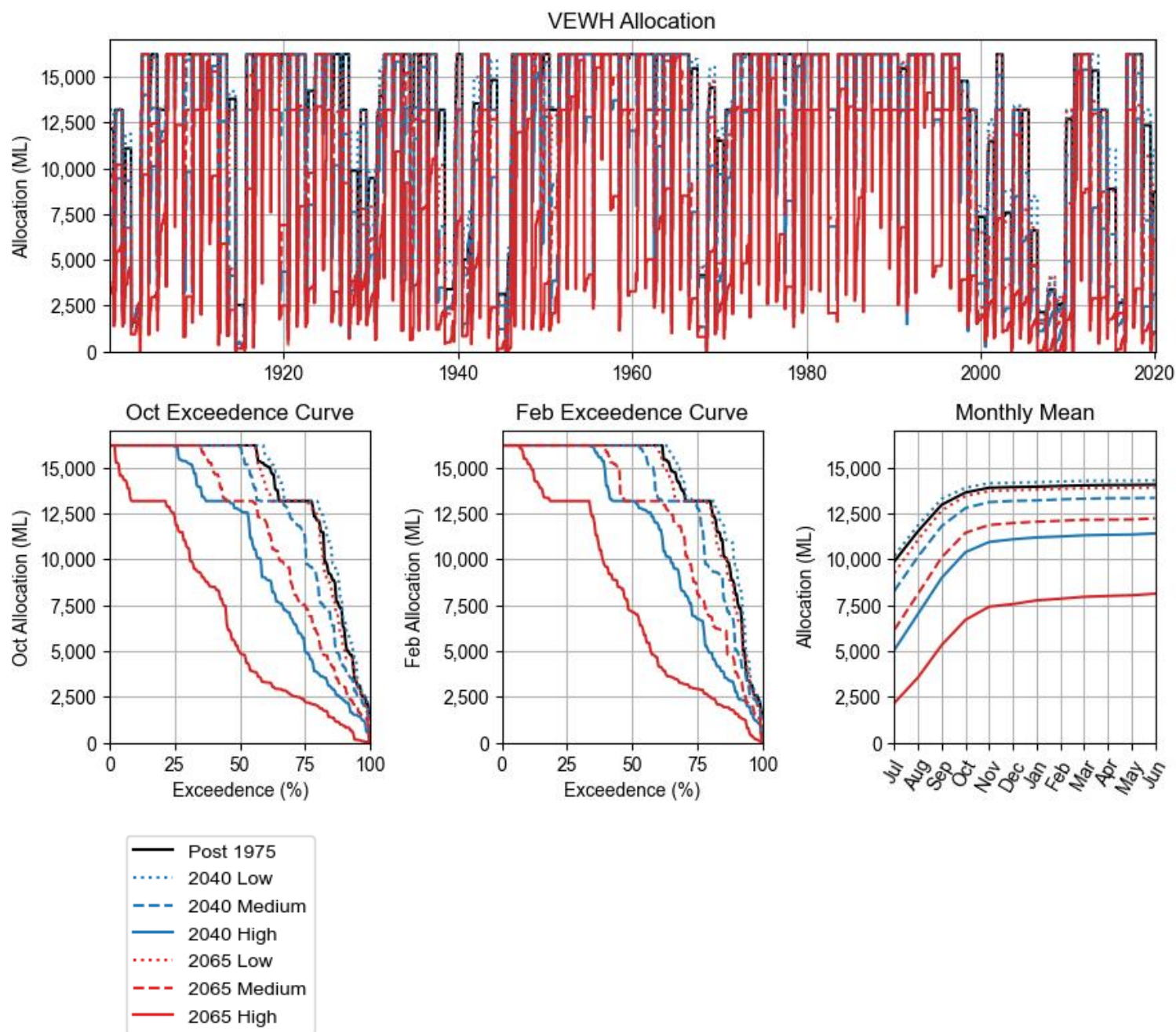
Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	31	34	30	22	31	26	16
Winter/spring low flow	53	59	51	39	52	44	31
Summer/autumn fresh	3.2	5.1	2.5	0.04	3.0	0.5	0
Winter/spring fresh	14	22	11	1.0	13	4.2	0

Table 38: Average success (%) – flow targets for the East Barwon River @ U/S King Creek Junction. Targets shown in red were not ordered in the Source model.

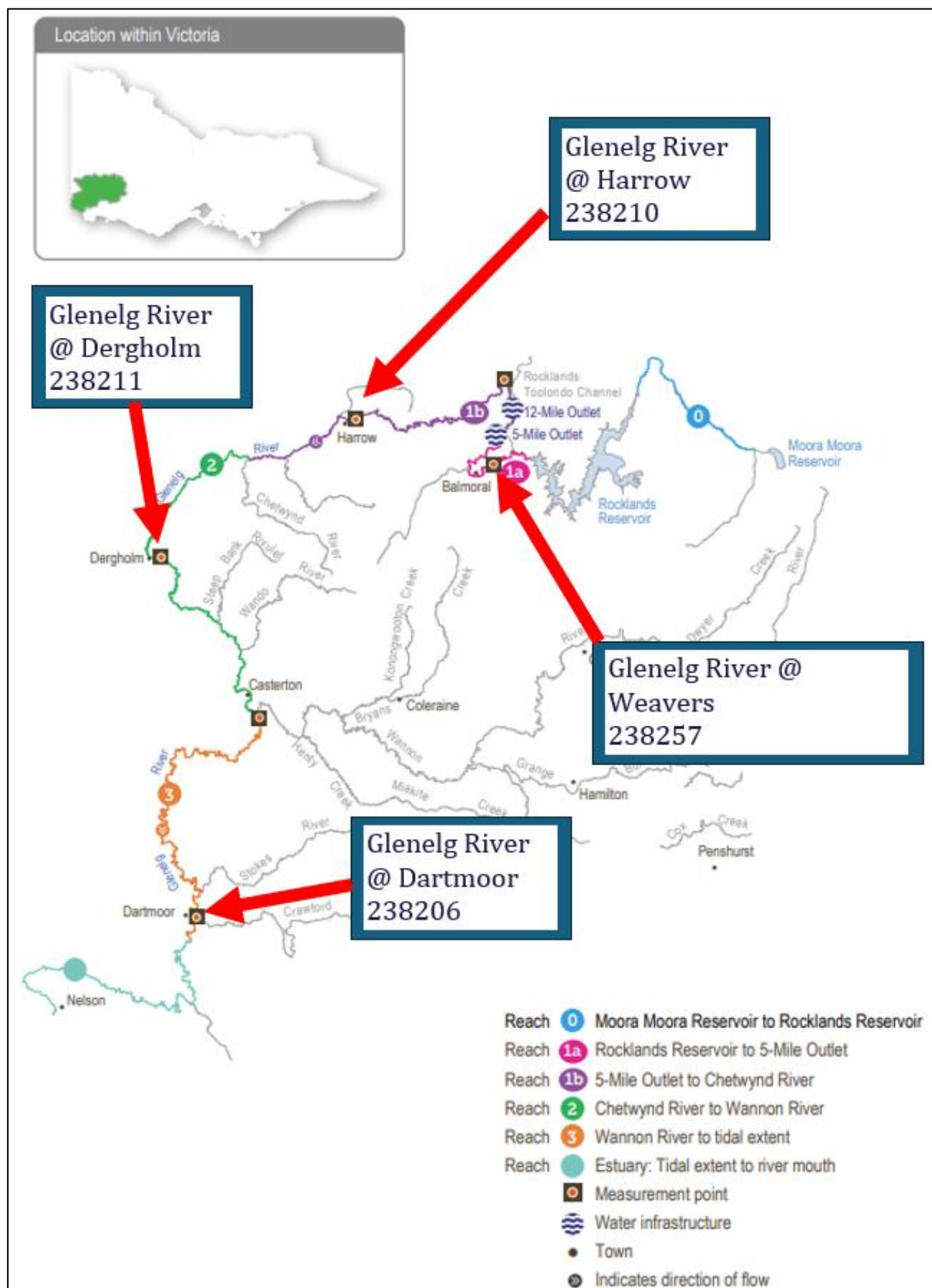
Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	82	85	81	72	82	77	64
Winter/spring low flow	100	100	100	99	100	100	98
Summer/autumn freshes	77	82	76	65	77	69	54

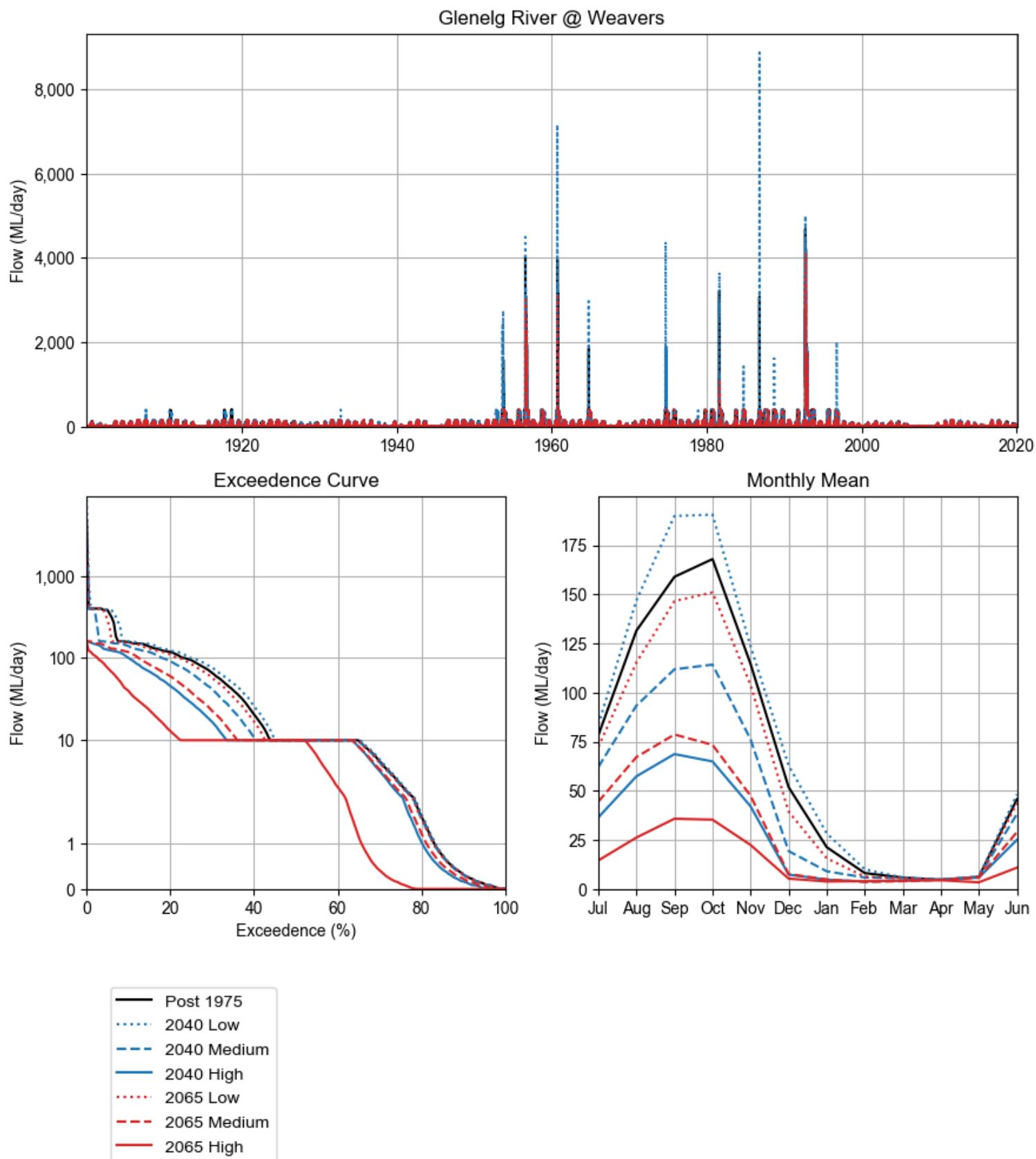
Appendix L Glenelg model results

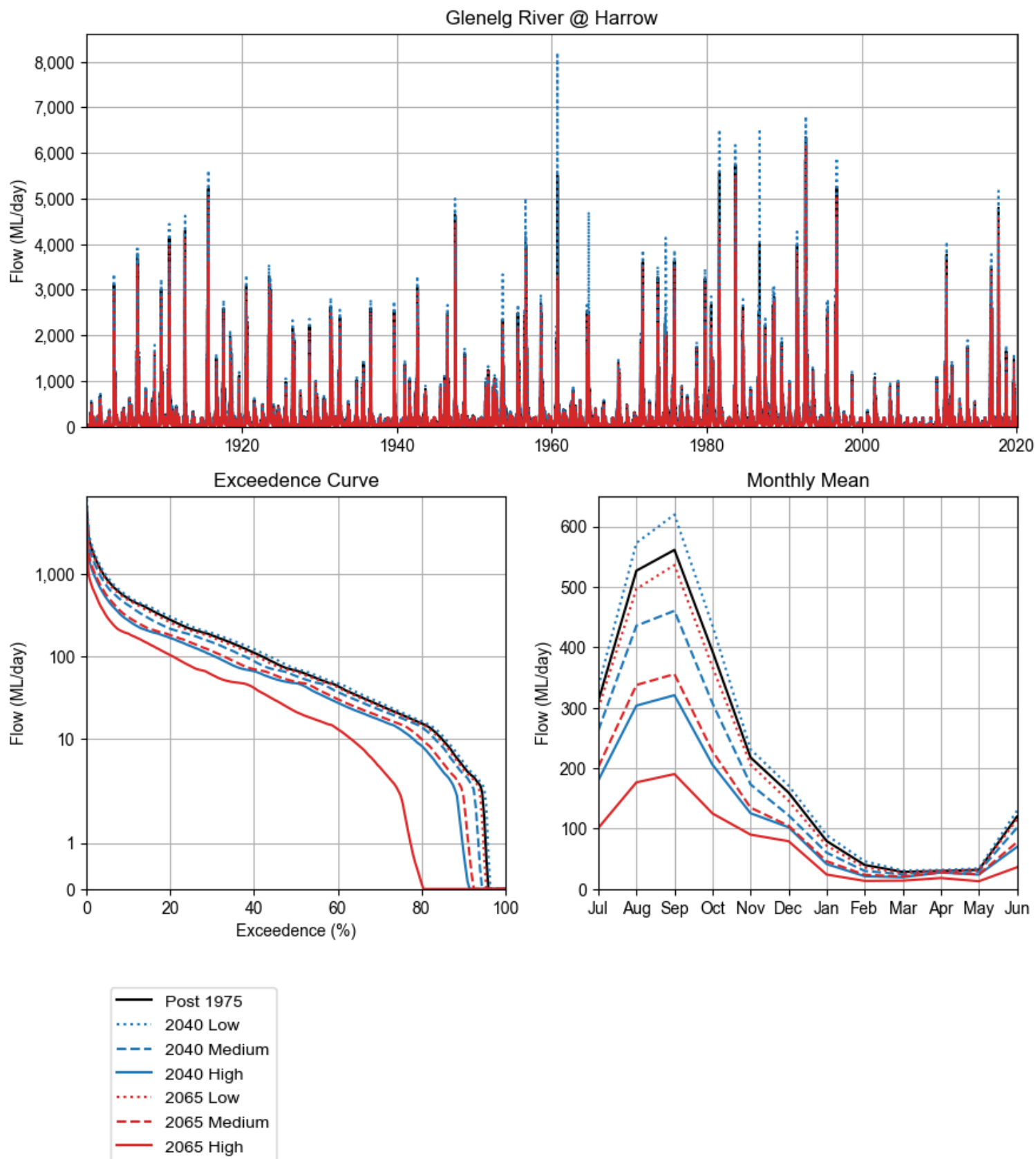
L.1 Environmental entitlement allocations

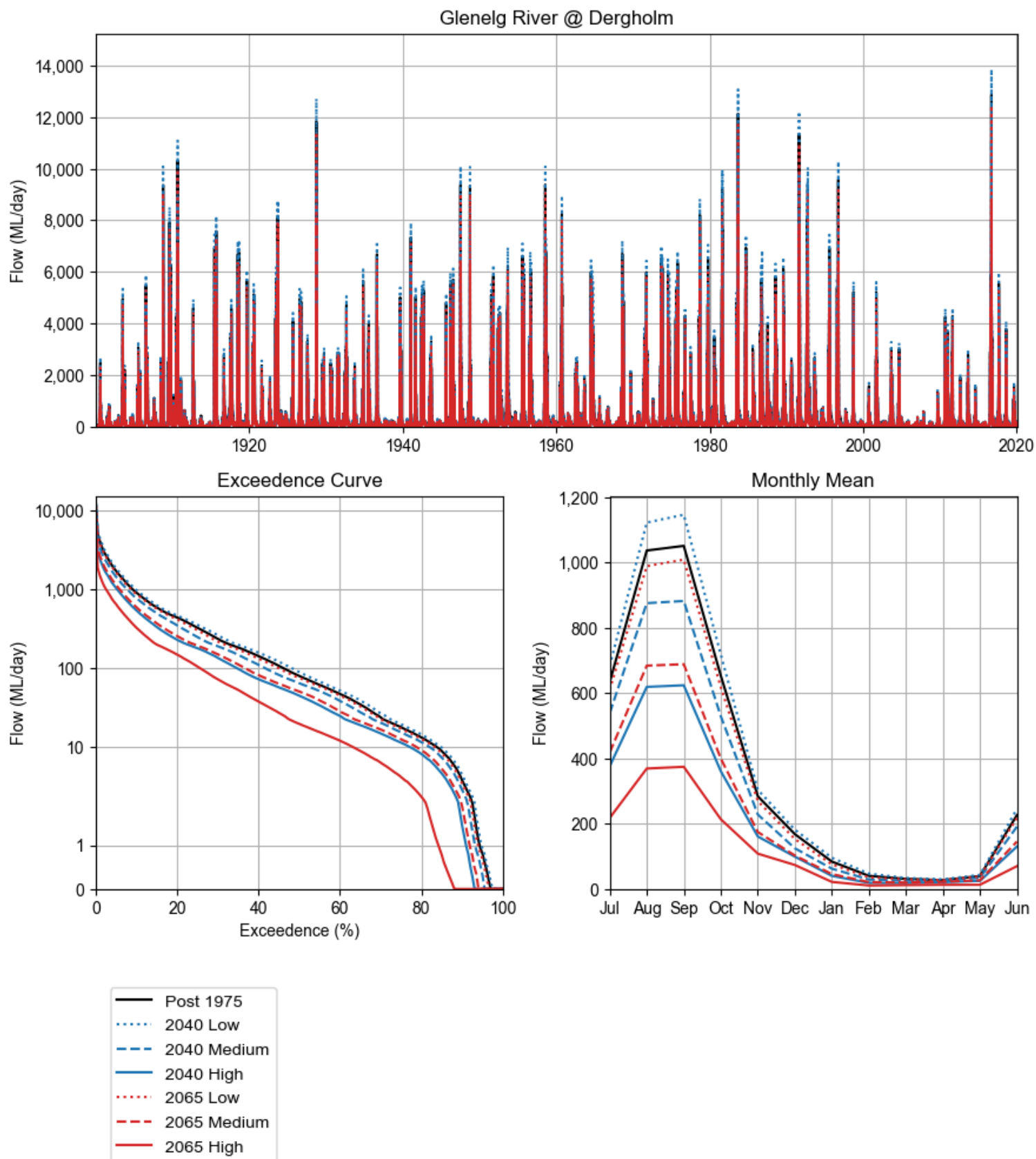


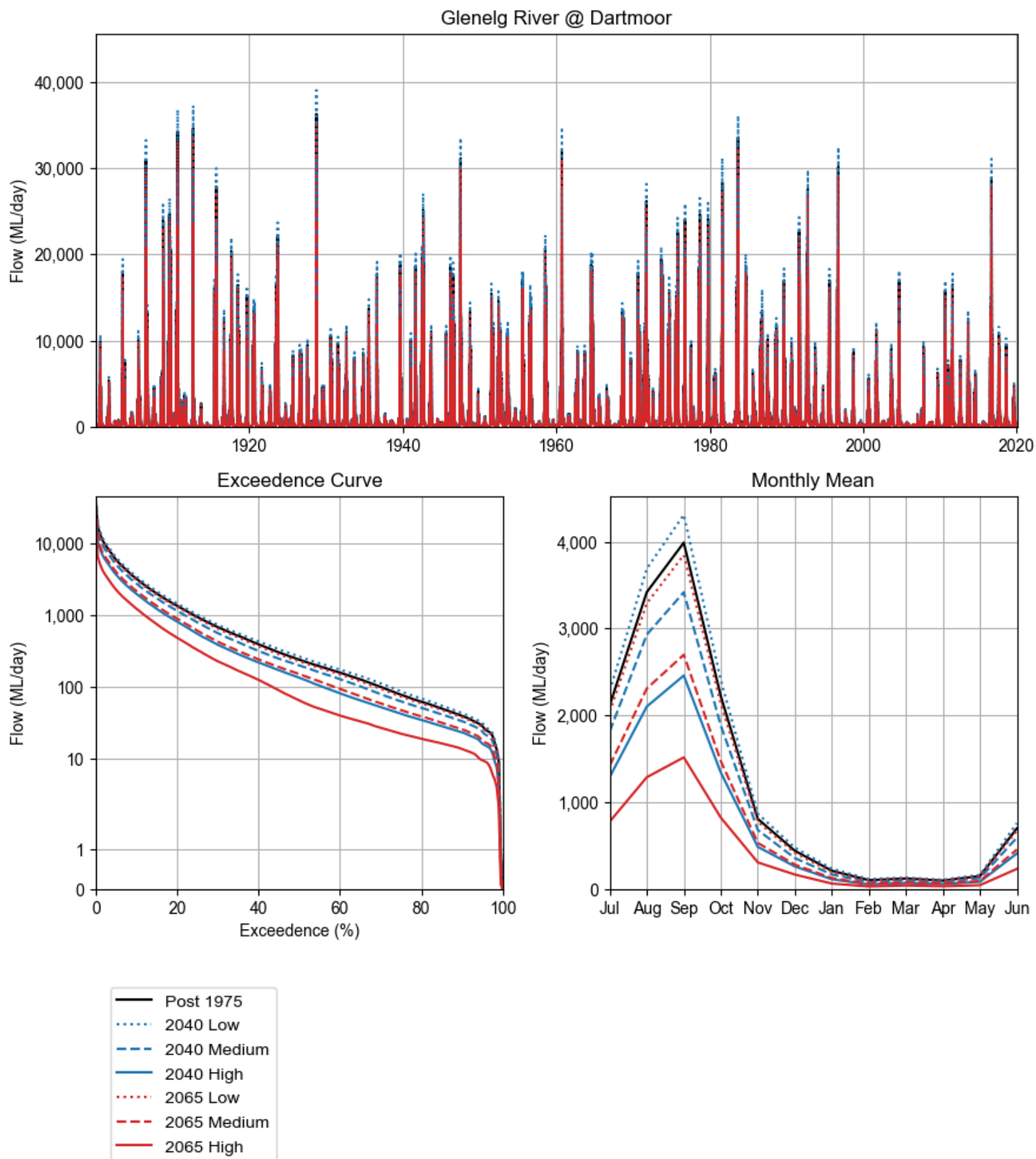
L.2 Streamflow











L.3 Hydrologic indicators

Table 39: Hydrological indicators for the Glenelg River @ Weavers

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	67	75	46	27	59	31	14
MA13 (ML/d)	8.1	10	5.8	3.8	6.2	3.6	4.0
MA19 (ML/d)	132	147	93	57	115	67	26
MH26	17	21	13	10	14	10	9.5
DL16 (days)	19	19	19	21	19	20	33
DL18 (days)	18	17	18	30	18	24	89
Avg0Dur (days)	9.3	8.9	9.4	14	9.4	12	28
Max0Dur (days)	108	108	108	292	108	232	590

Table 40: Hydrological indicators for the Glenelg River @ Harrow

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	209	228	170	121	198	133	74
MA13 (ML/d)	40	46	30	21	35	23	13
MA19 (ML/d)	527	573	436	303	497	338	176
MH26	18	19	18	15	18	16	13
DL16 (days)	31	29	29	37	30	33	55
DL18 (days)	15	13	21	32	17	28	72
Avg0Dur (days)	17	17	17	17	17	17	22
Max0Dur (days)	64	64	64	143	152	162	201

Table 41: Hydrological indicators for the Glenelg River @ Dergholm

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	358	390	297	209	341	230	125
MA13 (ML/d)	40	47	29	19	35	21	11
MA19 (ML/d)	1,037	1,122	875	619	989	684	369
MH26	32	33	29	22	32	23	16
DL16 (days)	36	34	38	41	38	40	56
DL18 (days)	12	10	17	26	14	22	45
Avg0Dur (days)*	17	17	19	20	18	19	20
Max0Dur (days)*	65	65	84	90	136	140	142

*A threshold of 1 ML/d instead of 0.1 ML/d was used

Table 42: Hydrological indicators for the Glenelg River @ Dartmoor

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	1,204	1,302	1,024	730	1,157	803	445
MA13 (ML/d)	102	114	79	52	93	58	29
MA19 (ML/d)	3,418	3,688	2,929	2,101	3,289	2,308	1,287
MH26	32	33	29	23	31	25	17
DL16 (days)	42	38	47	57	43	52	74
DL18 (days)	0.8	0.7	1.0	0.6	1.0	0.6	1.8
Avg0Dur (days)	11	11	11	13	11	12	14
Max0Dur (days)	83	82	83	115	83	114	121

L.4 eFlow Projector results

Table 43: Average success (%) – flow targets for the Glenelg River @ Weavers. Targets shown in red were not ordered in the Source model.

Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	51	52	51	51	51	50	44
Winter/spring low flow	86	86	86	83	86	84	66
Summer/autumn freshes	54	54	50	42	53	47	27
Winter/spring fresh	62	63	60	50	63	54	30
Bankfull	6.1	8.2	1.7	0	2.7	0	0
Overbank	2.9	4.9	0.4	0	1.2	0	0

Table 44: Average success (%) – flow targets for the Glenelg River @ Harrow. Targets shown in red were not ordered in the Source model.

Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	77	78	74	69	76	71	52
Winter/spring low flow	65	66	60	51	64	54	37
Summer/autumn freshes	100	100	99	98	100	99	91
Winter/spring low fresh	67	68	65	60	65	62	46
Winter/spring high fresh	75	77	71	63	75	65	49
Bankfull	60	62	55	46	59	49	33
Overbank	8.0	11	4.1	1.1	6.3	1.6	0.1

Table 45: Average success (%) – flow targets for the Glenelg River @ Dergholm. Targets shown in red were not ordered in the Source model.

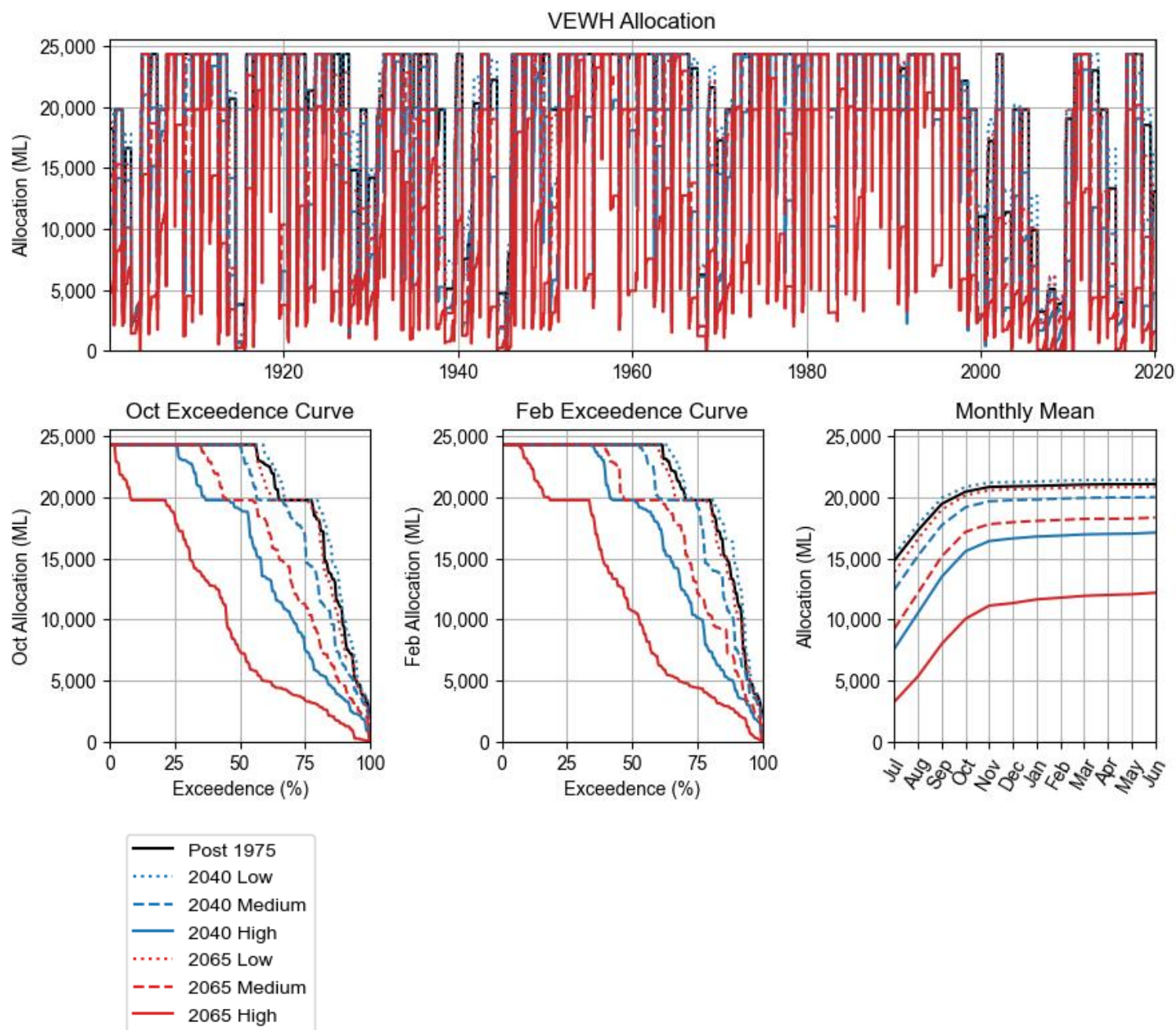
Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	61	63	58	53	60	55	39
Summer/autumn fresh	100	100	99	98	100	99	85
Winter/spring low flow	63	65	59	50	62	52	37
Winter/spring low fresh	60	60	60	63	60	62	58
Winter/spring high fresh	70	71	68	61	70	64	48
Bankfull	42	45	34	19	40	23	5
Overbank	12	15	8.3	3.0	11	4.2	0.5

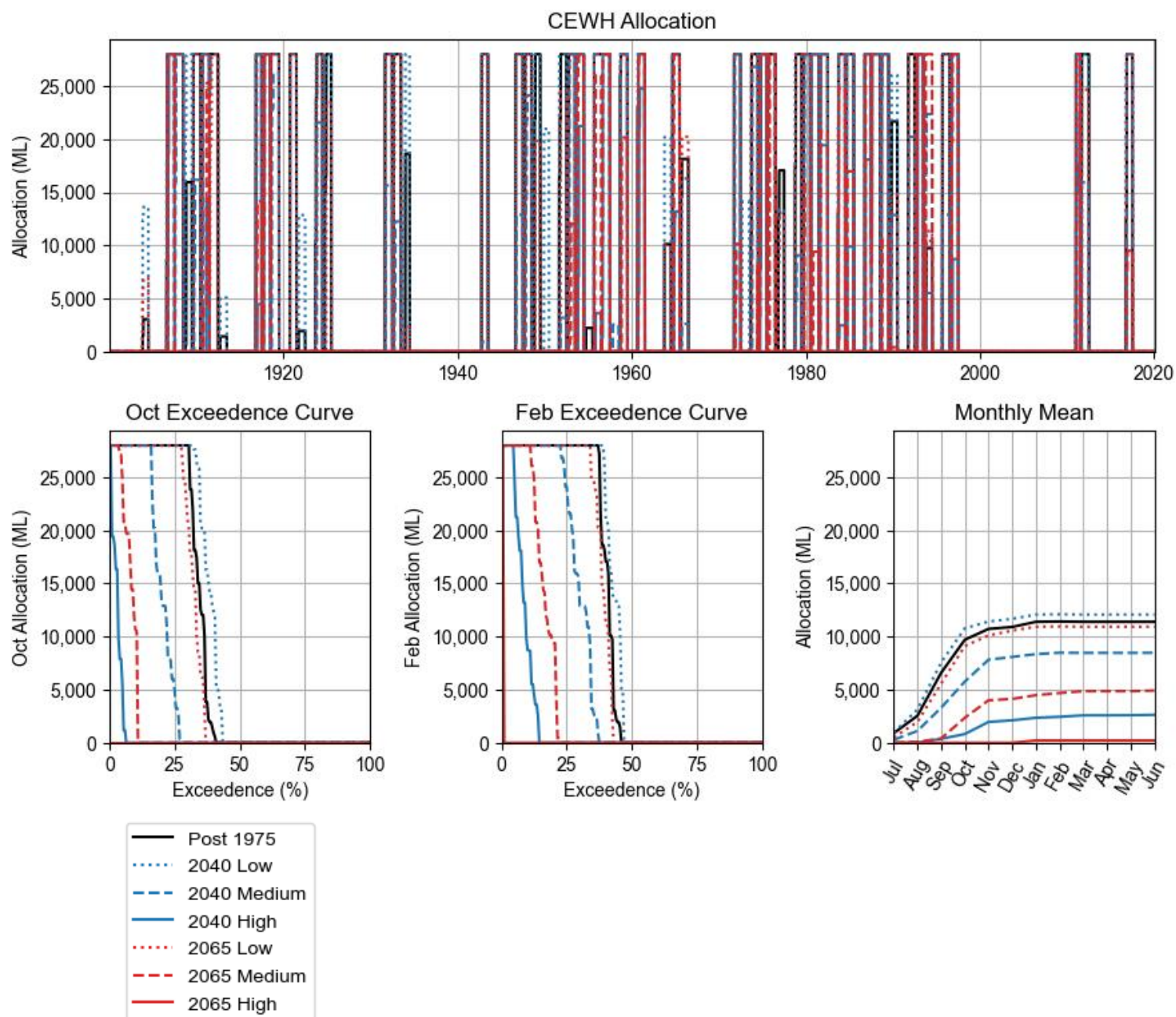
Table 46: Average success (%) – flow targets for the Glenelg River @ Dartmoor. Targets shown in red were not ordered in the Source model.

Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Jan - Apr low flow	60	64	50	32	57	37	14
May - Jun low flow	49	54	42	28	48	31	15
Jul - Dec low flow	80	82	75	66	78	68	53
Summer/autumn fresh	68	72	58	41	66	46	24
Winter/spring low fresh	70	69	68	65	70	67	61
Winter/spring high fresh	65	68	61	52	64	56	34
Bankfull	28	31	22	10	26	14	2.2

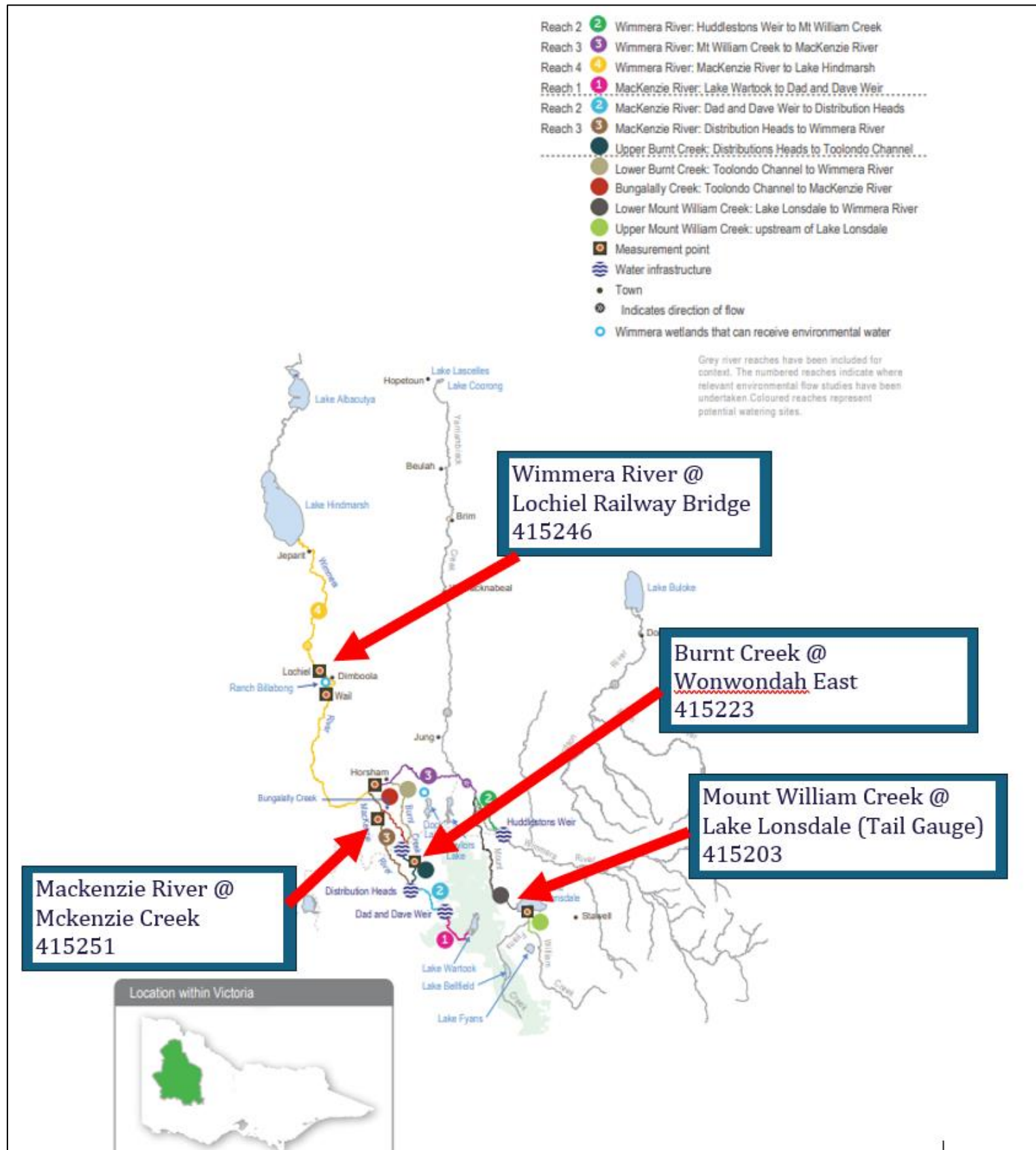
Appendix M Wimmera model results

M.1 Environmental entitlement allocations

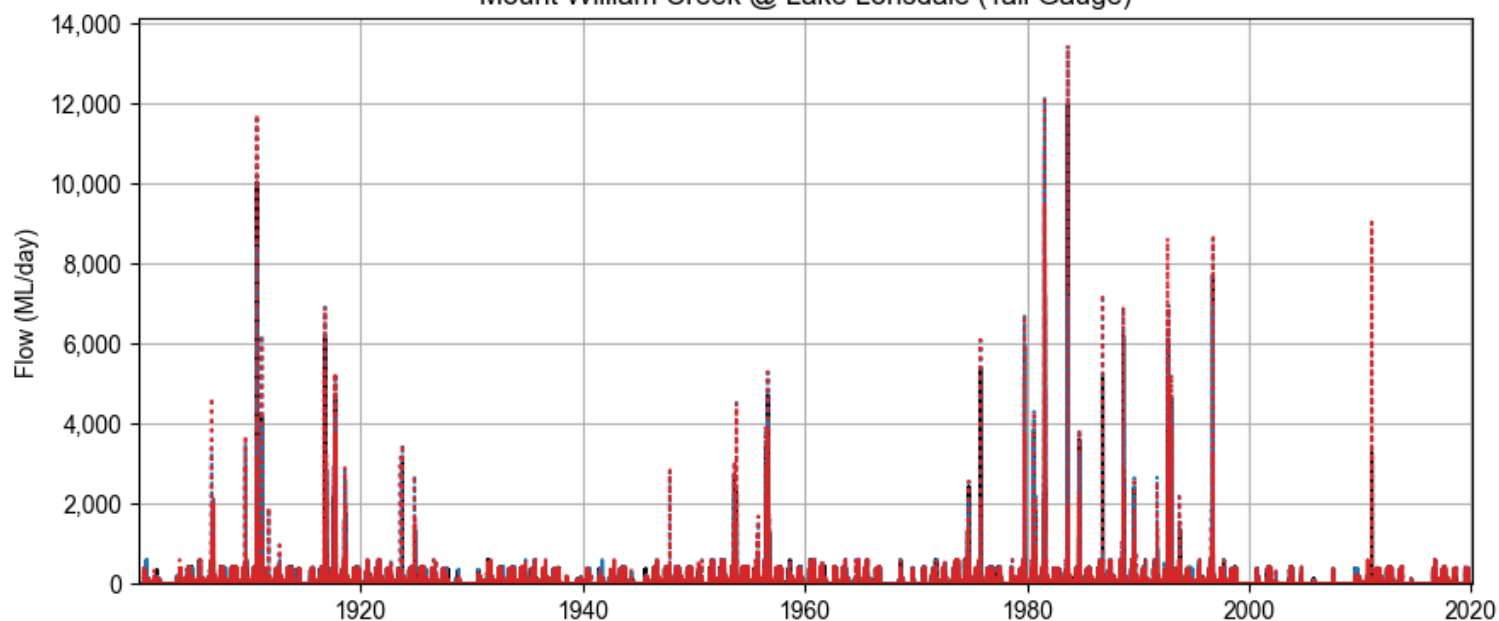




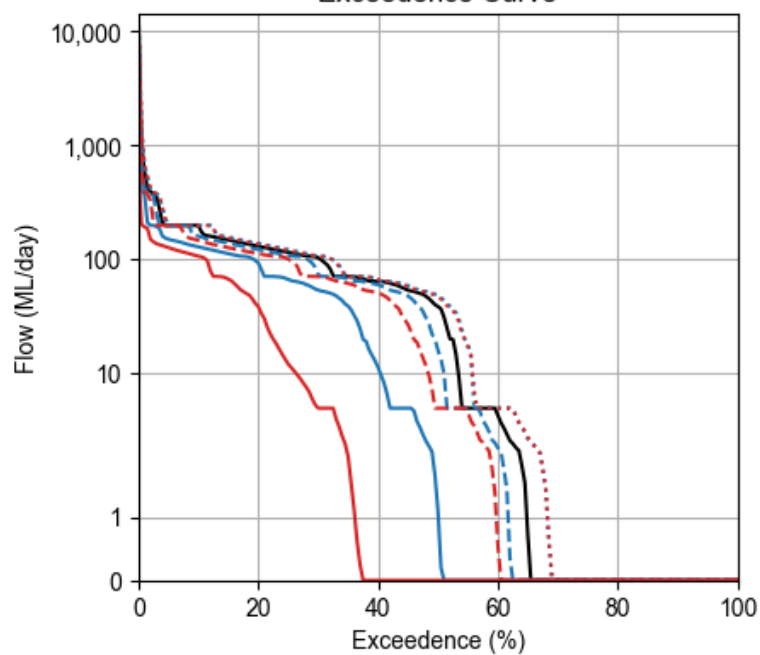
M.2 Streamflow



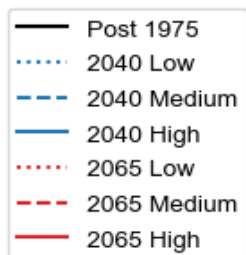
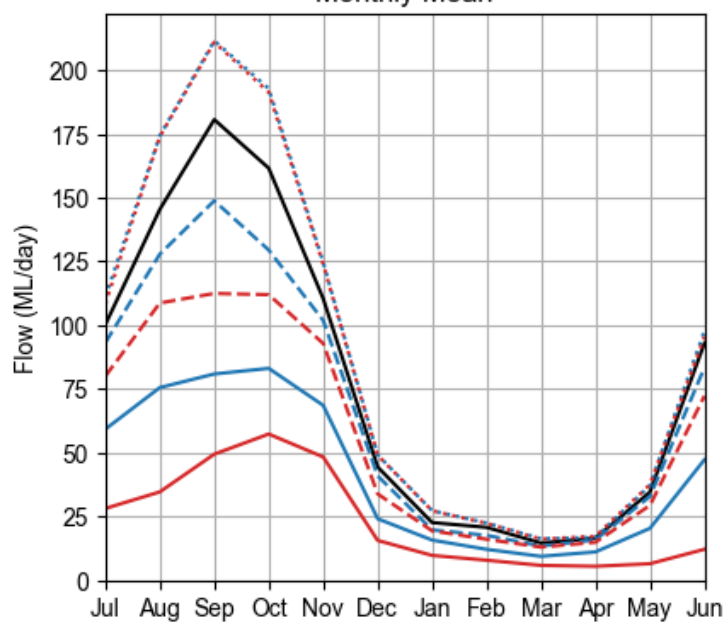
Mount William Creek @ Lake Lonsdale (Tail Gauge)

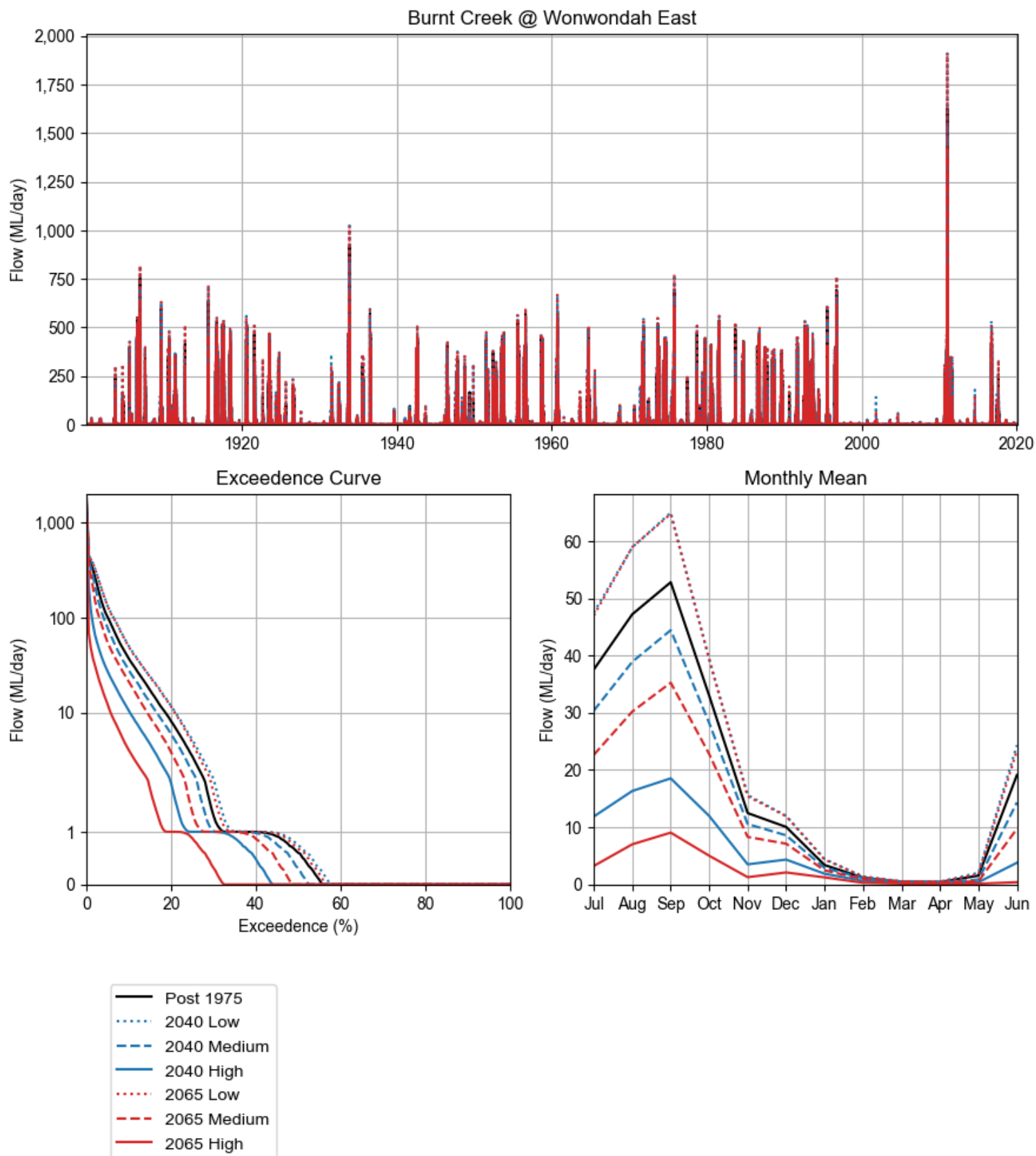


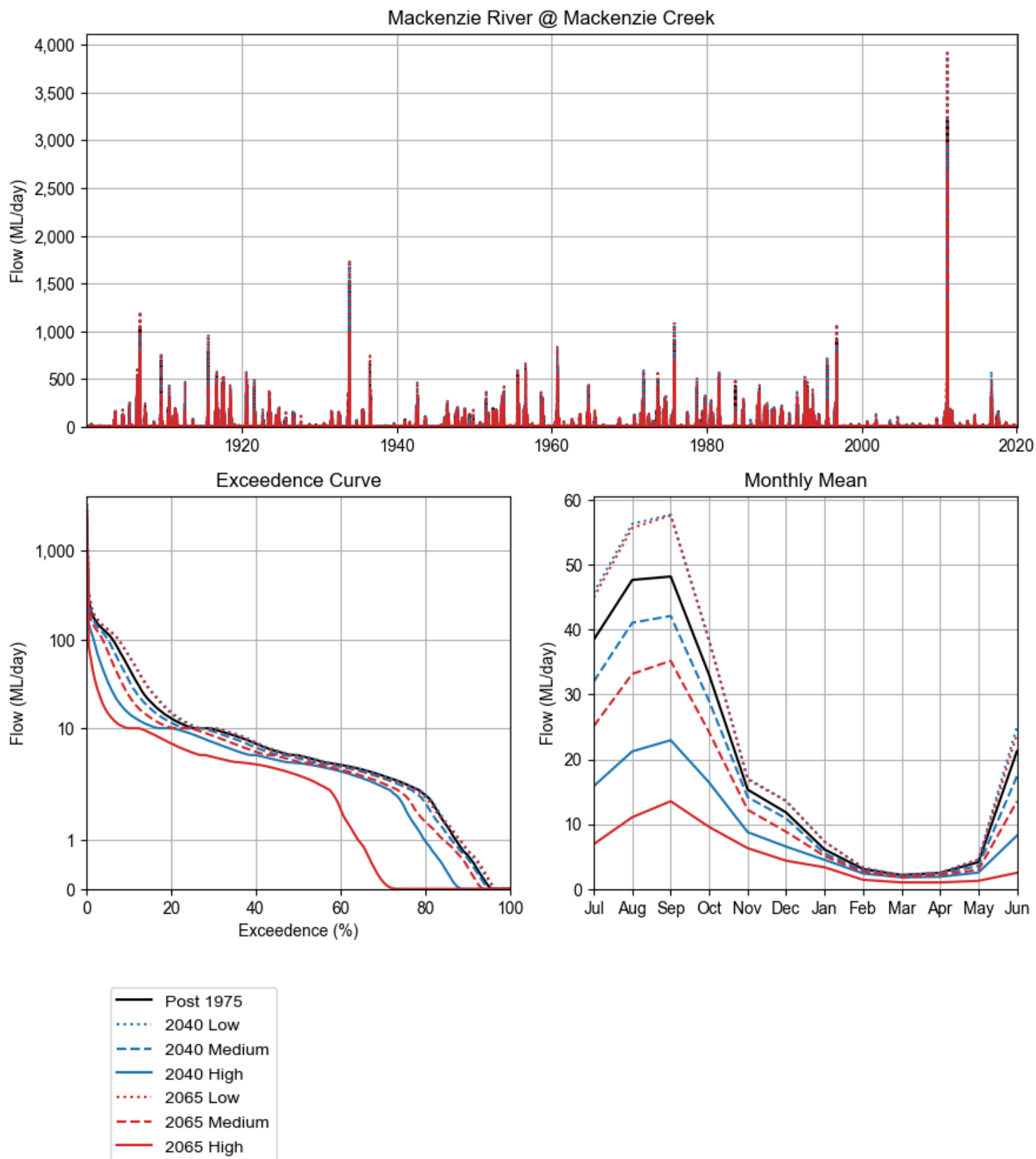
Exceedence Curve

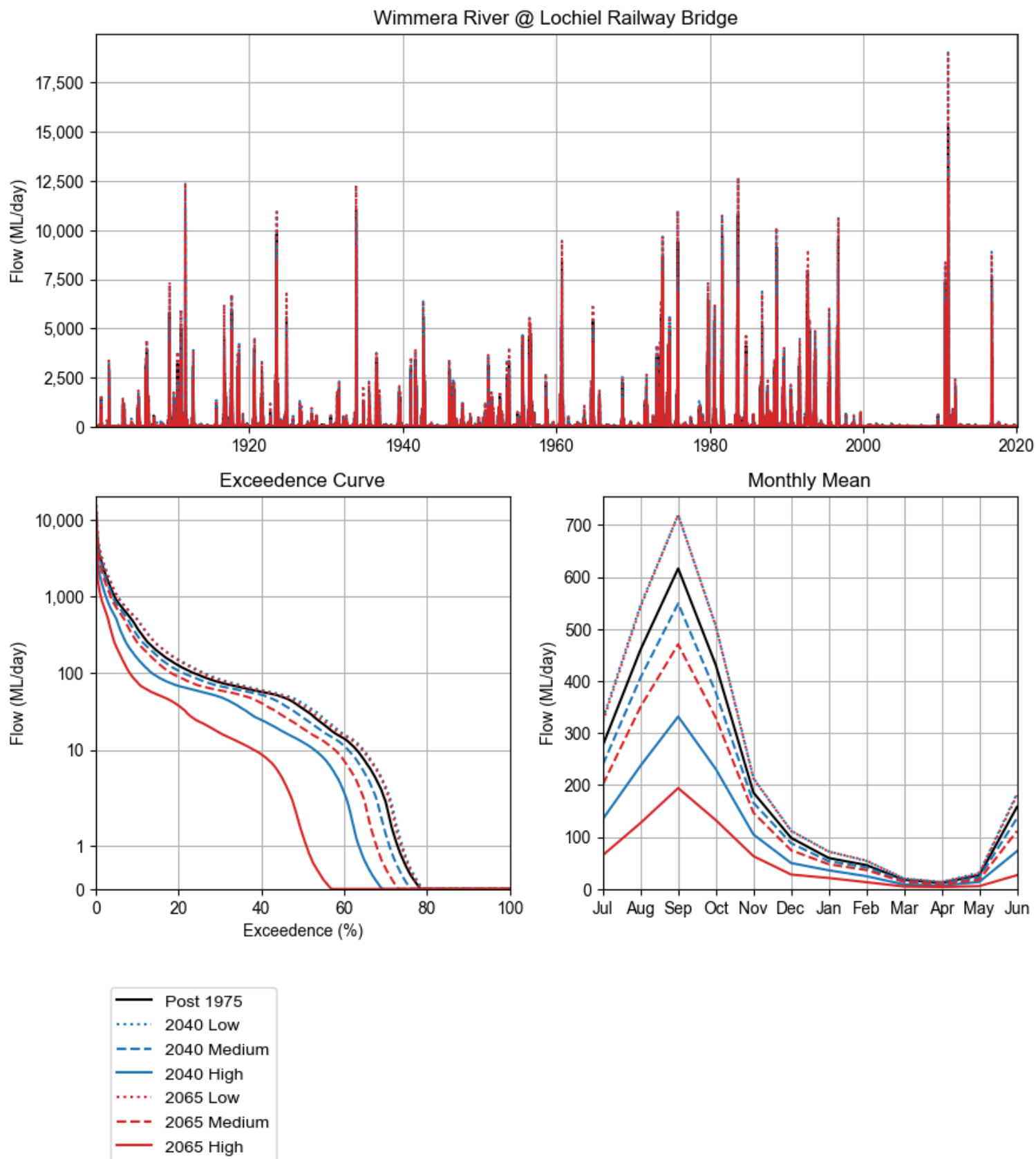


Monthly Mean









M.3 Hydrologic indicators

Table 47: Hydrological indicators for the Mount William Creek @ Lake Lonsdale (Tail Gauge)

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	79	91	69	42	90	59	24
MA13 (ML/d)	21	23	18	12	23	16	7.9
MA19 (ML/d)	145	174	128	76	174	109	35
MH26	26	27	21	11	27	17	8.4
DL16 (days)	49	36	53	48	35	47	68
DL18 (days)	126	113	137	180	113	144	229
Avg0Dur (days)	45	40	48	70	40	51	118
Max0Dur (days)	694	694	694	1,030	694	695	2,065

Table 48: Hydrological indicators for the Burnt Creek @ Wonwondah East

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	18	23	15	6.2	23	12	2.5
MA13 (ML/d)	1.2	1.4	1.1	0.6	1.4	1.0	0.3
MA19 (ML/d)	47	59	39	16	59	30	7
MH26	75	84	70	48	84	66	30
DL16 (days)	33	31	39	51	32	41	76
DL18 (days)	165	157	176	208	161	190	250
Avg0Dur (days)	23	22	25	32	22	28	48
Max0Dur (days)	214	399	406	558	399	411	784

Table 49: Hydrological indicators for the Mackenzie River @ Mackenzie Creek

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	20	23	17	9.5	23	14	5.2
MA13 (ML/d)	3.1	3.3	2.8	2.4	3.3	2.6	1.4
MA19 (ML/d)	48	56	41	21	56	33	11
MH26	37	40	34	24	41	31	19
DL16 (days)	18	18	18	31	18	22	51
DL18 (days)	20	16	21	47	16	27	107
Avg0Dur (days)	9.1	8.4	10	21	8.5	14	42
Max0Dur (days)	120	111	159	343	106	237	436

Table 50: Hydrological indicators for the Wimmera River @ Lochiel Railway Bridge

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
MA1 (ML/d)	200	234	176	105	233	151	57
MA13 (ML/d)	46	54	41	25	55	36	13
MA19 (ML/d)	460	546	407	237	542	350	127
MH26	37	39	35	29	40	33	23
DL16 (days)	67	65	69	74	64	72	100
DL18 (days)	81	79	90	115	81	101	160
Avg0Dur (days)	26	26	30	38	26	33	49
Max0Dur (days)	223	228	262	481	228	313	327

M.4 eFlow Projector results

Table 51: Average success (%) – flow targets for the Mount William Creek @ Lake Lonsdale (Tail Gauge). Targets shown in red were not ordered in the Source model.

Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	47	50	44	33	50	42	20
Winter/spring low flow	85	87	83	75	87	82	64
Summer/autumn freshes	67	72	64	48	72	62	32
Winter/spring freshes	81	84	79	71	84	78	56
Winter/spring high fresh	62	67	57	42	66	50	30

Table 52: Average success (%) – flow targets for the Burnt Creek @ Wonwondah East. Targets shown in red were not ordered in the Source model.

Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	44	45	41	32	44	37	18
Winter/spring low flow	53	57	50	43	56	47	35
Summer/autumn freshes	11	14	9.3	4.6	13	7.8	1.8
Winter/spring freshes	49	53	44	31	52	40	20
Winter/spring high fresh	53	57	47	30	56	42	13

Table 53: Average success (%) – flow targets for the Mackenzie River @ Mackenzie Creek. Targets shown in red were not ordered in the Source model.

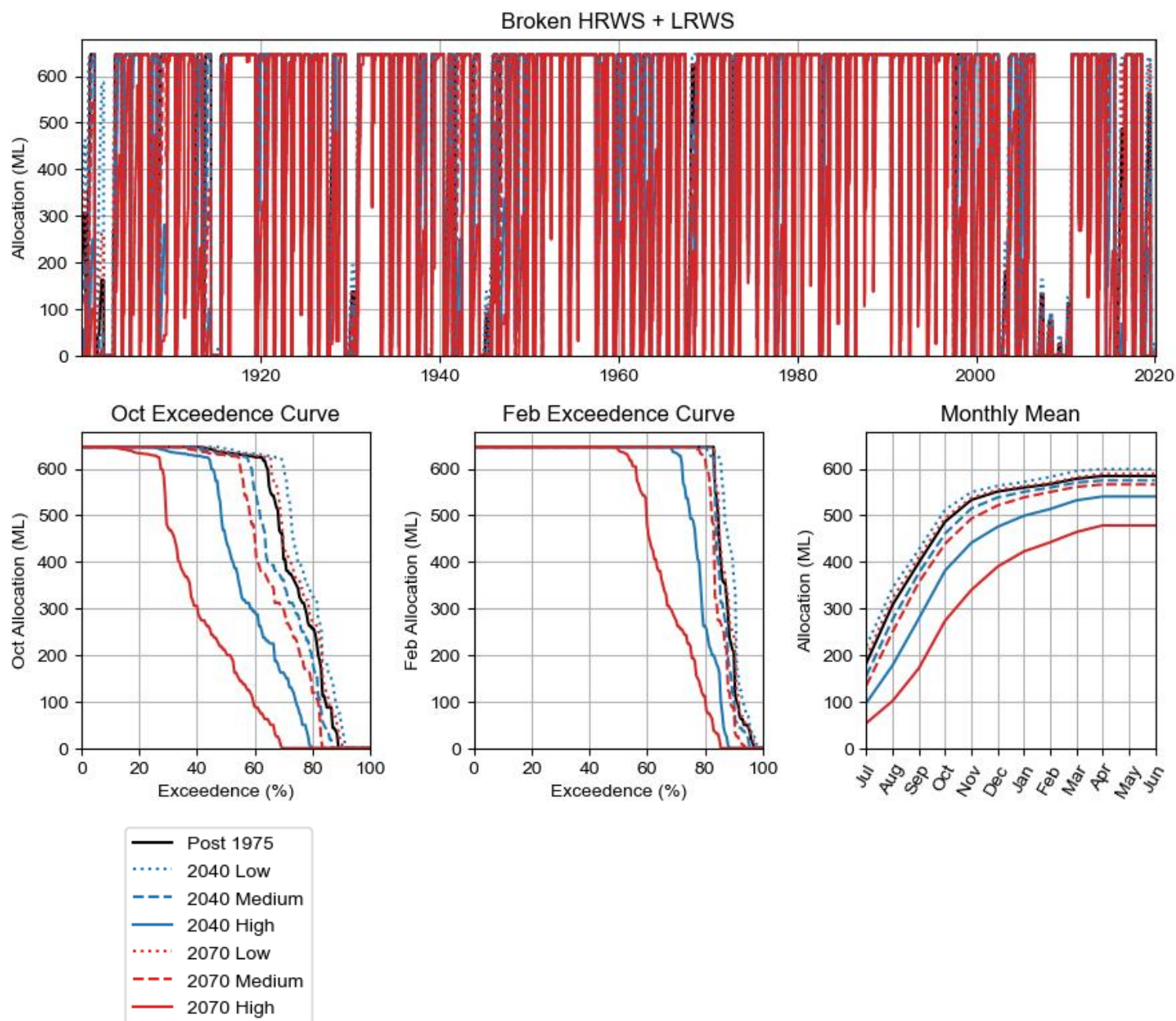
Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	38	38	37	34	37	34	24
Winter/spring low flow	74	75	70	59	74	65	40
Summer/autumn freshes	7.9	9.4	6.7	3.6	9.3	5.5	2.1
Winter/spring freshes	49	52	45	34	51	42	23
Nov fresh	22	25	20	13	24	18	6.5

Table 54: Average success (%) – flow targets for the Wimmera River @ Lochiel Railway Bridge.
Targets shown in red were not ordered in the Source model.

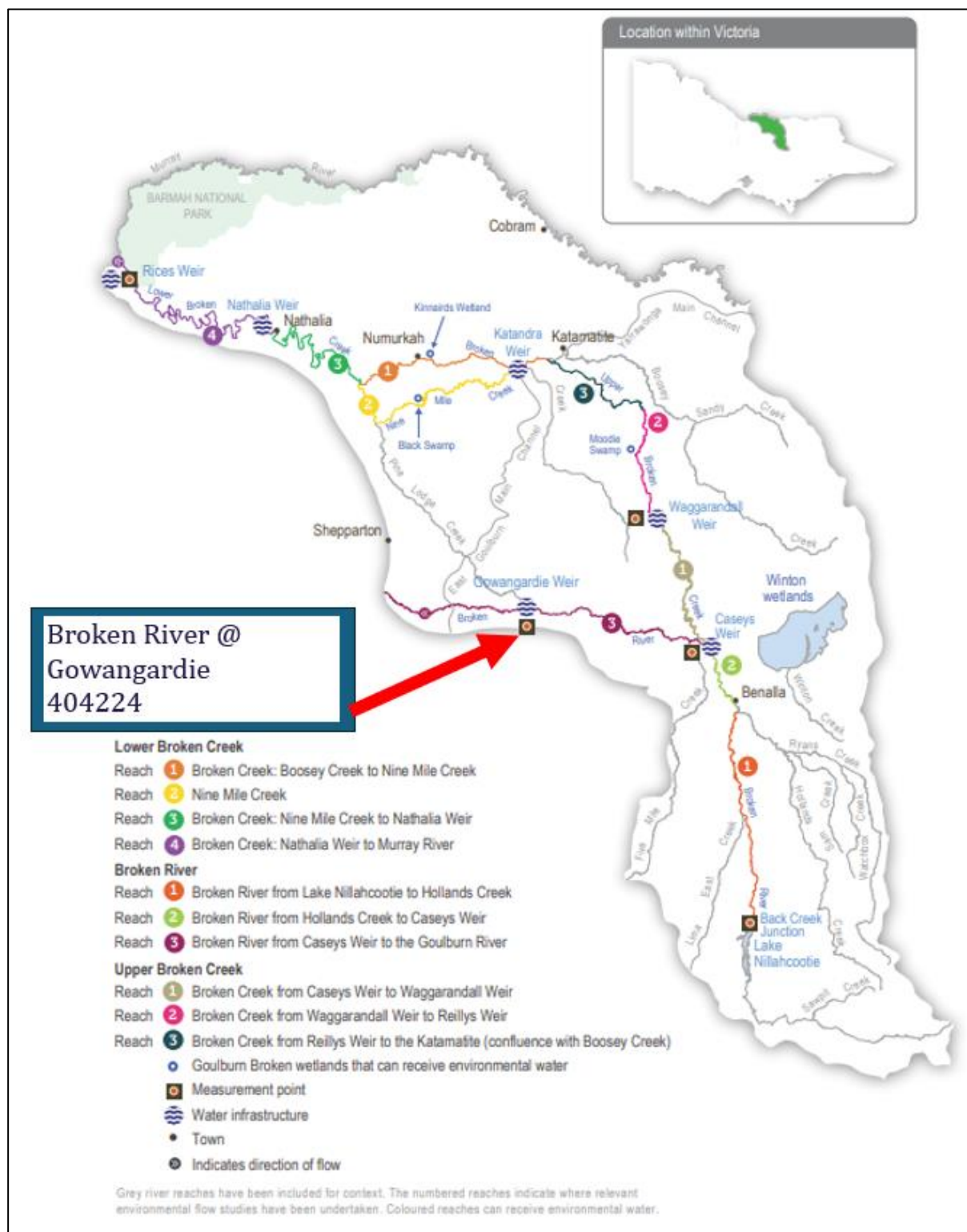
Name	Post 1975	2040 Low	2040 Medium	2040 High	2065 Low	2065 Medium	2065 High
Summer/autumn low flow	36	37	34	28	37	31	19
Winter/spring low flow	89	91	85	70	90	79	46
Summer/autumn freshes	51	55	48	33	54	42	18
Winter/spring low freshes	68	66	66	59	64	63	42
Winter/spring high fresh	76	80	72	58	79	66	47

Appendix N Broken model results

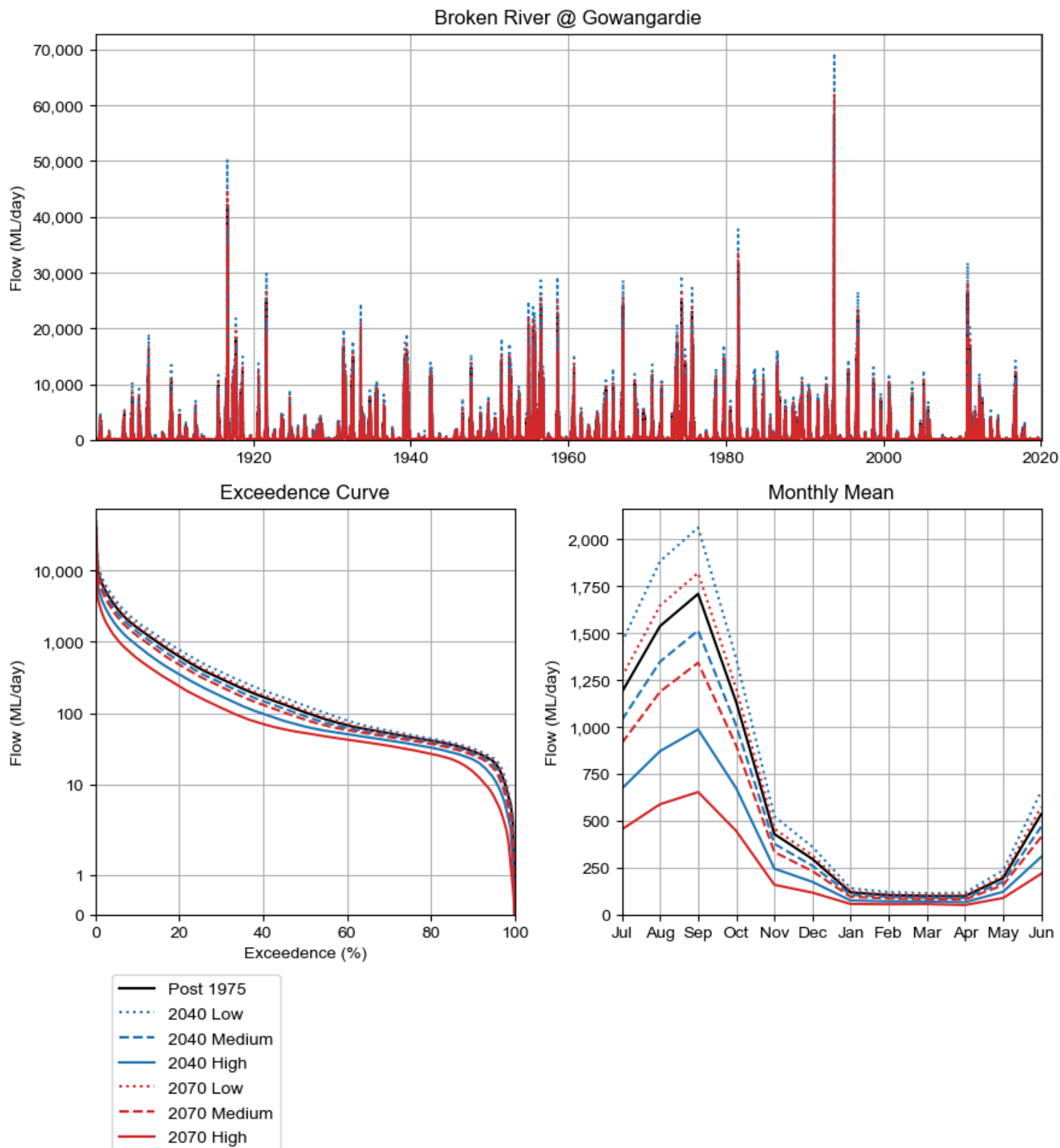
N.1 Environmental entitlement allocations



N.2 Streamflow



Note, analysis for Broken Creek @ Rices Weir (404210) and Broken Creek @ Waggarandall Weir (404239) was requested but not included because it is not modelled in the GBCCL Source Model (Rices Weir) or it is not modelled adequately (Waggarandall Weir – see Appendix S).



N.3 Hydrologic indicators

Table 55: Hydrological indicators for the Broken River @ Gowangardie

VEW00003_R_AdaptingToClimateChange-Stage2-Final

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
MA1 (ML/d)	622	755	549	362	664	487	246
MA13 (ML/d)	104	121	94	71	109	86	55
MA19 (ML/d)	1,537	1,883	1,348	871	1,646	1,187	588
MH26	42	47	39	29	44	35	23
DL16 (days)	17	16	19	26	18	21	37
DL18 (days)	0.1	0.05	0.3	0.7	0.1	0.4	0.9
Avg0Dur (days)	4.5	2.0	6.4	9.3	4.0	8.0	11
Max0Dur (days)	6.0	3.0	19	19	5.0	19	23

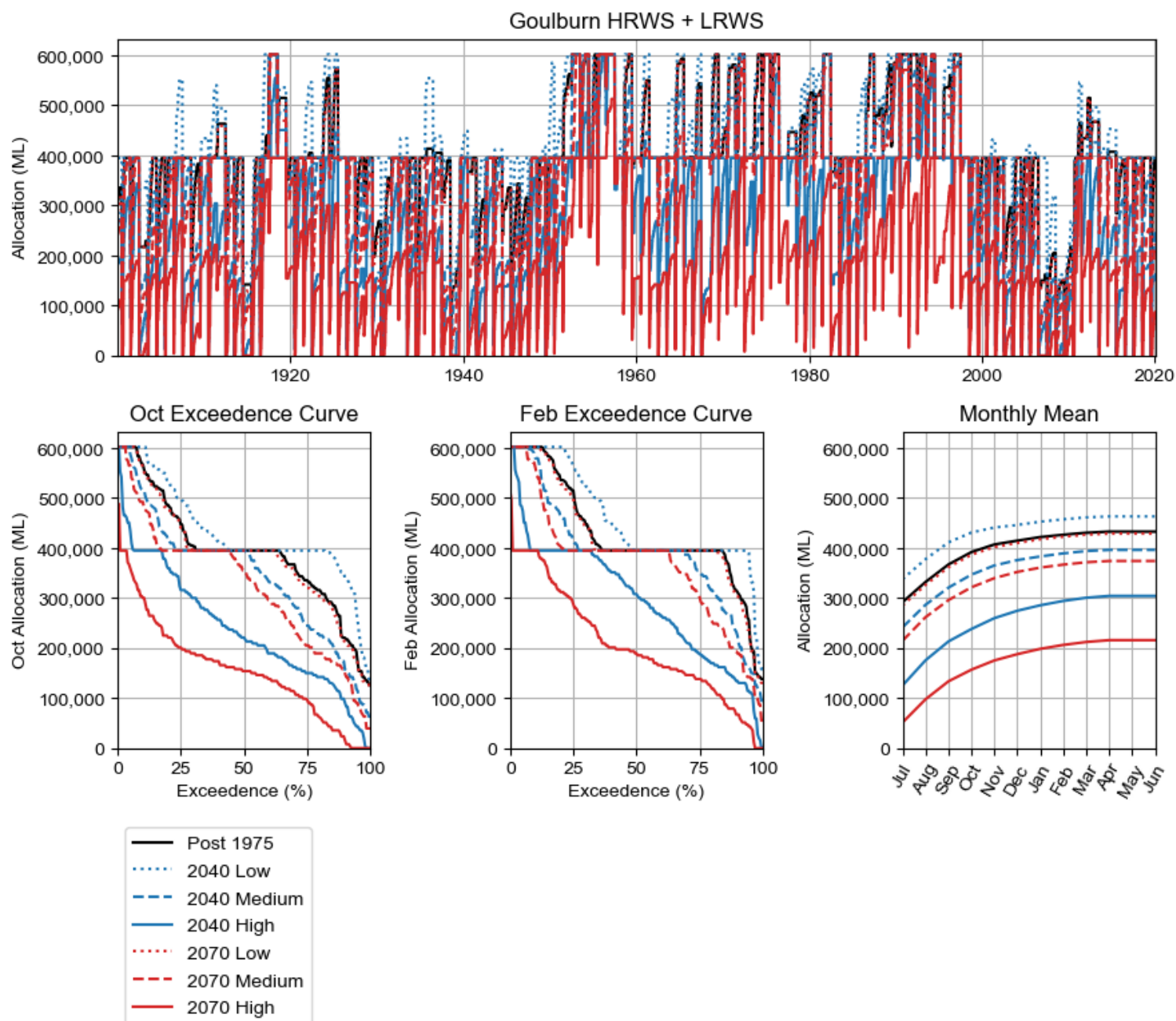
N.4 eFlow Projector results

Table 56: Average success (%) – flow targets for the Broken River @ Gowangardie

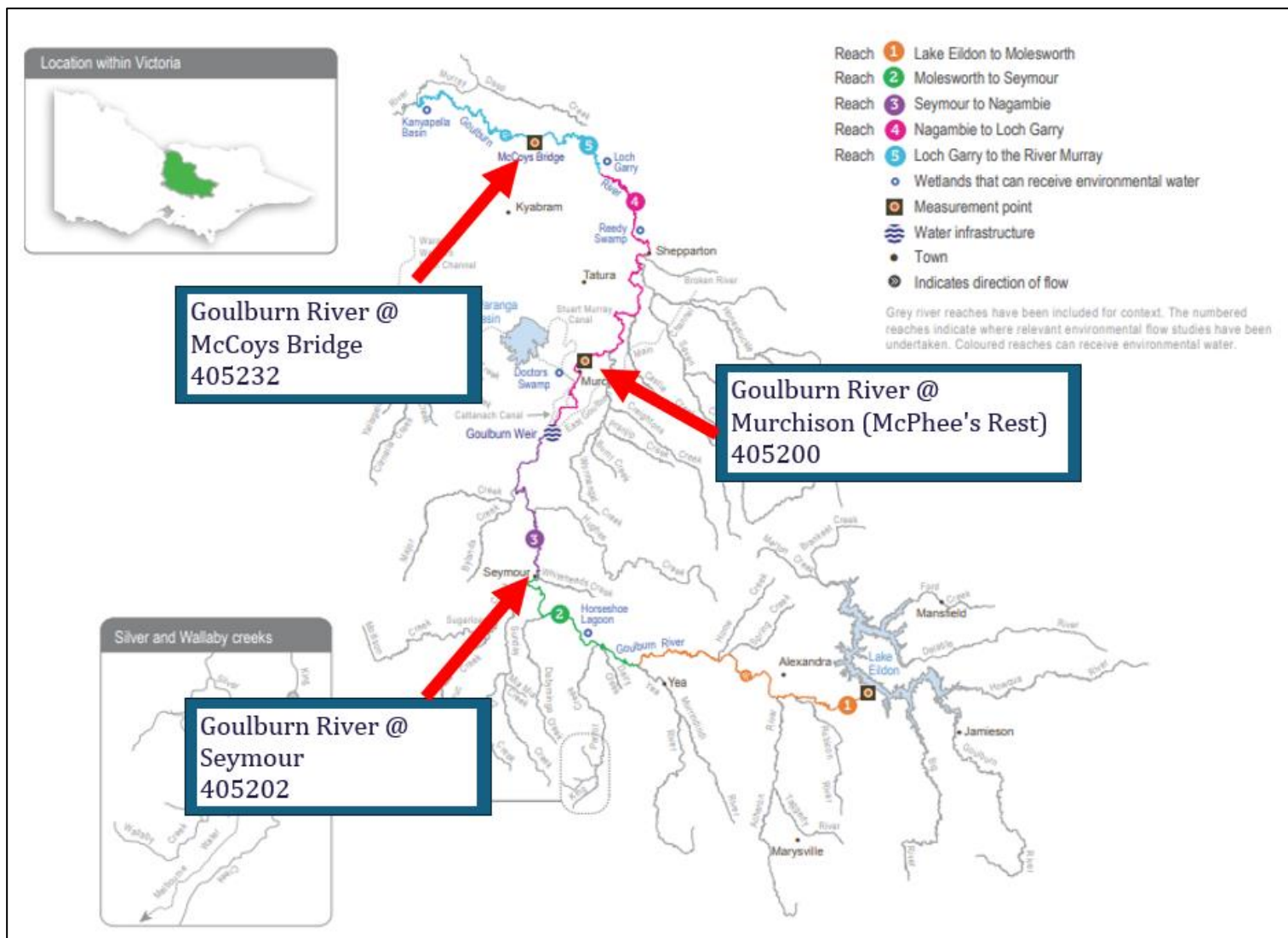
Name	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
Summer/autumn low flow	97	97	96	93	97	95	88
Winter/spring low flow	98	98	98	96	98	97	94
Summer/autumn fresh	67	74	63	44	69	59	32

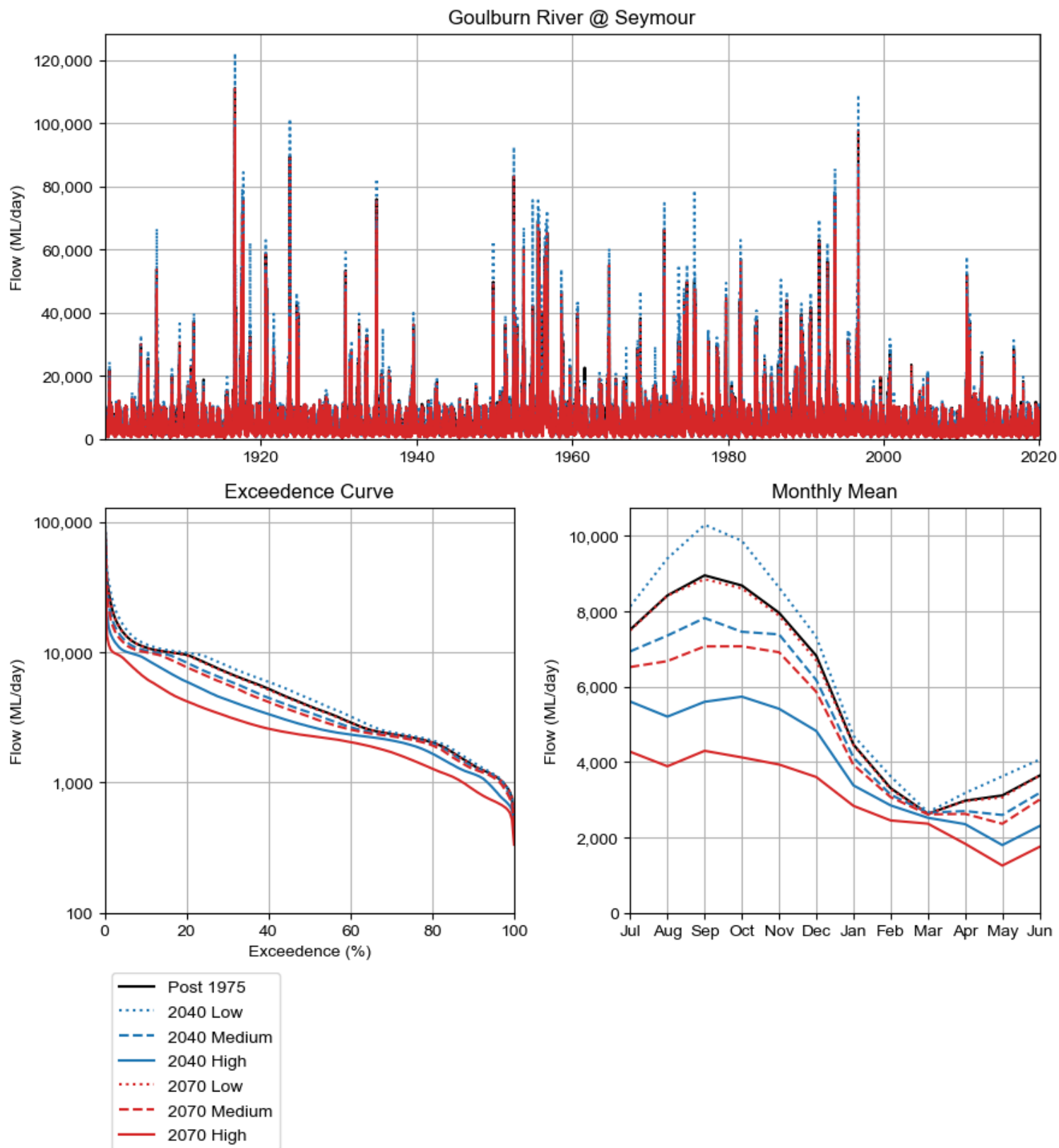
Appendix O Goulburn model results

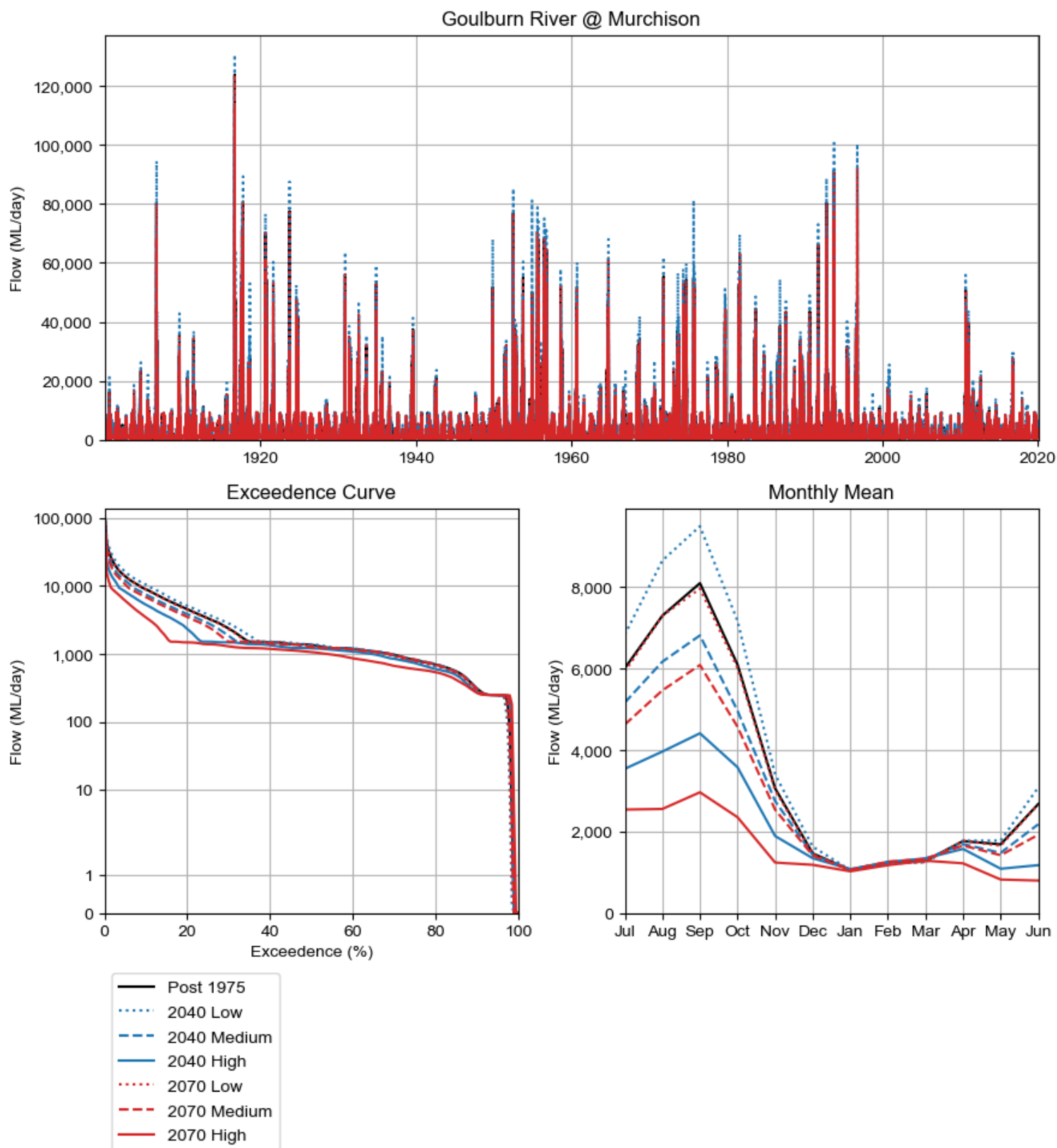
O.1 Environmental entitlement



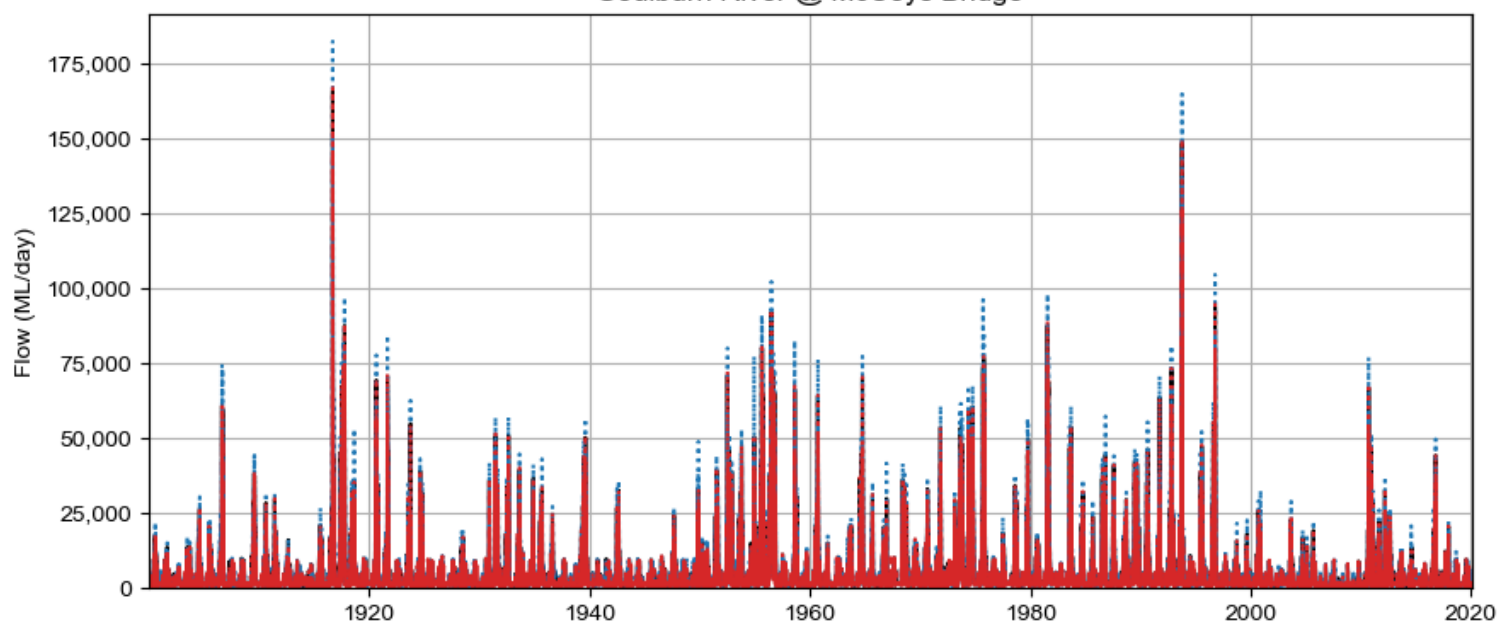
O.2 Streamflow



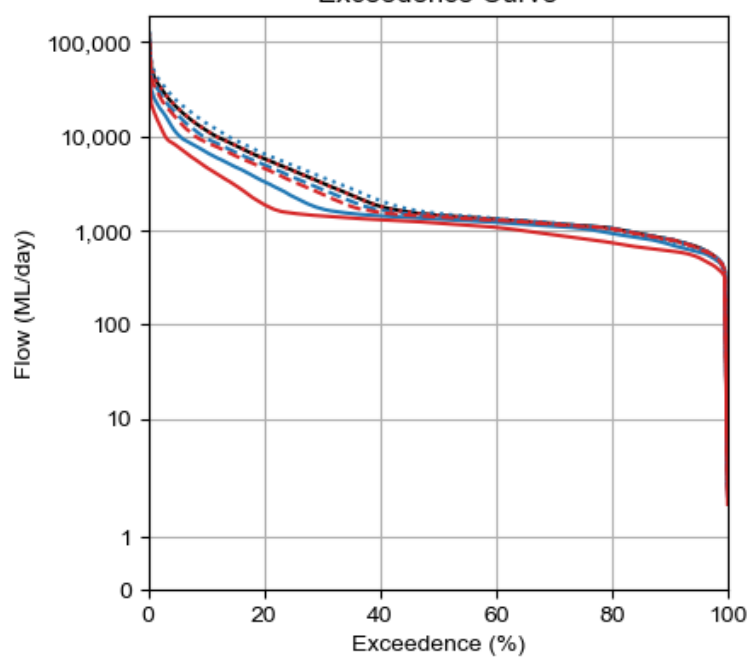




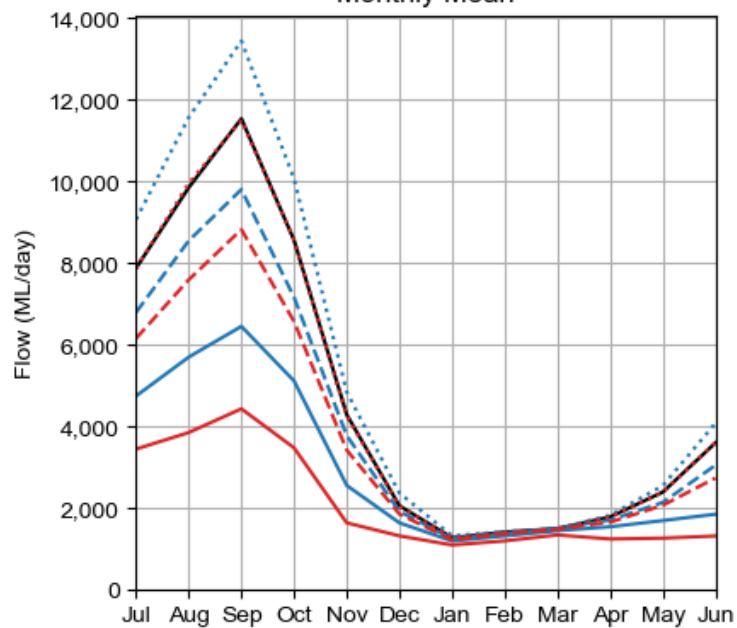
Goulburn River @ McCoys Bridge



Exceedence Curve



Monthly Mean



- Post 1975
- ... 2040 Low
- - - 2040 Medium
- 2040 High
- ... 2070 Low
- - - 2070 Medium
- 2070 High

O.3 Hydrologic indicators

Table 57: Hydrological indicators for the Goulburn River @ Seymour

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
MA1 (ML/d)	5,721	6,305	5,137	3,972	5,678	4,818	3,055
MA13 (ML/d)	3,315	3,632	3,137	2,851	3,282	3,071	2,453
MA19 (ML/d)	8,416	9,397	7,353	5,203	8,410	6,676	3,886
MH26	11	12	11	9.2	11	10	9.2
DL16 (days)	13	12	12	12	13	12	16
DL18 (days)	0	0	0	0	0	0	0
Avg0Dur (days)	0	0	0	0	0	0	0
Max0Dur (days)	0	0	0	0	0	0	0

Table 58: Hydrological indicators for the Goulburn River @ Murchison

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
MA1 (ML/d)	3,484	3,949	3,030	2,190	3,446	2,784	1,600
MA13 (ML/d)	1,242	1,211	1,251	1,244	1,220	1,261	1,176
MA19 (ML/d)	7,286	8,637	6,159	3,957	7,284	5,457	2,551
MH26	16	17	15	14	16	15	13
DL16 (days)	11	12	11	13	12	11	19
DL18 (days)	4.6	5.4	4.7	4.2	5.2	4.6	3.4
Avg0Dur (days)	5.2	5.4	5.3	6.0	5.1	6.1	5.6
Max0Dur (days)	22	25	25	23	23	25	27

Table 59: Hydrological indicators for the Goulburn River @ McCoys Bridge

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
MA1 (ML/d)	4,683	5,344	4,090	2,935	4,681	3,747	2,130
MA13 (ML/d)	1,401	1,410	1,373	1,305	1,378	1,363	1,185
MA19 (ML/d)	9,845	11,564	8,541	5,689	9,945	7,584	3,838
MH26	17	20	17	14	18	16	13
DL16 (days)	14	15	14	18	15	14	34
DL18 (days)	0	0	0	0	0	0	0
Avg0Dur (days)	0	0	0	0	0	0	0
Max0Dur (days)	0	0	0	0	0	0	0

O.4 eFlow Projector results

Table 60: Average success (%) – flow targets for the Goulburn River @ Seymour

Name	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
Summer/autumn low flow	100	100	100	100	100	100	100
Winter/spring low flow	100	100	100	100	100	100	100
Winter fresh	98	98	97	95	98	96	78
Winter/spring freshes	100	100	100	100	100	100	97
Spring fresh	100	100	98	93	100	97	77

Table 61: Average success (%) – flow targets for the Goulburn River @ Murchison

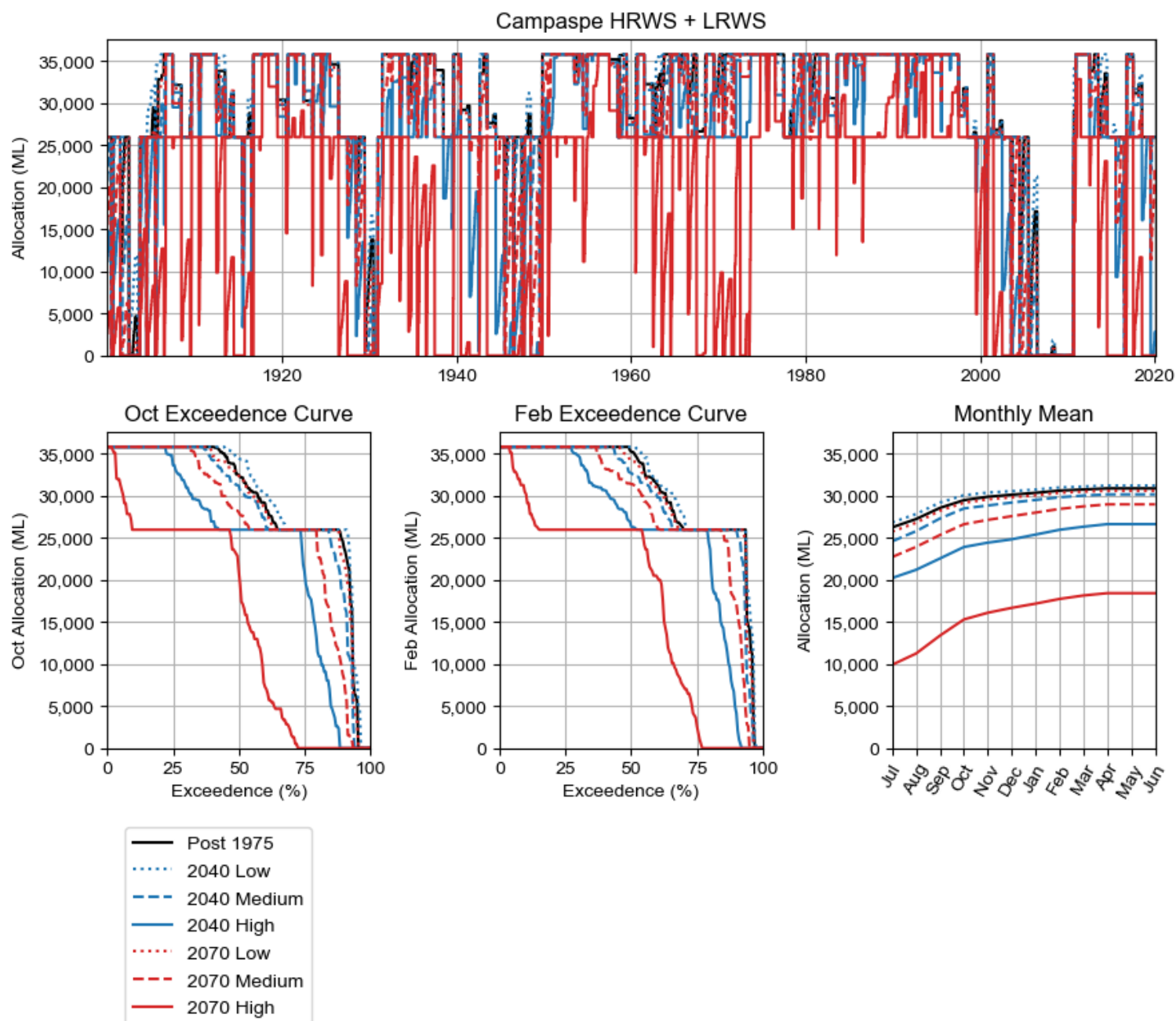
Name	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
Summer/autumn low flow	90	88	91	92	89	91	93
Winter/spring low flow	88	87	87	83	87	86	79
Autumn fresh	62	66	56	48	61	55	28
Winter/autumn fresh	92	93	91	85	92	90	69
Early-spring fresh	79	81	74	63	76	71	53
Late spring fresh	82	85	79	67	81	79	49

Table 62: Average success (%) – flow targets for the Goulburn River @ McCoys Bridge

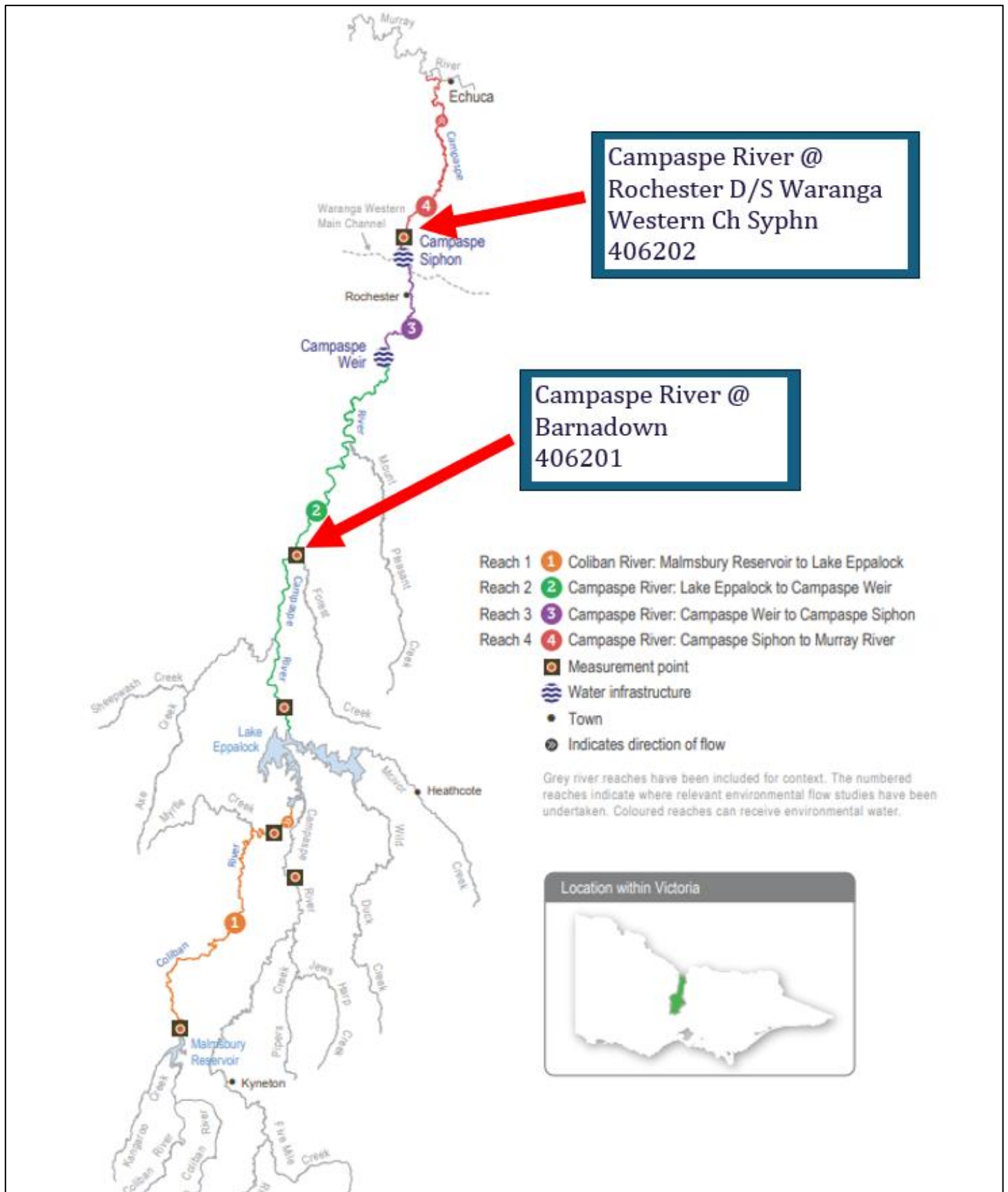
Name	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
Summer/autumn low flow	99	98	99	99	99	99	98
Winter/spring low flow	99	99	99	98	99	99	97
Autumn fresh	55	59	49	41	54	47	26
Early-spring fresh	84	86	82	71	83	80	63
Winter/autumn fresh	92	94	91	86	92	90	71
Late-spring fresh	84	85	81	70	82	79	54

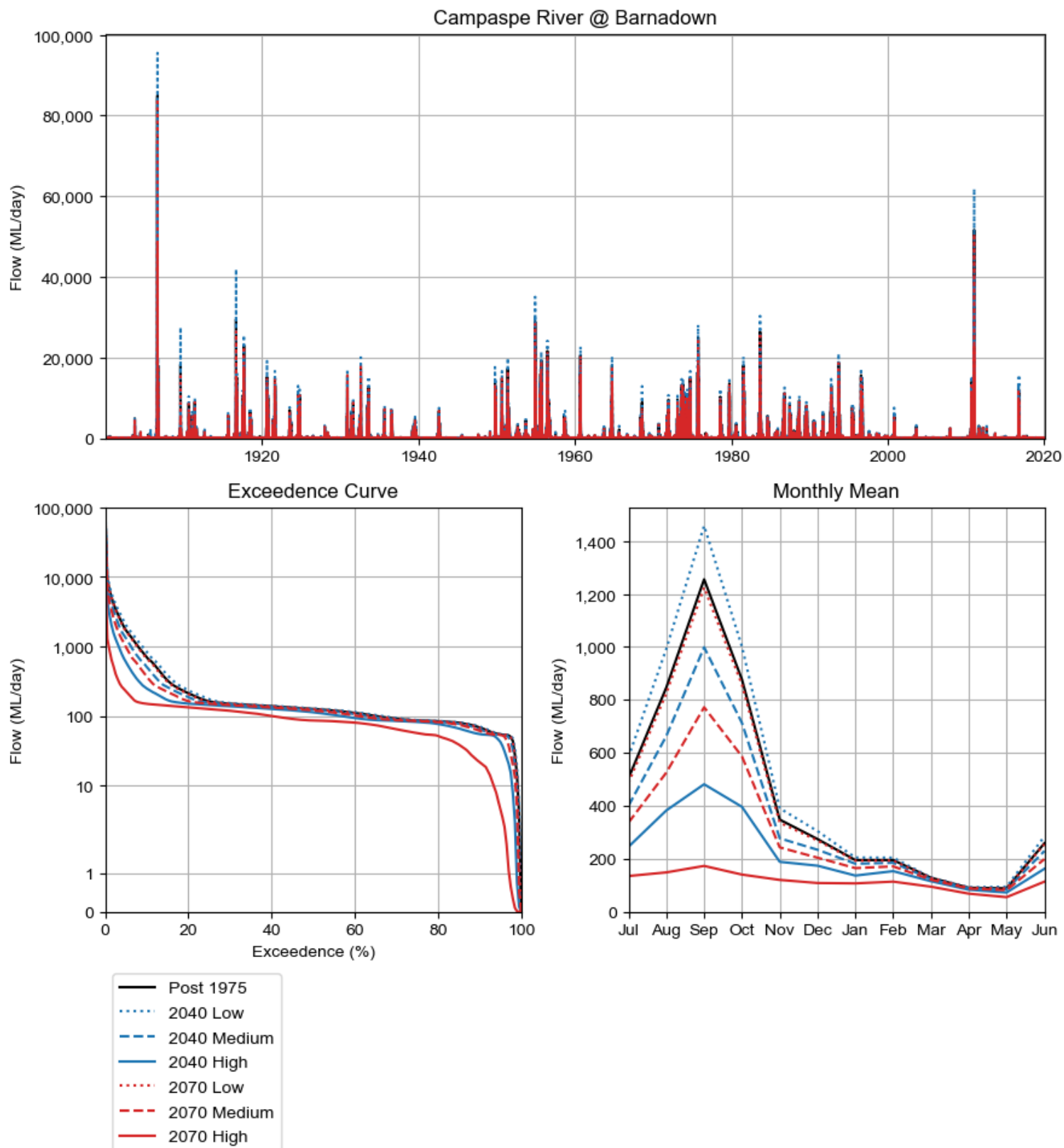
Appendix P Campaspe model results

P.1 Environmental entitlement

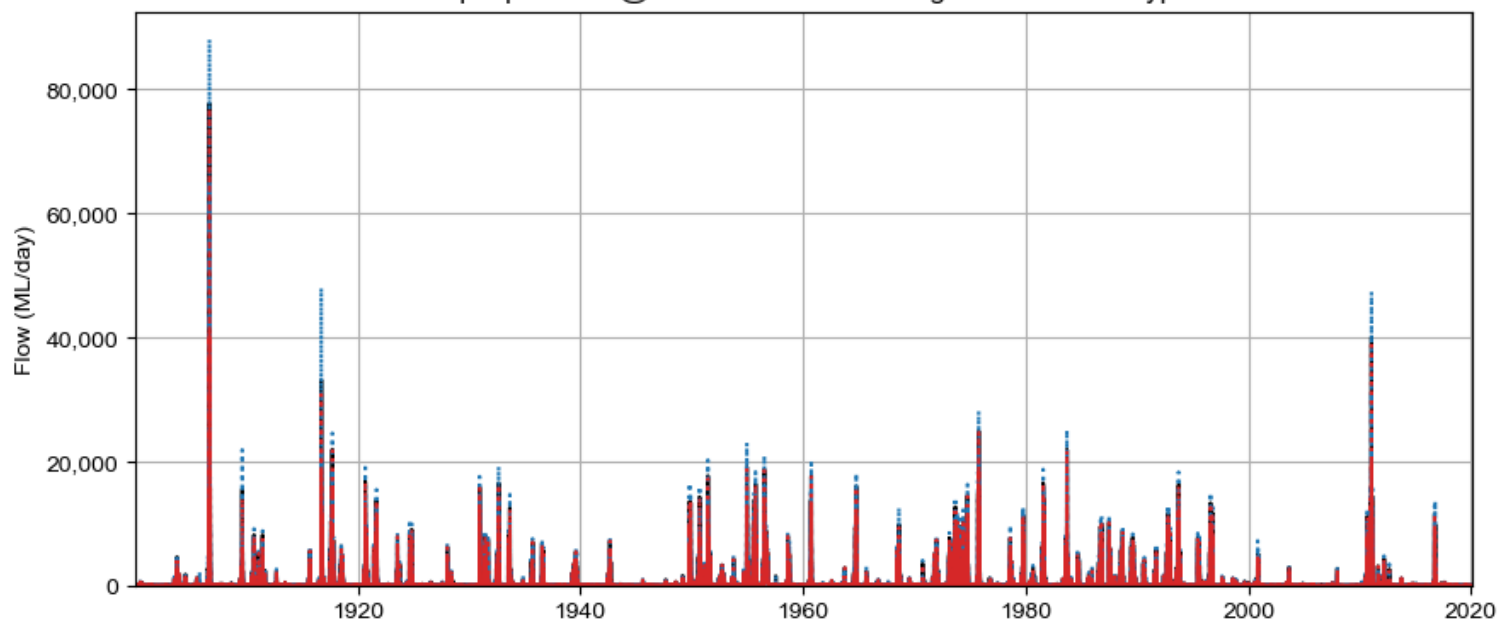


P.2 Streamflow

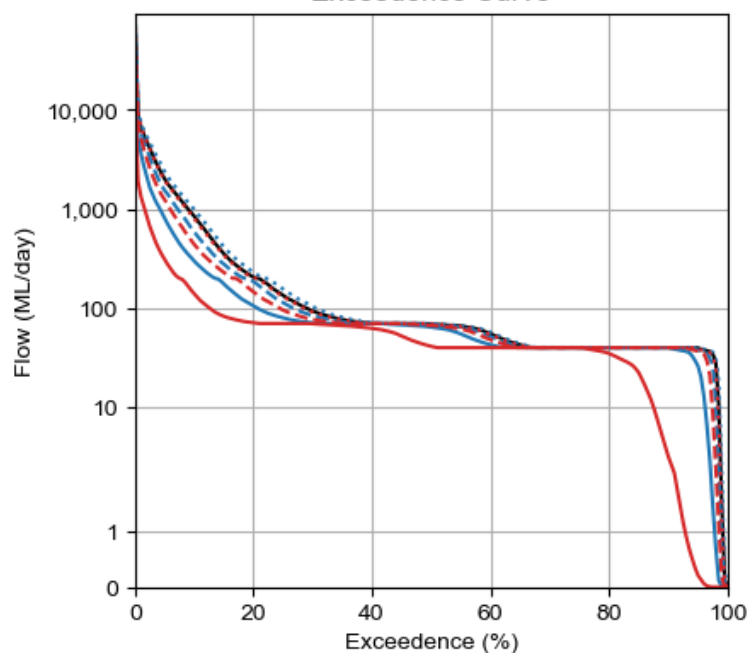




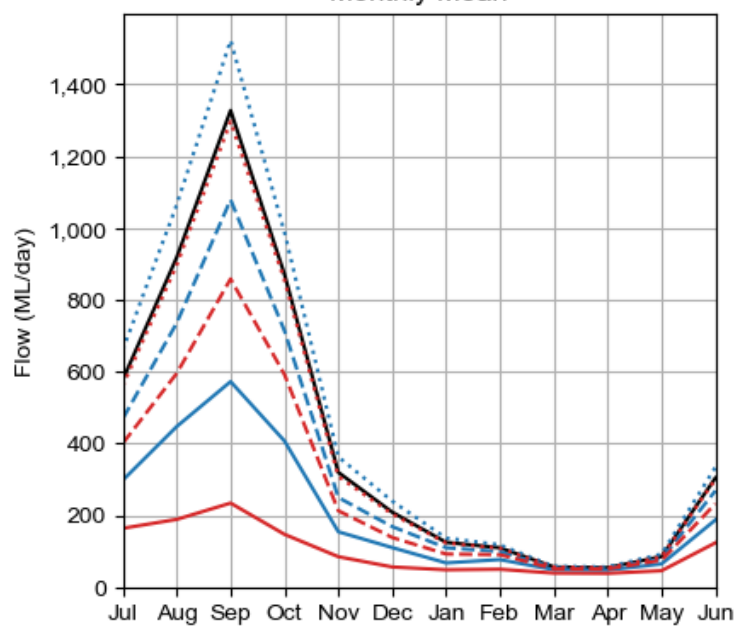
Campaspe River @ Rochester D/S Waranga Western Ch Syphn



Exceedence Curve



Monthly Mean



- Post 1975
- ... 2040 Low
- - - 2040 Medium
- 2040 High
- ... 2070 Low
- - - 2070 Medium
- 2070 High

P.3 Hydrologic indicators

Table 63: Hydrological indicators for the Campaspe River @ Barnadown

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
MA1 (ML/d)	423	480	349	217	413	292	115
MA13 (ML/d)	196	206	186	154	194	172	115
MA19 (ML/d)	847	993	664	383	825	526	149
MH26	38	42	34	24	38	31	17
DL16 (days)	17	15	17	20	16	19	33
DL18 (days)	0.1	0.1	0.4	1.7	0.2	1.1	5.5
Avg0Dur (days)	4.0	4.0	8.0	16	7.5	17	17
Max0Dur (days)	6.0	7.0	18	105	21	61	195

Table 64: Hydrological indicators for the Campaspe River @ Rochester

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
MA1 (ML/d)	414	471	341	207	405	283	102
MA13 (ML/d)	110	119	100	77	109	91	50
MA19 (ML/d)	918	1,065	735	447	897	595	188
MH26	63	70	55	39	62	47	27
DL16 (days)	20	19	22	27	20	22	33
DL18 (days)	1.7	1.4	2.5	5.4	2.0	3.3	16
Avg0Dur (days)	6.1	6.2	10	20	10	10	12
Max0Dur (days)	46	43	129	140	81	127	197

P.4 eFlow Projector results

Table 65: Average success (%) – flow targets for the Campaspe River @ Barnadown

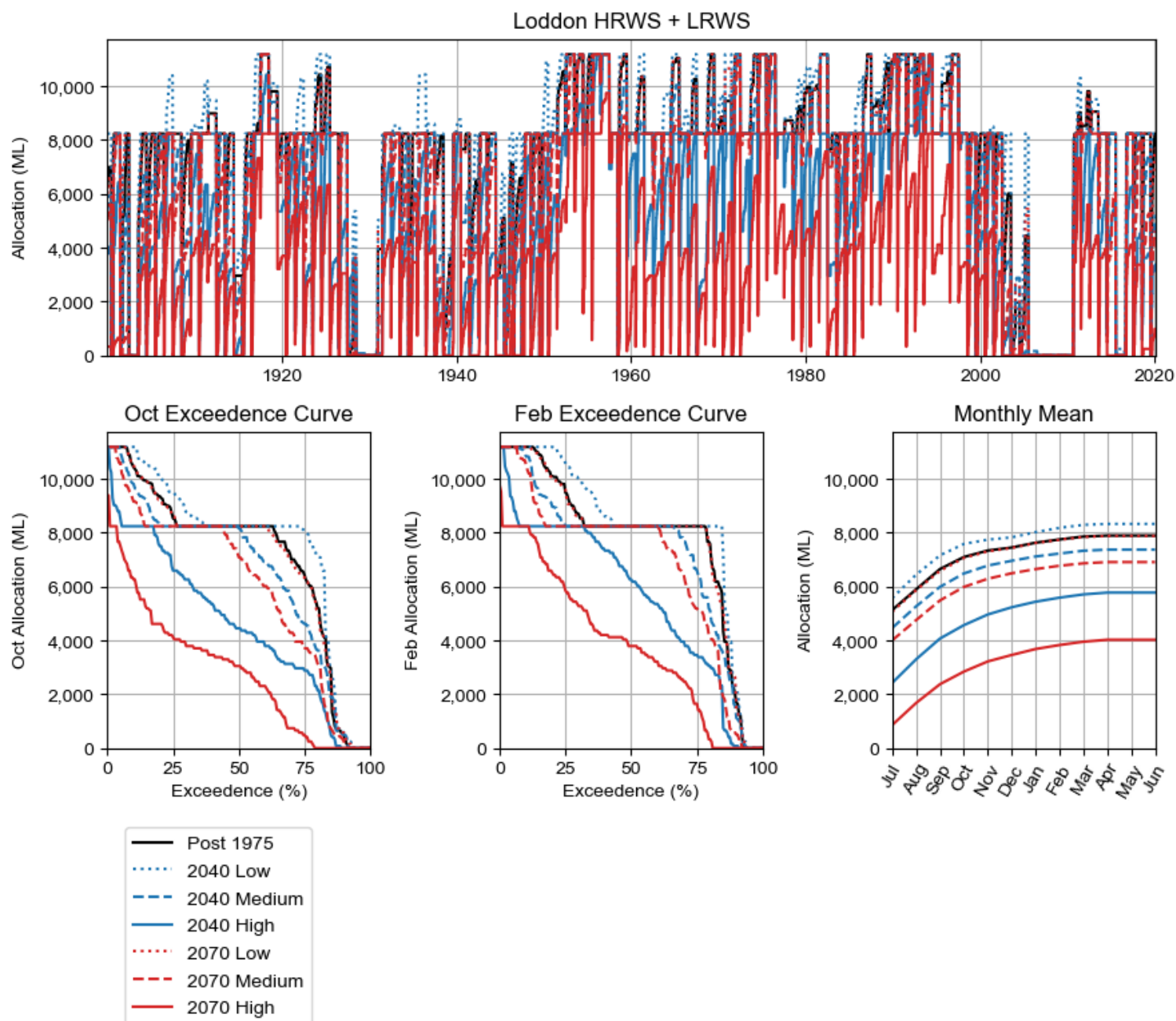
Name	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
Summer/autumn low flow	98	98	98	95	98	97	84
Winter/spring low flow	96	96	95	92	96	94	79
Summer/autumn freshes	84	85	82	73	83	79	50
Winter/spring freshes	60	62	56	47	59	53	39

Table 66: Average success (%) – flow targets for the Campaspe River @ Rochester.

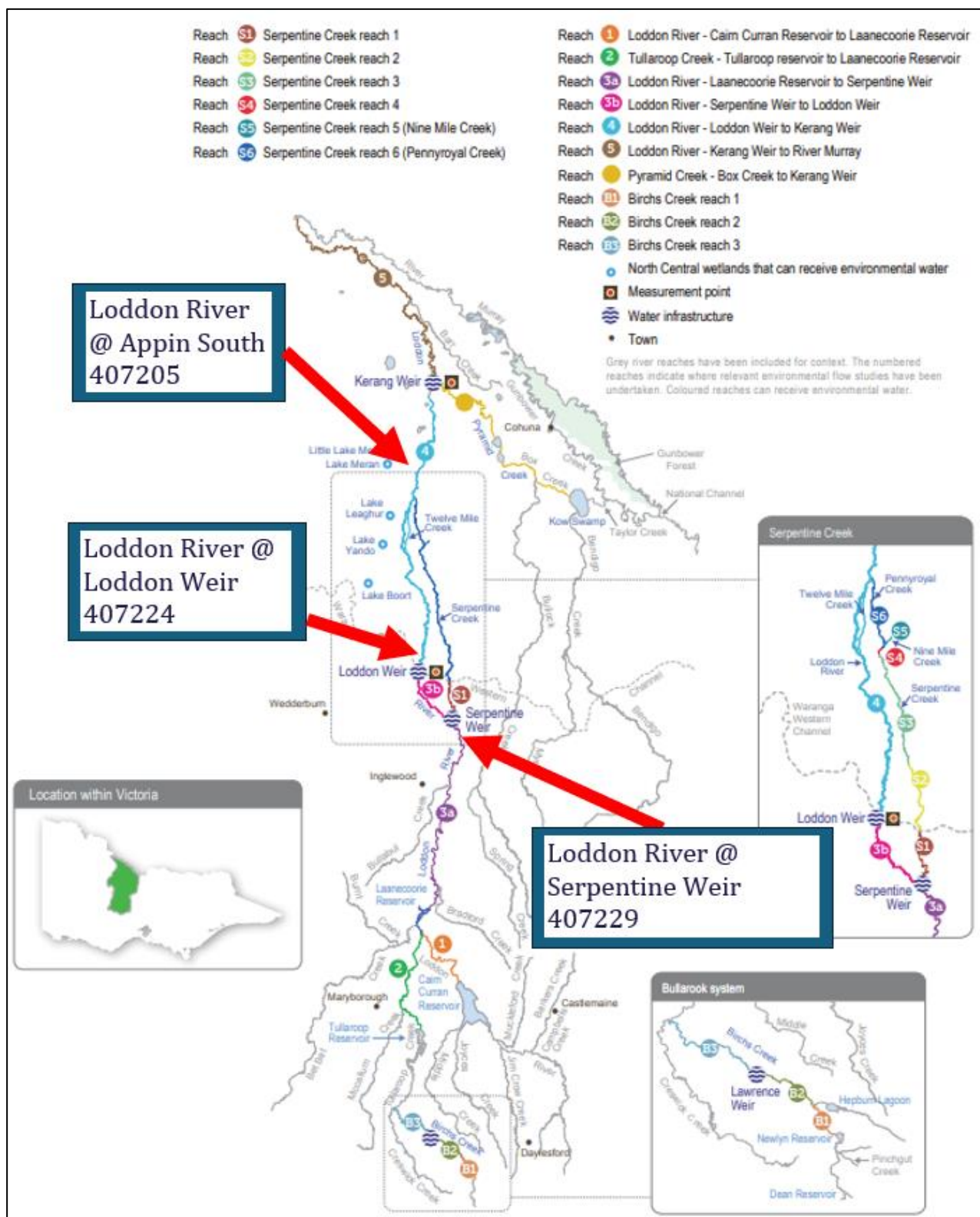
Name	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
Summer/autumn low flow	97	98	96	93	97	96	79
Winter/spring low flow	90	90	89	84	90	87	68
Summer/autumn freshes	44	45	41	33	44	37	22
Winter/spring fresh(es)	62	63	58	52	61	56	44

Appendix Q Loddon model results

Q.1 Environmental entitlement

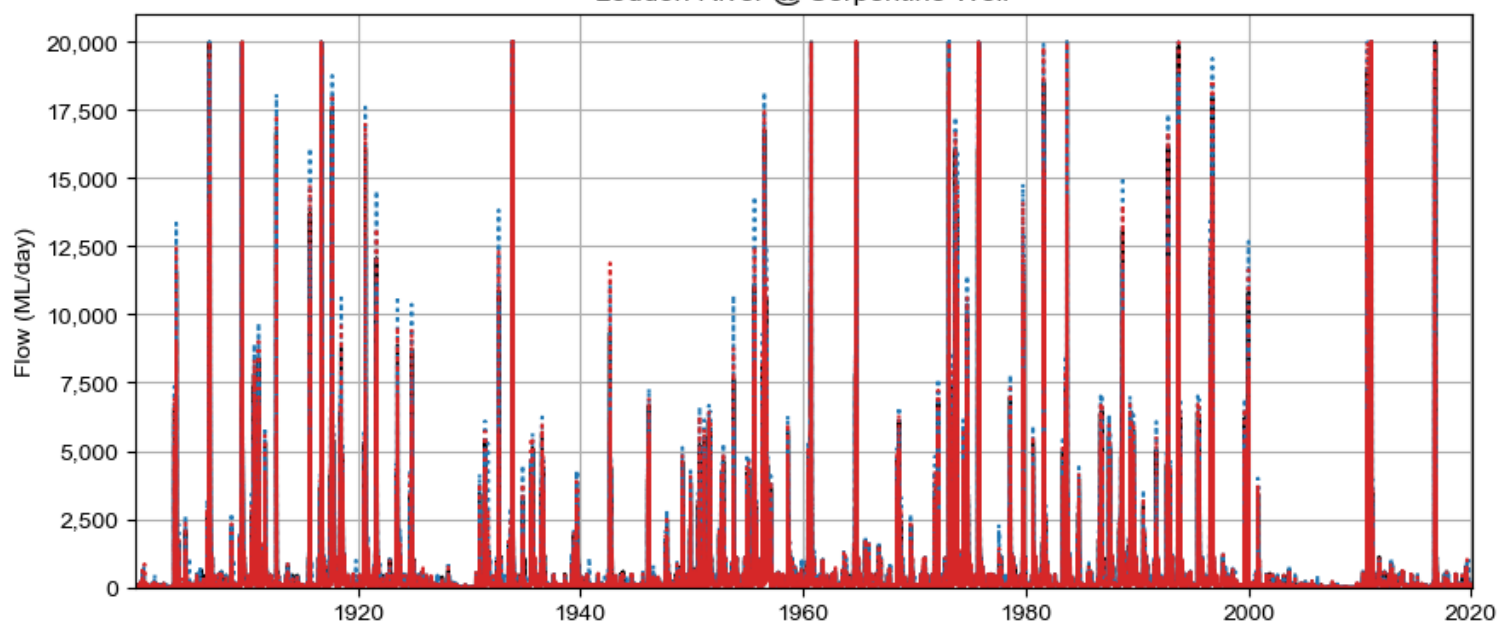


Q.2 Streamflow

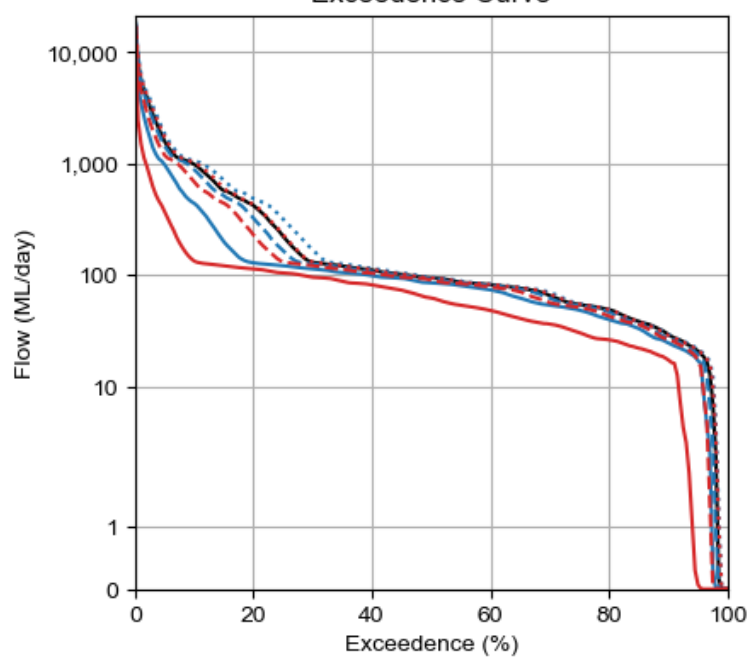


Note, analysis for Loddon River @ Bridgewater (407200) and Loddon River @ Kerang (407224) was requested but not included because it is not modelled in the GBCCL Source Model. Instead, analysis for Loddon River @ Serpentine Weir (407229) and Loddon River @ Appin South (407205) was included.

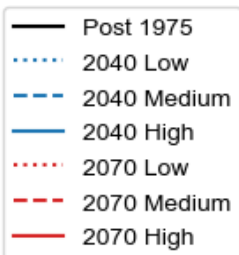
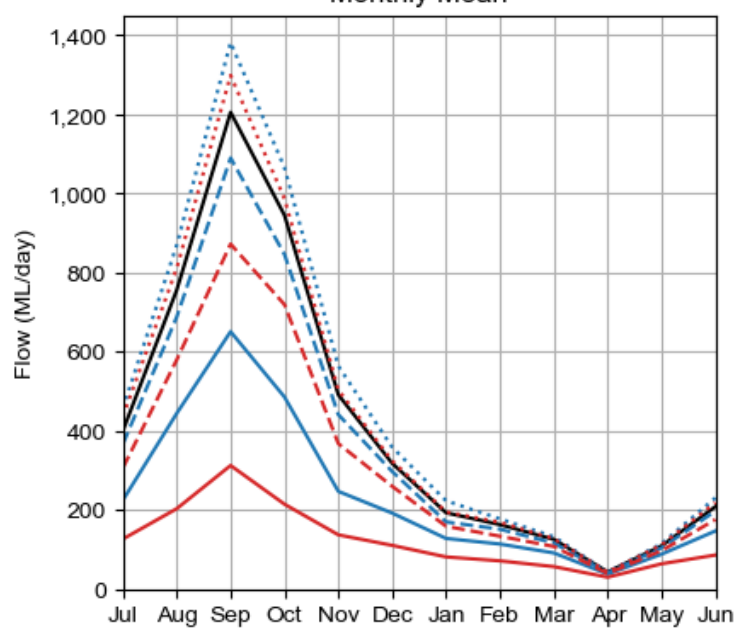
Loddon River @ Serpentine Weir

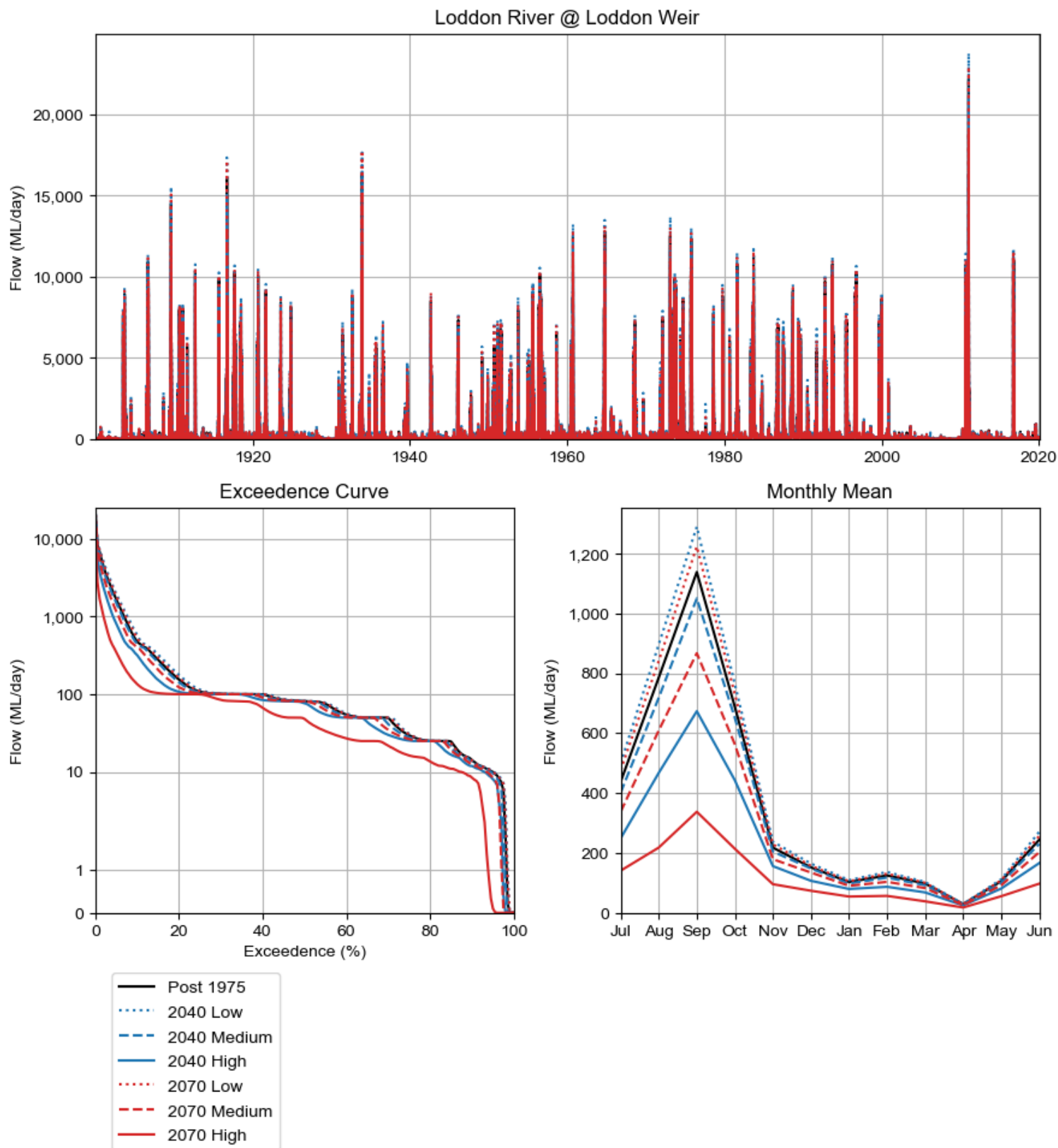


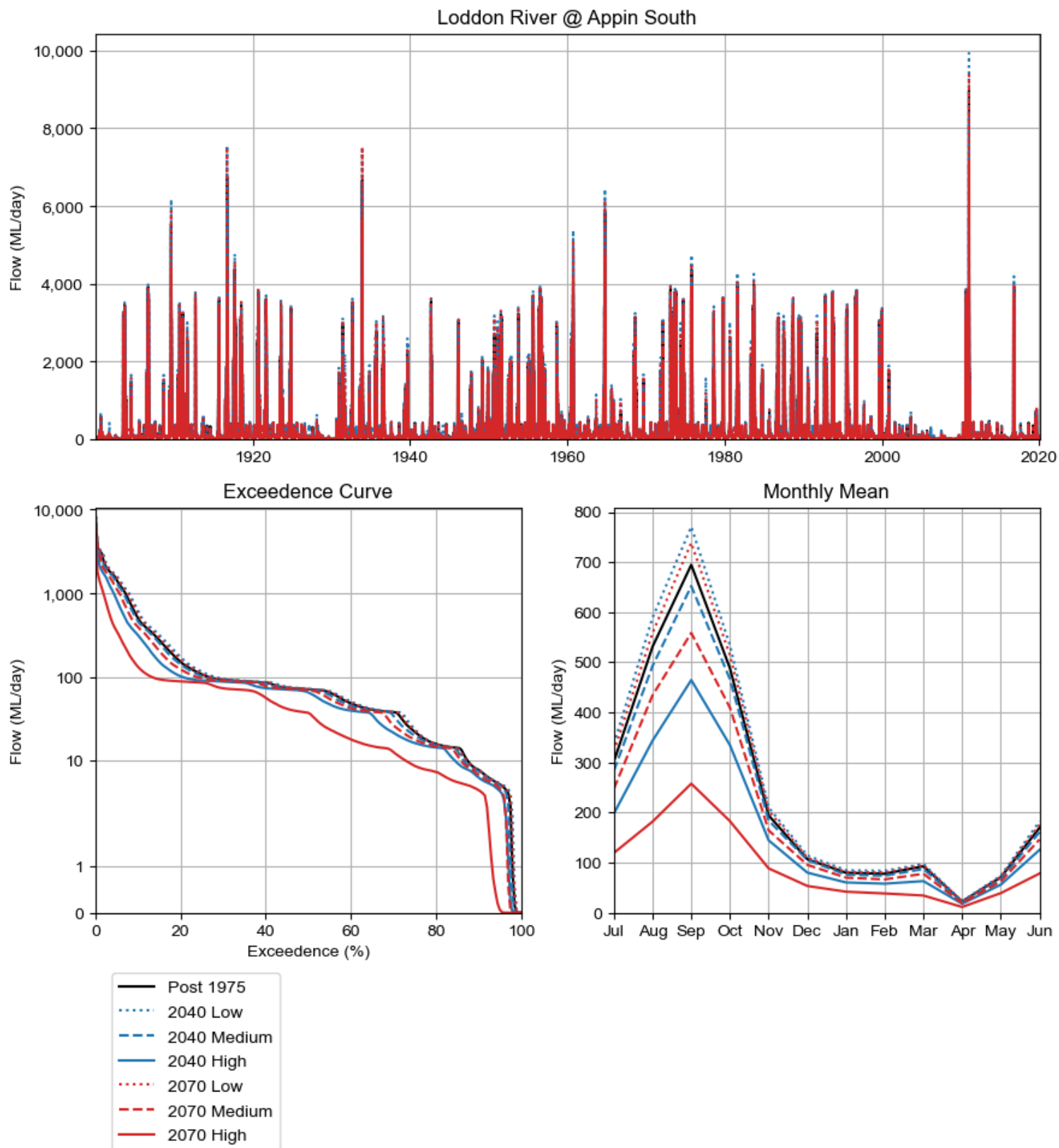
Exceedence Curve



Monthly Mean







Q.3 Hydrologic indicators

Table 67: Hydrological indicators for the Loddon River @ Serpentine Weir

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
MA1 (ML/d)	414	469	377	238	437	319	125
MA13 (ML/d)	164	179	153	115	170	135	72
MA19 (ML/d)	755	869	687	444	810	579	203
MH26	40	41	39	32	42	34	25
DL16 (days)	26	30	26	21	25	24	32
DL18 (days)	5.4	4.7	6.2	8.7	4.7	9.4	19
Avg0Dur (days)	46	51	38	74	43	52	51
Max0Dur (days)	197	193	227	274	199	264	324

Table 68: Hydrological indicators for the Loddon River @ Loddon Weir

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
MA1 (ML/d)	345	386	321	218	367	275	117
MA13 (ML/d)	126	138	119	88	132	104	57
MA19 (ML/d)	785	896	718	467	841	609	218
MH26	46	49	45	37	47	42	28
DL16 (days)	27	26	26	24	25	31	38
DL18 (days)	5.3	4.6	6.1	8.5	4.6	9.3	18
Avg0Dur (days)	57	66	44	85	49	50	58
Max0Dur (days)	197	193	227	274	199	266	325

Table 69: Hydrological indicators for the Loddon River @ Appin South

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
MA1 (ML/d)	237	260	224	163	249	197	94
MA13 (ML/d)	79	85	75	59	81	67	39
MA19 (ML/d)	531	590	493	344	559	434	182
MH26	29	29	27	23	29	26	20
DL16 (days)	41	39	40	39	42	47	59
DL18 (days)	5.4	4.7	6.2	8.6	4.6	9.4	19
Avg0Dur (days)	63	67	50	85	54	67	76
Max0Dur (days)	196	193	227	273	199	265	325

Q.4 eFlow Projector results

Table 70: Average success (%) – flow targets for the Loddon River @ Serpentine Weir

Name	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
Summer/autumn low flow	96	97	96	95	97	95	90
Winter/spring low flow	96	96	95	94	96	95	87
Summer fresh	97	98	97	97	98	96	93
Autumn fresh	87	90	88	89	90	88	80
Winter fresh	96	97	93	86	96	92	65

Table 71: Average success (%) – flow targets for the Loddon River @ Loddon Weir

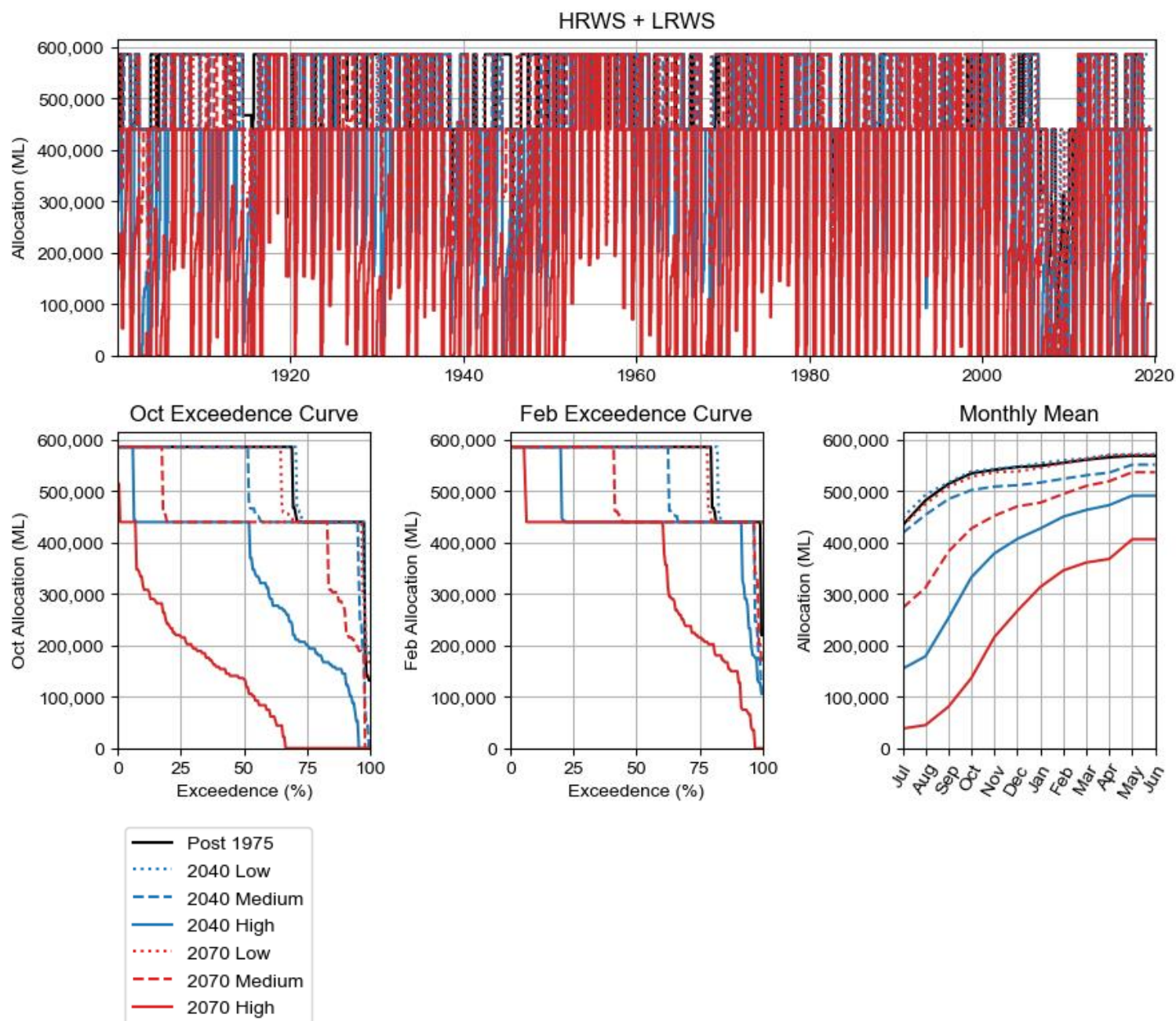
Name	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
Summer/autumn low flow	59	60	58	52	60	55	38
Winter/spring low flow	91	92	90	87	91	89	73
Summer/autumn freshes	86	87	86	79	88	84	61
Autumn high flow	45	46	42	29	46	38	16
Winter/spring high flow	81	84	78	64	82	75	47

Table 72: Average success (%) – flow targets for the Loddon River @ Appin South

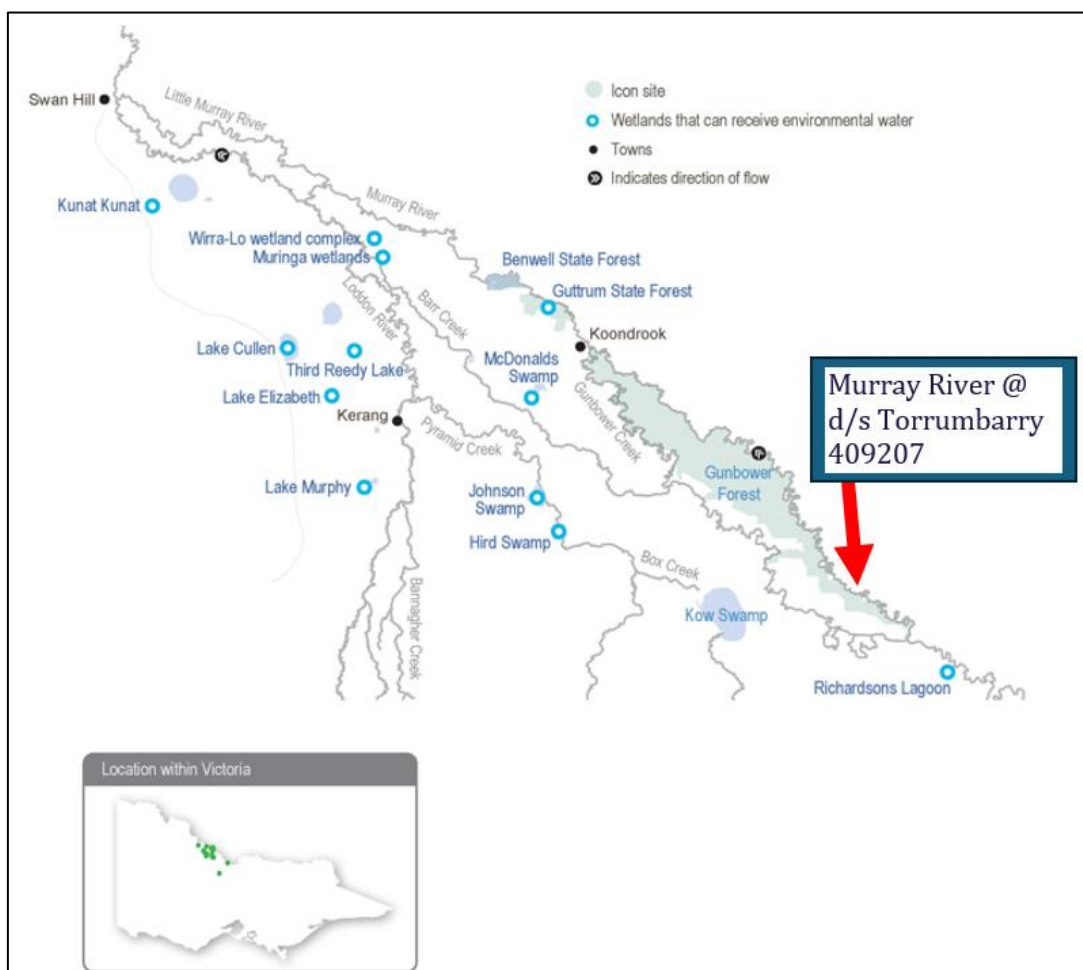
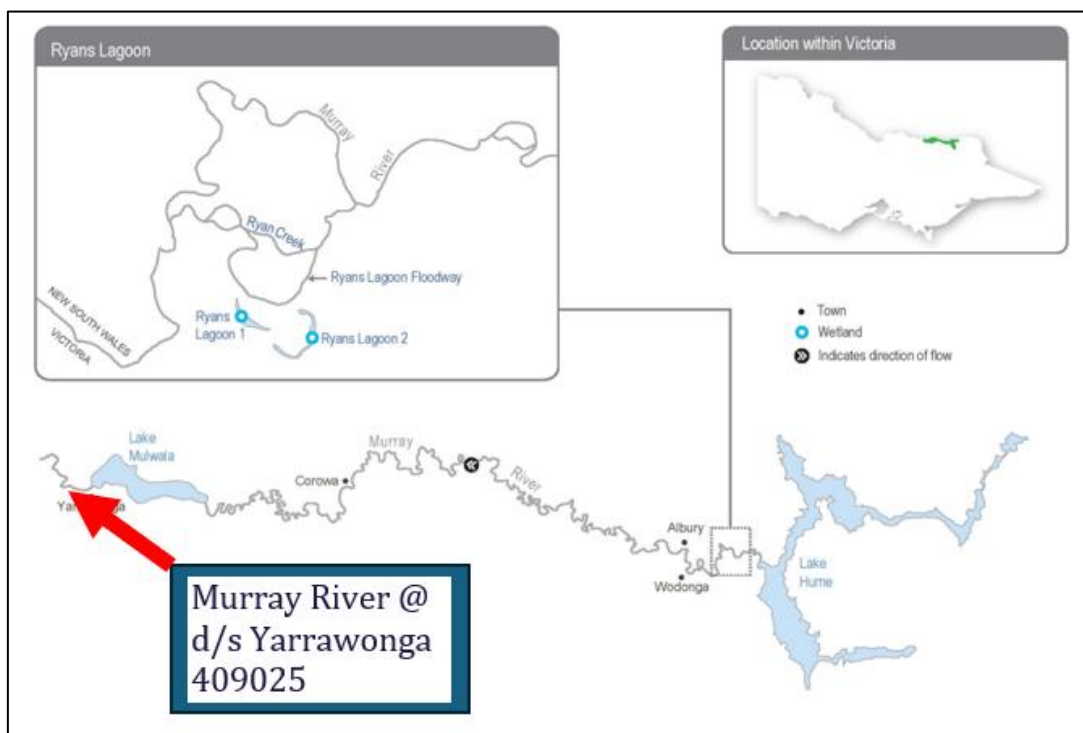
Name	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
Summer/autumn low flow	49	50	48	41	50	45	28
Winter/spring low flow	89	90	88	84	89	86	68
Summer/autumn freshes	63	66	62	51	64	58	36
Autumn high flow	36	37	33	23	36	29	13
Winter/spring high flow	81	83	78	62	81	73	47

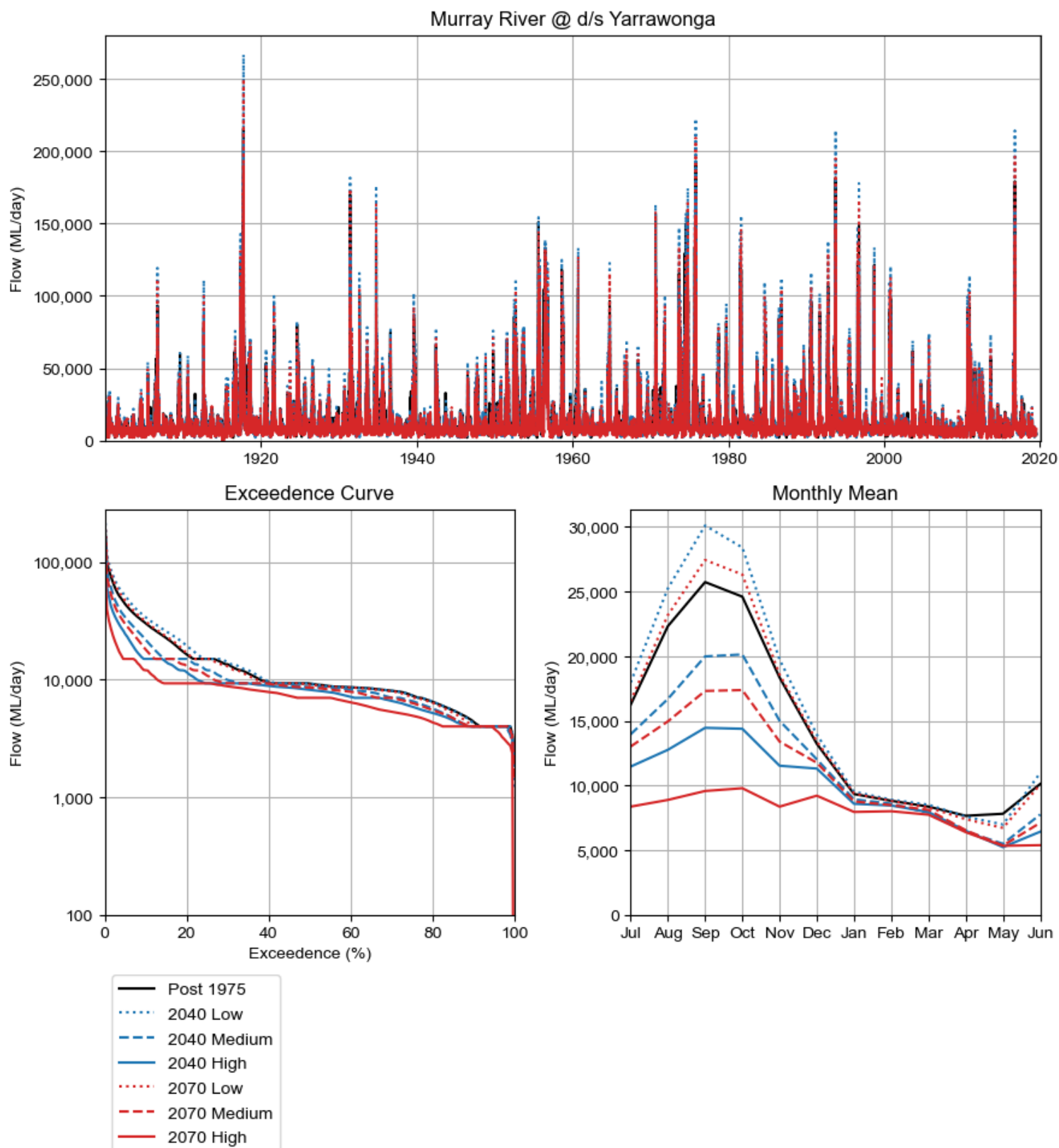
Appendix R Victorian Murray model results

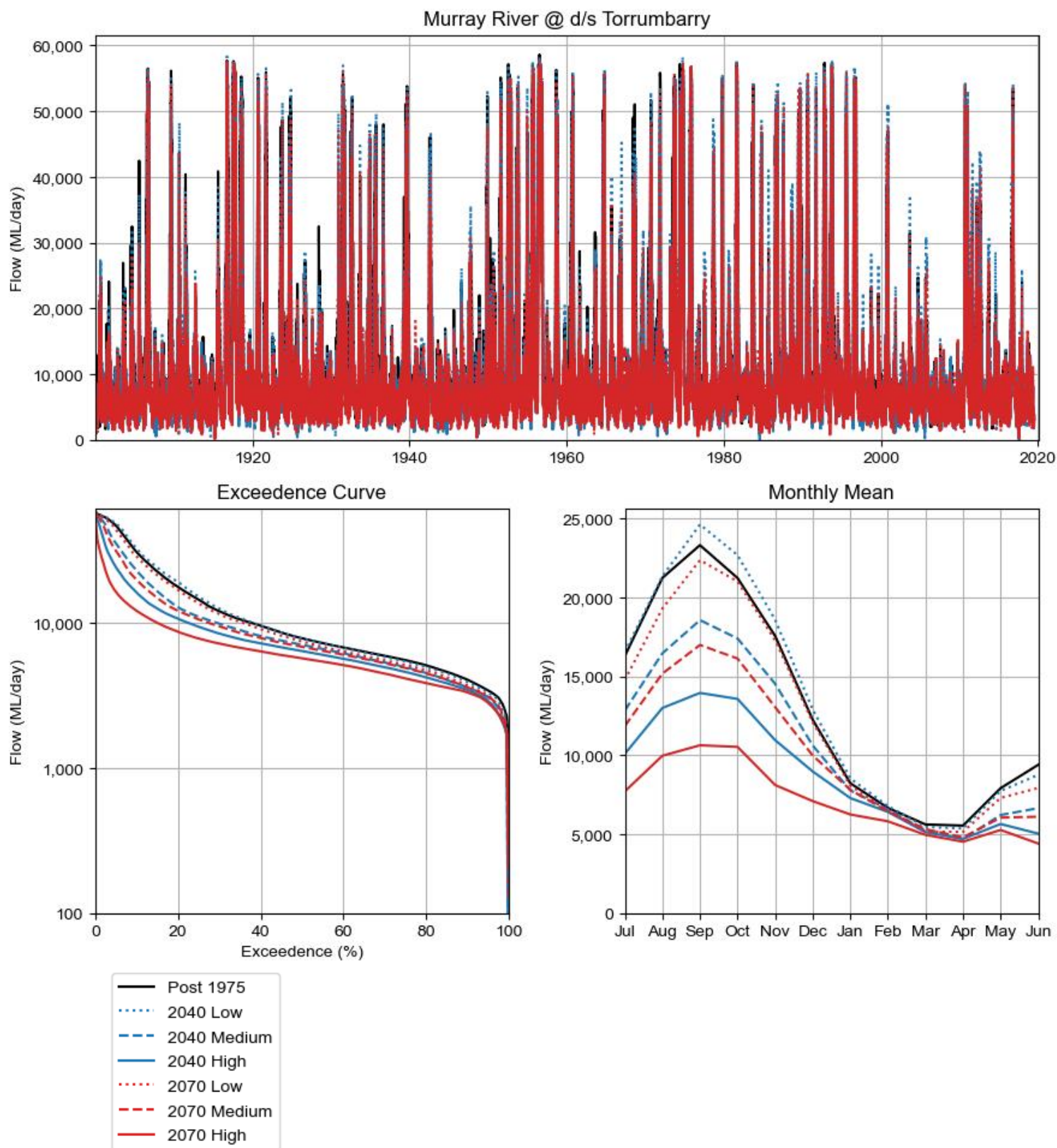
R.1 Environmental entitlement



R.2 Streamflow







R.3 Hydrologic indicators

Table 73: Hydrological indicators for the Murray River @ d/s Yarrawonga

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
MA1 (ML/d)	14,435	15,718	11,941	9,935	14,733	11,038	7,914
MA13 (ML/d)	8,818	8,902	8,590	8,454	8,815	8,481	8,004
MA19 (ML/d)	22,374	25,313	16,752	12,809	23,247	15,018	8,897
MH26	11	11	10	8.9	11	10	8.9
DL16 (days)	14	13	15	21	14	18	35
DL18 (days)	0	0	0	0	0	0	0.2
Avg0Dur (days)	0	0	0	0	0	0	4.0
Max0Dur (days)	0	0	0	0	0	0	6.0

Table 74: Hydrological indicators for the Murray River @ d/s Torrumberry

Hydrological indicator	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
MA1 (ML/d)	12,991	13,336	10,668	8,754	12,300	10,010	7,118
MA13 (ML/d)	6,656	6,792	6,579	6,410	6,503	6,430	5,812
MA19 (ML/d)	21,285	21,406	16,522	13,027	19,365	15,240	9,969
MH26	7.2	7.2	7.1	7.1	7.2	7.2	0
DL16 (days)	17	17	20	22	19	20	26
DL18 (days)	0	0	0	0	0	0	0
Avg0Dur (days)	0	0	0	0	0	0	0
Max0Dur (days)	0	0	0	0	0	0	0

R.4 eFlow Projector results

Table 75: Average success (%) – flow targets for the Murray River @ d/s Yarrawonga

Name	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
Winter/spring/summer low flow	97	97	94	87	96	91	72
Autumn/Winter Low Flow in the Murray River	100	100	100	100	100	100	100
Spring wetting of floodplain marshes	99	99	96	88	98	93	72
Spring wetting of floodplain marshes (full)	86	87	77	62	84	70	41

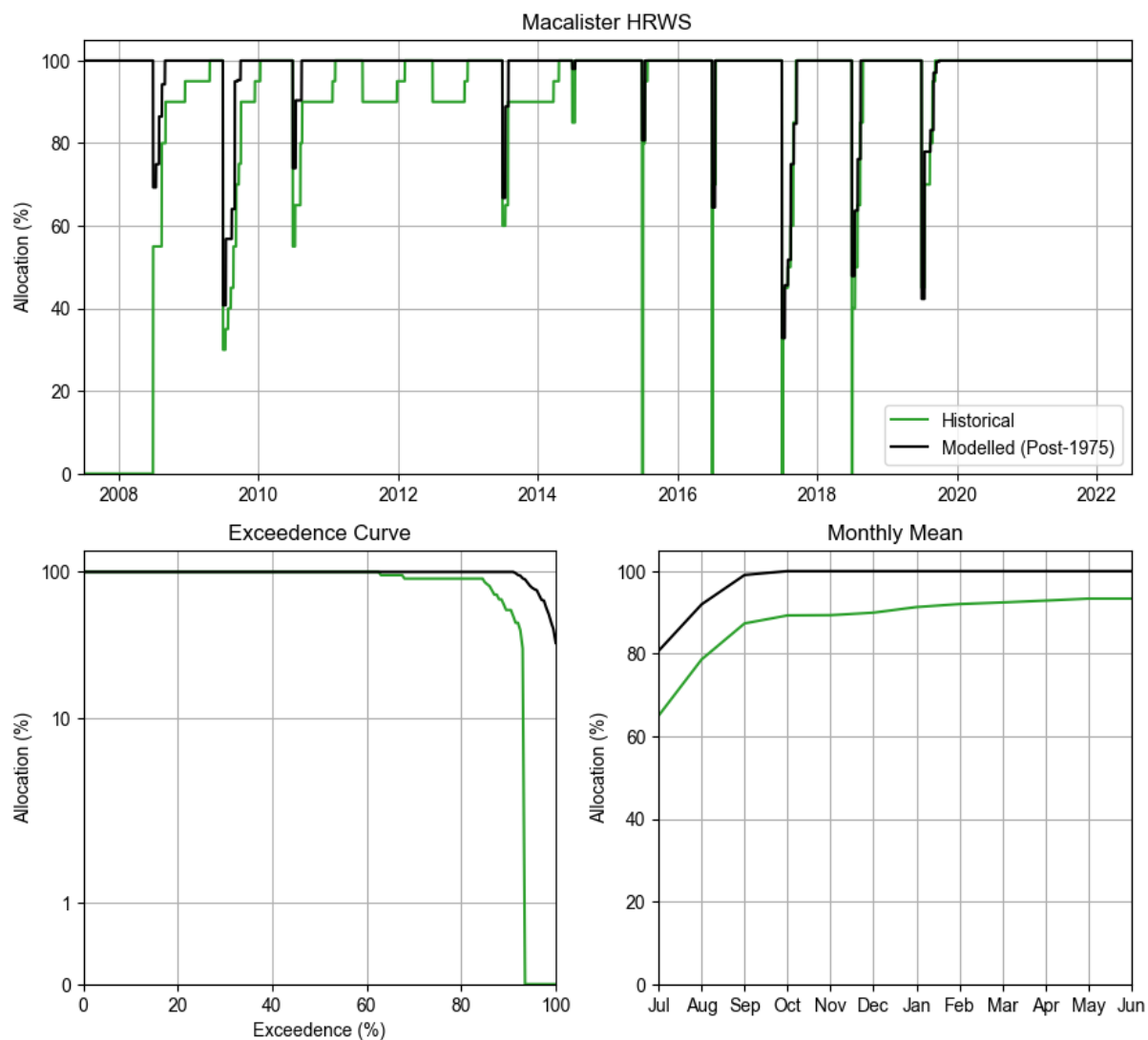
Table 76: Average success (%) – flow targets for the Murray River @ d/s Torrumberry

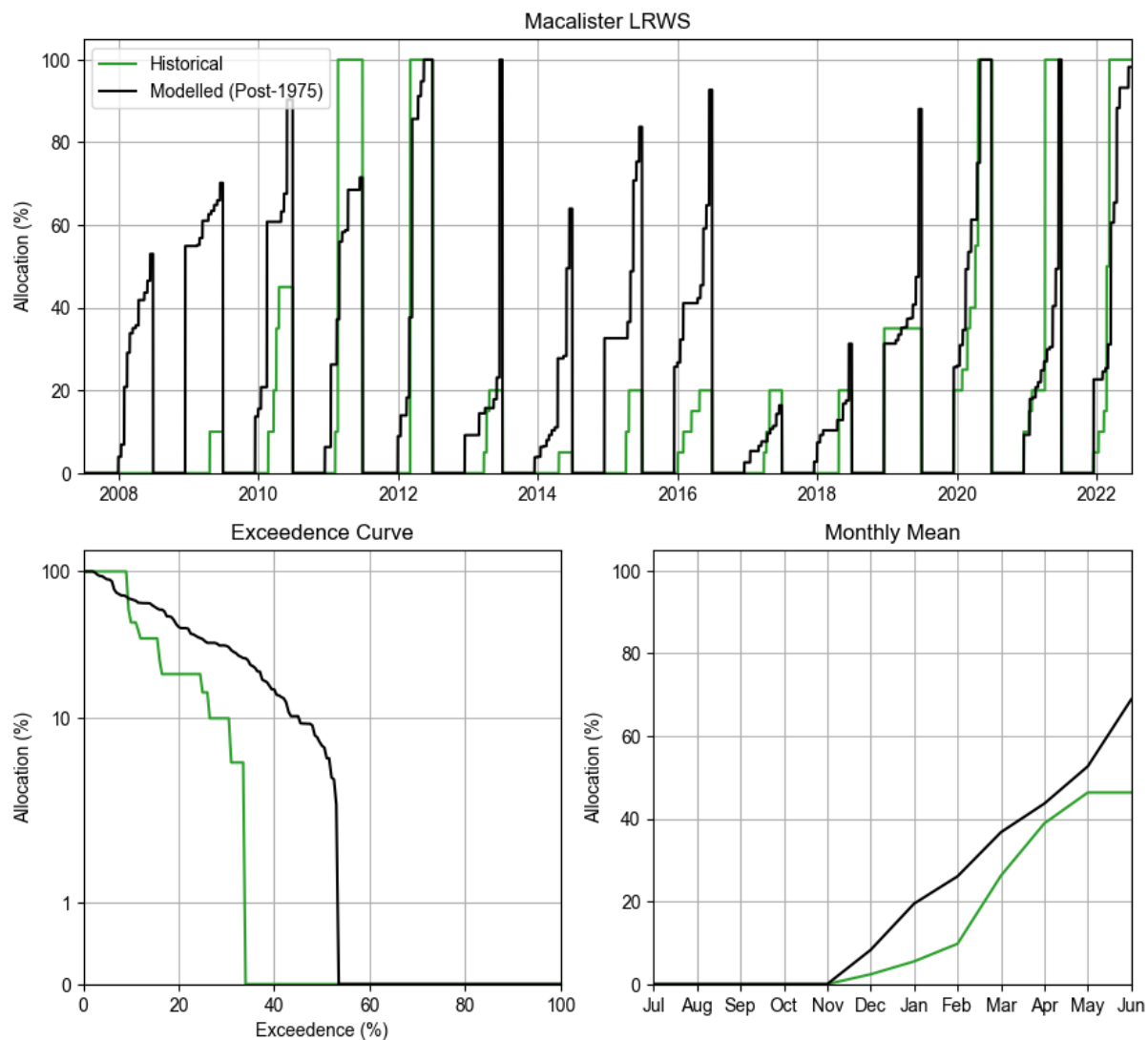
Name	Post 1975	2040 Low	2040 Medium	2040 High	2070 Low	2070 Medium	2070 High
Nesting support	100	100	100	100	100	100	100
Bankfull 1	85	85	75	65	82	73	55
Bankfull 2	75	77	64	54	73	62	42

Appendix S Modelled vs observed data

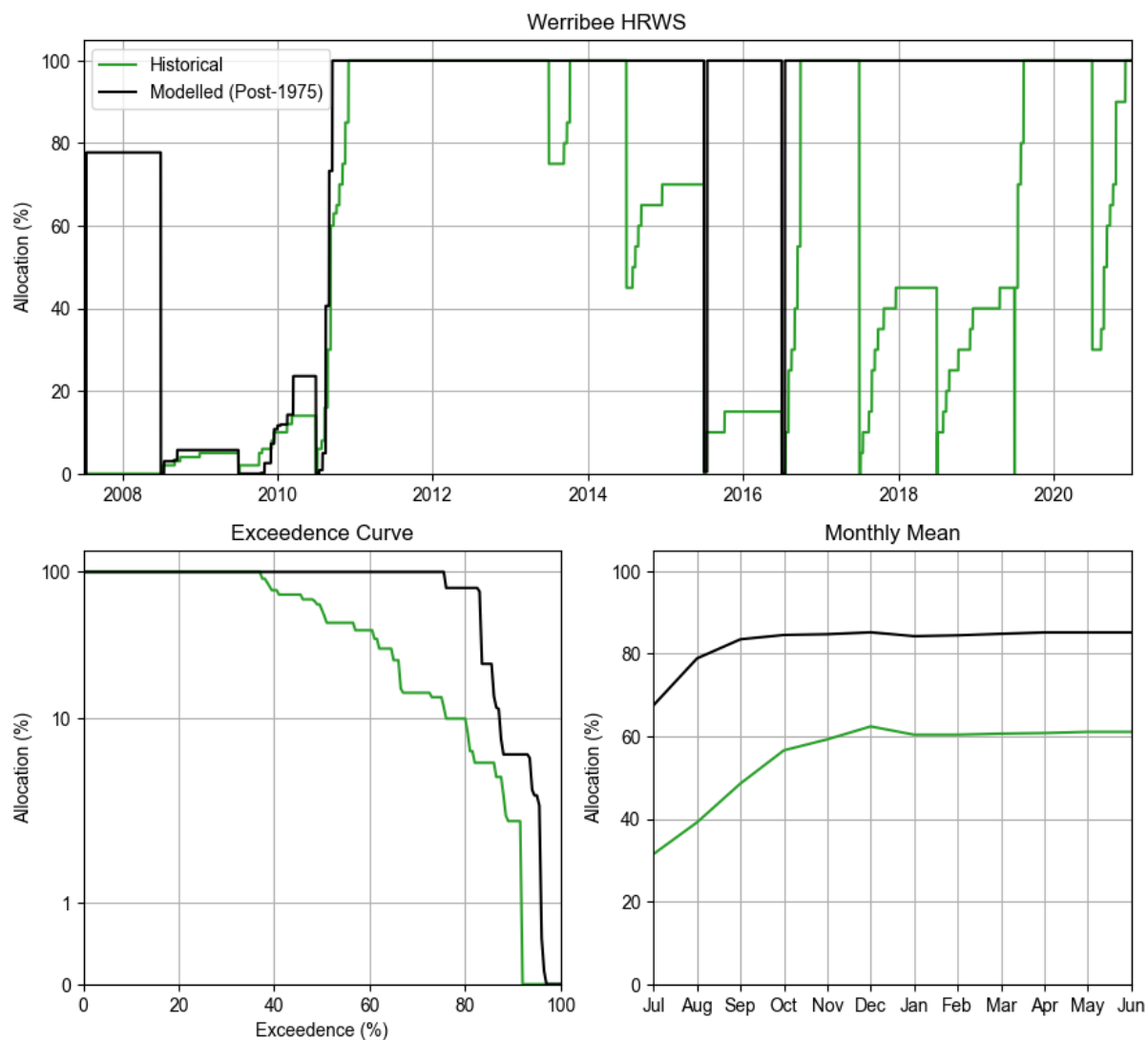
S.1 Allocations

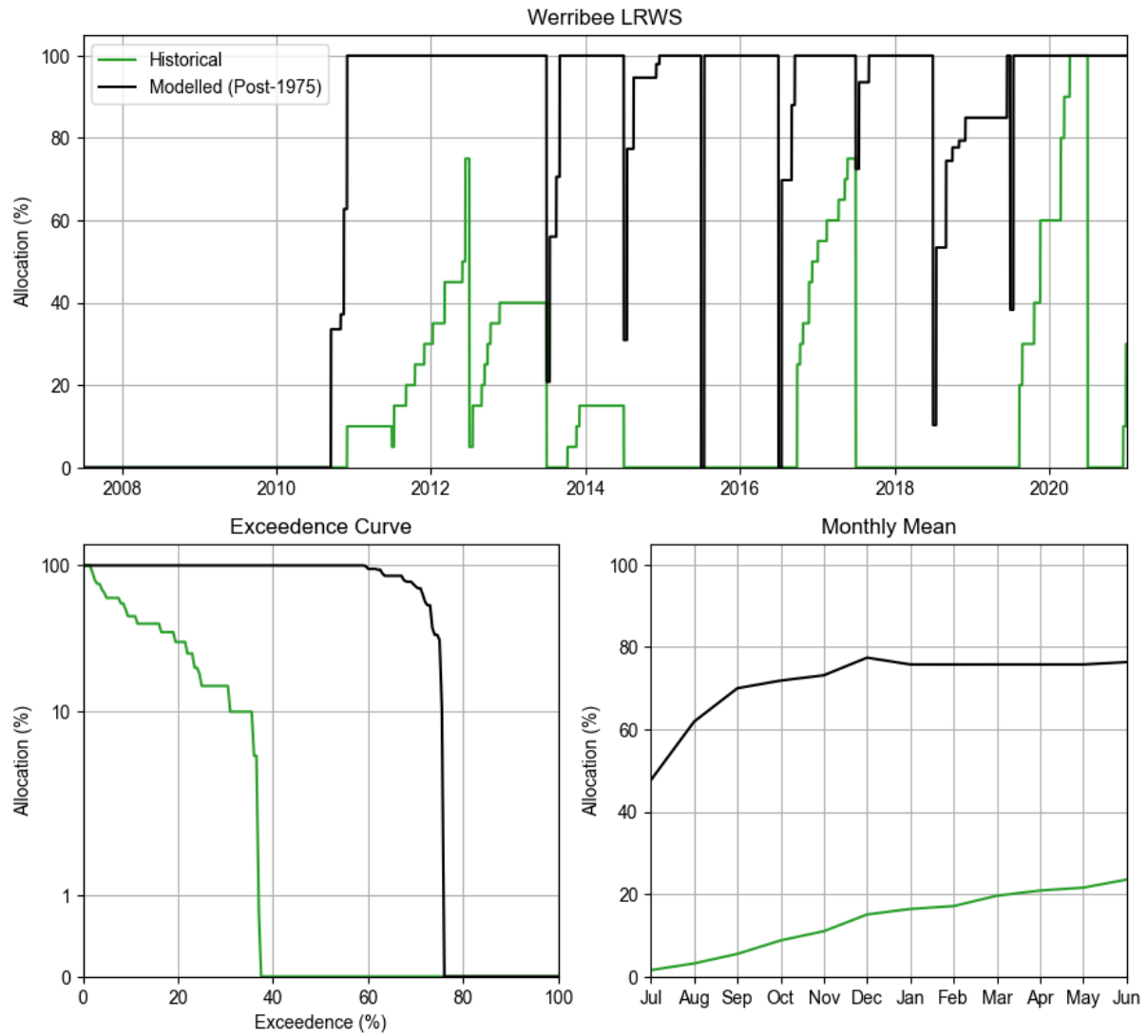
S.1.1 Macalister



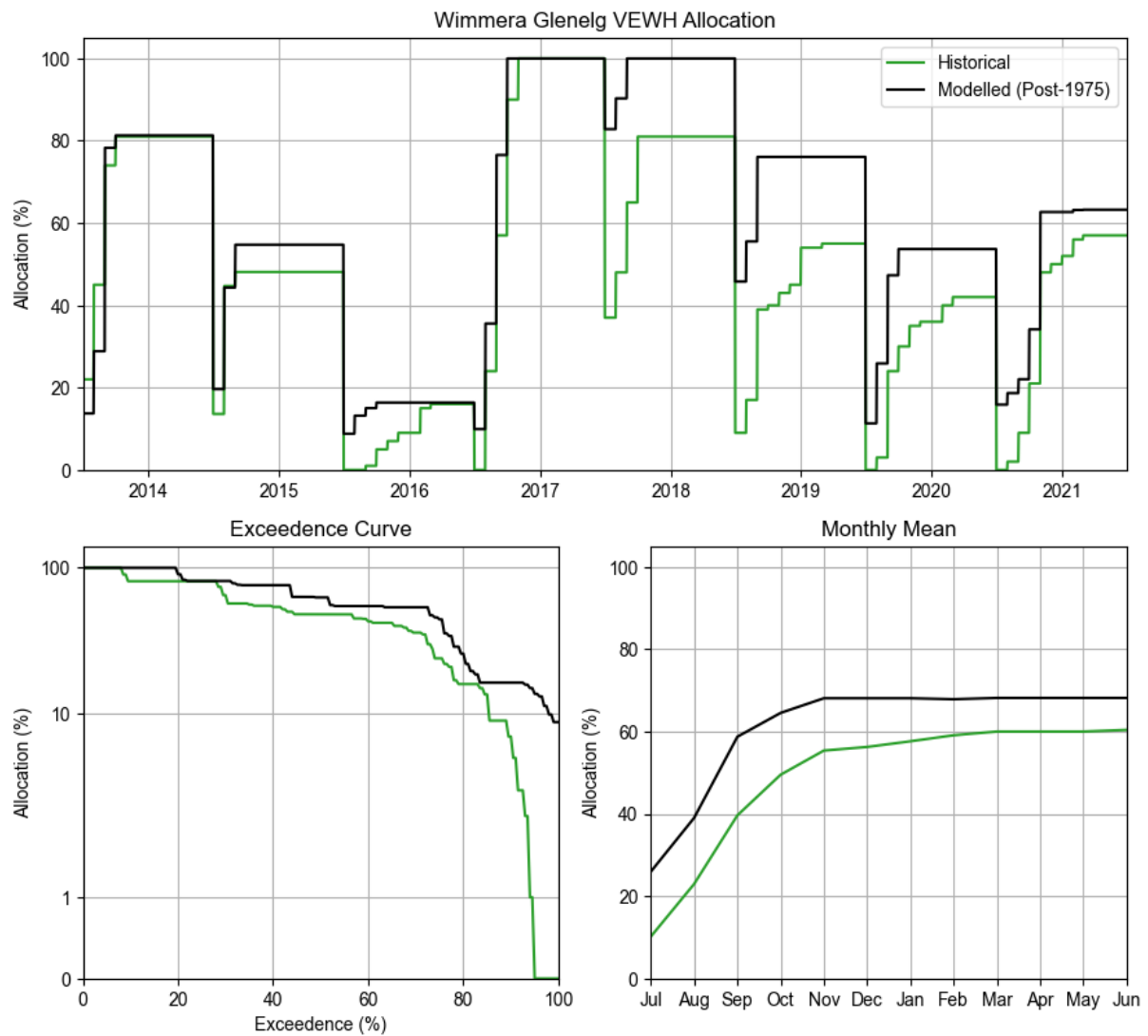


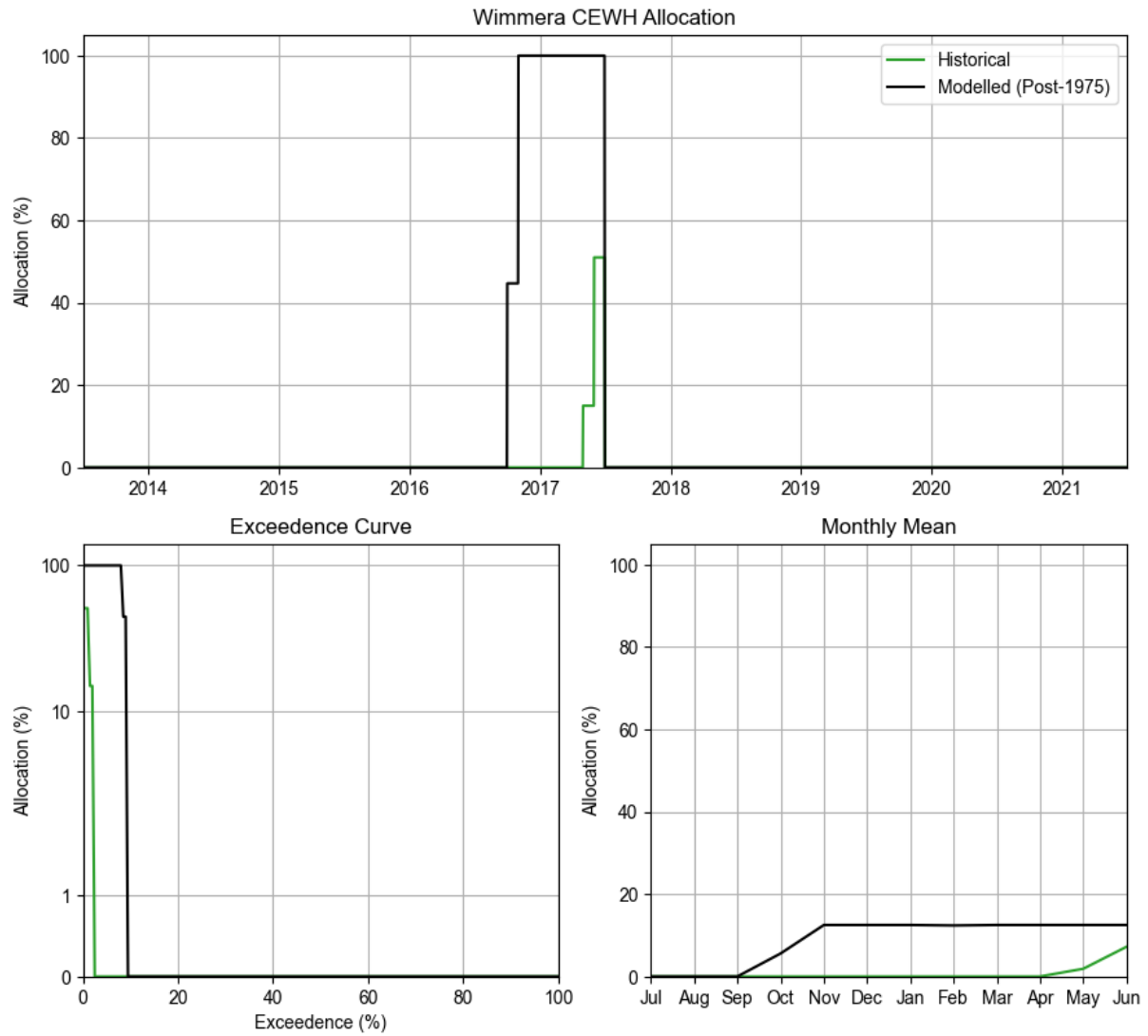
S.1.2 Werribee



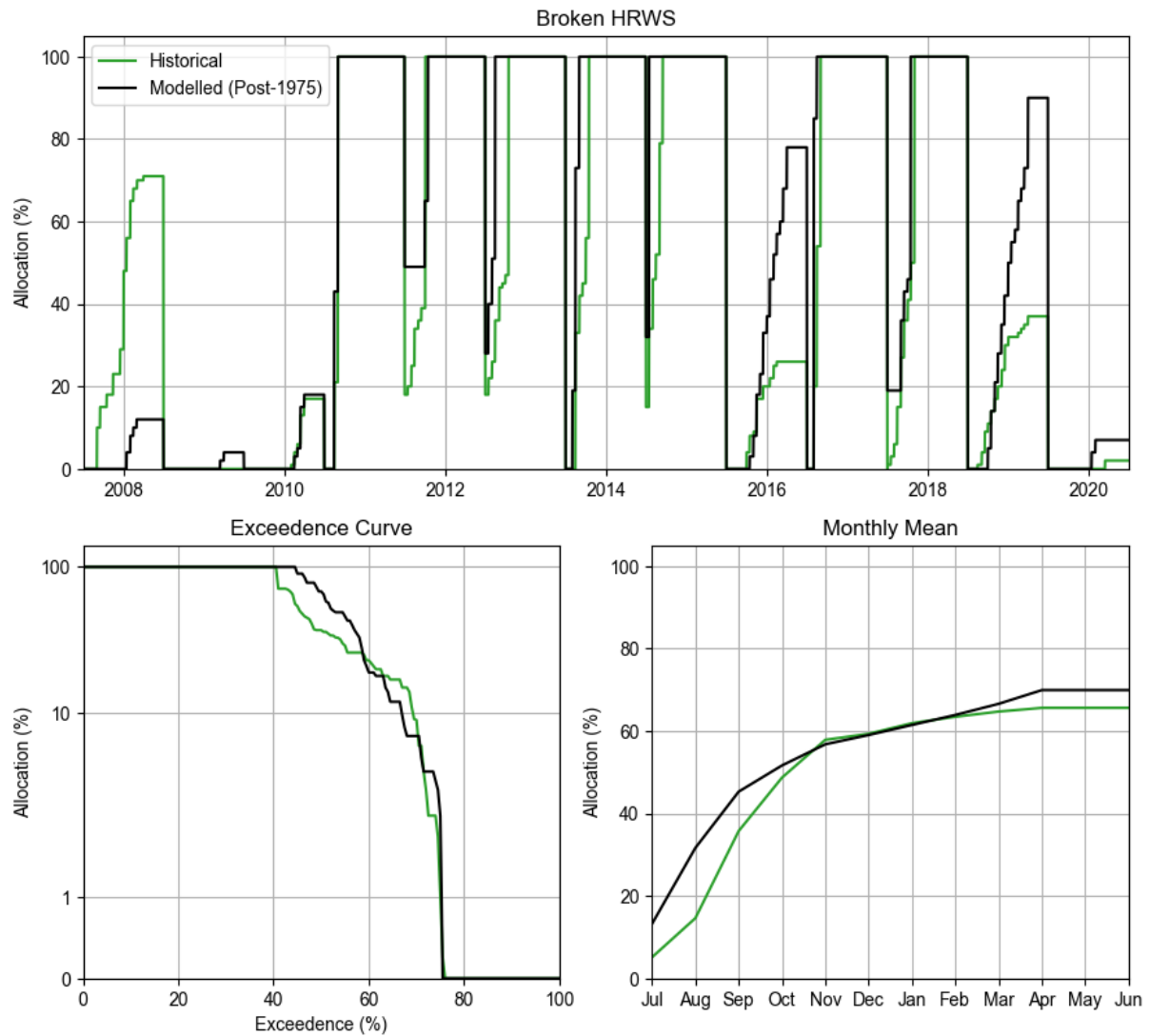


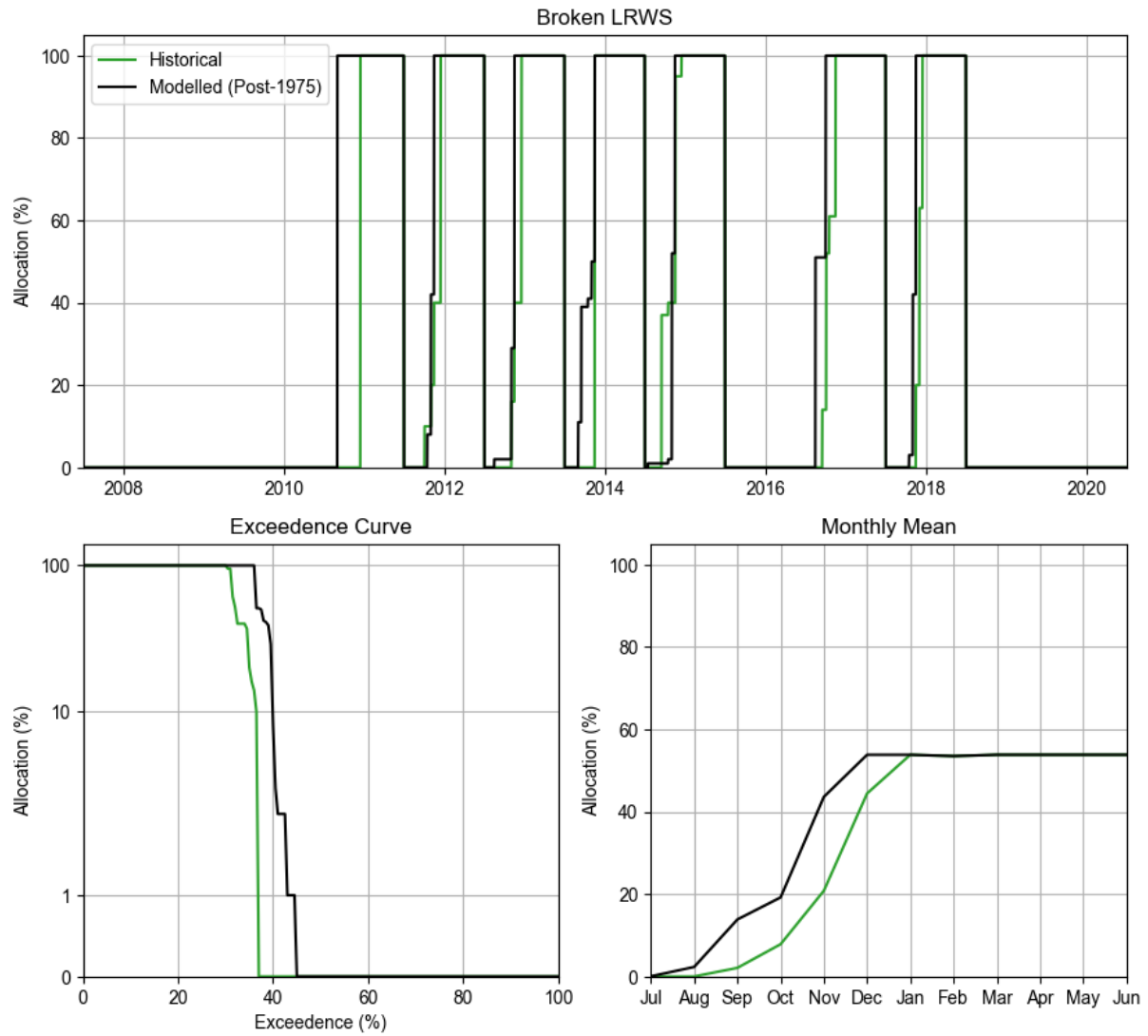
S.1.3 Wimmera-Glenelg



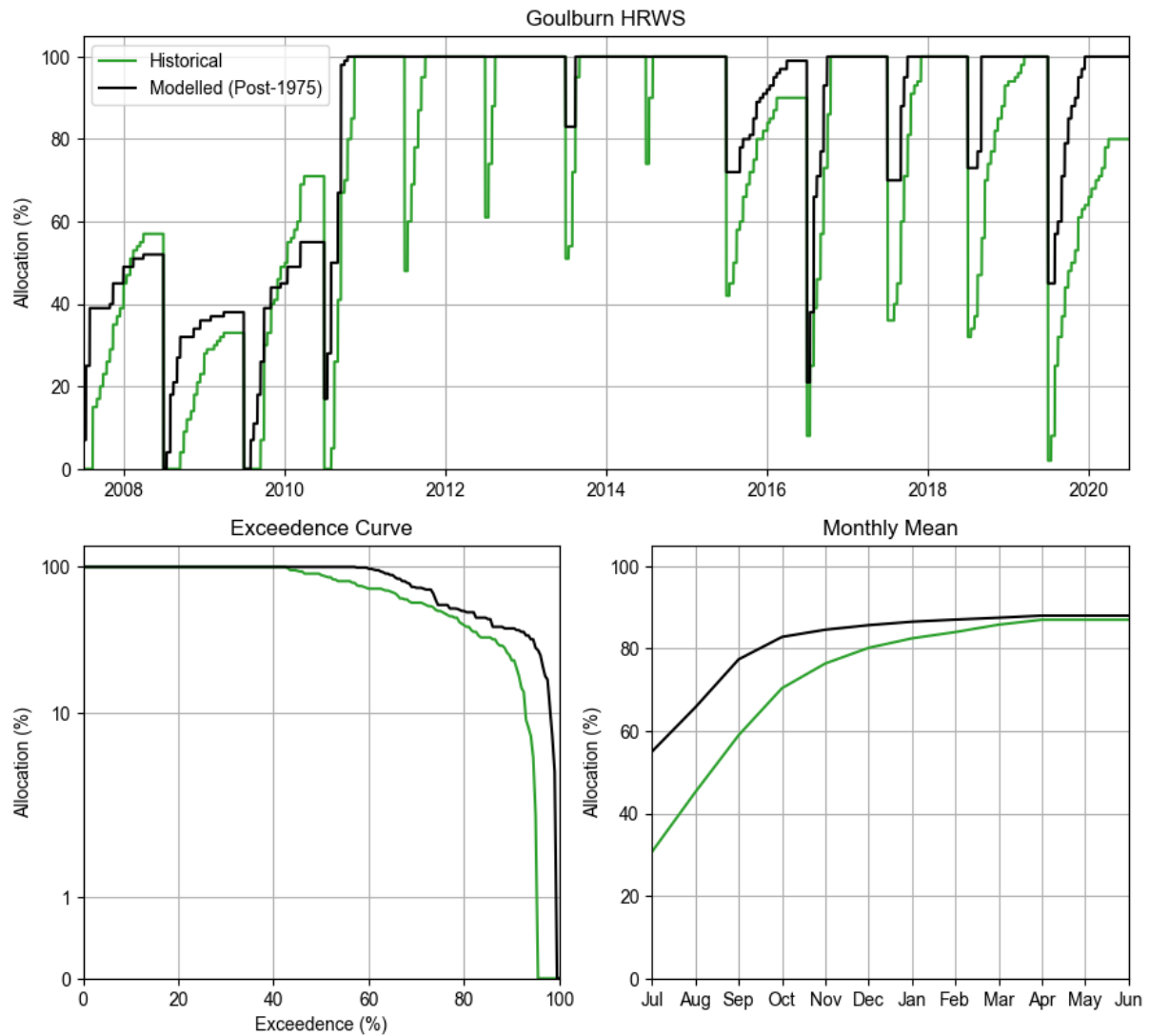


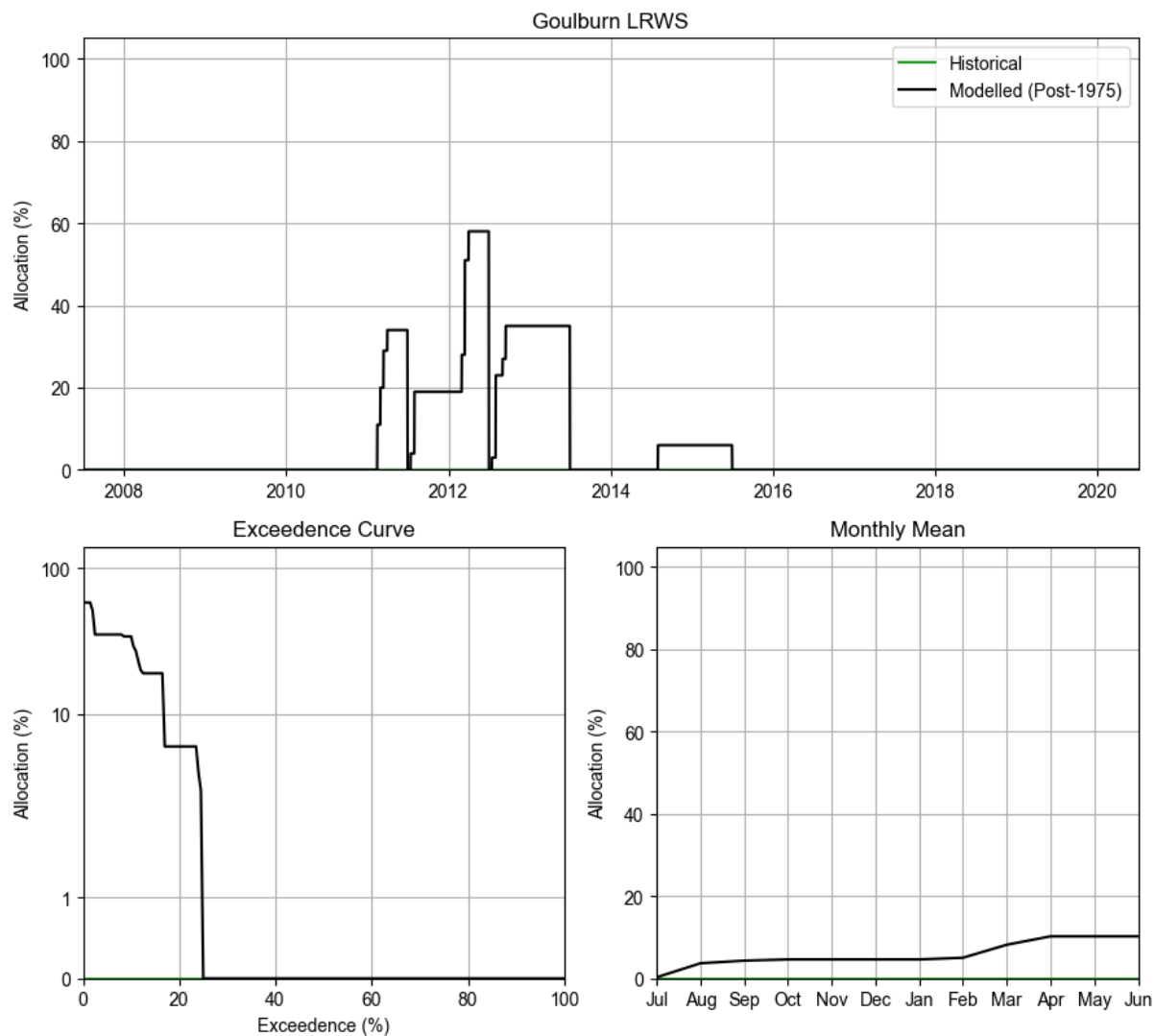
S.1.4 Broken



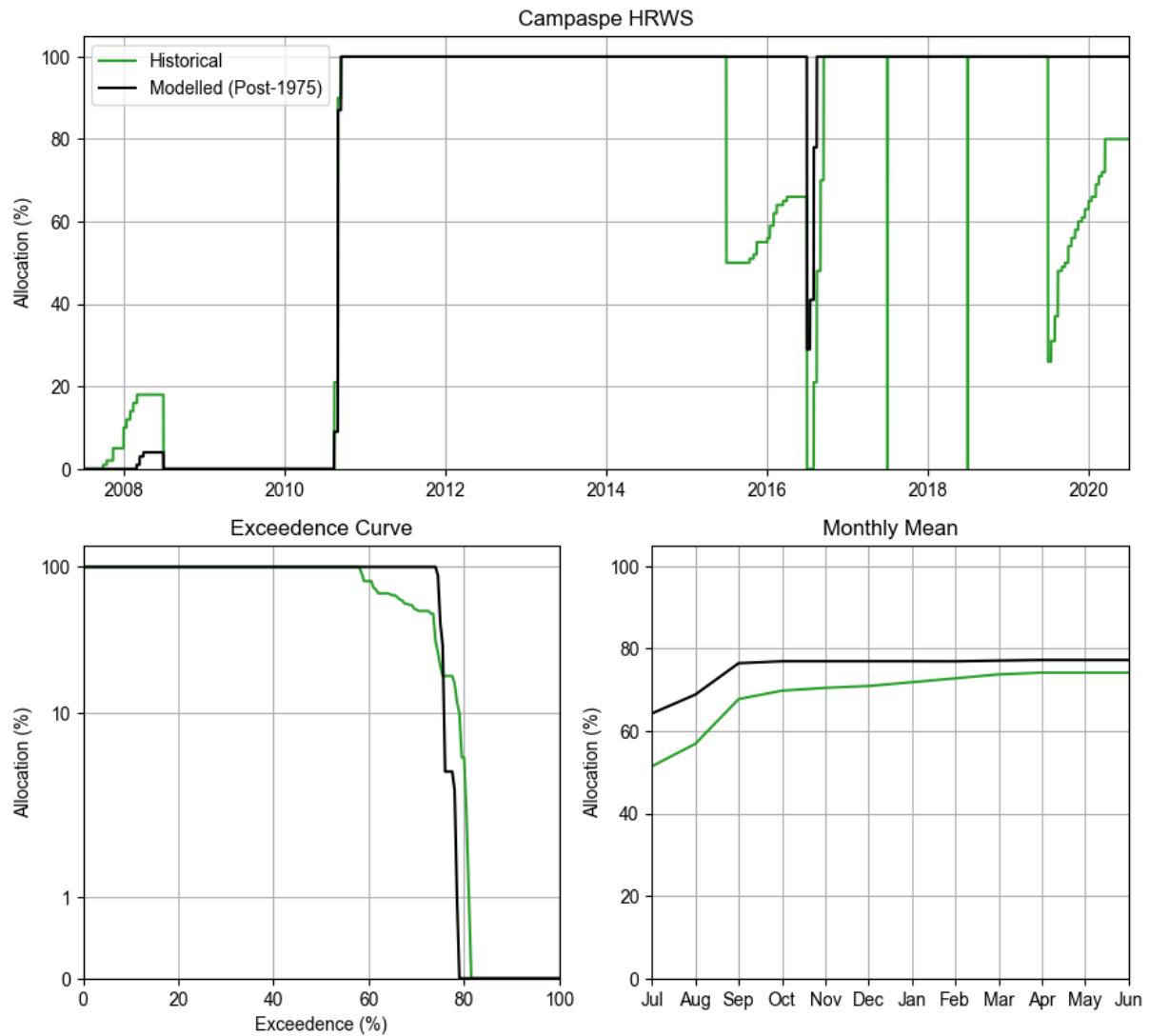


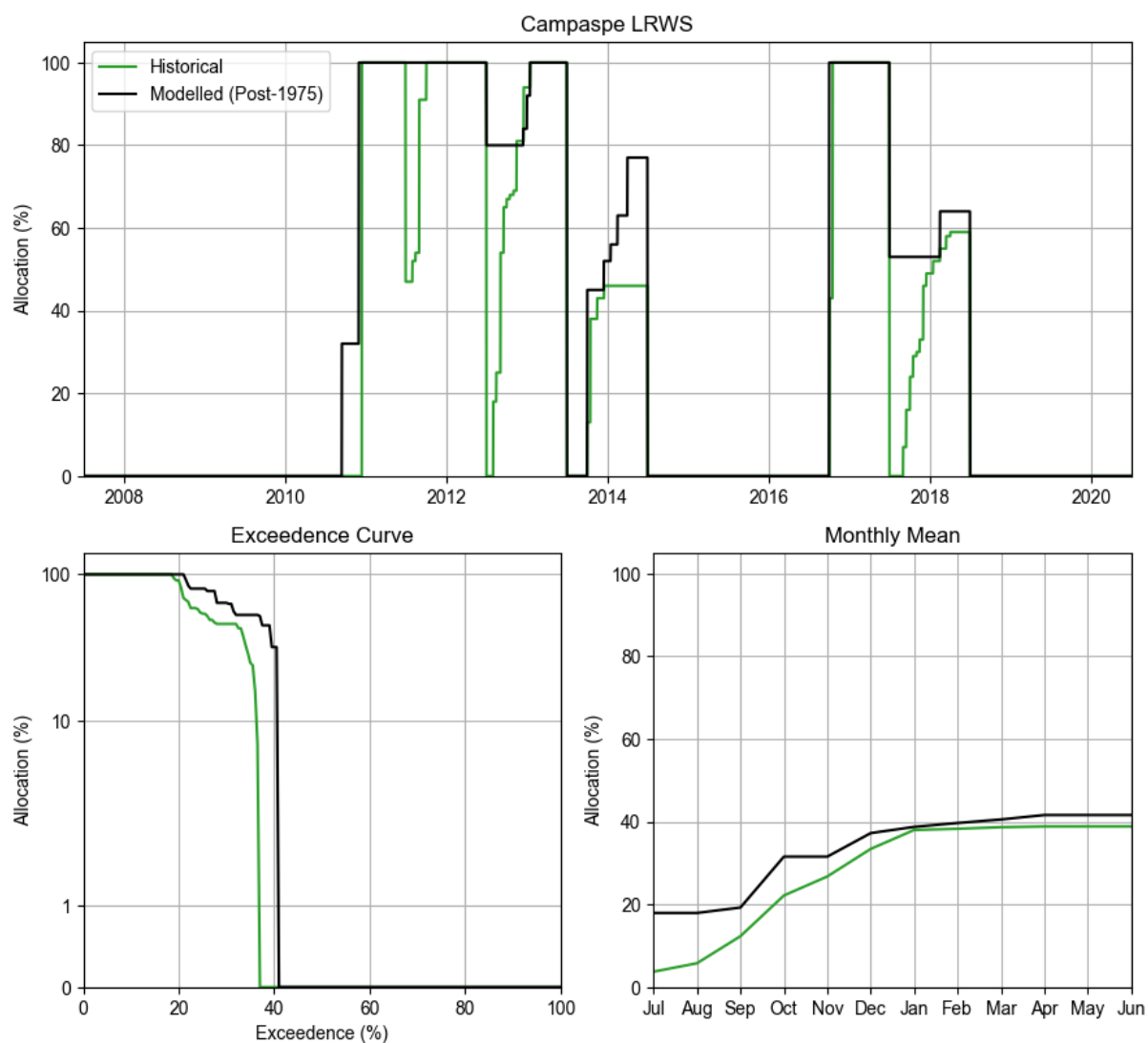
S.1.5 Goulburn



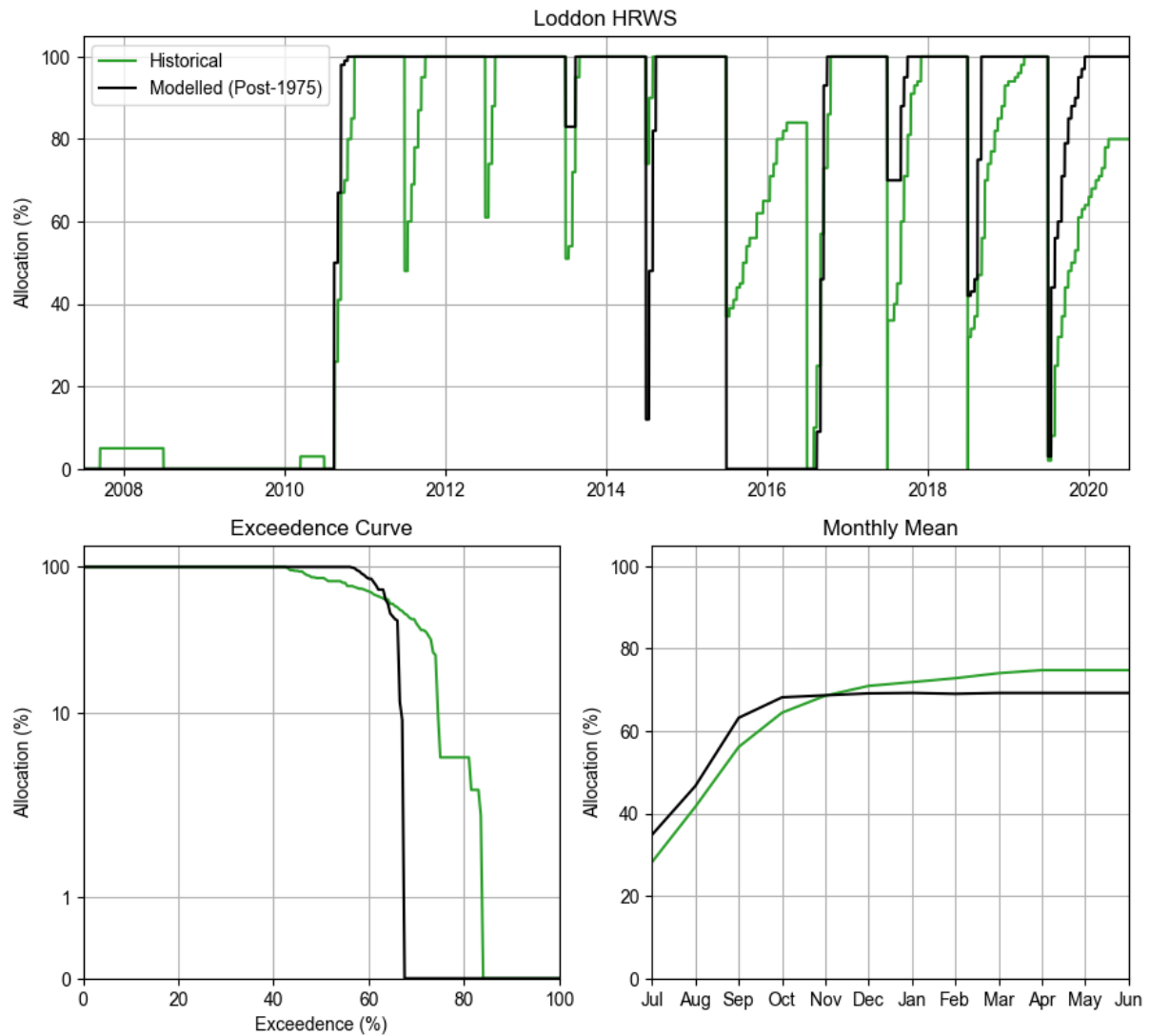


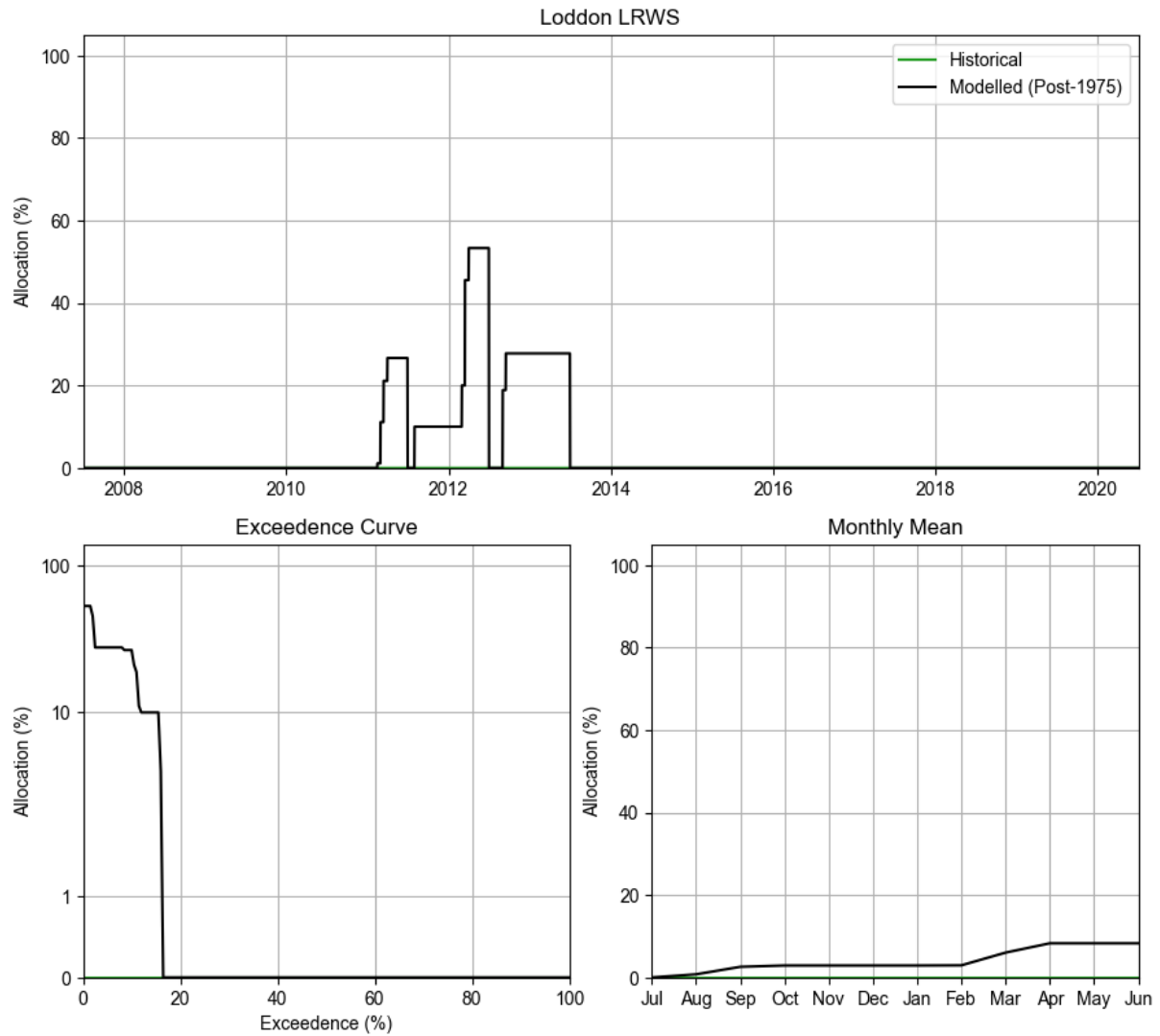
S.1.6 Campaspe



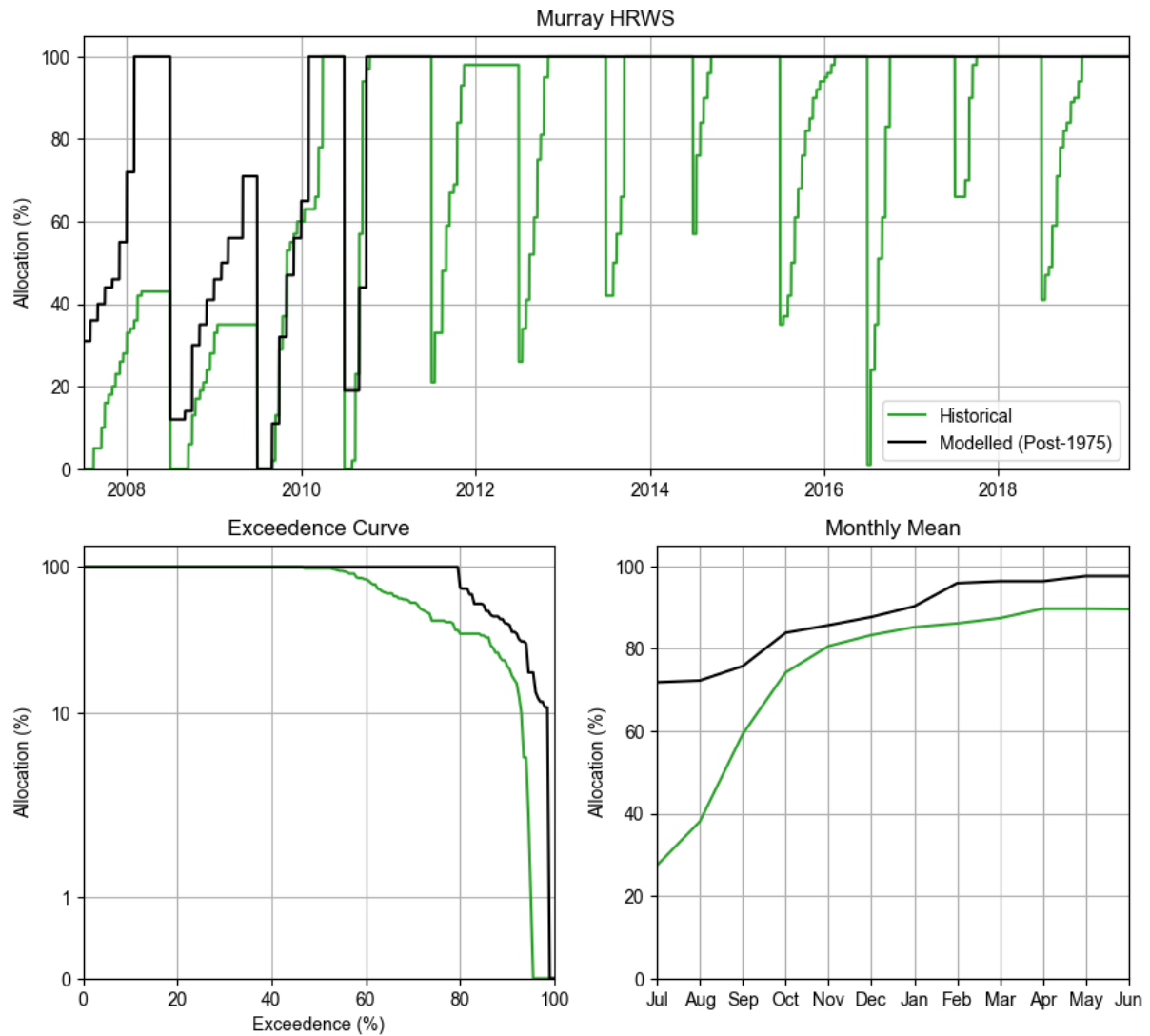


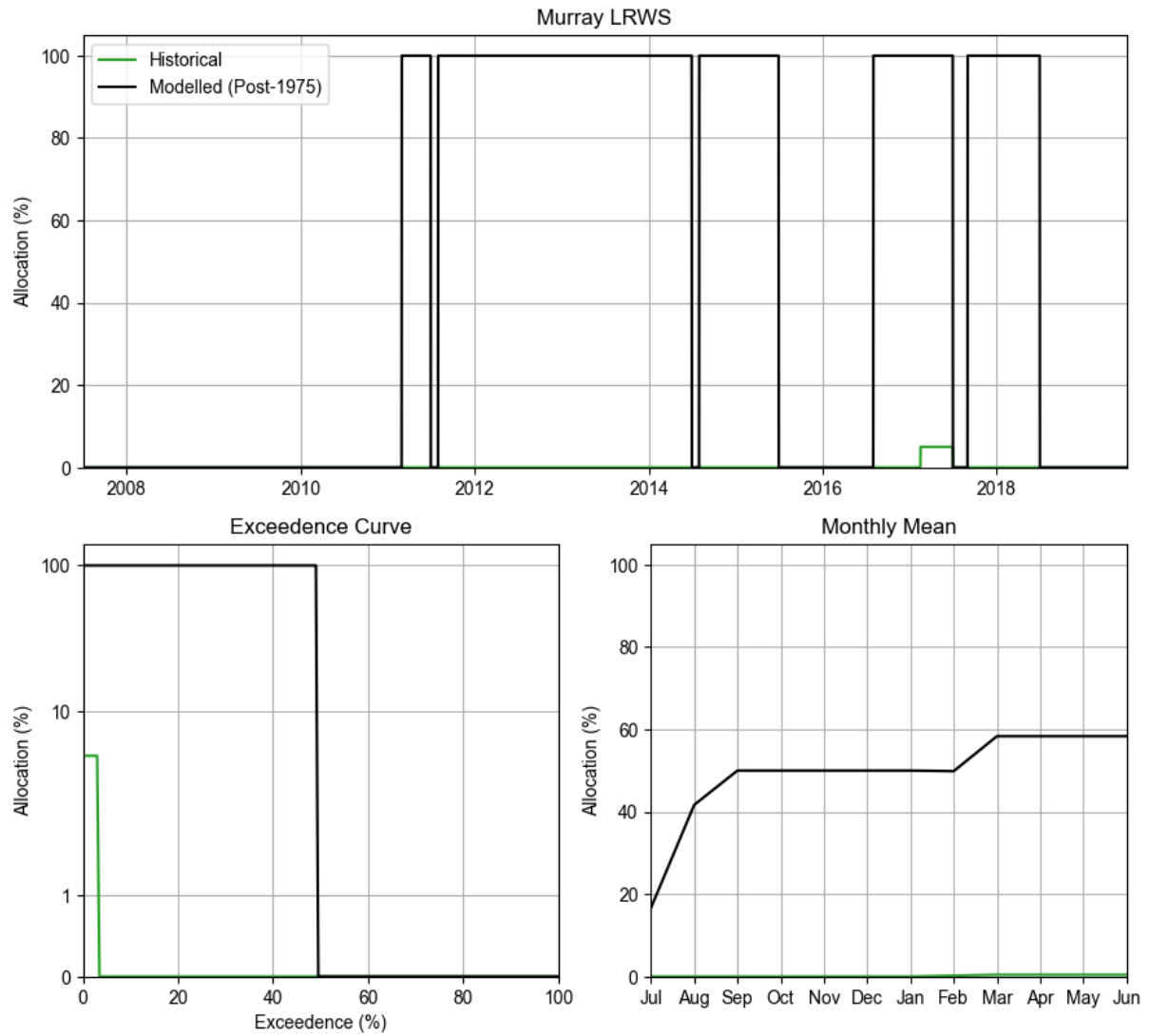
S.1.7 Loddon





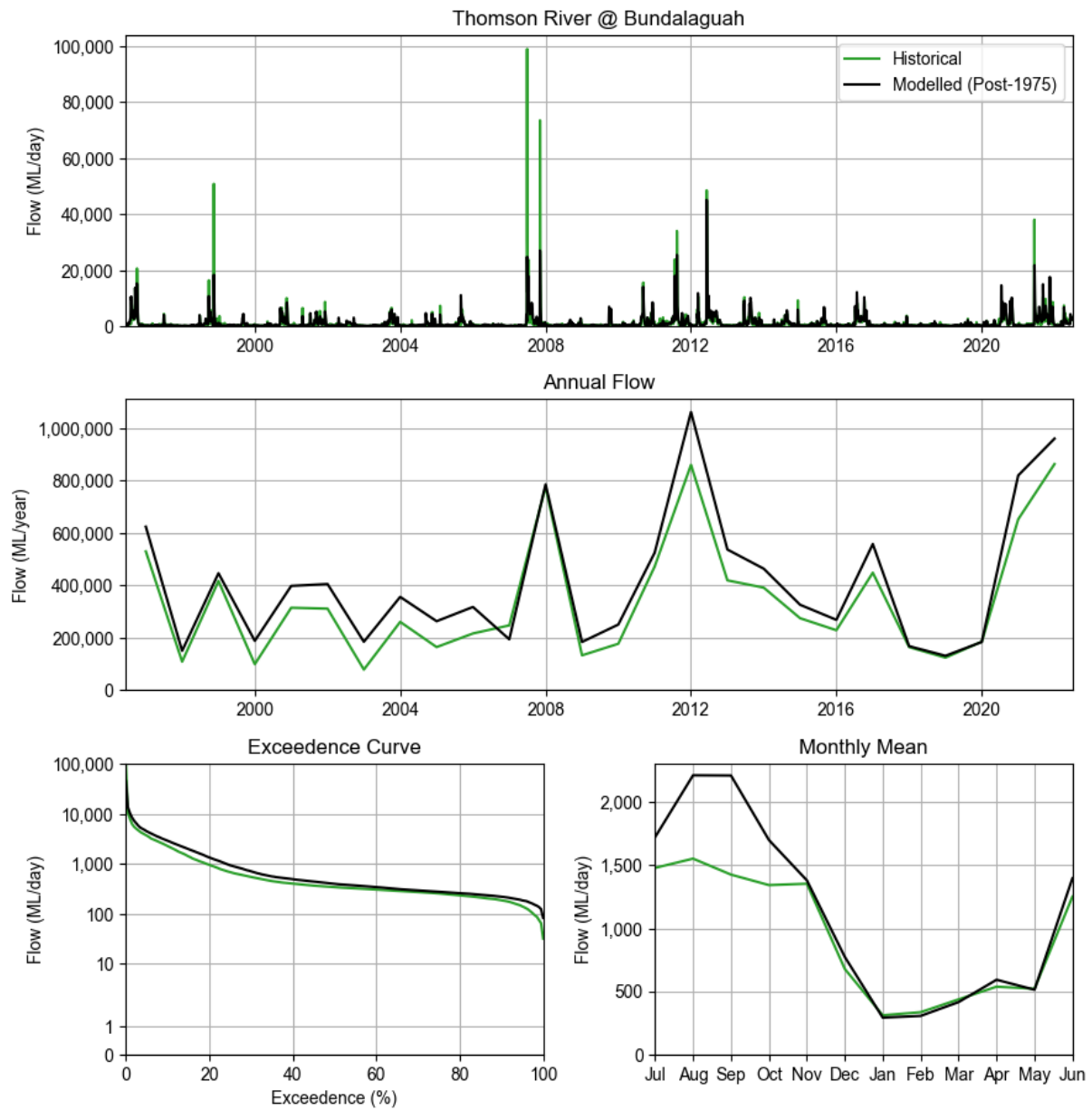
S.1.8 Victorian Murray



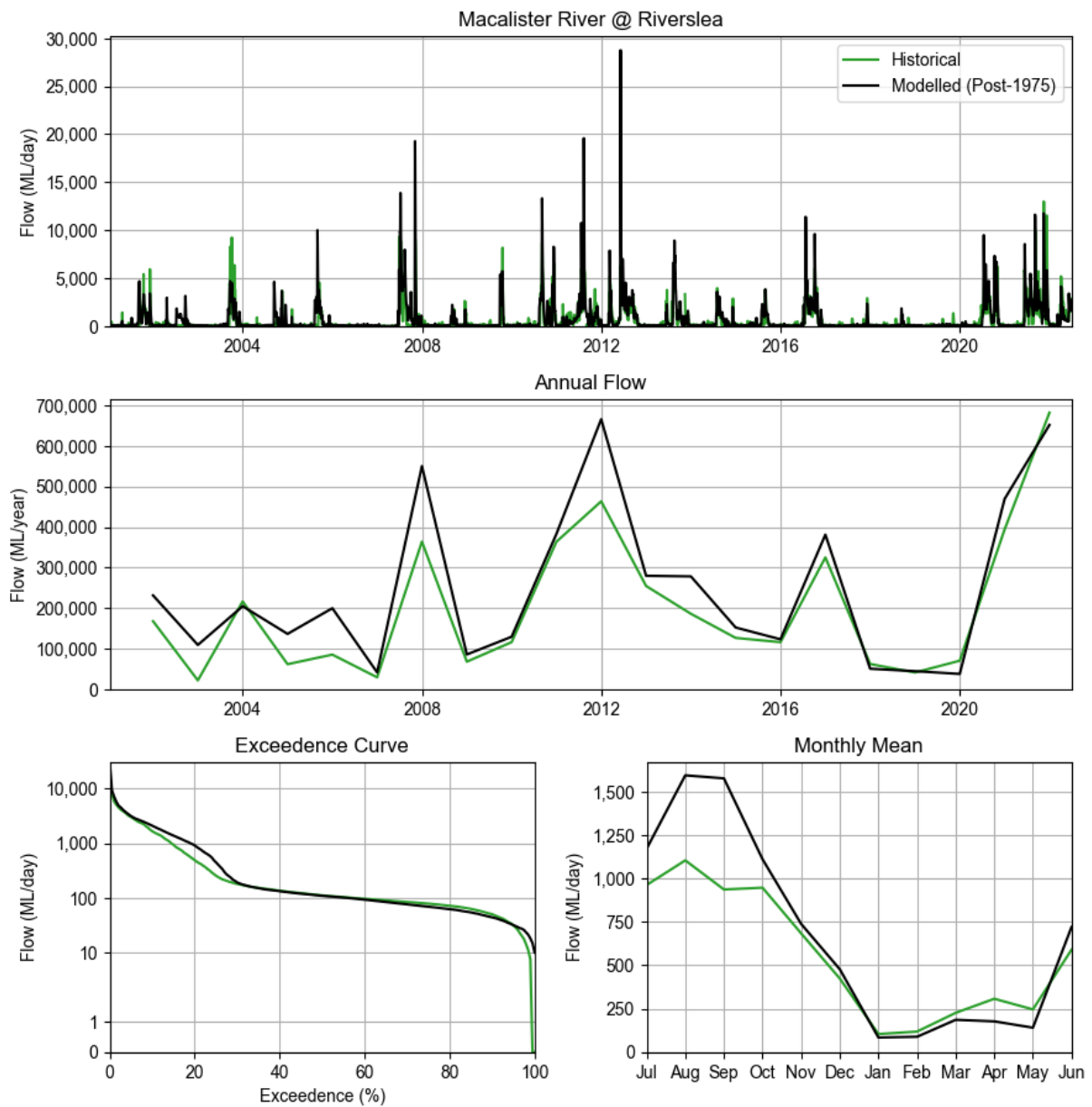


S.2 Streamflow

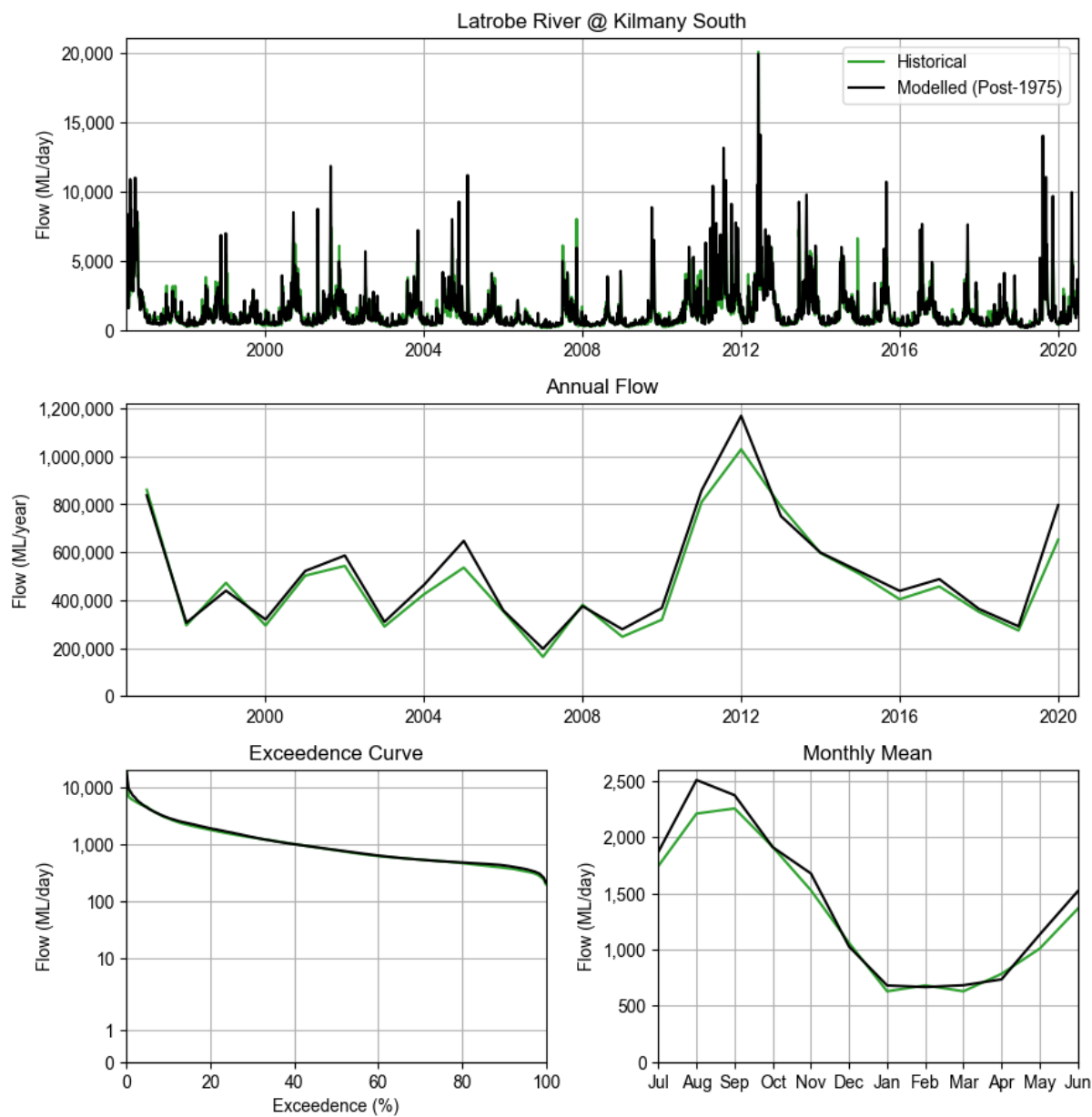
S.2.1 Thomson



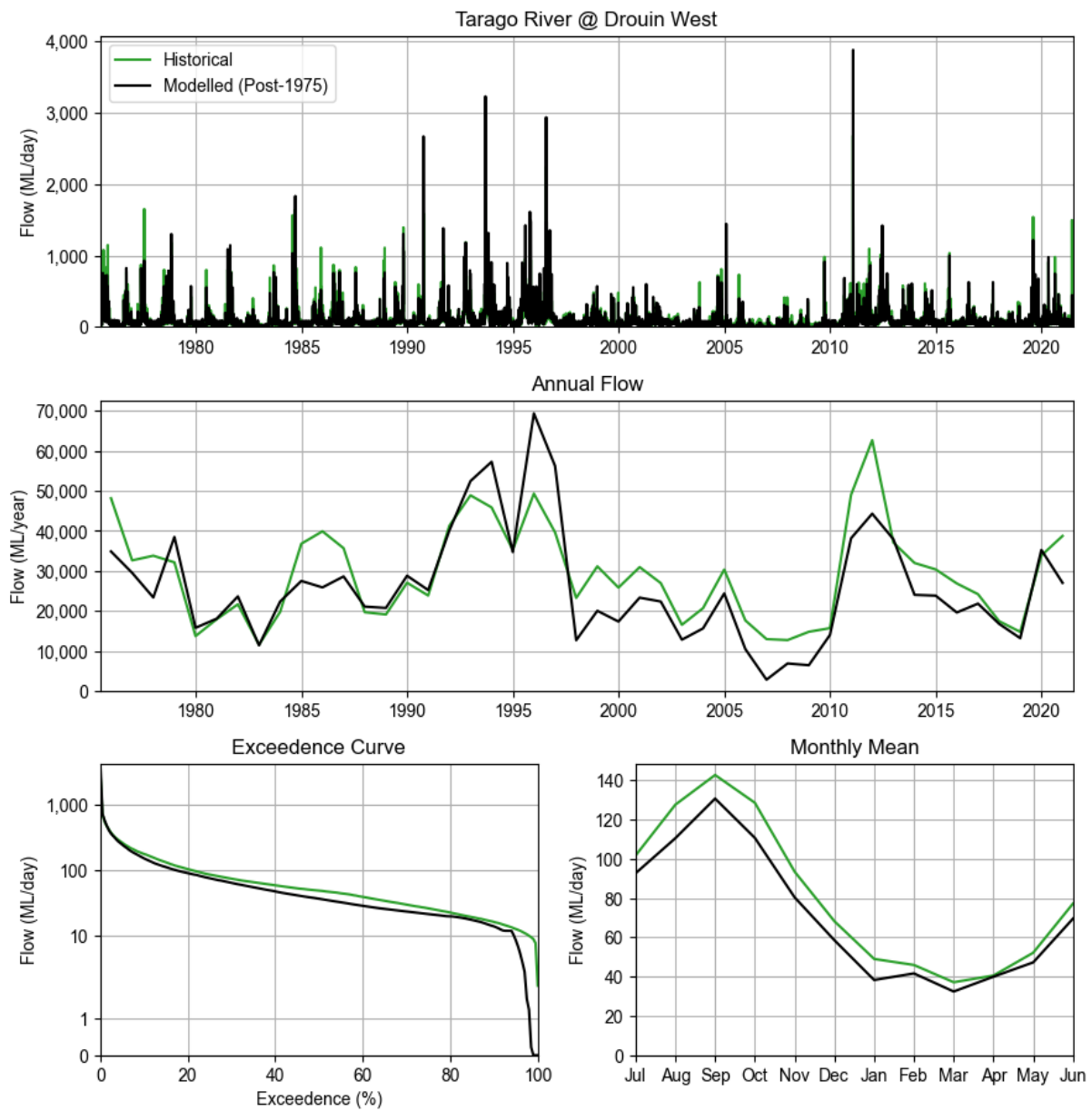
S.2.2 Macalister



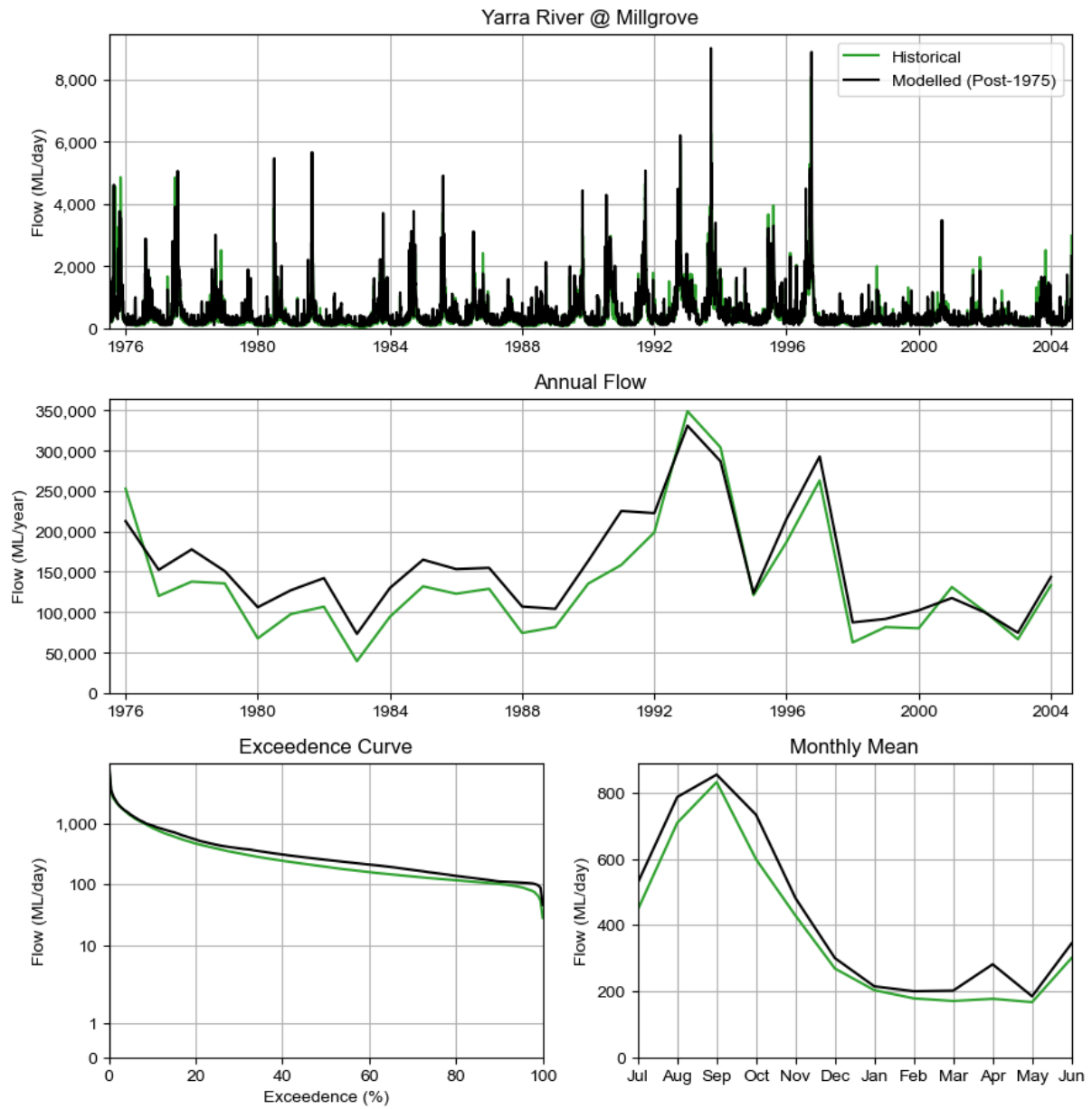
S.2.3 Latrobe

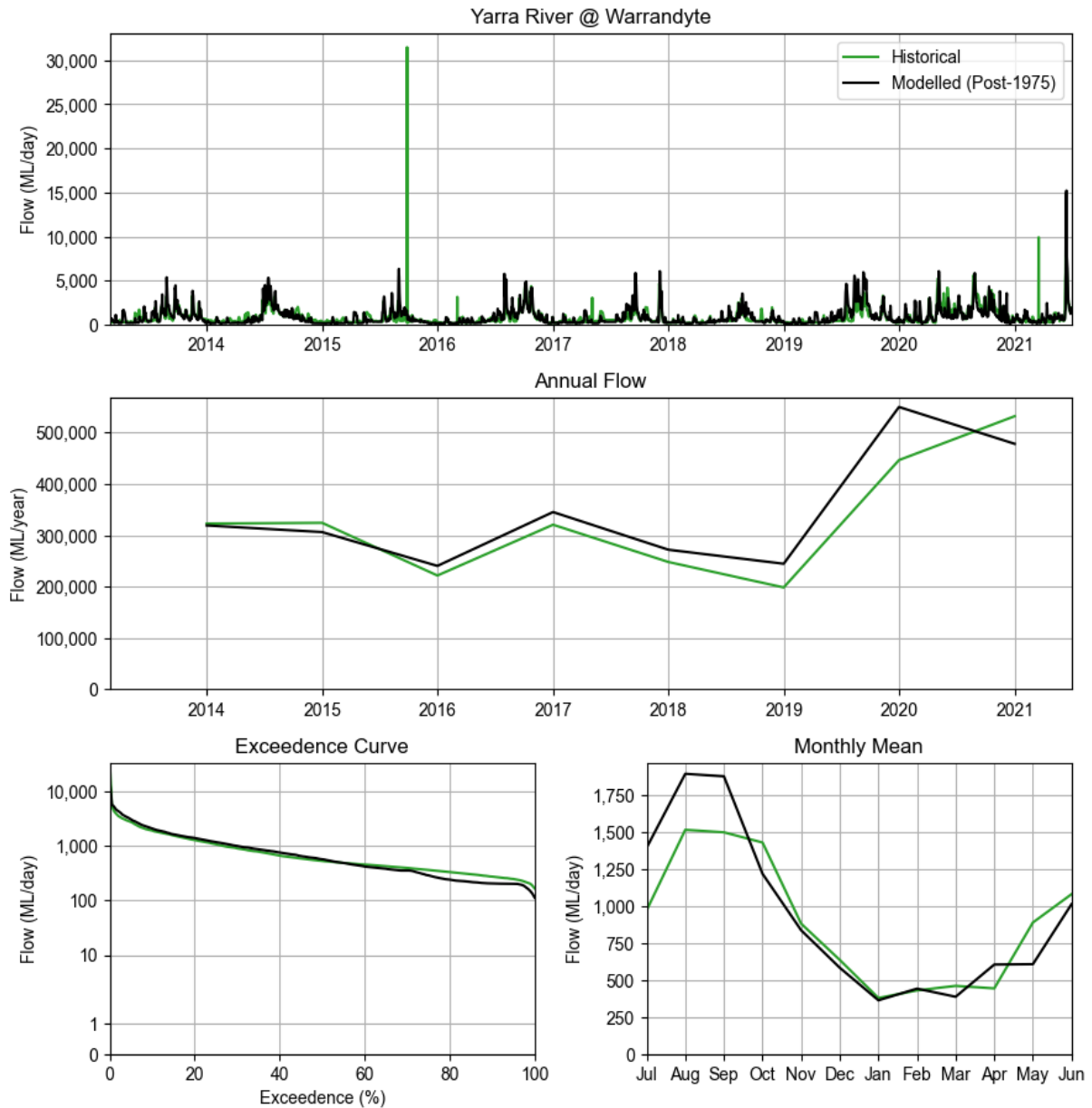


S.2.4 Tarago

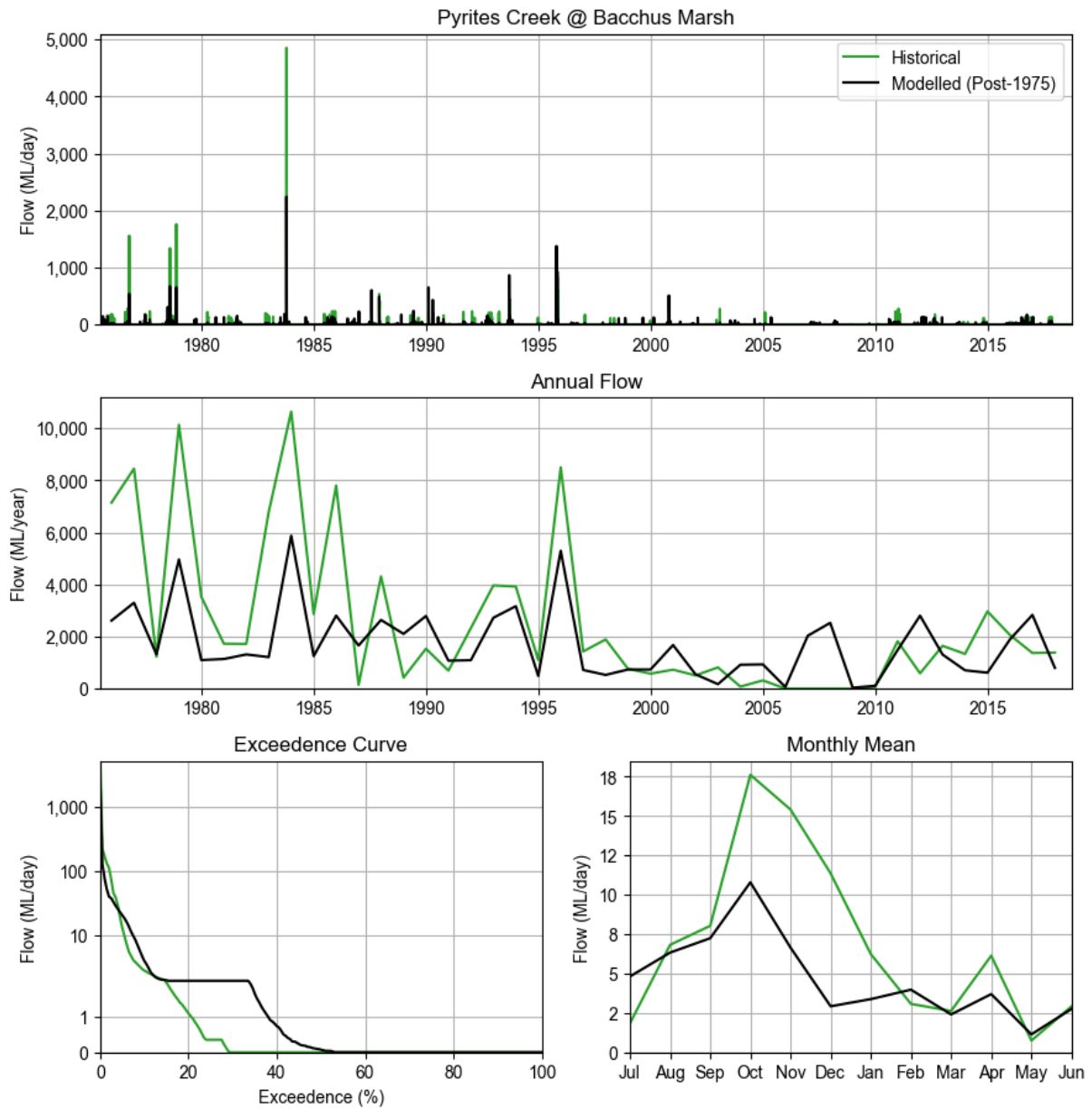


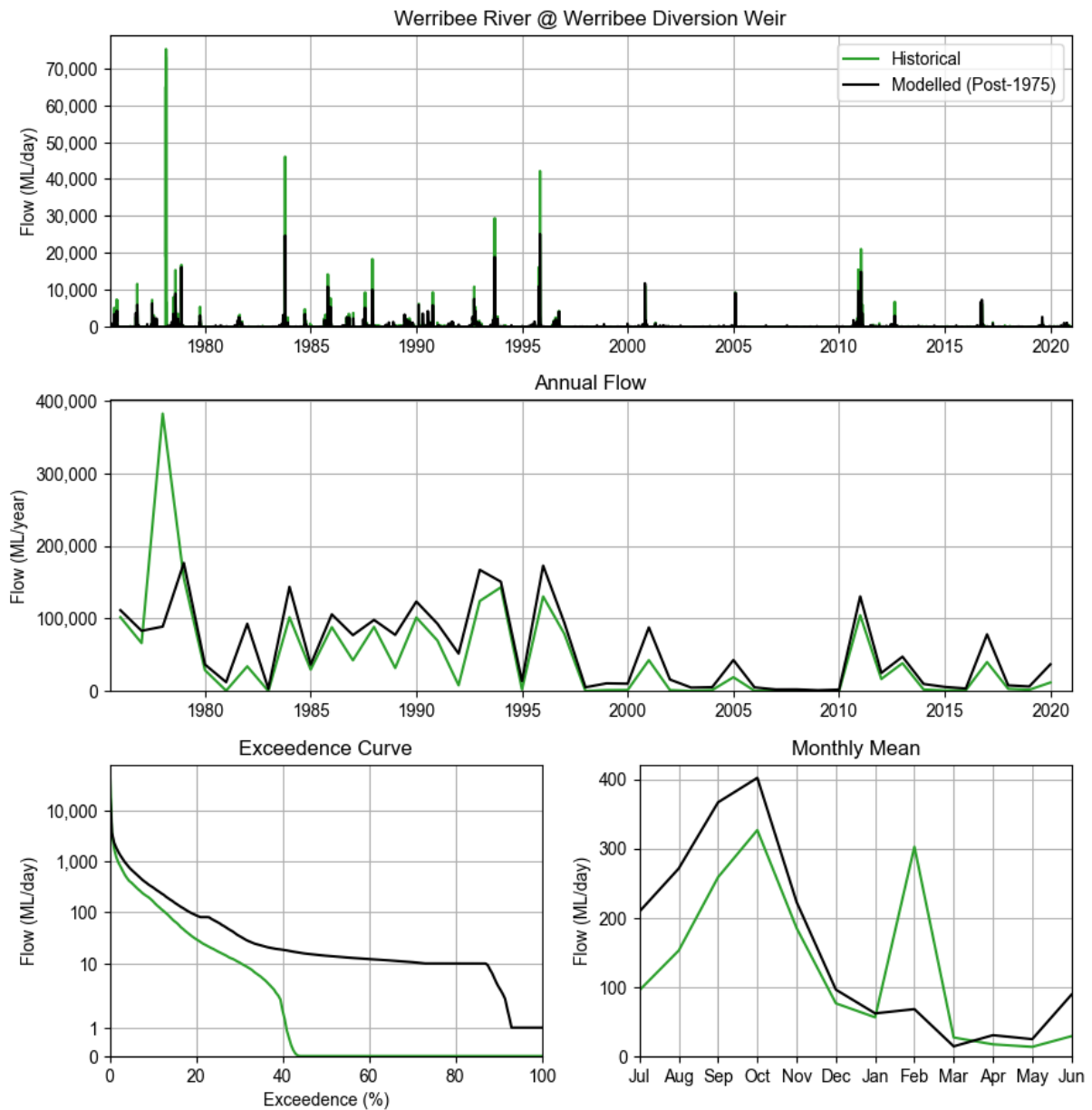
S.2.5 Yarra



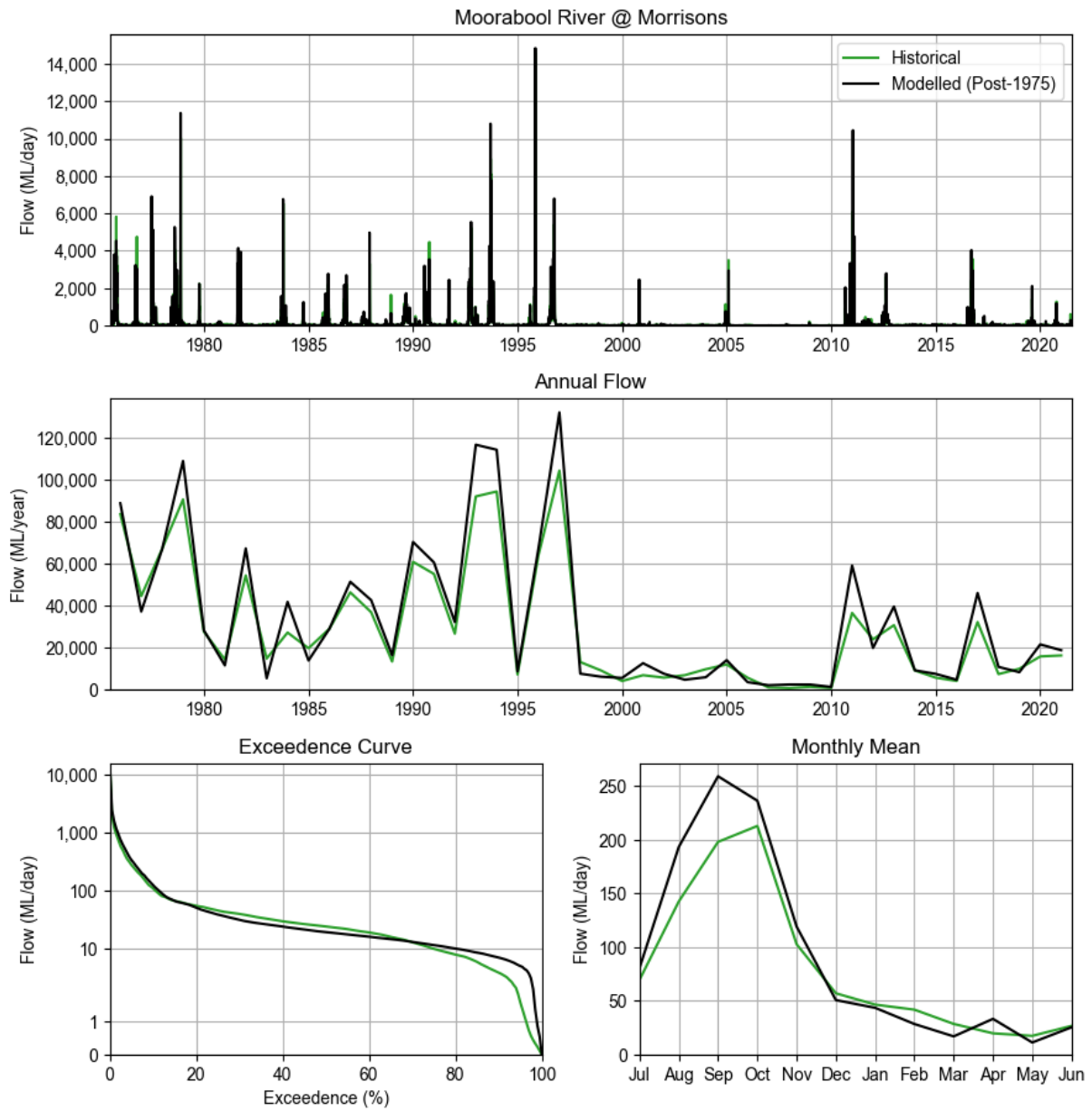


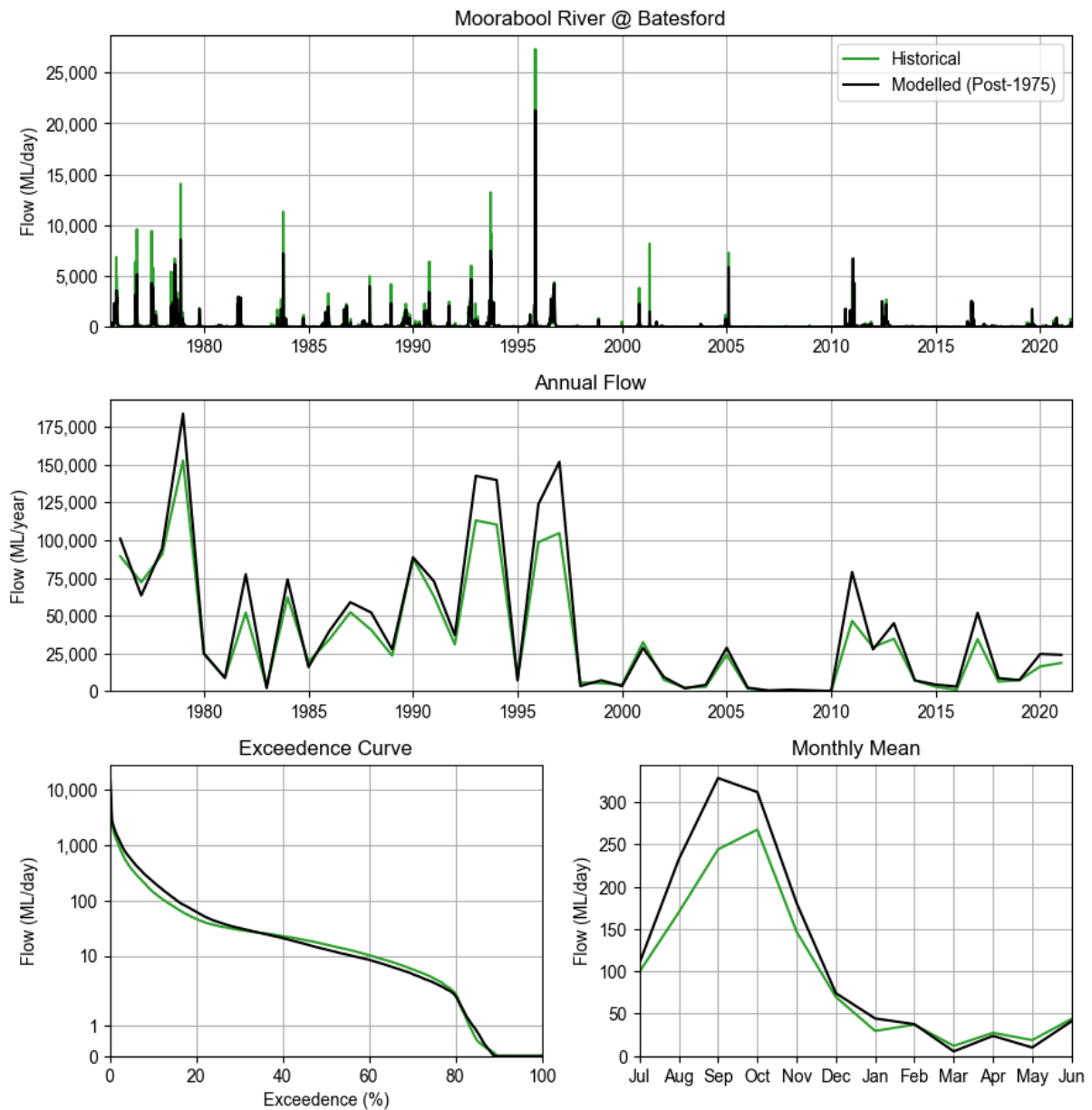
S.2.6 Werribee



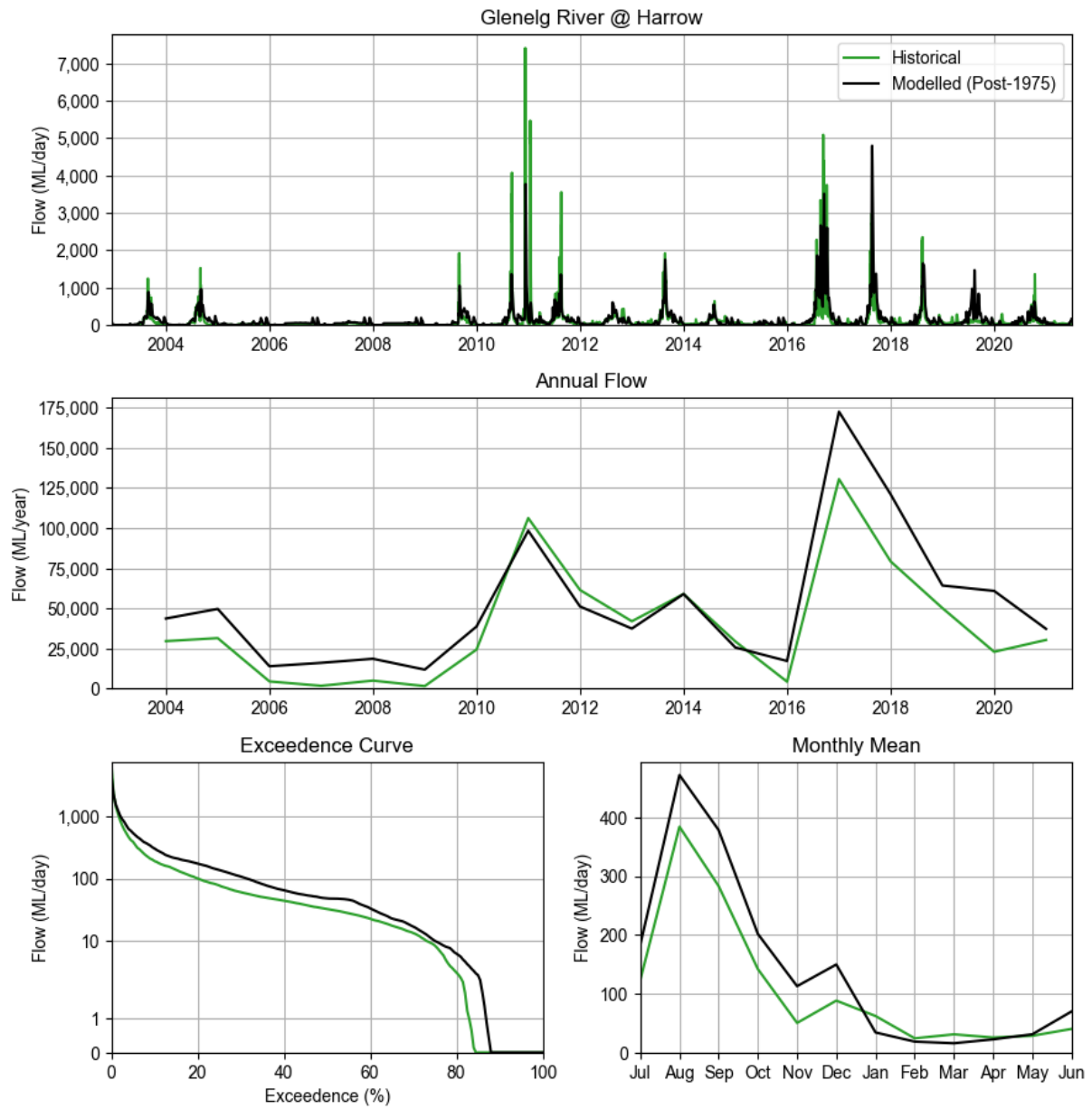


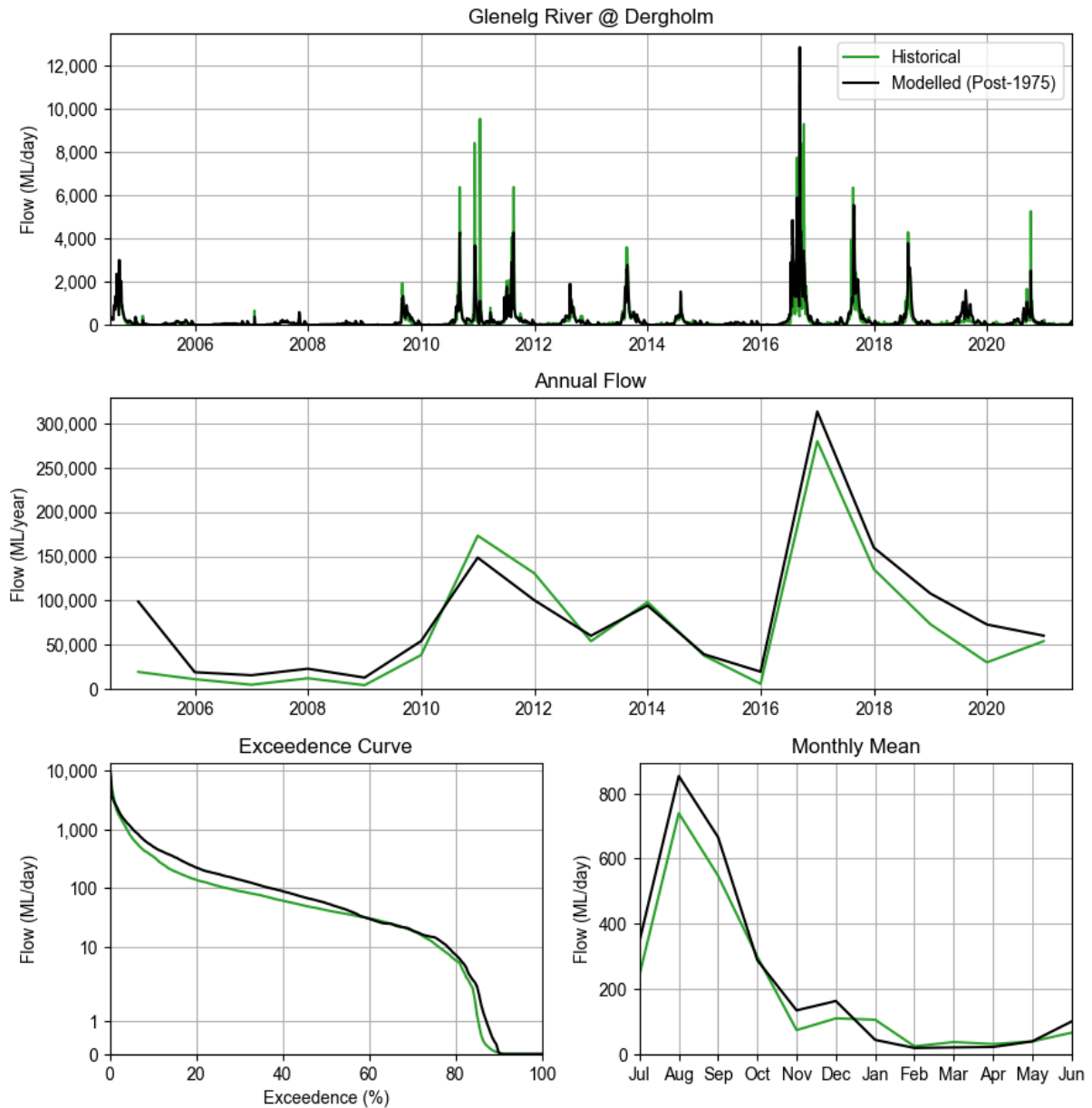
S.2.7 Moorabool



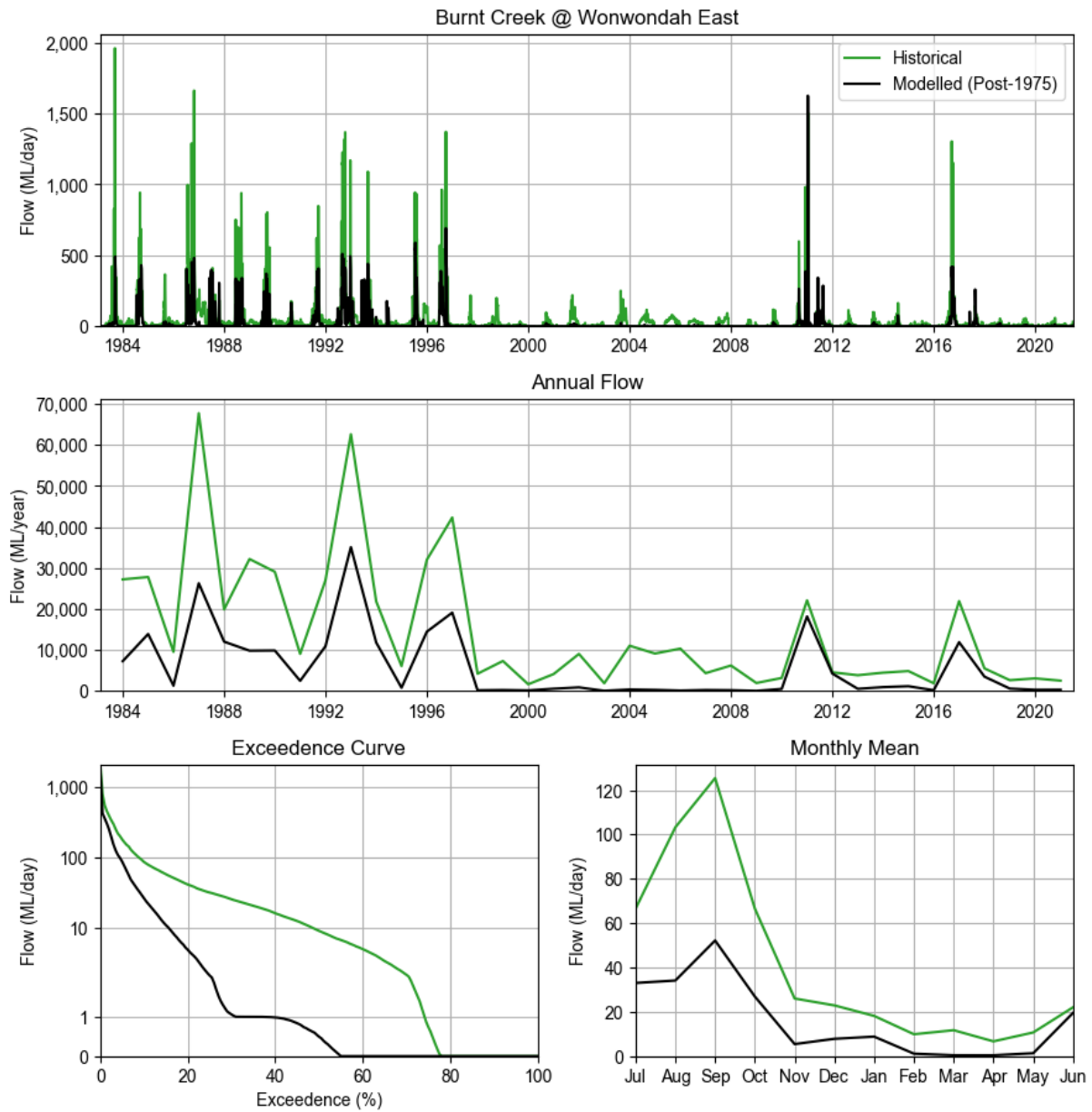


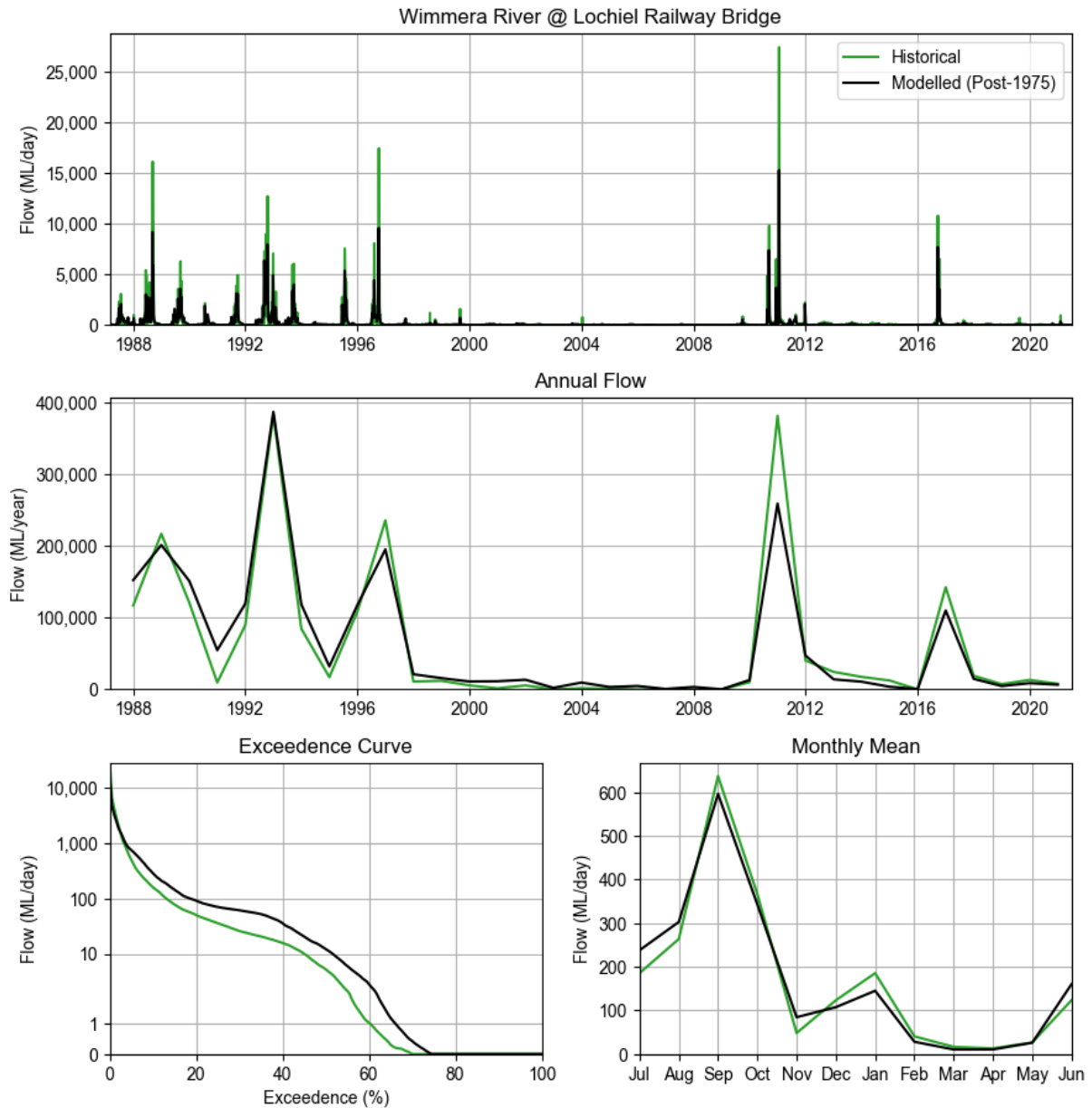
S.2.8 Glenelg



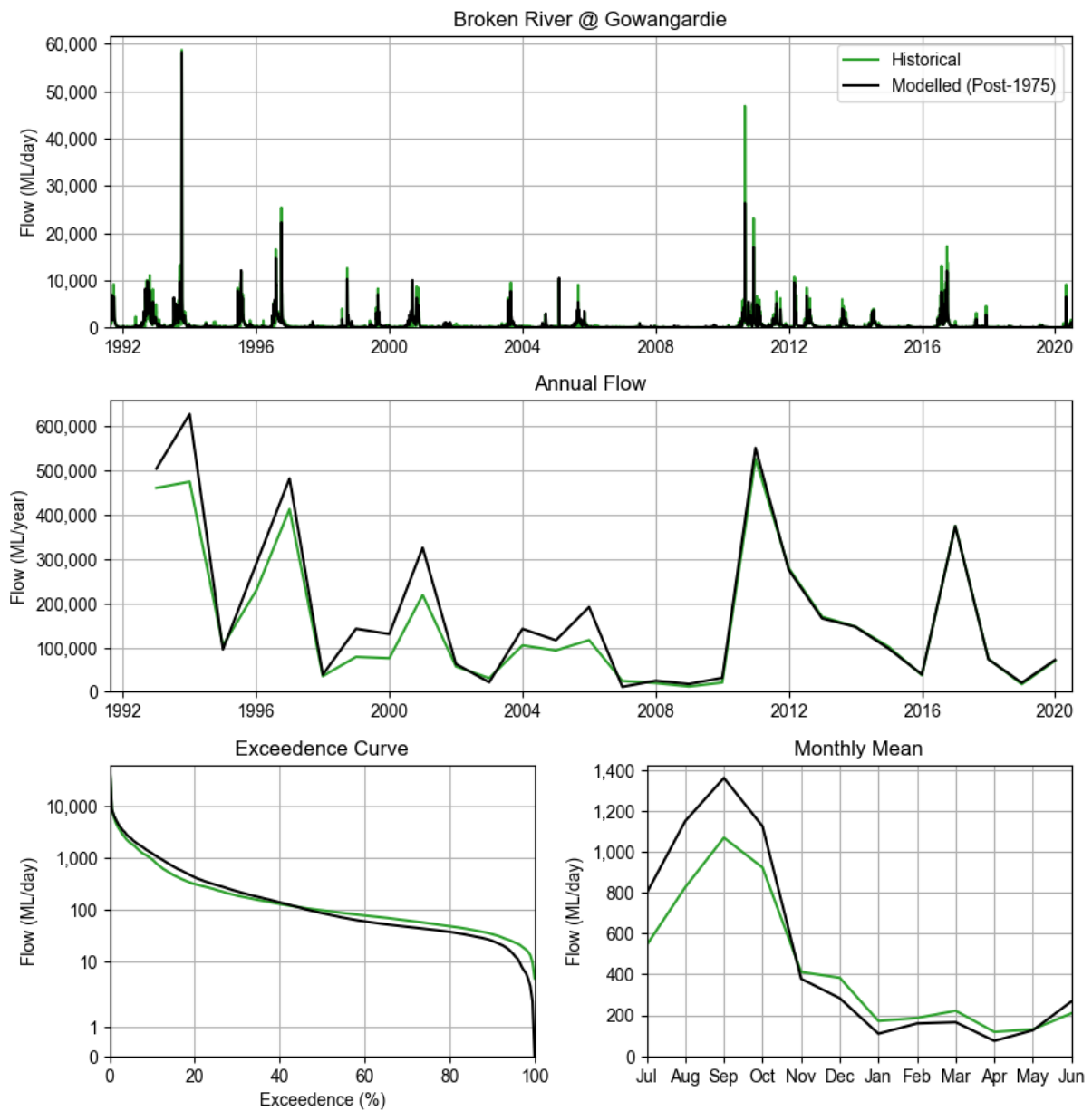


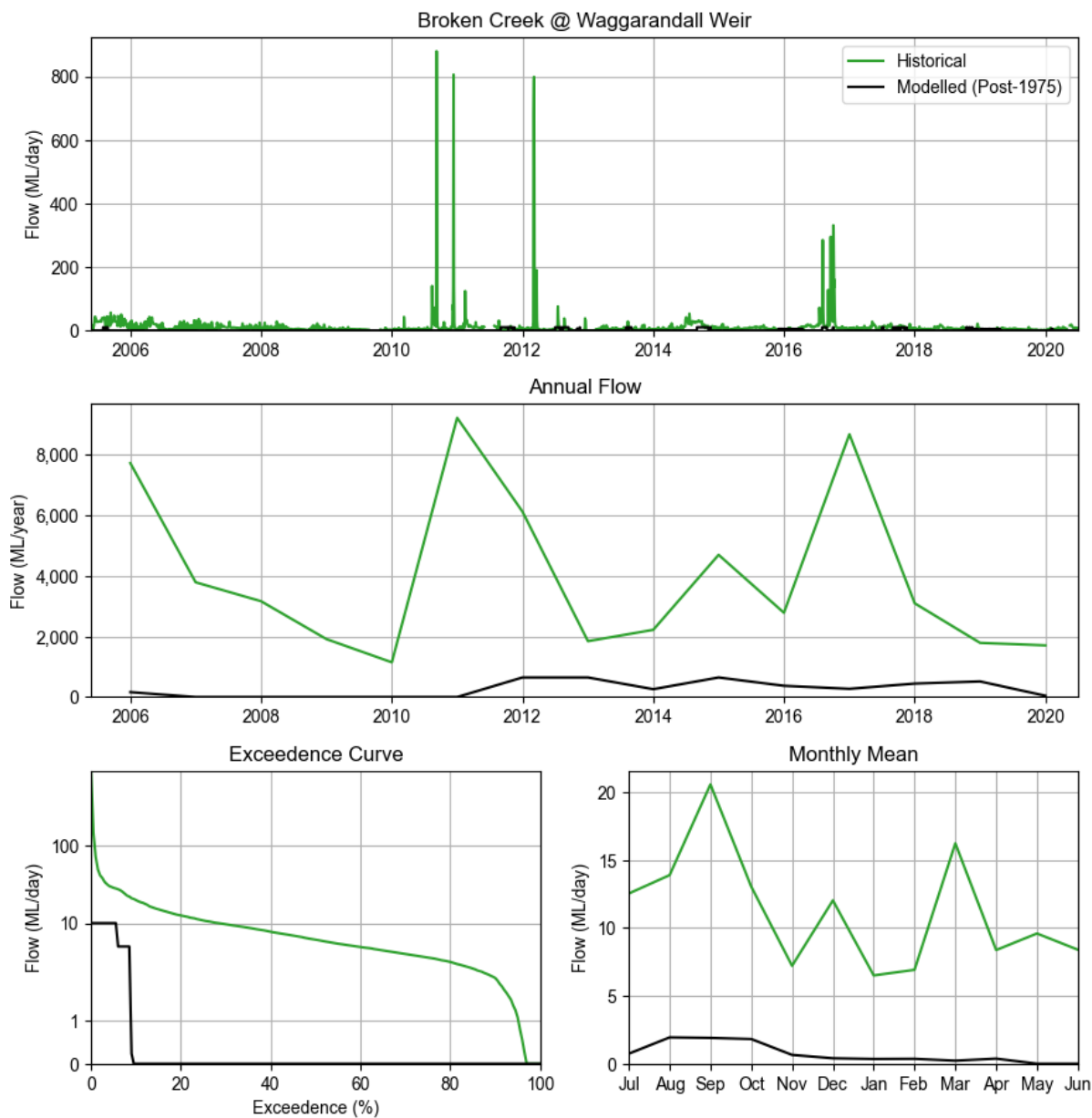
S.2.9 Wimmera





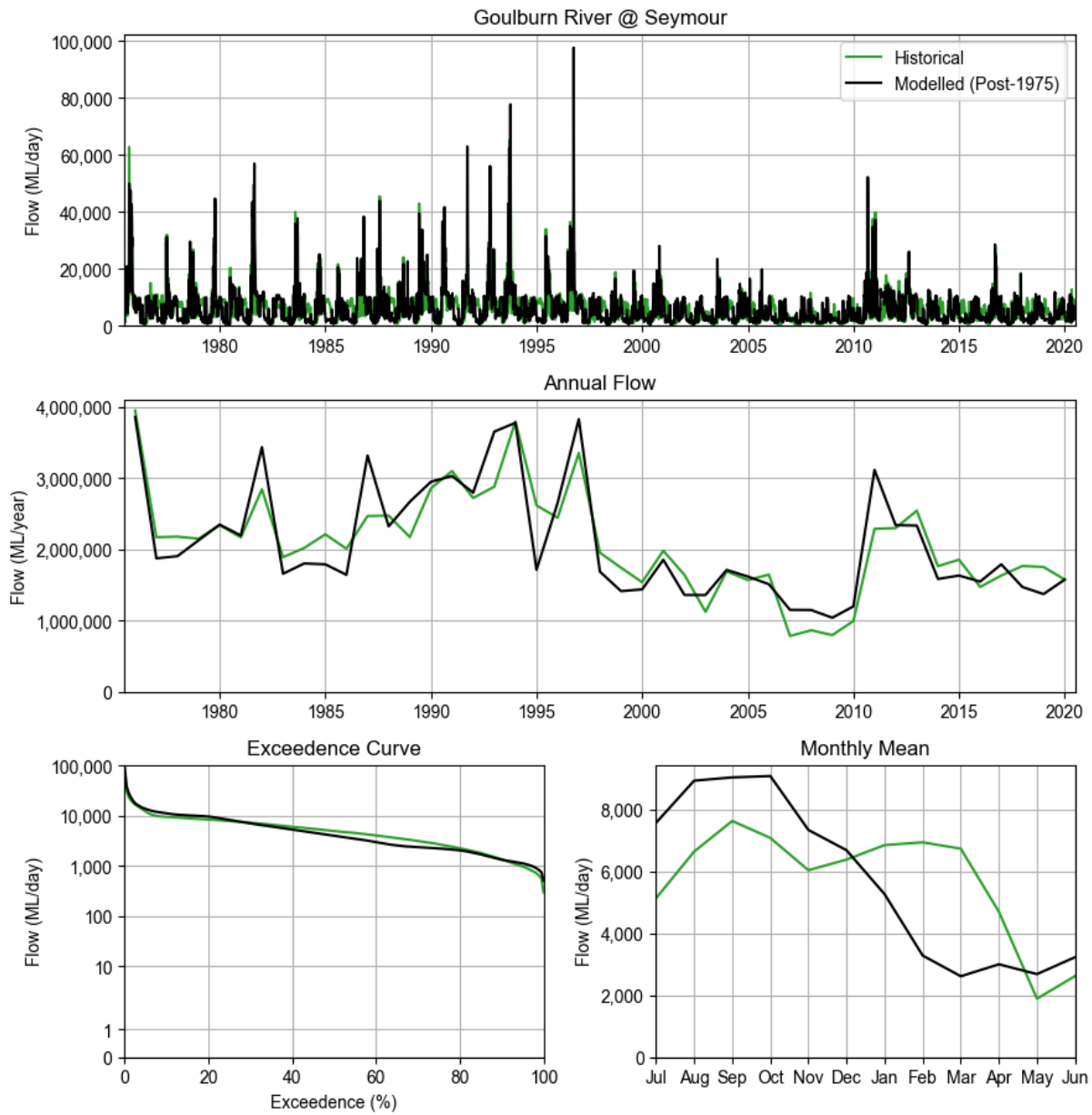
S.2.10 Broken

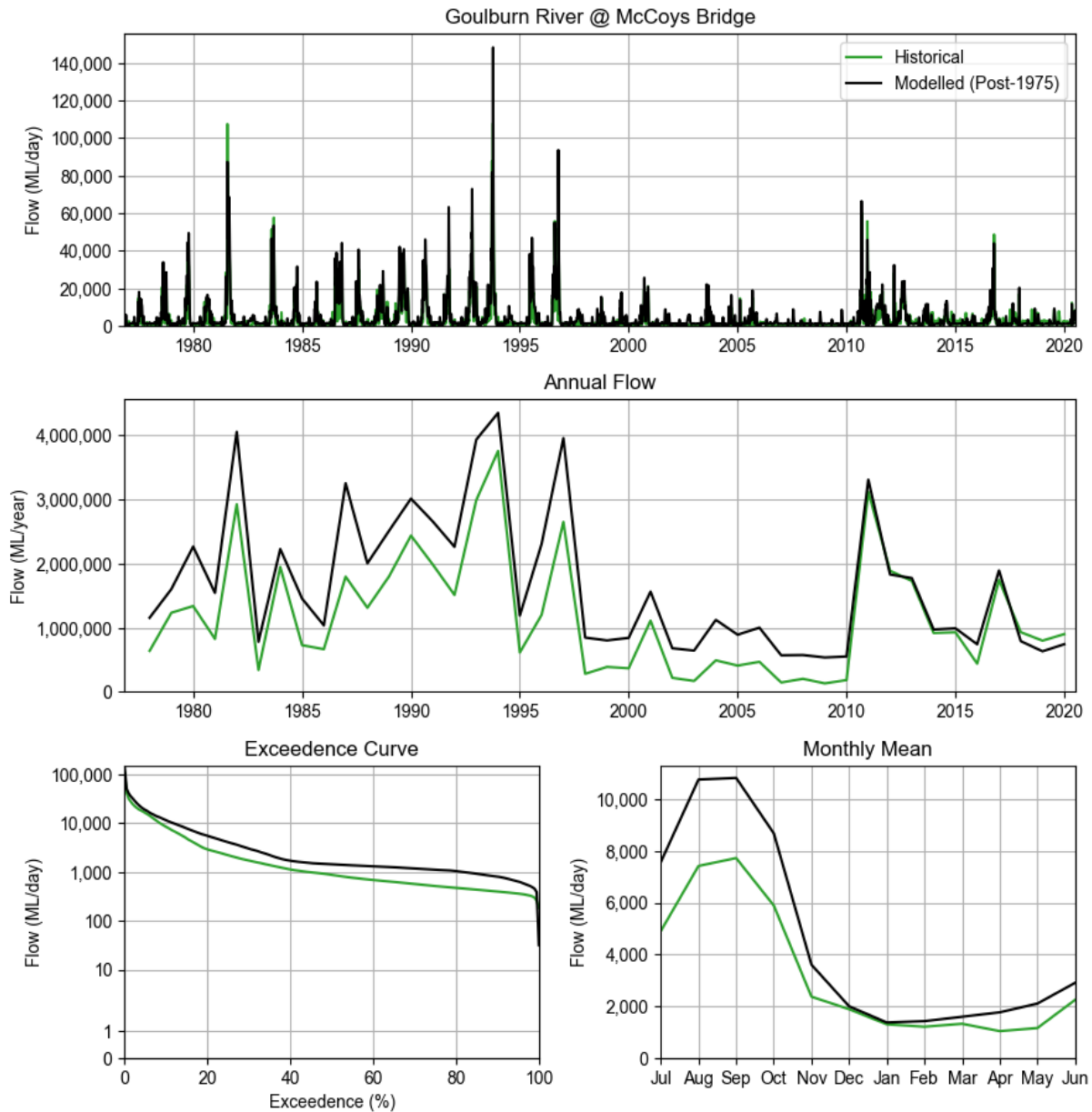




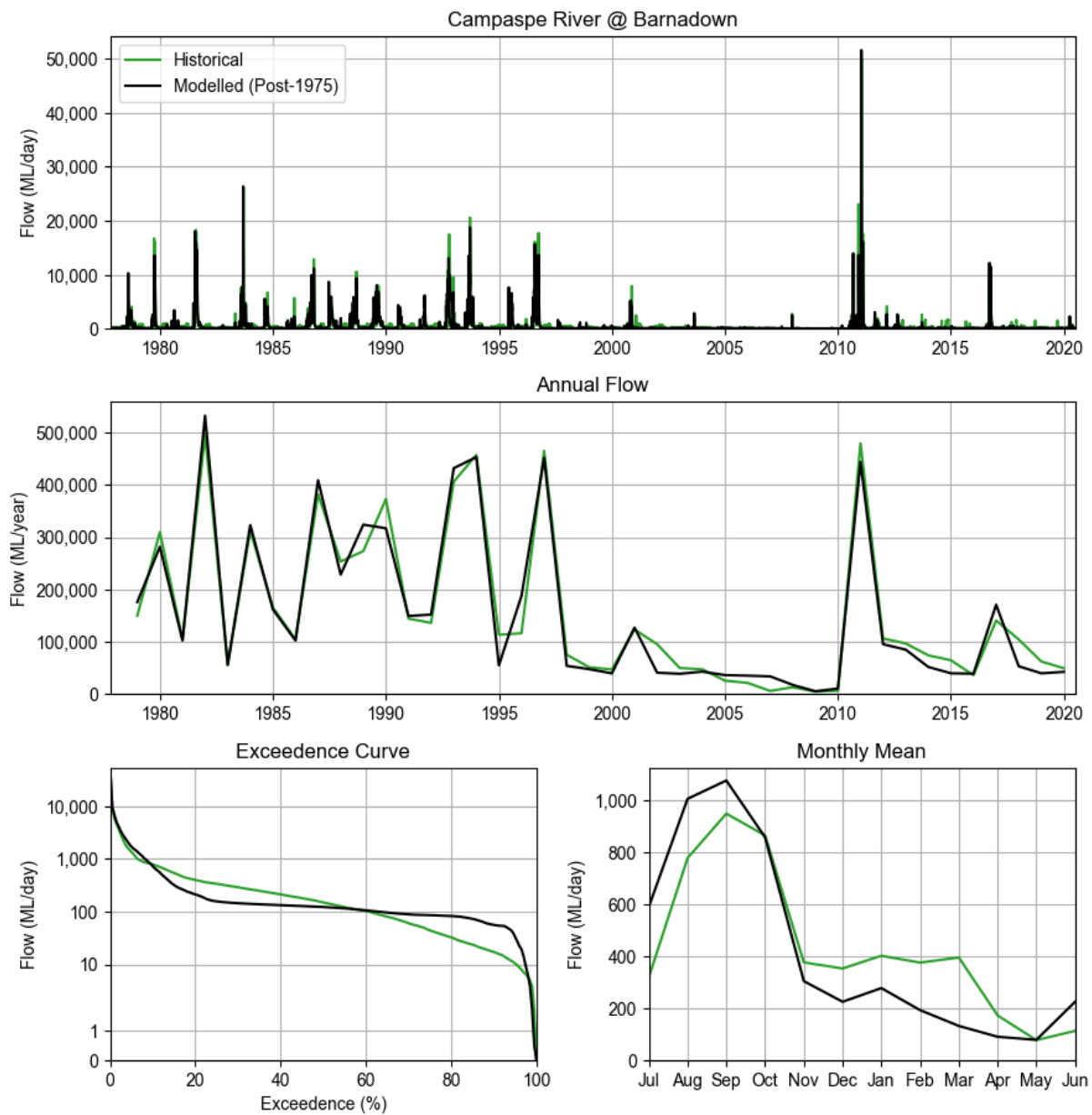
Note, analysis of this site was excluded from this report due to the poor model performance shown above.

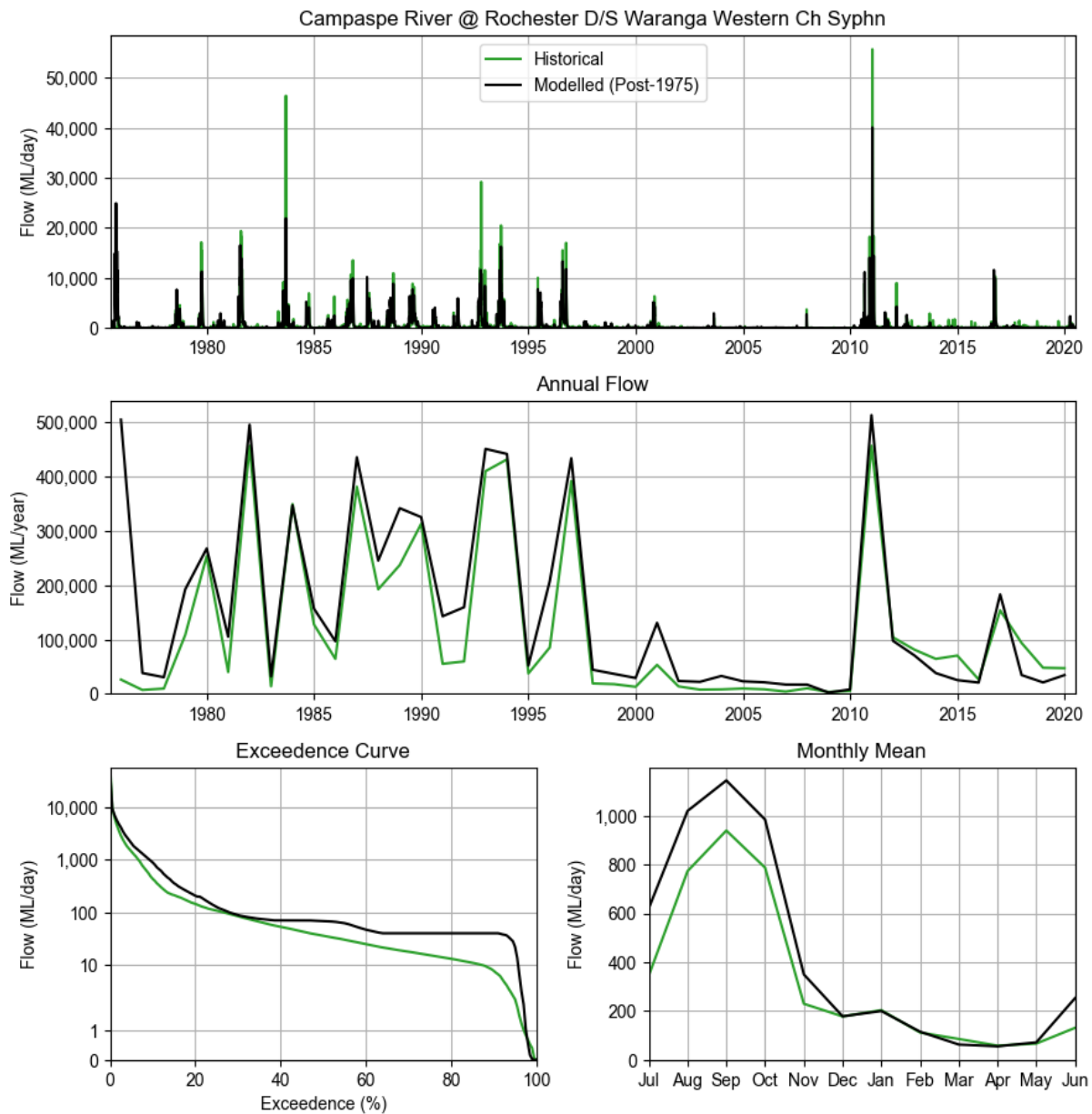
S.2.11 Goulburn



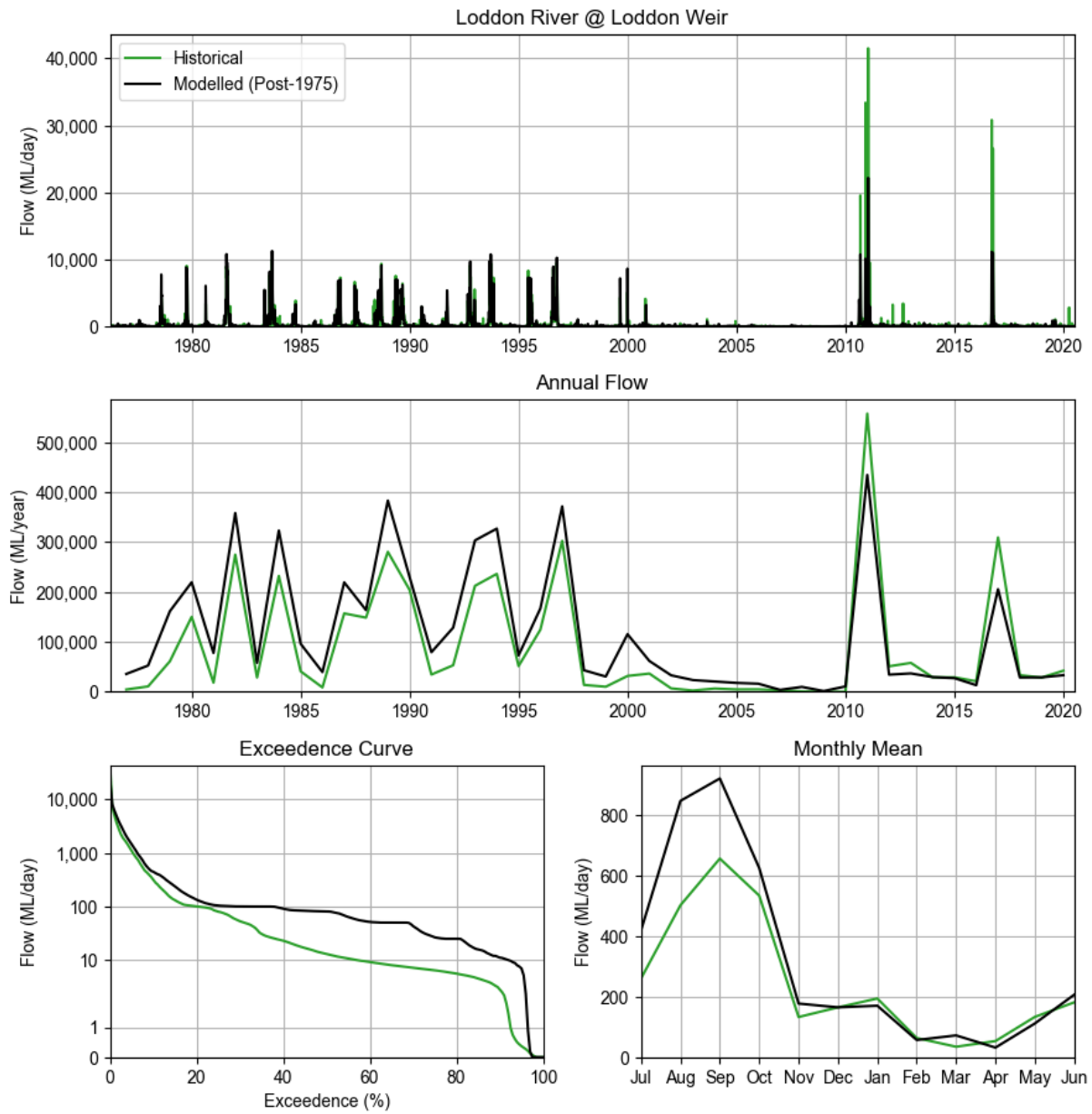


S.2.12 Campaspe





S.2.13 Loddon



S.2.14 Victorian Murray

