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Murray constraints modelling to inform Victorian Constraints Measures Program: Methodology, assumptions, and key outcomes

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Contents

Figures

Tables

1 Background

The Murray Darling Basin Authority (MDBA) and Victorian Department of Environment, Land, Water and Planning (DELWP) entered a Head Agreement in 2022 for a collaborative river Murray constraint modelling study. The study builds on a modelling study undertaken recently for the NSW Reconnecting River Country Program (MDBA, 2022).

Under this bi-lateral agreement between the MDBA and the DELWP, additional constraints modelling is undertaken using Source Goulburn, Broken, Campaspe, Coliban and Loddon (GBCCL) Model by DELWP and Source Murray Model (SMM) by MDBA for the first time to understand flow dynamics and environmental outcomes in the lower Goulburn and Murray with different levels of constraint relaxation. Focus of the study is:

- Determination of environmental orders from Murray to Goulburn calculated by Source Murray Model, coordinating with local environmental water requirements in the lower Goulburn modelled by Source GBCCL model, which is described in detail in this report,
- Assessment of flow dynamics and environmental outcomes with different levels of channel capacity constraints relaxation in both the Goulburn and Murray system, and
- Understanding impacts of different level of constraints relaxation on environmental flow delivery, outcomes and other risks

Murray system at upstream of Torrumbarry responds dynamically with tributary inflows, especially from largely unregulated catchments of the Kiewa and Ovens systems and the Victorian tributaries joining Murray River just downstream of Yarrawonga. While unregulated flows from the Kiewa and Ovens catchments provide piggybacking opportunities to improve environmental outcomes, coordination of regulated flows from the Goulburn system is challenging to manage floodplain outcomes without unintentionally increasing risks of the existing current river operations.

Although the Goulburn-Murray model link is still not dynamic, outputs from GBCCL model at daily timestep are made available to SMM as direct input where SMM generates additional demands for Murray downstream. The total (local and Murray downstream) environmental demands are then used to finalise a scenario in GBCCL model and then SMM model. There are some conversations to improve how to incorporate this connected nature of the southern system using different models and how to coordinate environmental water delivery from multiple sources. Once outcomes from these programs or other improved approaches become available, the current approach should be reviewed and revised.

The study provides likely environmental flow delivery from the Goulburn to Murray systems as an estimate from GBCCL model with varying degrees of relaxing constraints at number of locations along Goulburn River, with and without additional requirements for Murray downstream locations.

This report describes the modelling methodology and assumptions applied in relation to channel capacity constraints relaxation in the Murray and Goulburn system including an estimation of Murray environmental orders by SMM based on the GBCCL output and subsequent inclusion of these orders in the GBCCL to provide final set of environmental flows to the Murray which the SMM uses as input. There are some key findings from this modelling study documented at the later part of this report.

2 Model version and data sharing arrangement

The MDBA is using Git as a version control system and Bitbucket as a web client to manage the changes to the source code over time. Source framework is built, tested, and deployed using Bitbucket Pipelines, while Source models are committed to the repository after internal checks and testing for quality assurance. Individual Source models are either in their individual repositories or branched out to manage them efficiently. Changes to the branch is committed to the repository after running a Python script, Pre-Commit Test, to ensure all the key model scenario results are within an acceptable and explainable range of differences from the previous version.

2.1 Model provenance

For this study, a version (commit number: f378d67) in the Menindee branch, which is used to maintain progressive developments of Basin Plan settings, is used with required changes to support the current project. This branch is also used to inform the NSW Reconnecting River Country Program (RRCP) modelling project. Due to large numbers of scenarios with different input timeseries from GBCCL especially for climate changes scenarios, a sub-branch (commit number: 550887f) is created from the Menindee branch so that key model scenarios can be retraced back to replicate their model set-ups and results.

Table 1 Provenance of SMM

Scenario	Component	Version	Repository
Historical climate with different levels of constraints relaxed	Software	Source 5.14.0	https://bitbucket.org/ewater/source-murray-model/src/Menindee/ Commit: f378d67
	Model	River Murray Model 5.14.0.rsproj	
Future climates with a key relaxing constraint scenario	Software	Source 5.14.0	https://bitbucket.org/ewater/source-murray-model/src/VicCMP/ Commit: 550887f
	Model	River Murray Model 5.14.0.rsproj	

2.2 Input preparation

A python script has been developed to convert outputs from GBCCL in excel to readable csv format as an input to SMM. This script is also maintained in the Menindee and VicCMP branch.

2.3 Environmental Watering Requirement tool

Flow results are analysed for environmental watering requirement (EWR) indicators as developed by NSW for Long term watering plan (LTWP). This analysis is used for flow spell comparison between different constraints and climate scenarios along Murray, Lower Darling system. For this analysis MDBA has used an inhouse tool in python, developed in collaboration with NSW, called "EWR tool".

Table 2 Provenance of EWR tool

Component	Version	Repository
Software	py-ewr 0.9.3	https://pypi.org/project/py-ewr

2.4 Data sharing

Data and results produced by VIC and MDBA is shares in a common sharepoint platform created by Sequana. That platform has been used to share model results from GBCCL and SMM for iteration and interaction between the two models and analysis of scenario results.

3 Current condition scenario

The base case scenario used in this study represents our best representation of current river conditions, policy and operation rules. The base model scenario was also used to develop a number of scenarios to inform NSW RRCP project. The key assumptions and updates included during the process of development from a Baseline Diversion Limit (June 2009) condition to Water Resource planning (WRP) condition to a Current (June 2019) condition is described in MDBA (2022). This section highlights the key model representations that are related to this project.

3.1 Environmental water recovery

There are majority of entitlements acquired by Commonwealth Environmental Water Holder (CEWH) from 2011 to 2016, with no significant recovery in recent years. The setup used for this project includes environmental water recovered by CEWO as of June 2019. There have been some further water recovery activities in recent years. However, they would not be substantial enough to warrant a revision to model representation of current conditions. Table 3 presents different types and volumes of environmental entitlements included in the model.

Table 3 Water recovery included in the model

Catchment	Location	Type	Entitlement (GL)
Victorian Murray	Above Choke	HRWS	88.2
		LRWS	10.78
	Below Choke	HRWS	274.1
		LRWS	24.6
NSW Murray	Above Choke	HS	0
		GS	304.85
		Conveyance	20.2
	Below Choke	HS	17.9
		GS	64.8
		Conveyance	0
Lower Darling		HS	3.1

	GS	21.56
SA Murray	HS	161.4
Campaspe	HRWS	6.6
	LRWS	0.4
Goulburn-Broken	HRWS	318.0
	LRWS	42.5
Loddon	HRWS	3.4
	LRWS	0.5
Murrumbidgee[1]	HS	14.2
	GS	286.5
	Conveyance	50.3
	Supplementary	22.0
	Lowbidgee	406.6

3.2 Current constraints

The Current level of constraints is modelled at a number of different locations along the Murray, Lower Darling and tributaries. The constraints represent physical capacity in placed, but also informed by operational and management limits in the system. The current level of constraints that are related to this project and investigated for relaxation is listed in Table 4.

3.3 Environmental watering strategy

Environmental water delivery in this study is adopted from an approach used to inform the NSW RRCP project. A brief description is presented below, but more detailed information is available in MDBA (2022).

To implement environmental watering requirements, it uses built in capabilities of the Environmental Flow Node (EFN[2]) and Environmental Flow Manager (EFM[3]) in the Source platform. The EFN provides comprehensive ways to generate environmental demands depending on various conditions such as the required frequency and duration of an event. In general, an opportunistic event is sought based on existing flow conditions, and then additional environmental water is released to enhance or extend the existing conditions. If an opportunistic trigger does not occur over a certain period, then it builds an environmental event from a scratch without waiting an opportunity if there is sufficient water availability in the environmental water account.

When environmental water demands are bigger than water available in the environmental account, the EFM prioritises them based on some decision parameters including the time since the last event delivered, required frequency, and importance weightings which can be defined by users.

[1] https://www.awe.gov.au/water/cewo/about/water-holdings#commonwealth-environmental-water-holdings

[2] Environmental Flow Node - Source User Guide 5.10 - eWater Wiki

[3] Environmental Flow Manager - Source User Guide 5.10 - eWater Wiki

3.3.1 Environmental demand in the Edward-Wakool system

There are 7 actions included in the model at the three locations of Wakool River D/S offtake regulator, Yallakool Creek D/S offtake regulator, and Colligen Creek D/S offtake regulator. The environmental demands are developed in consultation with CEWO (Shean, 2018). These actions are designed to achieve various flow regimes and their associated outcomes within the current environmental watering capacity of 15,000 ML/d at Yarrawonga, so these strategies are applied for current and all constraints relaxed scenarios.

3.3.2 Environmental demand at Yarrawonga downstream

Environmental demand is placed at Yarrawonga downstream guided by the Long-Term Watering Plan (LTWP) prepared by NSW for the Murray-Lower Darling system (NSW DPIE, 2020a and 2020b). Broadly they represent the following flow regimes.

- Baseflow and in-channel freshes requirement of flows below 9,000 ML/d,
- Small overbank flows of 12,000 – 18,000 ML/d,
- Medium overbank flows of 20,000 – 30,000 ML/d,
- High overbank flows of 30,000 – 45,000 ML/d.

These environmental orders are delivered by releasing water from Hume storage considering antecedent hydrologic condition, environmental water availability and several other operational criteria including likelihood of pre-releases and dam spills, necessity of flood risk management and / or Yarrawonga weir pool management due to high or low Ovens flow, opportunities for extension of natural events, Hume dam and Yarrawonga weir storage volume, and flood risk management at Torrumbarry downstream due to high Goulburn flow events.

These environmental flows are expected to contribute to achieving improved environmental outcomes at system scale along the length of the river further downstream locations. For details refer to a technical report by MDBA (2022).

Depending on the constraints level of the scenario the medium and high overbank flow demands are either restricted or turned off for this study.

3.3.3 Environmental demand at Lower Darling

Environmental water requirement in the Lower Darling is placed at Weir 32 guided by the NSW Long-Term Watering Plan (LTWP). In the current constraint condition of 9,000 ML/d only the baseflow and fresh flow demands are active as below.

- Baseflow requirement of flows below 1,100 ML/d,
- Fresh flows requirement of 2,000 – 7,000 ML/d,

Any bank full or overbank events are not targeted as they are beyond the regulating capacity of Lower Darling. In this study, undertaking impact of different constraint relaxation in the Lower Darling is out of scope and is kept at the current level. Therefore, the EWRs used for the current conditions are remained same.

4 Goulburn environmental demand

4.1 Locations and level of constraints relaxation

In this modelling, channel capacity constraints are relaxed at several locations in the Southern basin. A summary of system constraints currently being practiced and assumed relaxed for Goulburn in this modelling is provided in Table 4. Constraints assumed for other valleys are also included for reference.

Table 4 Comparison of constraint level (ML/d) under current operational practices and proposed by Victoria to be investigated in this study

River System	Current condition	Relaxed Constraints Scenario 1 (M10L17)	Relaxed Constraints Scenario 2 (M10L21)	Relaxed Constraints Scenario 3 (M12L21)	Relaxed Constraints Scenario 4 (M14L25)
River Murray @ Doctors Point[c]	25,000	40,000	40,000	40,000	40,000
River Murray @ Yarrawonga downstream[c]	15,000[a]	40,000	40,000	40,000	40,000
Lower Darling @ Weir 32	9,000[b]	9,000	9,000	9,000	9,000
Murrumbidgee @ Balranald	9,000	12,000	12,000	12,000	12,000
Goulburn @ Eildon releases	9,500	9,500	9,500	12,000	13,700
Goulburn @ Molesworth (Mid Goulburn)	10,000	10,000	10,000	12,000	14,000
Goulburn @ Shepparton (Lower Goulburn)	9,500	17,000	21,000	21,000	25,000

[a] 9,500 ML/d for irrigation water delivery, up to 22, 000 ML/d for BFM-EWA and 15,000 ML/d for other environmental water delivery.
[b] Constraint level at Weir 32 is not modelled as per the constraint management bussiness which recommends it to be 14,000 ML/d but is set to the current level.
[C] For examing different Murray constraints, constraint levels at these locations are varied from 25,000~40,000 ML/d at Doctors Point and 15,000~45,000 ML/d at Yarrwonga downstream.

The model run with constraints set under current condition is used as the basis for comparing other constraints relaxed scenarios.

In the River Murray, constraints at Doctors Point and downstream of Yarrawonga are relaxed to deliver high flow and/or large volume of environmental water during the winter-spring season between 1 June and 30 November. A number of scenarios tested with different level of constraints relaxation in the Murray and Goulburn system are discussed in detail in Section 7 below.

In the Goulburn system, constraints at several locations are relaxed as shown in Table 4 from 9,500 ML/d to allow end of system flow pulses of up to 25,000 ML/d in delivering environmental water from Goulburn to the Murray system between 1 April and 30 November.

In the Murrumbidgee River, the constraint at Balranald is relaxed from 9,000 ML/d to allow end of system flow pulses of up to 12,000 ML/d in delivering environmental water from Murrumbidgee to the Murray system between 1 July and 31 December.

4.2 Goulburn local environmental flow without Murray orders

The Goulburn consists of two types of environmental demands:

1. Goulburn in-valley environmental demands for local outcomes within the lower Goulburn as shown in Table 4 above, and
2. Murray environmental demands for system outcomes in the lower Murray

DELWP (2022) details how GBCCL calculates local demand while the SMM calculates Murray downstream demands, which involves an iterative process. Firstly, local environmental demand by the GBCCL is calculated and passed to the SMM for calculating additional demand for the Murray system. This is a zero iteration and does not include Murray environmental orders. Secondly, the SMM uses GBCCL output from zero iteration as input to calculate additional demand for the Murray and passes the additional demand back to GBCCL to include it by GBCCL as Murray orders in its next iteration. In each iteration, the additional demand calculated by SMM tend to become smaller and smaller as the GBCCL includes more additional demand for the Murray. Ideally, the process would be repeated until the system stabilises and final set of environmental demands is achieved, which then the SMM uses as Goulburn inflows to the Murray. However, given the short timeframe, only a limited number of scenarios are iterated with the GBCCL and the SMM as explained in Chapter 7 below.

Goulburn in-valley environmental demands are modelled by the GBCCL at Shepparton, approximately 2 days travel time from McCoy's Bridge (DELWP, 2022). These demands are meant for local environmental outcomes in the lower Goulburn and are exclusive of Murray to Goulburn environmental orders.

Based on these environmental demands, flow targets are set which are limited to the lesser of the desired EWR targets and the channel capacity constraints assumed in the modelling.

From the zero iteration, the following GBCCL model outputs are provided by DELWP to MDBA for estimating environmental orders for the Murray system using the Source Murray Model:

1. Goulburn River Flow at Eildon (405203) (ML/d)
2. Goulburn River Flow at Molesworth (ML/d)
3. Goulburn River Flow at Trawool (405201) (ML/d)
4. Goulburn River Flow at Seymour (405202) (ML/d)
5. Goulburn River Flow at Murchison (405200) (ML/d)
6. Goulburn River Flow at Shepparton (405204) Flow (ML/d)
7. Goulburn River Flow at McCoys Bridge (405232) (ML/d)
8. Campaspe River Flow at Rochester (ML/d)

9. Loddon River Flow at Appin South (ML/d)
10. Goulburn HRWS Seasonal Determinations (%)
11. Goulburn LRWS Seasonal Determinations (%)
12. Campaspe HRWS Seasonal Determinations (%)
13. Campaspe LRWS Seasonal Determinations (%)
14. Lake Eildon Spill Volume (ML)
15. Lake Eppalock Spill Volume (ML)
16. Goulburn Environmental Flow at Shepparton (ML/d)
17. Goulburn Environmental Water Balance (ML)
18. Campaspe Environmental Flow at Rochester (ML/d)
19. Campaspe Environmental Water Balance (ML)
20. Goulburn IVT Delivery (ML/d)

Based on the river flows with local environmental demands, water balance in the environmental account, spills and the specified channel capacity constraints, additional Murray environmental demands are calculated.

5 Murray environmental orders to Source GBCCL model

For constraints modelling until now, Goulburn to Murray environmental flow targets have been estimated within the Source Murray Model mimicking natural flow cues based on without development flows and channel capacity constraints at McCoy's Bridge.

Now that Source GBCCL model is available with in-built local environmental demand for lower Goulburn, an additional environmental demand for Murray is estimated by the SMM based on the initial GBCCL model output. The SMM estimates are then passed on to the GBCCL model to include them as Murray orders in the next iteration.

Several modelling assumptions are made in calculating these demands analytically within SMM for the Murray linking to the Goulburn system at McCoy's Bridge. Constraints relaxation at several locations along the length of the Goulburn system is considered including initial estimates by GBCCL of IVT delivery at McCoy's Bridge, local environmental flow at Shepparton and Eildon spills.

Firstly, Goulburn's delivery capacity for additional Murray environmental demand is assessed analytically in SMM using the Source GBCCL modelled flows with local environmental demands assuming current constraint applies in all scenarios for the mid-Goulburn and modelled (current or relaxed) constraint applies for the lower Goulburn. Local environmental demand by GBCCL includes CEWH, VEWH and TLM water all bundled together. This is split to account for CEWH water to be consistent with what has been done in the SMM.

An analysis of long-term entitlement allocation for the environment indicates Goulburn environmental portfolio consists about 78% of CEWH water. So, the delivery capacity of Goulburn for Murray additional demand is calculated assuming 78% of local environmental demand as CEWH water at Shepparton. The delivery capacity is checked with environmental water balance and minimum reserve assumption, Eildon spills and flows that are considered unregulated for the given constraints.

It is assumed that the Source GBCCL model commences to deliver the Murray demand from 1 May onwards until 31 October when the Goulburn system has operational capacity to do so as long as the account balance remains above the minimum reserve volume.

Murray additional environmental demand attempts to reflect natural variability in the system considering that the resulting flow peaks remain within the natural flow regime as well as the specified channel capacity limits. So, the environmental flow commencing from May onwards better represent Goulburn's natural pulses earlier in the season than in the Murray.

Account balance is updated at each timestep and checked to ensure the account is not over drawn. The Source GBCCL model assumes minimum reserve volume of 450 GL in the environmental water balance for delivery of Murray orders. This means the Murray orders are delivered only if total water in the Goulburn environmental accounts (VEWH + CEWO + TLM) remains above 450 GL. This volume was selected to minimise the impact of the additional environmental water use on the modelled Goulburn environmental flow targets. When Eildon spills, Murray order is set to zero assuming that Murray orders would not be delivered under the spilling condition.

Channel capacity in the lower Goulburn is relaxed between 1 May and 31 October to deliver larger volume and relatively higher peak of environmental flows during the winter-spring reflecting Goulburn's natural flow regime. For the remaining period (1 November to 30 April), additional demand for Murray is set to zero.

Additional environmental demand for each day is then calculated as a lesser of delivery capacity, environmental water balance in excess of reserve volume and natural flow regime at Shepparton. Calculation is done automatically in SMM at each timestep. Timeseries of this Murray demand is fed back to the GBCCL model to combine with the initial local demand and the GBCCL model is re-run. This would ensure operational aspects of Goulburn system including losses and travel time is appropriately reflected when the Murray calls this additional environmental demand.

When the GBCCL model provides a new set of environmental flow from its iteration with Murray orders, the SMM will use it as Goulburn's inflow input and the Murray environmental orders are passed further downstream ensuring that they are protected and accounted at Lake Victoria. They are added to the green account at Lake Victoria (Ta Ru) assuming a travel time of 23 days and an operational loss of nine percent (ie 91% of the Murray environmental orders are added to the green account in 23 days' time). This ensures that environmental water is not reregulated at Lake Victoria.

Note Murray environmental orders are calculated only for the Goulburn system at this stage, not for the Campaspe system.

6 Murray environmental orders to Murrumbidgee

Similar to the Goulburn, the SMM also requires environmental flow from the Murrumbidgee system as an input. At this stage this information is not available so environmental flows from Murrumbidgee are assumed to be delivered following the natural Hydro Cues approach in which Murray orders at Balranald are analytically calculated within the SMM. Channel capacity at Balranald is relaxed to 12,000 ML/d from 9,000 ML/d between 1 July and 31

December reflecting the natural flow regime. The Murray orders are protected and passed further downstream and added to the green account in Lake Victoria in 13 days' time assuming 26% operational loss.

When the environmental flow output from Source Murrumbidgee model becomes available, the Hydro Cues based orders would be replaced.

7 Model Scenarios

Initially, a total of sixteen scenarios have been modelled including the reference scenario representing the current constraints (M10L9.5_Y15D25) and three different levels of Goulburn constraints (M10L17, M12L21 and M14L25) applied to five different constraint relaxation scenario for Murray (Y25D25, Y30D30, Y35D35, Y40D40 and Y45D40) as outlined below. These scenarios include Goulburn environmental demand calculated by the Source Murray Model at McCoy's Bridge as the end of system flow which the Murray used as inflows from the Goulburn. In this calculation, only the Goulburn CEWO allocation volume and the McCoy's Bridge constraint are considered. Model results of these scenarios have been provided to Victoria and Sequana.

1. Current condition reference scenario (M10L9.5_Y15D25): The current condition scenario is essentially a derivative of the Baseline and the WRP scenarios which carry legacy water sharing arrangement assumptions as per the Murray Darling Basin Agreement with constraints set to represent current practices.
2. Relaxed constraint scenario 1: M10L17 * 5 Murray constraints scenarios
3. Relaxed constraint scenario 2: M12L21 * 5 Murray constraints scenarios
4. Relaxed constraint scenario 3: M14L25 * 5 Murray constraints scenarios

These initial scenarios are used to confirm model's compatibility to the previous studies provided to the NSW RRCP team.

At a second stage, results from the GBCCL model are used by the Source Murray Model to calculate Murray environmental orders, which are then passed to the GBCCL as additional demand to integrate them with the local in-valley demand. So, the model iterations involved following steps:

1. **GBCCL Iteration 0**: Victoria runs GBCCL with inclusion of local Goulburn environmental demands and the model output is provided to MDBA.
2. **SMM Iteration 0.1**: MDBA runs Source Murray Model with GBCCL model output from iteration 0. It is done to replicate GBCCL scenario as it is without additional environmental demand for Murray. Model results are checked for quality assurance and understanding system behaviour. For example, SMM run number 13361 represents this step for a scenario M10L9.5_Y15D25 which is one of many scenarios provided in Table 5.
3. **SMM Iteration 0.2**: Like iteration 0.1 but it is done to calculate additional Murray environmental demand estimates to be passed to the Goulburn system. For example, SMM run number 13355 represents this step for a scenario M10L9.5_Y15D25 provided

in Table 2. In this calculation, Goulburn environmental water balance including CEWH, VEWH and TLM with 450 GL minimum reserve assumption, Eildon spill, current mid-Goulburn constraint from GBCCL iteration 0 is considered. The additional Murray demand is calculated at Goulburn's end of system point so there is no consideration of operational aspects of its delivery from headwater storage Eildon.

4. **GBCCL Iteration 1**: MDBA provides additional Murray environmental demand estimates to Victoria from SMM iteration 0.2. Victoria iterates the GBCCL model with additional Murray environmental demand. Simulating additional demand in the GBCCL model will have a more realistic representation of operational aspects of Goulburn-Broken system and environmental flow delivery to the Murray including losses, travel times and attenuation of peaks. The model output is provided to MDBA for next iteration of SMM.
5. **SMM Iteration 1**: GBCCL model output from iteration 1 is considered final in this study and with this data, MDBA runs Source Murray Model as final iteration. For example, SMM run number 13487 represents this step for a scenario M10 L9.5_Y15D25 provided in Table 5.

As shown in Table 5, only five scenarios are modelled in SMM in each iteration. These scenarios include one current practice reference scenario (M10L9.5_Y15D25) and four constraints relaxed scenarios.

The four constraints relaxed scenarios include three sets of Eildon constraints at 9,500 ML/d, 12,000 ML/d and 13.7 ML/d with its corresponding Molesworth constraints at 10,000 ML/d, 12,000 ML/d and 14,000 ML/d (which are denoted by M10, M12 and M14) and three sets of Lower Goulburn constraints at Shepparton which are set to 17,000 ML/d, 21,000 ML/d and 25,000 ML/d (denoted by L17, L21 and L25). These scenarios are modelled with only one set of Murray constraints (Y40D40).

Table 5 Model scenarios used to estimate additional Murray demand for Goulburn system

Scenarios	Iteration 0.1: SMM using GBCCL output with Goulburn local environmental flow excluding Murray downstream orders	Iteration 0.2: SMM using GBCCL output with Goulburn local environmental flow including estimates of Murray downstream orders	Iteration 1: SMM using GBCCL output with Goulburn environmental flow that includes both the local and Murray downstream orders
Current condition reference M10L9.5_Y15D25	13361	13355	13487
Goulburn constraints relaxation			
M10L17_Y40D40	13362	13356	13490
M10L21_ Y40D40	13430	13420	13491
M12L21_ Y40D40	13428	13424	13492
M14L25_ Y40D40	13364	13360	13493
Murray constraints relaxation M10L17_Y25D25	-	-	13494

M10L17_Y30D30 M10L17_Y35D35 M10L17_Y40D40 M10L17_Y45D40	- - 13362 -	- - 13356 -	13495 13496 13490 13498
Climate Change scenarios under relaxed constraints M10L17_Y40D40 Post 1975 2070Med 2070High	13581 13583 13582	13586 13589 13590	13664 13665 13666
Climate Change scenarios under current condition M10L9.5_Y15D25 Post 1975 2070Med 2070High	13718 13719 13720	13721 13722 13723	13763 13764 13765

Similarly, two sets of constraint levels (current and M10L17_Y40D40) are picked for simulating three climate change scenarios as provided in Table 5. The three future climate scenarios are:

1. Post 1975 climatic conditions,
2. 2070 medium projection and
3. 2070 high projection.

8 Model Results and Discussion

Modelling results are checked to ensure the Source GBCCL model is behaving as intended with and without the Murray environmental orders for scenarios under the current conditions and the constraints relaxed conditions.

Table 6 and Table 7 provide a summary of Goulburn inflows including spills, environmental flows and account balance.

Few examples of this analysis are provided in Figure 1 to Figure 4. Figure 1 shows distribution of environmental flow at Shepparton with and without the Murray orders for two Goulburn scenarios, namely current condition and a constraints relaxed scenario M10L17 from GBCCL. Under the current condition, it shows ~99 GL/y increase of environmental flow delivery at Shepparton from ~165 G/y local in-valley only usage to ~264 GL/y usage on average annually with inclusion of the Murray orders. Note the peak is limited to 9,500 ML/d constraints assumed under the current condition. Because of the increased use of environmental water due to additional order from Murray, Eildon spill is reduced by ~59 GL/y on average from ~478 GL/y to ~419 GL/y.

When the constraints in the lower Goulburn are relaxed to 17,000 ML/d (M10L17), the environmental flow peak increases to 17,000 ML/d as expected and system capacity to deliver more environmental water enhances overall delivering more water in volumetric terms. Without the Murray orders, ~130 GL/y more environmental flow is delivered locally on average annually compared to the current condition. The system also has an increased capacity to deliver more additional orders from Murray as seen by an increase of 68 GL/y of Murray orders from ~264 G/y under current condition to ~332 GL/y with the constraints relaxation (RC Scn1). Spills from the Lake Eildon reduces by ~88 GL/y with constraints relaxation (RC Scn1) from 478 GL/y under the current condition without the Murray orders. Similarly, spills from the Lake Eildon reduces by ~54 GL/y with constraints relaxation (RC Scn1) from 419 GL/y under the current condition with the Murray orders.

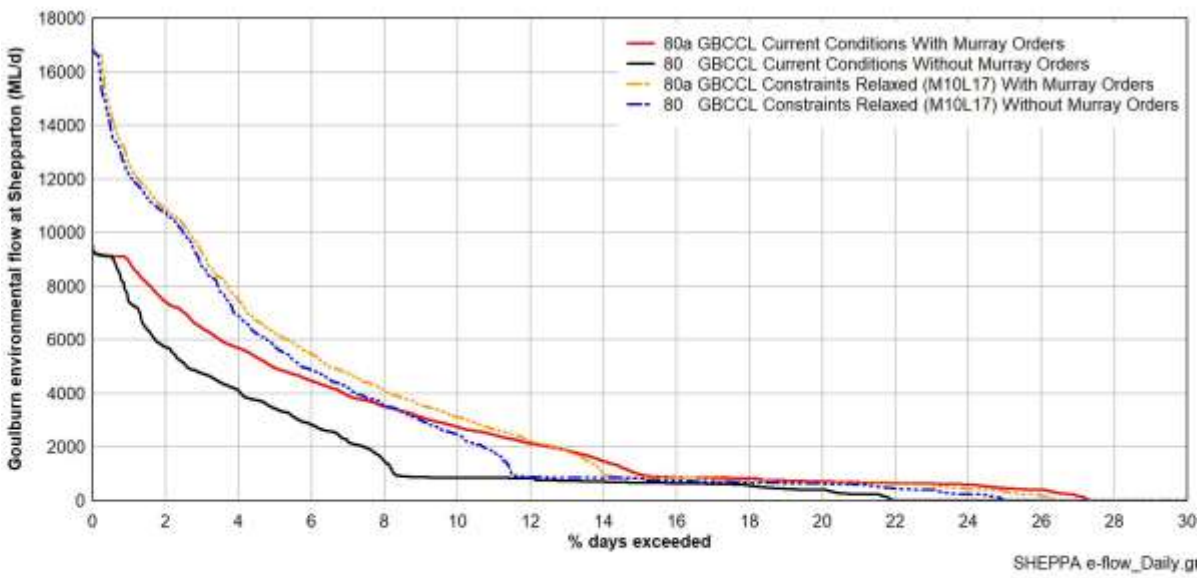
Table 6 GBCCL model output provided by DELWP to the MDBA: change due to Murray environmental orders to Goulburn system

	Without Murray Environmental Orders					Change due to Murray environmental orders to Goulburn system under historical climate				
	Reference	M10L17	M10L21	M12L21	M14L25	Reference	M10L17	M10L21	M12L21	M14L25
Goulburn River Flow at Eildon (GL/y)	1,300	1,305	1,307	1,306	1,306	4	0	0	1	2
Goulburn River Flow at Molesworth (GL/y)	1,852	1,856	1,857	1,855	1,855	4	0	0	0	2
Goulburn River Flow at Trawool (GL/y)	2,155	2,159	2,160	2,158	2,158	4	0	0	0	2
Goulburn River Flow at Seymour (GL/y)	2,258	2,261	2,262	2,261	2,261	4	0	0	0	2
Goulburn River Flow at Murchison (GL/y)	1,421	1,418	1,410	1,418	1,418	16	1	0	-1	-2
Goulburn River Flow at Shepparton Flow (GL/y)	1,850	1,847	1,839	1,847	1,847	16	1	0	-1	-2
Goulburn River Flow at McCoys Bridge (GL/y)	1,882	1,878	1,870	1,879	1,878	16	1	1	-1	-2
Campaspe River Flow at Rochester (GL/y)	191	191	191	191	191	0	0	0	0	0
Loddon River Flow at Appin South (GL/y)	98	98	97	98	98	0	0	0	0	0
Lake Eildon Spill Volume (GL)	478	391	349	350	320	-59	-25	-16	-17	-15
Lake Eppalock Spill Volume (GL)	125	125	125	125	125	0	0	0	0	0
Goulburn Environmental Flow at Shepparton (GL/y)	165	294	349	348	386	99	37	32	26	18
Goulburn Environmental Water Balance (GL)	514	376	299	296	255	-76	-42	-36	-24	-24
Campaspe Environmental Flow at Rochester (GL/y)	16	16	16	16	16	0	0	0	0	0
Campaspe Environmental Water Balance (GL)	31	31	31	31	31	0	0	0	0	0

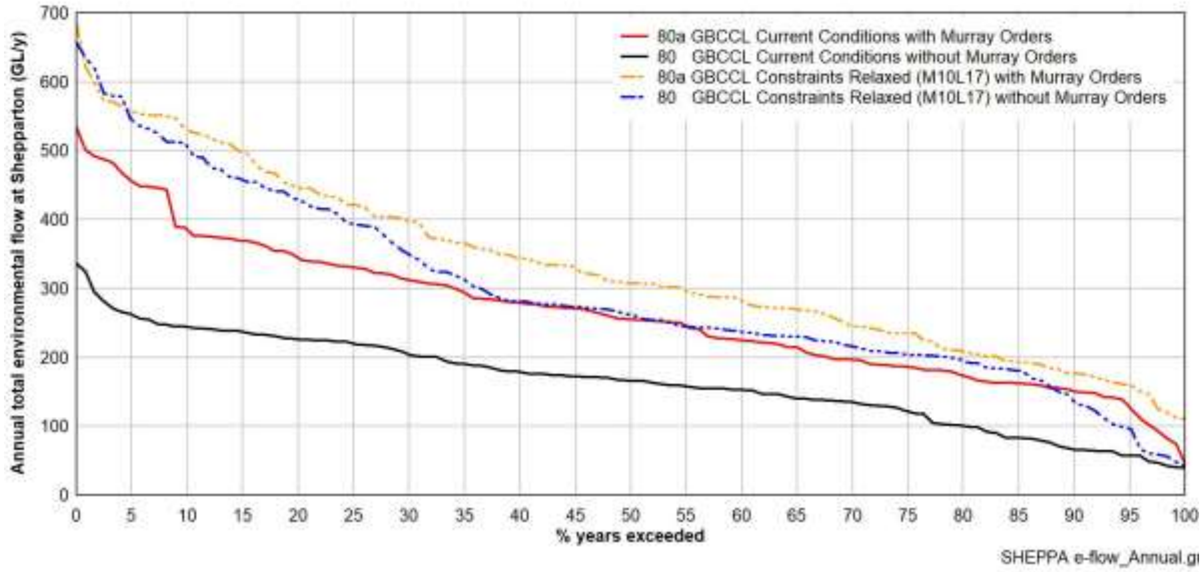
Table 7 GBCCL model output provided by DELWP to the MDBA: change from current reference due to constraints relaxation in the Goulburn system including with and without the Murray environmental orders

	Without Murray Environmental Orders					Change due to Murray environmental orders to Goulburn system under historical climate				
	Reference	M10L17	M10L21	M12L21	M14L25	Reference	M10L17	M10L21	M12L21	M14L25
Goulburn River Flow at Eildon (GL/y)	1,300	5	7	6	6	1,304	1	3	2	3

Goulburn River Flow at Molesworth (GL/y)	1,852	4	5	3	3	1,856	-1	1	0	1
Goulburn River Flow at Trawool (GL/y)	2,155	4	5	3	3	2,159	-1	1	-1	1
Goulburn River Flow at Seymour (GL/y)	2,258	4	5	3	3	2,262	-1	1	-1	1
Goulburn River Flow at Murchison (GL/y)	1,421	-3	-11	-3	-3	1,438	-19	-27	-20	-21
Goulburn River Flow at Shepparton Flow (GL/y)	1,850	-3	-11	-3	-3	1,866	-19	-27	-20	-21
Goulburn River Flow at McCoys Bridge (GL/y)	1,882	-3	-12	-3	-3	1,898	-19	-27	-21	-21
Campaspe River Flow at Rochester (GL/y)	191	0	0	0	0	191	0	0	0	0
Loddon River Flow at Appin South (GL/y)	98	0	-1	0	0	98	0	-1	0	-1
Lake Eildon Spill Volume (GL)	478	-88	-129	-128	-158	419	-54	-86	-87	-114
Lake Eppalock Spill Volume (GL)	125	0	0	0	0	125	0	0	0	0
Goulburn Environmental Flow at Shepparton (GL/y)	165	130	184	183	221	264	68	117	110	141
Goulburn Environmental Water Balance (GL)	514	-138	-214	-217	-259	437	-103	-174	-165	-206
Campaspe Environmental Flow at Rochester (GL/y)	16	0	0	0	0	16	0	0	0	0
Campaspe Environmental Water Balance (GL)	31	0	0	0	0	31	0	0	0	0



(a)



(b)

Figure 1 Goulburn environmental flow at Shepparton modelled by GBCCL under the current conditions: comparing with and without the Murray orders for whole modelling period 1895-2019 as probability distribution ((a) daily and (b) annual total)

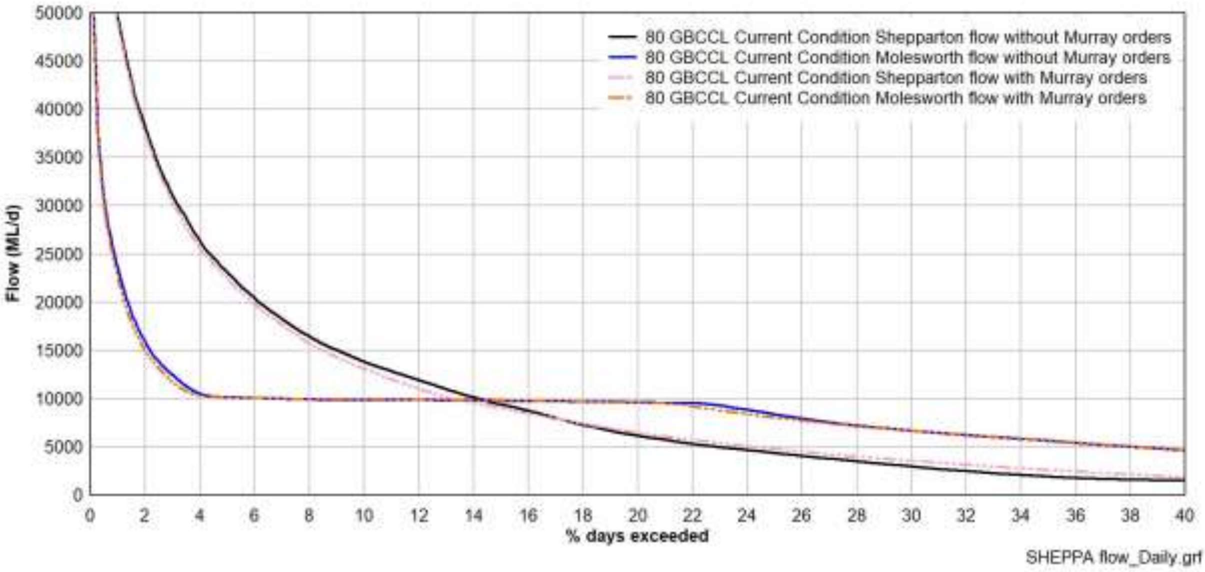


Figure 2 Goulburn flows at Molesworth and Shepparton modelled by GBCCL under the current conditions: comparing with and without the Murray orders for whole modelling period 1895-2019 as probability distribution

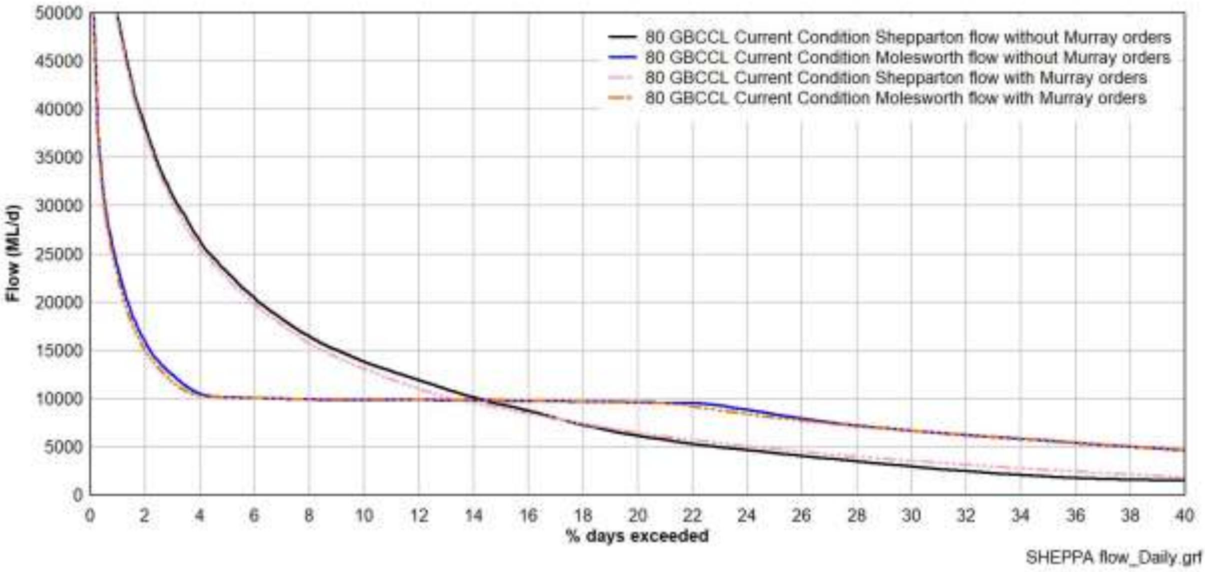


Figure 2 demonstrates how this increased environmental flow at Shepparton is translated into the total flows at Shepparton and at Molesworth. The resulting flows tend to improve within the constraints limit while the flows that were above the constraints limit tend to decrease because of the reduced spills from Eildon.

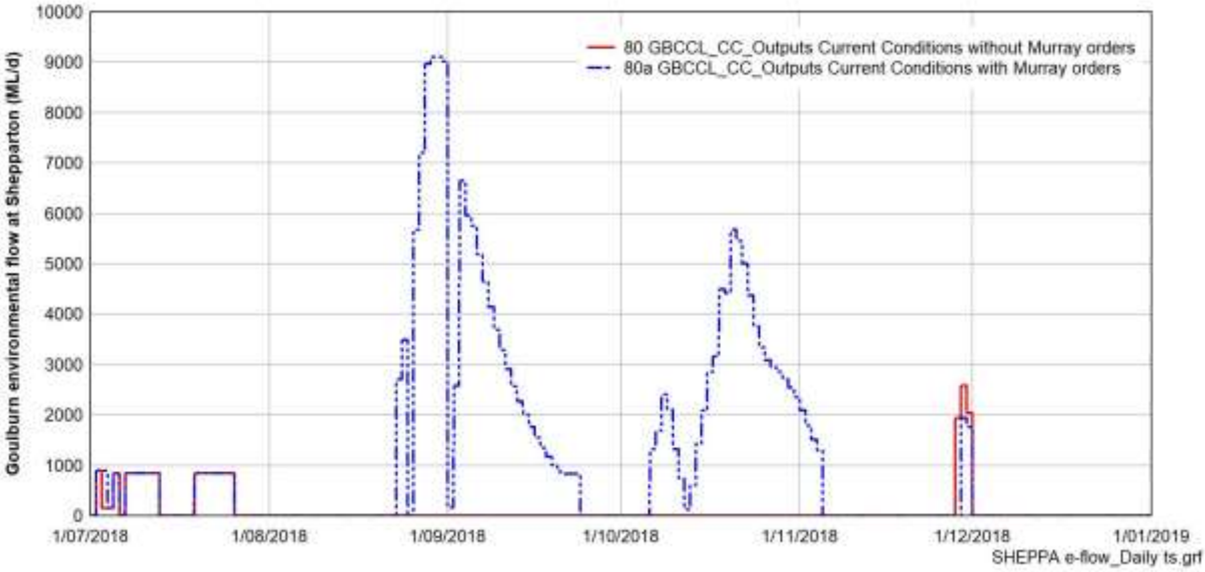


Figure 3 and Figure 4 show what it means for an individual year picking 2018 as an example. Additional orders for Murray placed in Shepperton as shown in

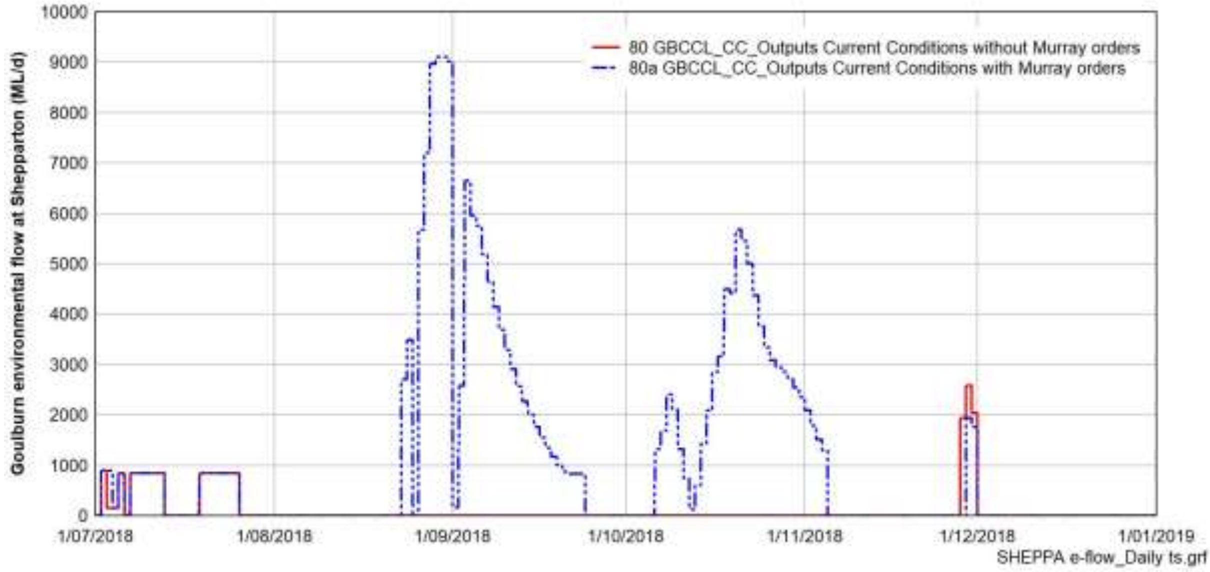


Figure 3 results different flow hydrograph at McCoy's Bridge as shown in Figure 4.

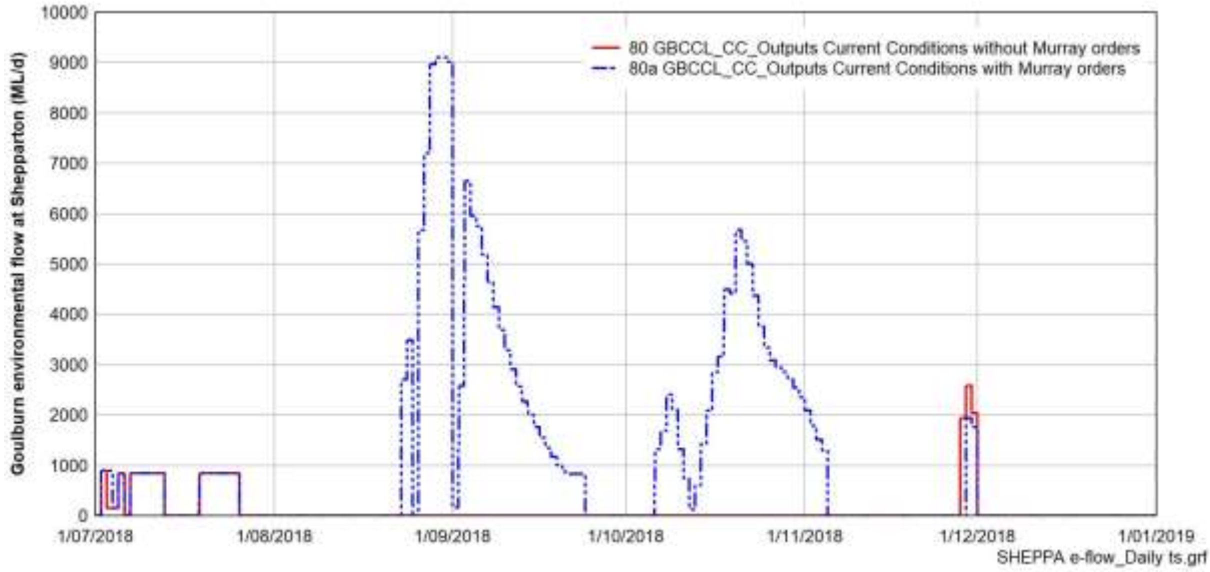


Figure 3 Goulburn environmental flow at Shepparton modelled by GBCCL under the current conditions: comparing the 2018 season as an example with and without the Murray orders

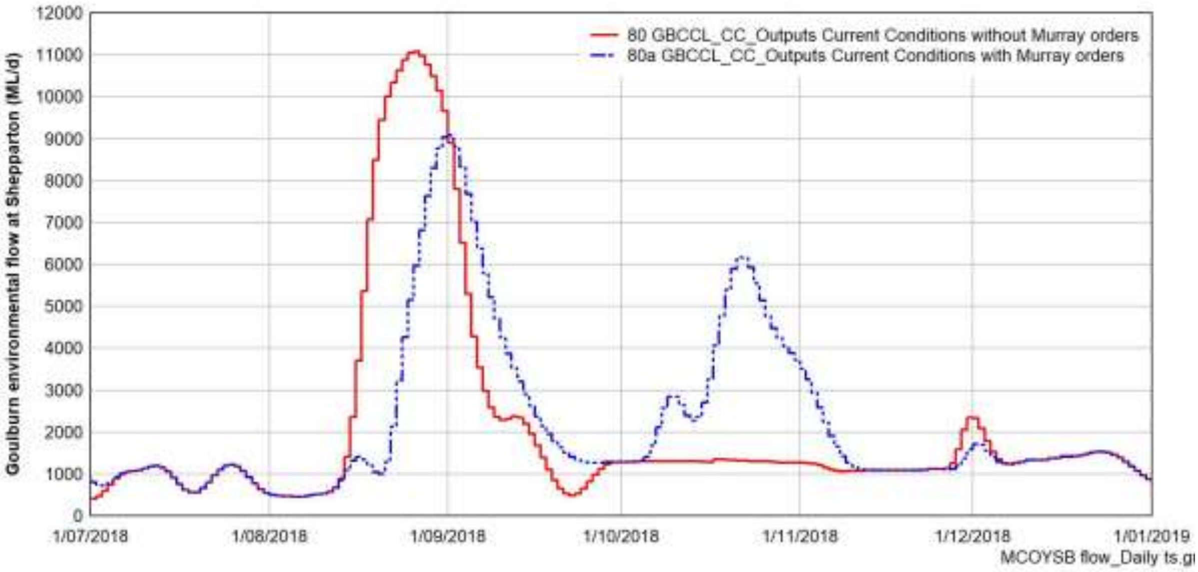


Figure 4 Goulburn River flow at McCoy's Bridge modelled by GBCCL under the current conditions: comparing the 2018 season as an example with and without the Murray orders

Similar to the current condition, Murray environmental orders estimated in the SMM for four Goulburn constraints relaxed scenarios are provided to GBCCL. Probability distribution of these orders is shown in

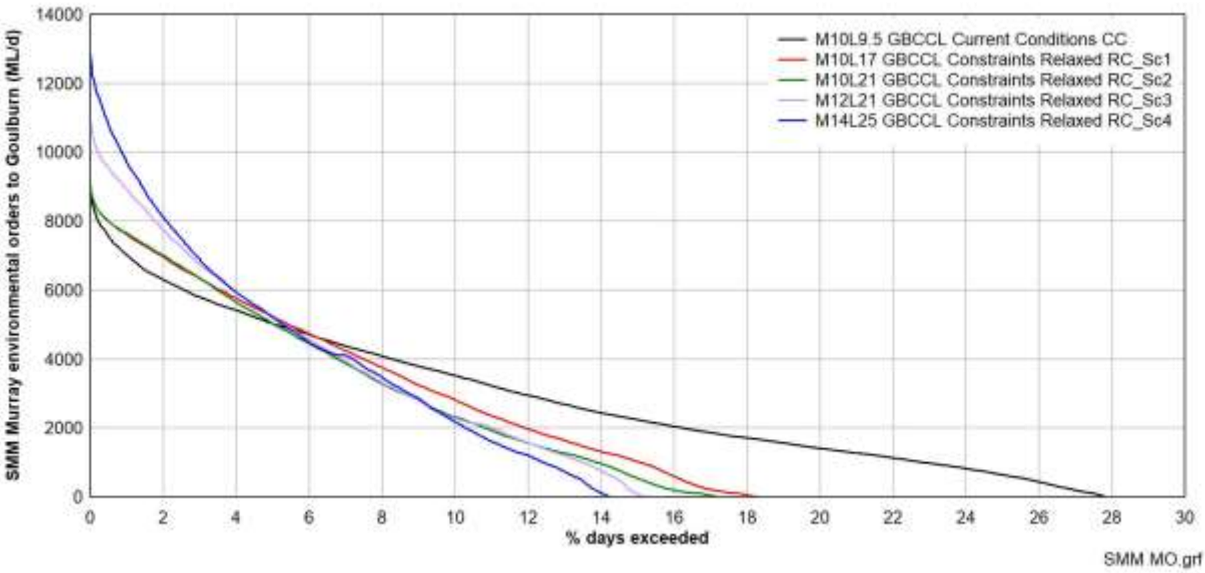


Figure 5, which indicates that relaxing constraints tend to generally enhance peak environmental flow rates as well as volumetric flow delivery. The increased environmental water delivery by constraints relaxation shows reduced spills as expected as it tends to keep Eildon storage level lower.

One thing that is noticeable is environmental peak flow rate does not increase when only the Goulburn constraints at Shepparton / McCoy's Bridge is relaxed from 17,000 ML/d (RC_Sc1 represented by red line) to 21,000 ML/d (RC_Sc2 represented by green line) while keeping constraints at Molesworth and Eildon unrelaxed. When constraints at Molesworth and Eildon are also relaxed to 12,000 ML/d (RC_Sc3 represented by purple line), the environmental peak flow rate does increase. When constraints at all three locations are further relaxed, the environmental flow peaks are further enhanced as shown by blue line representing RC_Sc4 scenario. This indicates that Molesworth and Eildon can potentially pose as bottlenecks when only the constraint in lower Goulburn is relaxed beyond 17,000 ML/d. This is based on the SMM estimates only and needs to be confirmed with the GBCCL model output simulated including the Murray orders.

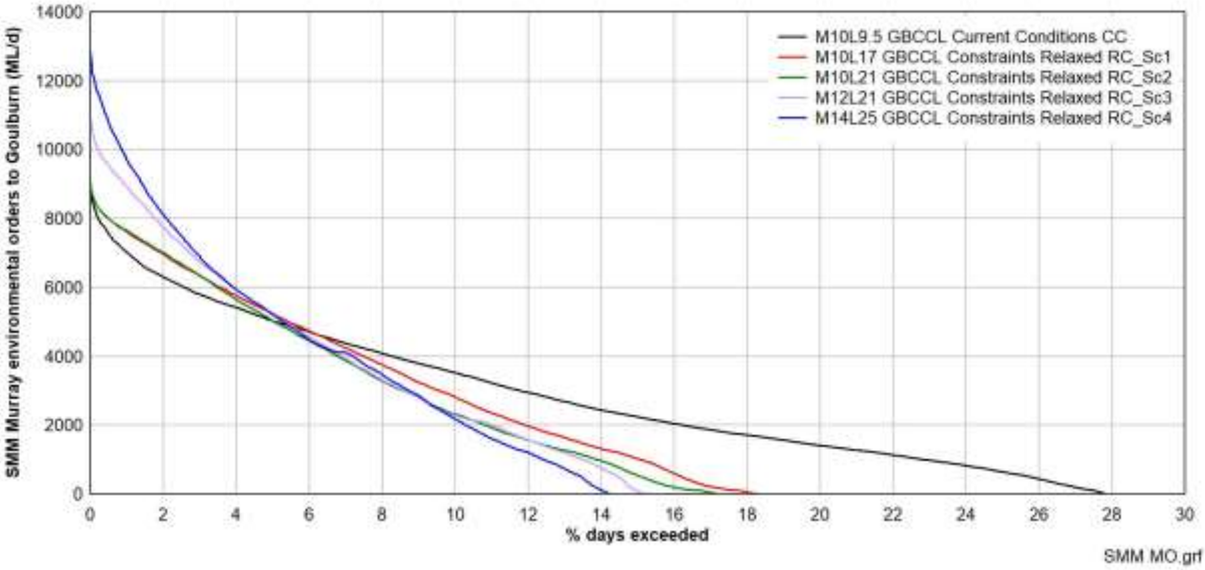


Figure 5 Murray environmental orders estimated by SMM provided to DELWP Victoria for inclusion in the Source GBCCL model for current condition and various constraints relaxed scenarios

8.1 Environmental water allocation and use

The long-term environmental water use under different constraint relaxed scenarios in the Murray, Goulburn and in different climatic conditions gives an idea of how relaxed constraints allow to effectively use the environmental water. Figure 6 the grey shaded part demonstrates the average volume allocated over the year from start of year (SOY) to end of year (EOY). The bars compare the SOY account balance and annual use by environment. With increasing constraints in Murray, environmental water use increases as environment gets more opportunity to target higher flow events. Consequently, the environmental water balance and allocation get reduced due to higher utilisation of environmental portfolio. Relaxing Goulburn constraint shows more utilisation of environmental water as the Goulburn constraint is relaxed from current condition to 17,000 ML/d. However further relaxation in Goulburn has minimal impact in Murray environmental use.

In future climatic conditions, due to reduced water availability in the system the allocation and balance both are reduced substantially under both the current constraint and constraint relaxed (Y40D40) scenarios. In the 2070 medium climate, the account balance is utilised more to deliver the increased demand of the environment. Under current constraint regime, the environmental portfolio has more unused account balance to be used than under the relaxed constraint scenario. So, the increased use in the 2070 medium climatic condition is more prominent under the current constraint. In the 2070 high climate scenario, the environmental water balance and allocation gets reduced significantly. The environmental water use eventually shows a very high utilisation of the available balance.

This indicates that the relaxed constraints can be effectively used by environmental water holders to sustain environmental outcomes under the medium future climates, but their effectiveness is dramatically diminished under much drier future climate condition. This is mostly because of much reduced piggybacking opportunities as well as limited water available due to reduced allocation to initiate environmental events from scratch without unregulated events to augment environmental demand on.

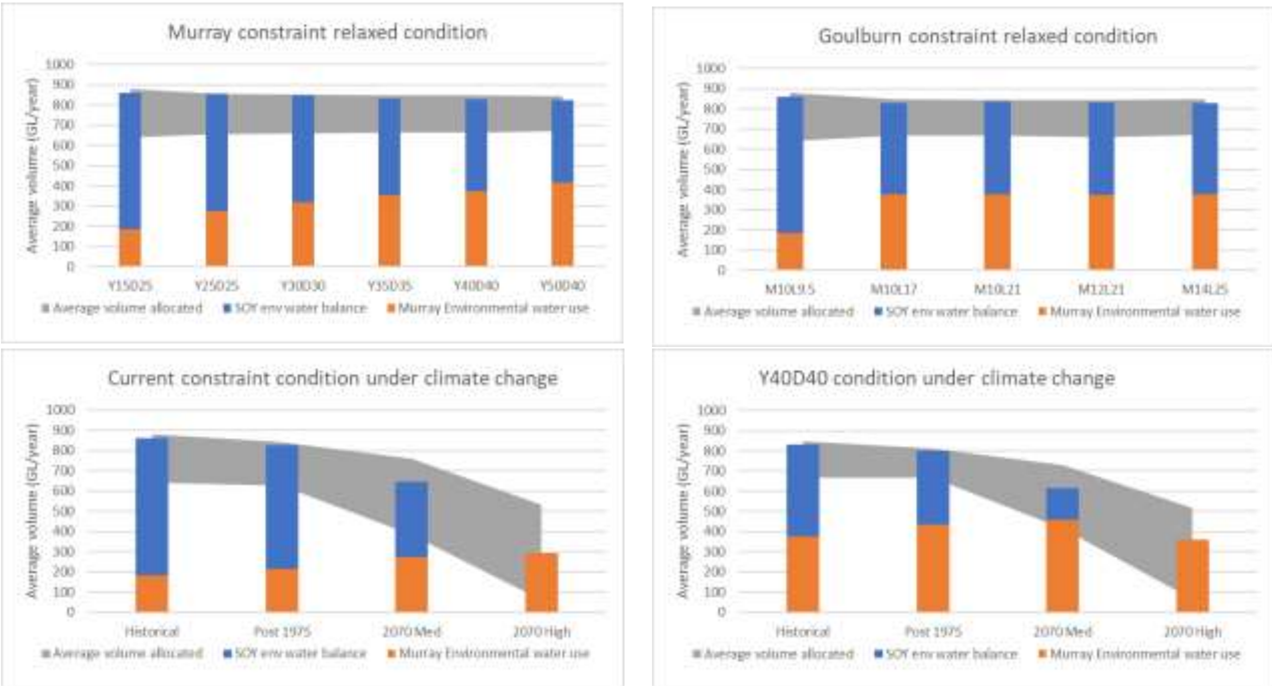


Figure 6: Environmental water use in Murray compared to environmental water balance and allocation

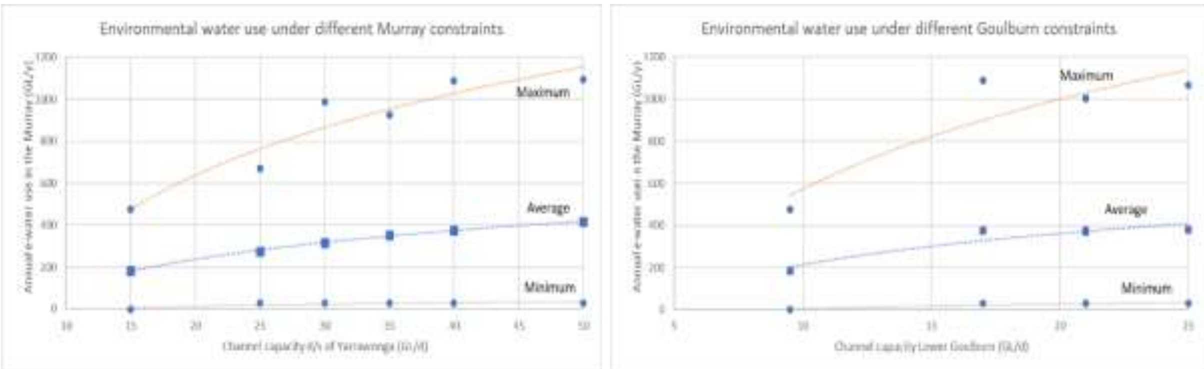


Figure 7: Range of annual environmental water use in Murray under Murray and Goulburn relaxed constraint scenarios

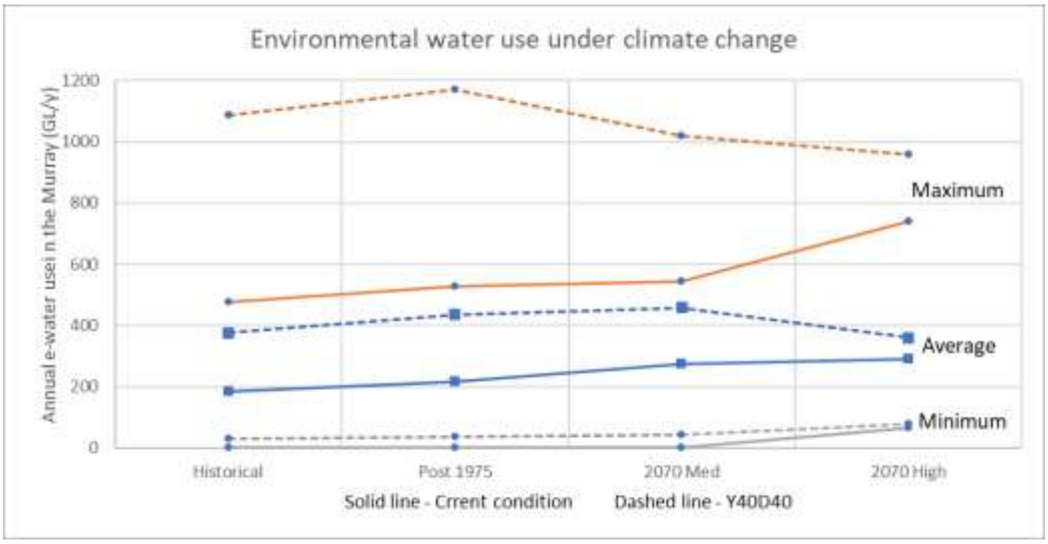


Figure 8: Range of annual environmental water use in Murray in future climate scenario

There are numbers of figures presented at Appendix A ~ Appendix C where different flow regimes based on exceedance probabilities are presented at key gauging stations along the Murray and Edward-Wakool systems for various scenarios. Key findings are similar to what has been observed from Figure 6 to Figure 8. Detailed observations can be found at each Appendix and key findings are summarised as below:

- At upper Murray, there are significantly increased benefits as constraints are relaxed to higher levels.
- The benefits are decreased at the mid and lower parts of the Murray and Edward-Wakool systems as flow regimes are mostly determined by wide and flat geographical characteristics, requiring a large volume of water to increase peaks. As a results, benefits are captured by some noticeable extension of duration at lower Murray.
- They are some limited but clear improvements shown at lower Murray by increasing levels of constraints in Goulburn. The improvements are likely increased once the coordination of environmental water from Murray and Goulburn is enhanced.
- Under all climate change scenarios,
    - Significant reductions in flows for the entire flow regimes as future climates become drier
    - Flows during Winter-Spring seasons are more heavily affected while flows during typical irrigation season are well maintained
    - At upper Murray, the constraint relaxation scenarios show significant improvements of overbank flow regimes (ie 25 percent exceedance probability) up to the 2070 medium climate and benefits tend to decrease substantially under the 2070 dry climate scenario. Relative improvements from the current constraint scenario are greatest under the 2070 medium scenario
    - At mid and lower Murray, there are improved flow regimes with the relaxed constraint scenarios which are more evenly distributed across the different future climate scenarios. It indicates potential benefits of relaxing constraints and importance of coordinated water delivery under the dry climatic conditions.

8.2 Coordination of environmental water and future work

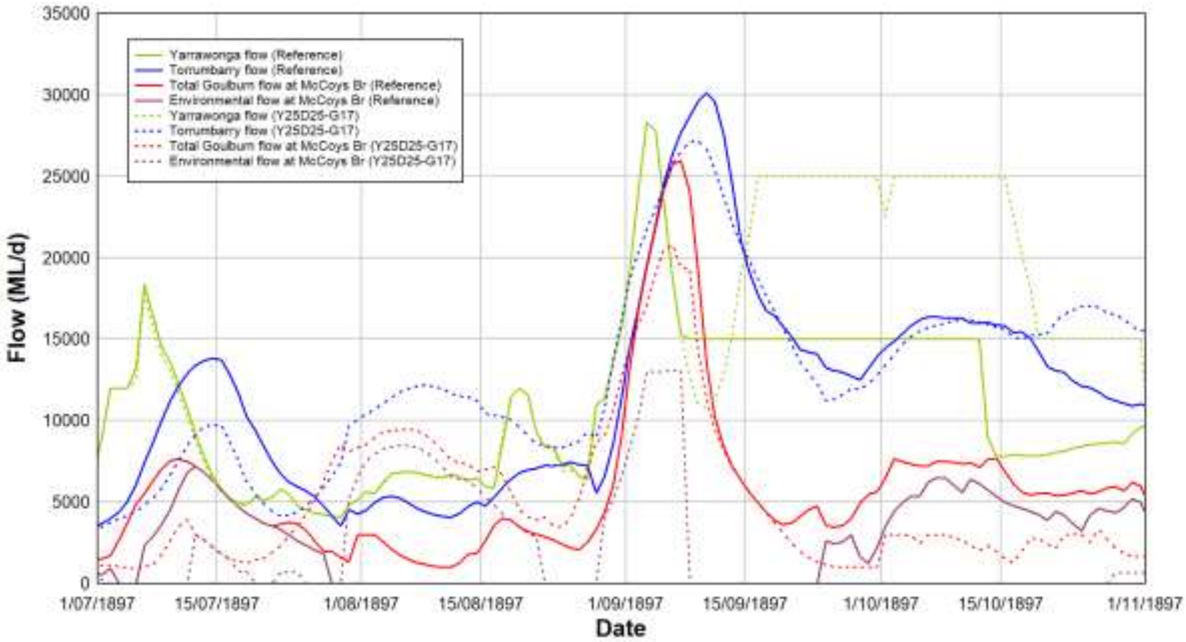


Figure 9 Comparison of constraints relaxed flows against the current condition reference

It is found that Murray environmental outcomes at Torrumbarry are marginally changed when more environmental water is called from the Eildon dam with progressively increased level of constraints relaxation in the Goulburn system. It is partly due also to different timing window of environmental water delivery in the Goulburn and the Murray system. For example, as shown in Figure 9 upper Murray is managed to achieve environmental outcomes at 25,000 ML/d with environmental releases in September-October, Goulburn peak flows at McCoy's Bridge are reduced in September from the reference scenario as the environmental water in the Goulburn is used in August. This led to additional environmental flows from upper Murray being seen as ineffective to result additional environmental outcomes at Torrumbarry. This is because environmental water is called out much earlier in the Goulburn than in the Murray.

Therefore, timing of environmental demands and releases are equally important as much as the amount of environmental water volume being used. Improved ways of build coordinated interventions in the model would be beneficial in subsequent modelling studies.

9 Conclusions

A collaborative Goulburn and River Murray constraints modelling is undertaken by DELWP and MDBA using the Source GBCCL Model and the Source Murray Model to inform development of Goulburn constraints management strategy and environmental flow delivery to the Murray.

For the first time in the modelling history of the Murray-Darling Basin, daily model output of the Goulburn system from Source GBCCL model becomes available to the Source Murray

Model. The process is iterative and focusing on environmental demands for now where GBCCL output with only the local environmental flow for lower Goulburn (ie without the Murray environmental orders) are input to the Source Murray Model to calculate additional Murray orders. The estimates of potential Murray orders from SMM output are then fed back to the GBCCL model to iterate the run with the Murray orders which are essentially passed to the Eildon storage for releases. The GBCCL output with the Murray orders is then input to the SMM as Goulburn environmental inflows for simulating Murray constraints scenarios.

This modelling improvement connects River Murray and Goulburn system better hydrologically and enables us to pass Murray environmental orders to Eildon storage through the GBCCL model. This allows Murray system to order environmental releases from Eildon considering operational aspects of the Goulburn-Broken system including losses and travel time.

Numbers of scenario models in this report show that the current constraints are one of limitations of environmental water being used frequently and efficiently. Environmental water use is increased gradually leading to improved hydrologic conditions for the environment with increased levels of constraint relaxations.

Modelling under future climates is also undertaken in this report and it shows significant reductions of piggybacking opportunities for environmental water augmentation. Under extreme dry climates (ie the 2070 high scenario), there is very limited water available for the environment to initiate overbank watering events. However, relaxing constraints provide the highest improvements of some hydrologic regimes relative to the current constraint level under the 2070 med scenario indicating relaxing constraints would be very useful and beneficial to achieve environmental outcomes under future drier climate conditions.

This report also shows benefits of increased channel constraints from the current level in the Goulburn system by examining flow distributions at various locations along the Murray and Edward-Wakool systems. There are significant improvements of flow regimes in Murray when the current constraints are lifted in the Goulburn system. However, it indicates that incremental benefits by relaxing the constraints to a higher level are reduced even though some improvements of hydrologic regimes at mid and lower Murray are observed. It is thought that this observation is highly influenced by the iterative process of how environmental demands at Murray downstream are aggregated and factored into the Goulburn system.

There are some improvements identified to better coordinate environmental watering events from the Murray and Goulburn system. Assessing different options of coordinating environmental events would be critical to understanding how these cross-catchment watering actions can be operationalised on ground. In addition, there are more opportunities to enhance the coordination at further downstream of the Murray system including sourcing environmental water from the Murrumbidgee and Lower Darling systems. The modelling undertakings would likely be only possible progressively and iteratively. Therefore, modelling improvements to build a connected system more seamlessly and efficiently should continue to the next stage of the constraint management program and other future policy developments.

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NSW DPIE (2020b). Murray-Lower Darling Long Term Water Plan, Part B: Murray-Lower Darling planning units, Department of Planning, Industry and Environment, September 2020

Appendix A: Typical flow behaviour under different levels constraints relaxation scenarios in the river Murray system

There are 5 scenarios modelled to represent different levels of constraints relaxation at Doctors Point and Yarrawonga downstream which are denoted by letter D or Y followed by levels of constraints relaxed in GL. In these scenarios, Goulburn constraints are maintained at the Scenario 1 constraints levels which are 9,500 ML/d, 10,000 ML/d and 17,000 ML/d at Eildon downstream, Molesworth and lower Goulburn respectively. For Murray, the reference scenarios are represented by setting regulated flows at Doctor Points and Yarrawonga downstream at 25,000 ML/d and 15,000 ML/d, respectively.

In figures below, there are four different flow regimes depicted using exceedance probability which includes:

- Low flow regimes represented by 75 percent exceedance probability,
- Medium flow regimes represented by 50 percent exceedance probability,
- Upper bound of regulated flow regimes by 25 percent exceedance probability and likely representing fully regulated flow distribution, and
- Unregulated flow regimes by 5 percent exceedance probability and indicating beyond regulated flow conditions.

These flow regimes are presented at key gauging stations along the system including Doctors Point, Yarrawonga, Torrumbarry, Stevens Weir, Stoney Crossing, Wakool Junction, Euston and flow to South Australia.

At the Upper Murray reach (ie flows at Doctors Point and Yarrawonga), there are higher changes of maintaining low flow regimes (ie at 75 % exceedance probability) under the current constrain level. In November and December, it is more strongly observed indicating more regulated water movements from upper to lower storages to be able to service water requirements during the peak irrigation seasons. In contrast, when environmental watering is taking advantage of the constraints relaxed, low flows are peaked around 14,000 ML/d about one month earlier and regulated releases in later months are reduced.

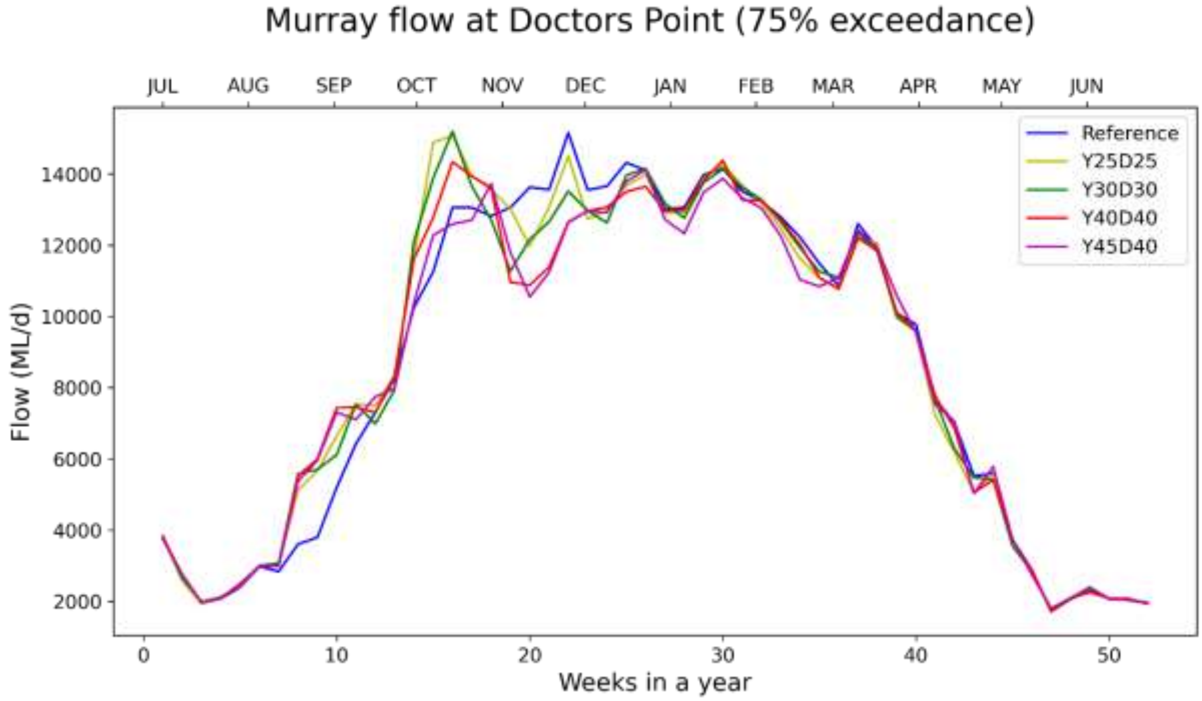
Flows under the current constraints and some scenarios with lower levels of constraints relaxation tend to be boosted to medium flow regimes more regularly during winter-spring season. Also regulated flows during summer are closely maintained to the Barmah Choke capacity of 9,300 ML/d.

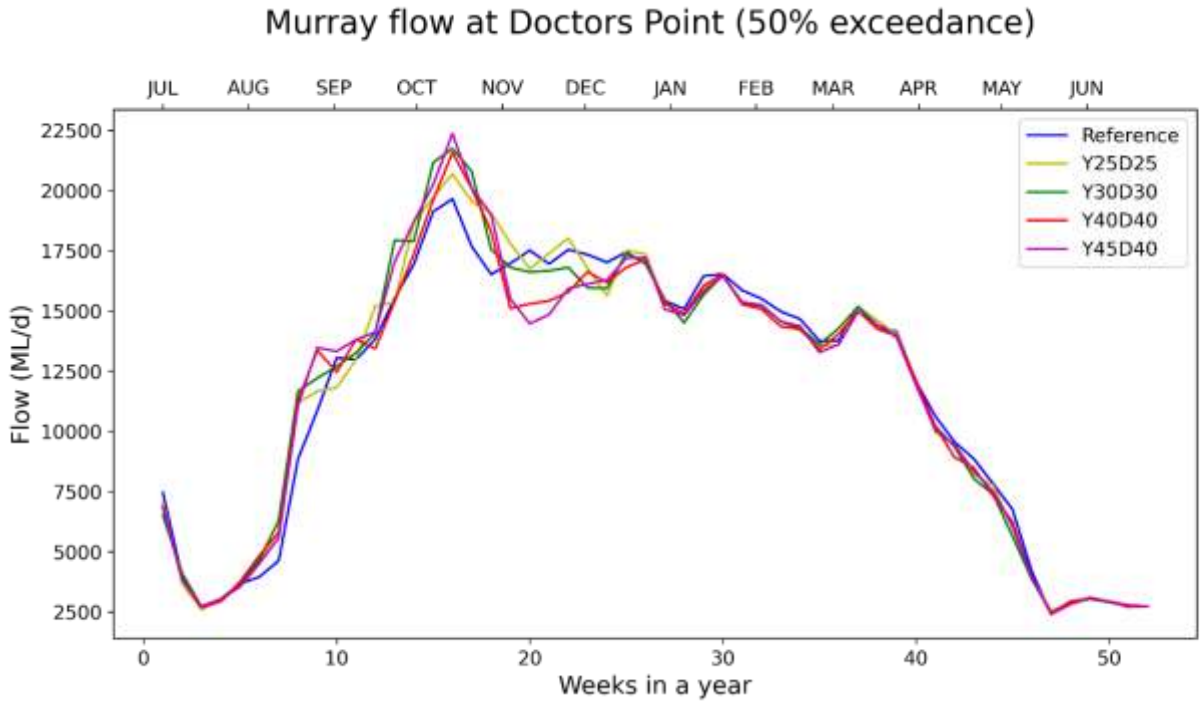
At Doctors Point, the current constraint level of 25,000 ML/d is reached under the current constraint and Y25D25 scenarios for the 25 % exceedance probability distribution, but there are still some air spaces still available for scenarios with the constraint levels relaxed to higher values. At Yarrawonga for the same probability distribution, flows during winter-spring under the current and Y25D25 scenarios are all exceeding the constraint levels indicating the flows are beyond regulated conditions. During the same season, flows under the constraint relaxation to 25,000 and 30,000 ML/d are slightly less than flows from the current constraint level while scenarios with relaxations to higher constraint levels indicate flows are unlikely to be exceeding the designated levels for 75% of times. At this upper bound of regulated regimes, flows during irrigation season are very tightly managed at the choke constraint of 9,300 ML/d.

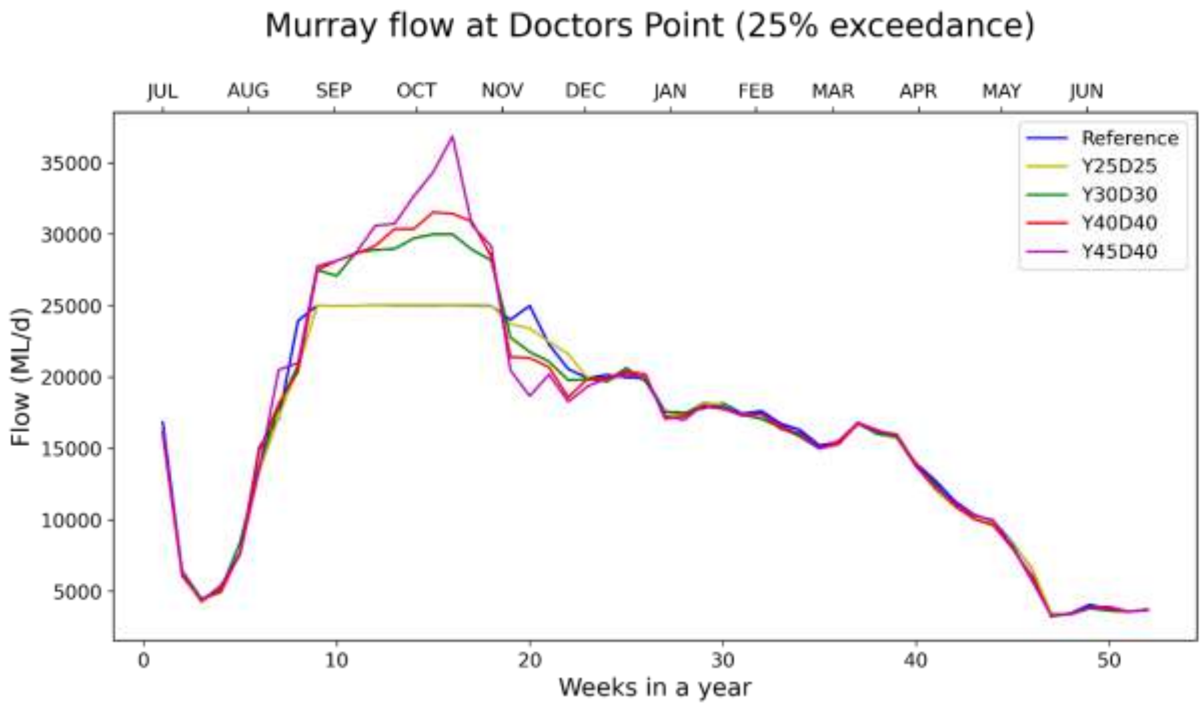
The flow behaviour to deliver water during irrigation season is still observed even at the unregulated flow regimes (ie 5 % exceedance probability) while flows during wet season are all above channel capacities with some evidence of reduced uncontrolled spill even under the lowest capacity relaxed scenario of Y25D25.

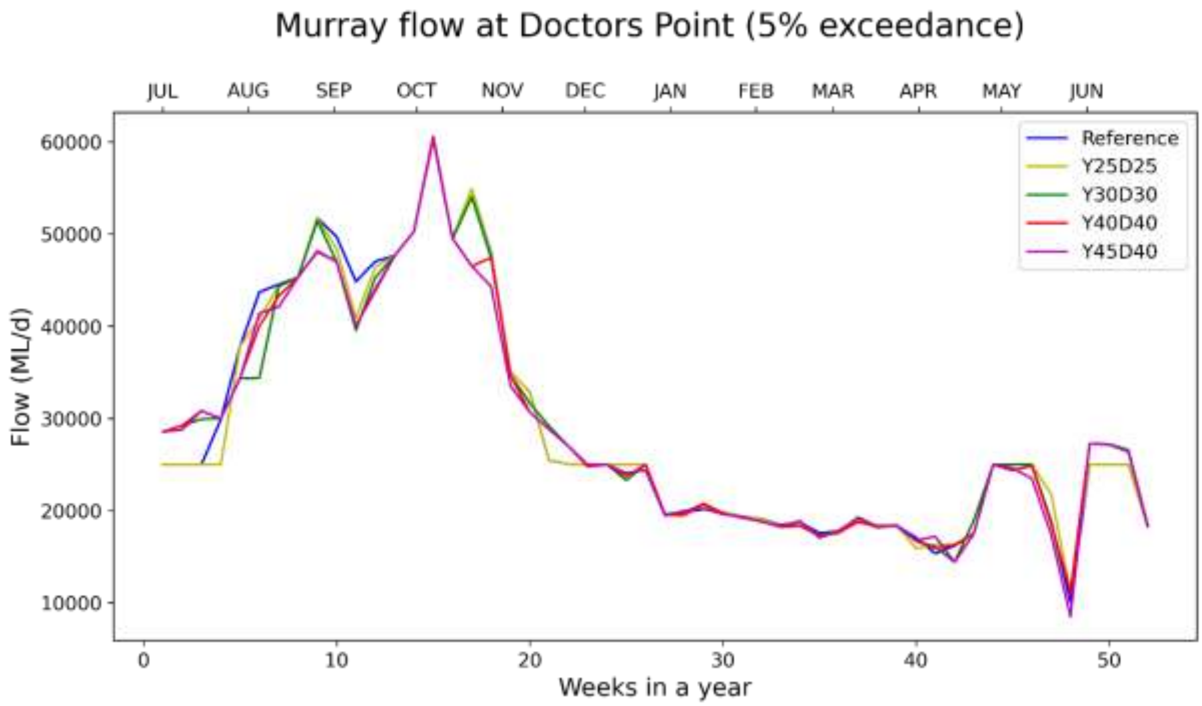
At the mid Murray section (ie Torrumbarry and Edward-Wakool system), similar flow behaviours are observed where most improvements on flows occur in the lower and medium flow regimes. This is because they are mostly affected by water releases from upper storages and Victorian tributaries remain unchanged during this set of scenarios tested.

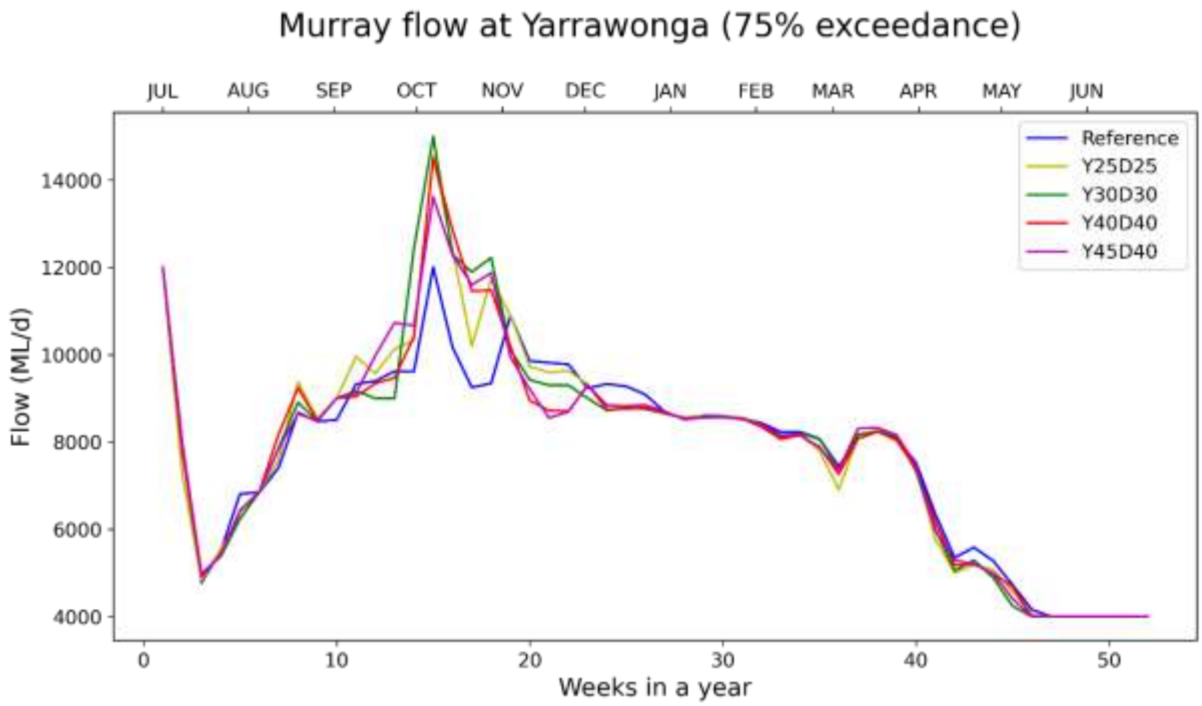
At the lower Murray section (ie Wakool Junction, Euston and Flow to SA), Some increased low flow regimes are observed while medium flow durations are extended as channel capacities are relaxed to higher levels. This reflects geographical nature of the mid Murray section and the Edward-Wakool section where water needs to travel through the flat and wide landscapes once water goes beyond in-channel pathways. Therefore, the peak of events is largely attenuated by the time it reaches to Wakool Junction. It also shows difficulties to influence the peak of events just by releasing environmental water from upper storages. This indicates that significant volume of water from natural events is needed to boost the peaks in the lower reaches of the Murray system.

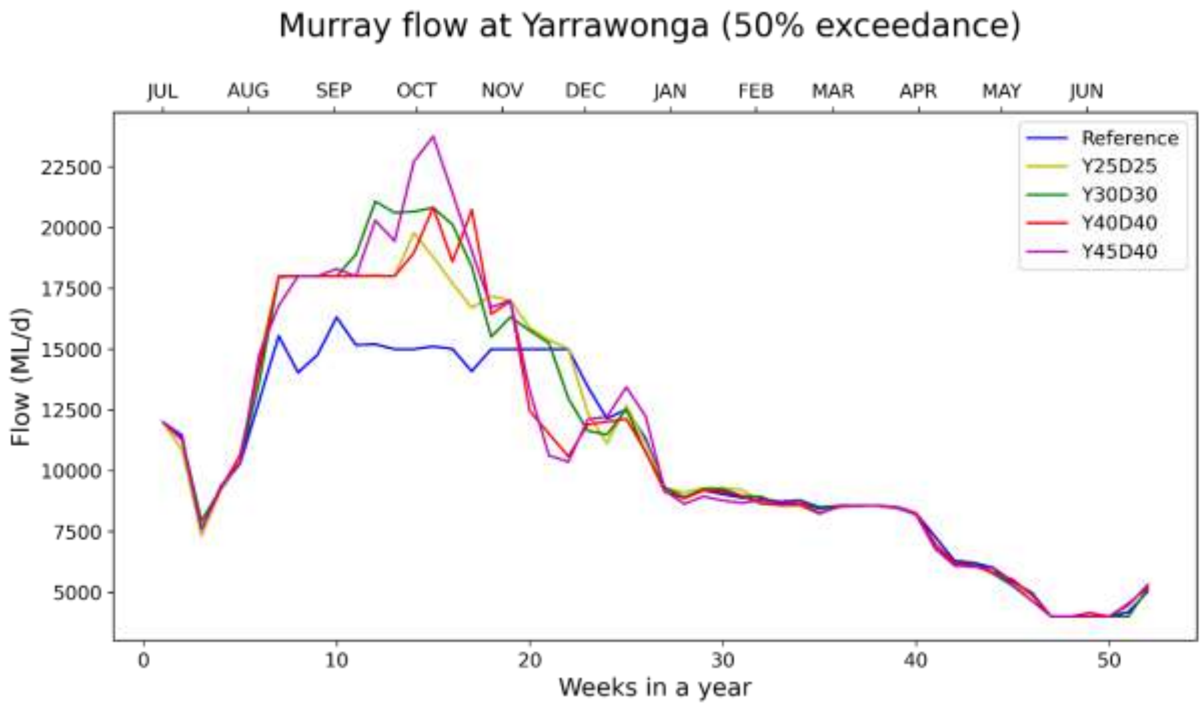

Murray flow at Doctors Point (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
14000
12000
10000
8000
6000
4000
2000
0
10
20
30
40
50
Weeks in a year

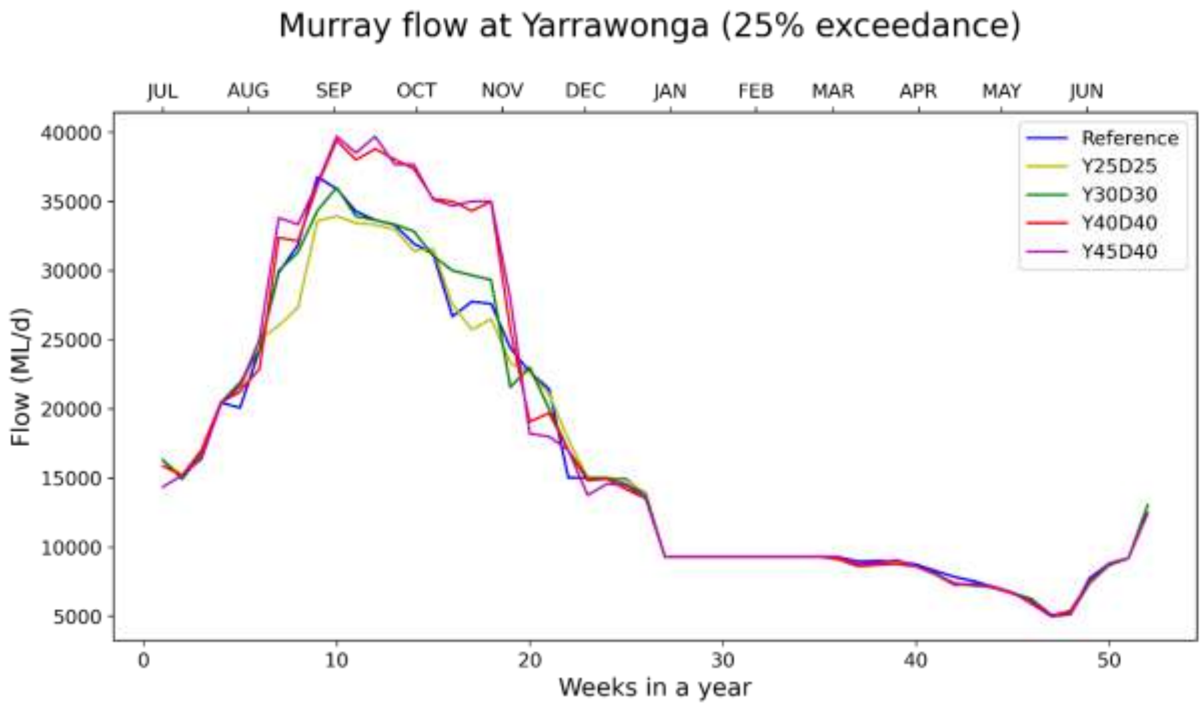

Murray flow at Doctors Point (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
22500
20000
17500
15000
12500
10000
7500
5000
2500
0
10
20
30
40
50
Weeks in a year

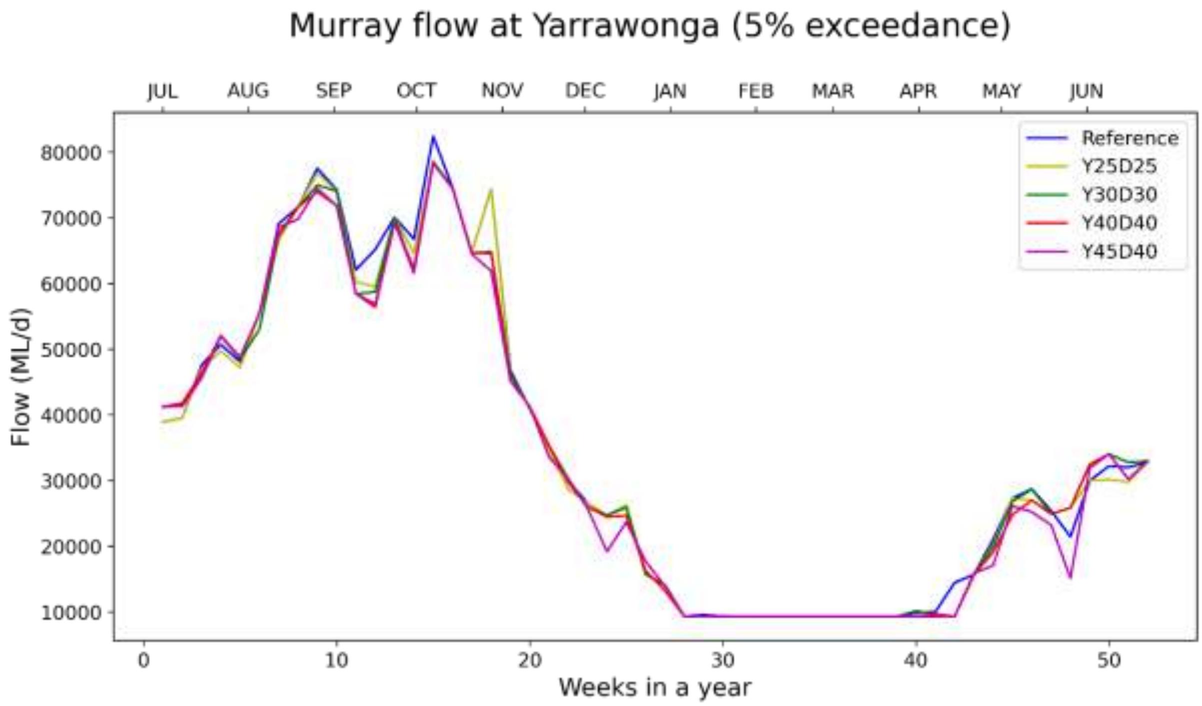

Murray flow at Doctors Point (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
35000
30000
25000
20000
15000
10000
5000
0
10
20
30
40
50
Weeks in a year

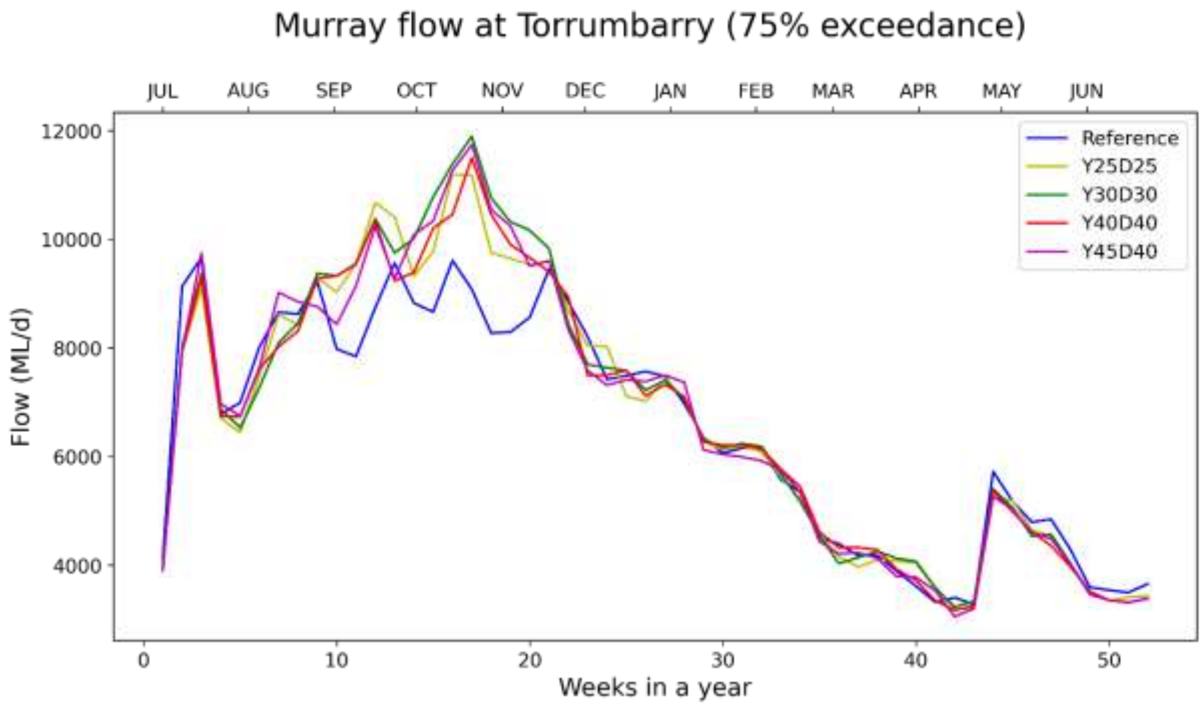

Murray flow at Doctors Point (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
10
20
30
40
50
Weeks in a year

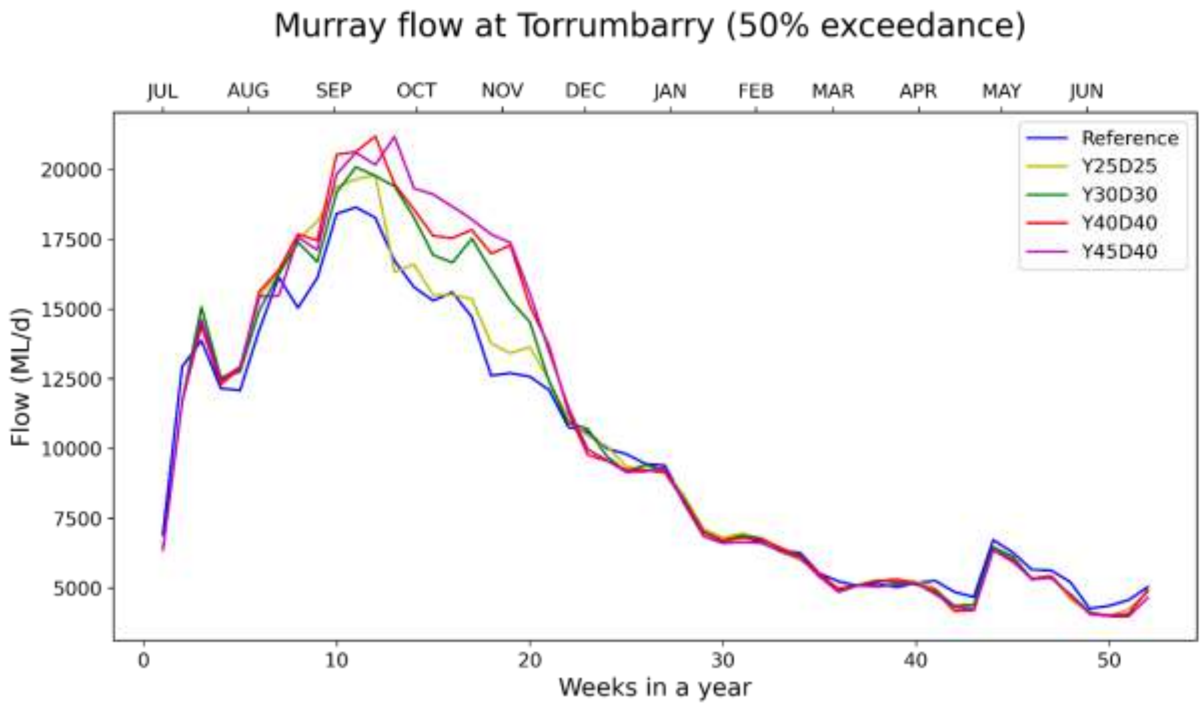

Murray flow at Yarrawonga (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
14000
12000
10000
8000
6000
4000
0
10
20
30
40
50
Weeks in a year

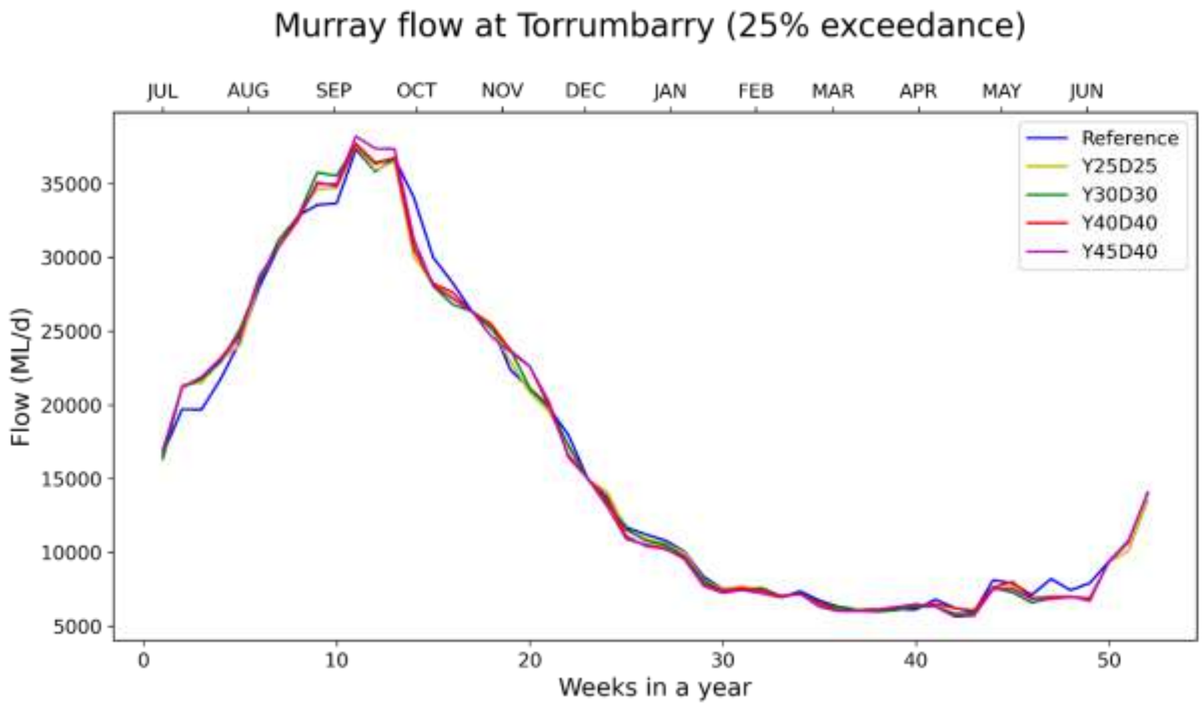

Murray flow at Yarrawonga (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
22500
20000
17500
15000
12500
10000
7500
5000
0
10
20
30
40
50
Weeks in a year

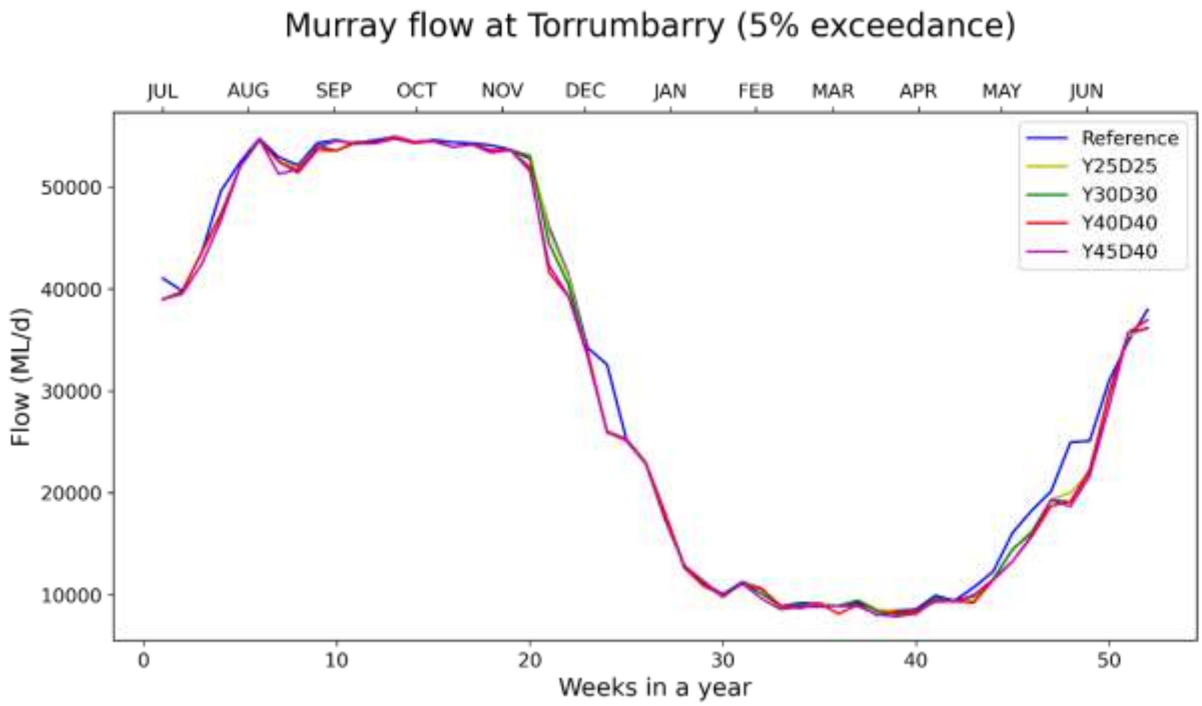

Murray flow at Yarrawonga (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
Weeks in a year
Reference
Y25D25
Y30D30
Y40D40
Y45D40

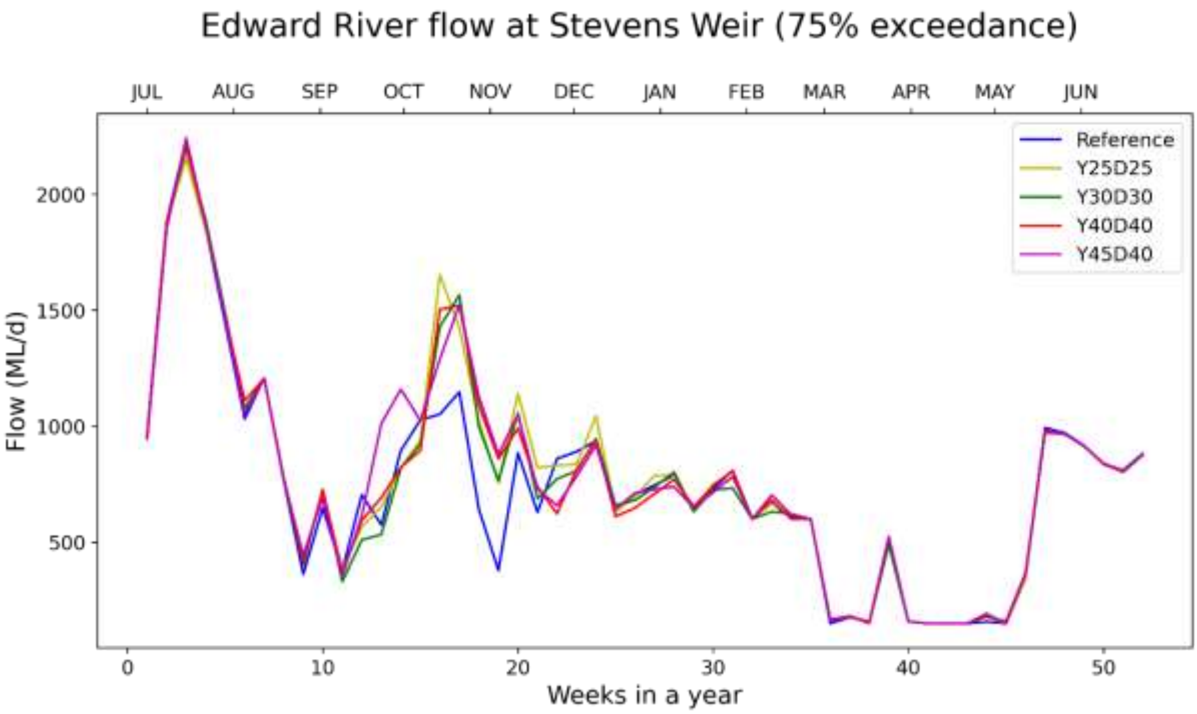

Murray flow at Yarrawonga (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
Weeks in a year
Reference
Y25D25
Y30D30
Y40D40
Y45D40

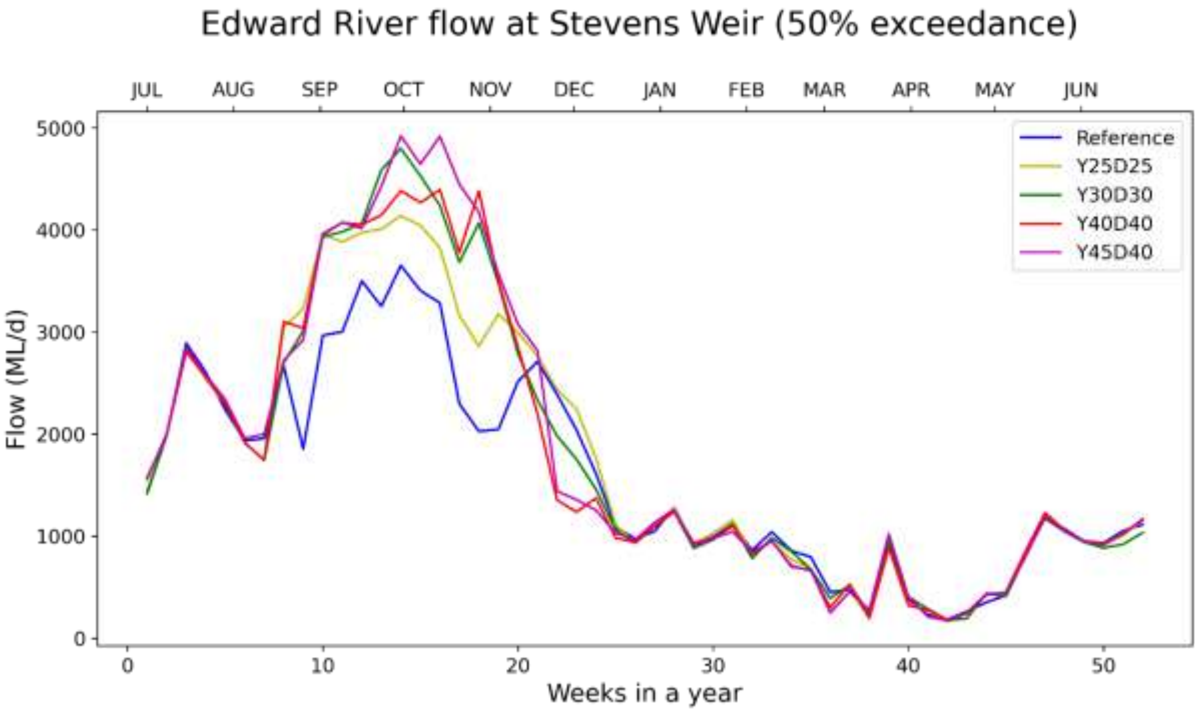

Murray flow at Torrumbarry (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
Weeks in a year
Reference
Y25D25
Y30D30
Y40D40
Y45D40

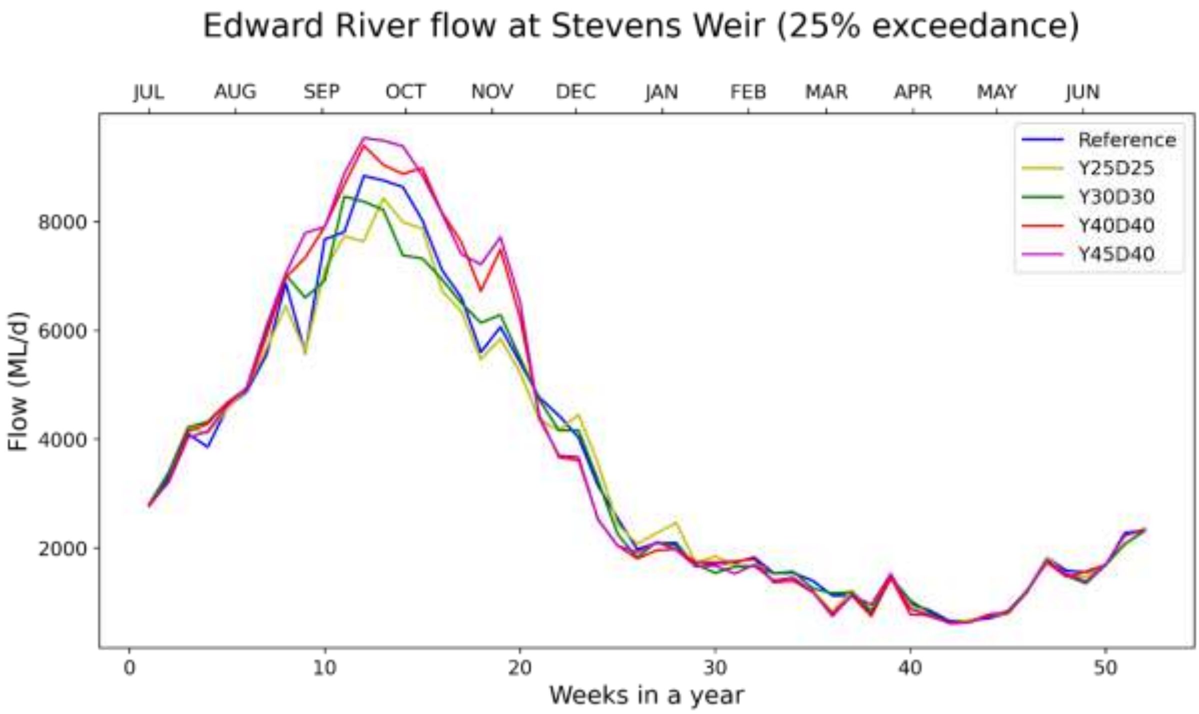

Murray flow at Torrumbarry (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
Weeks in a year
Reference
Y25D25
Y30D30
Y40D40
Y45D40

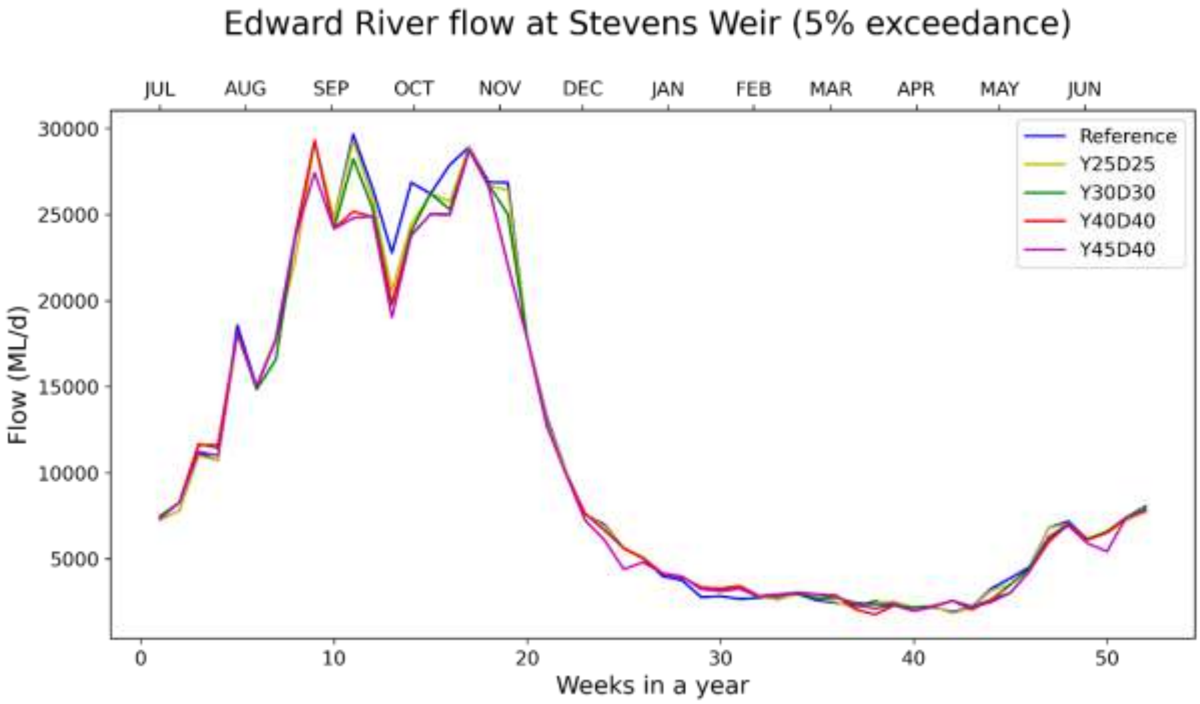

Murray flow at Torrumbarry (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
Weeks in a year

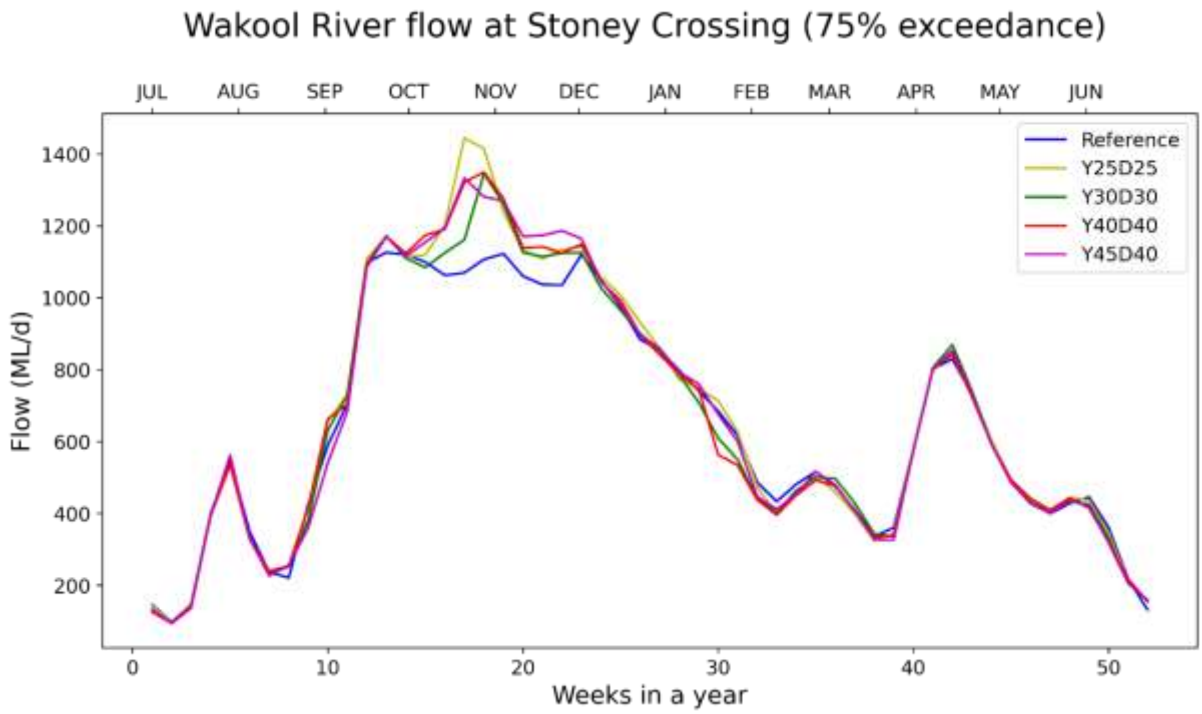

Murray flow at Torrumbarry (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
Weeks in a year

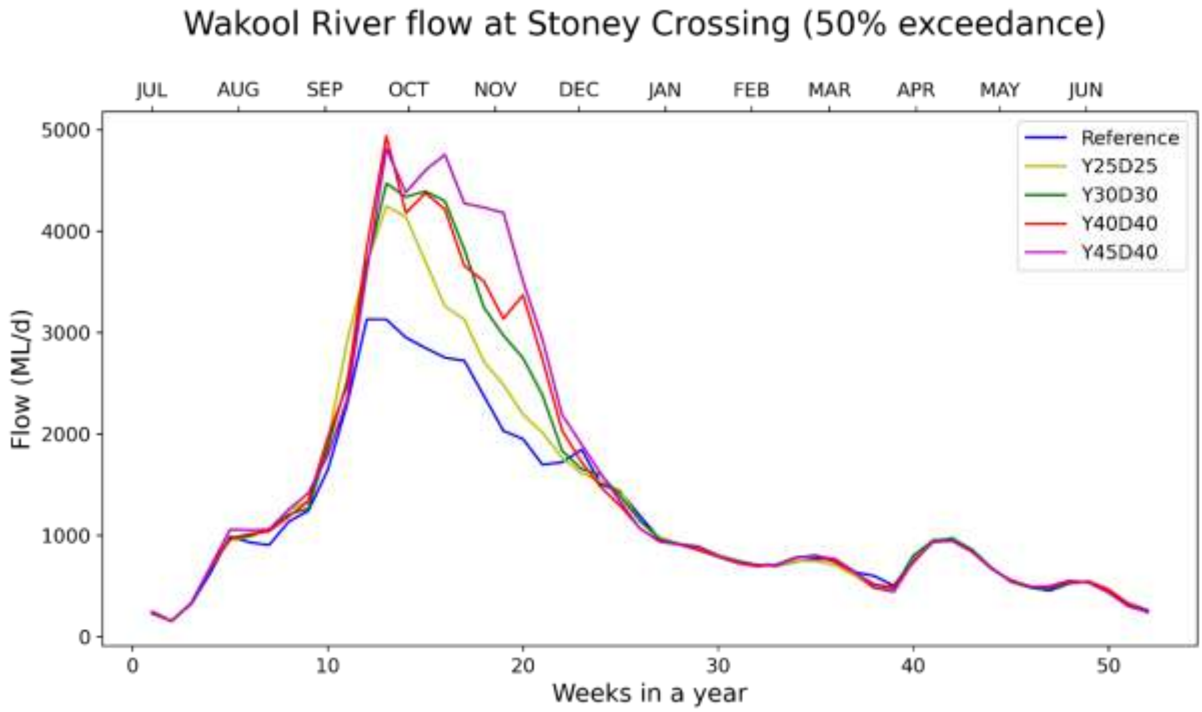

Edward River flow at Stevens Weir (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
Weeks in a year

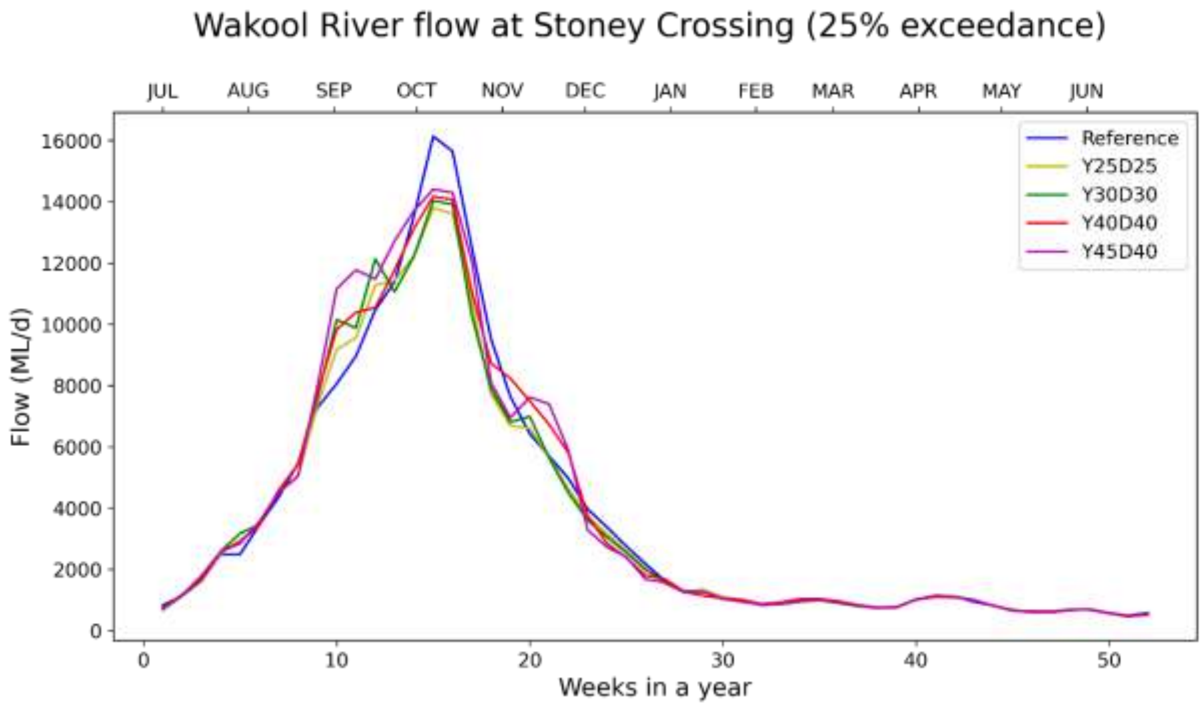

Edward River flow at Stevens Weir (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
Weeks in a year

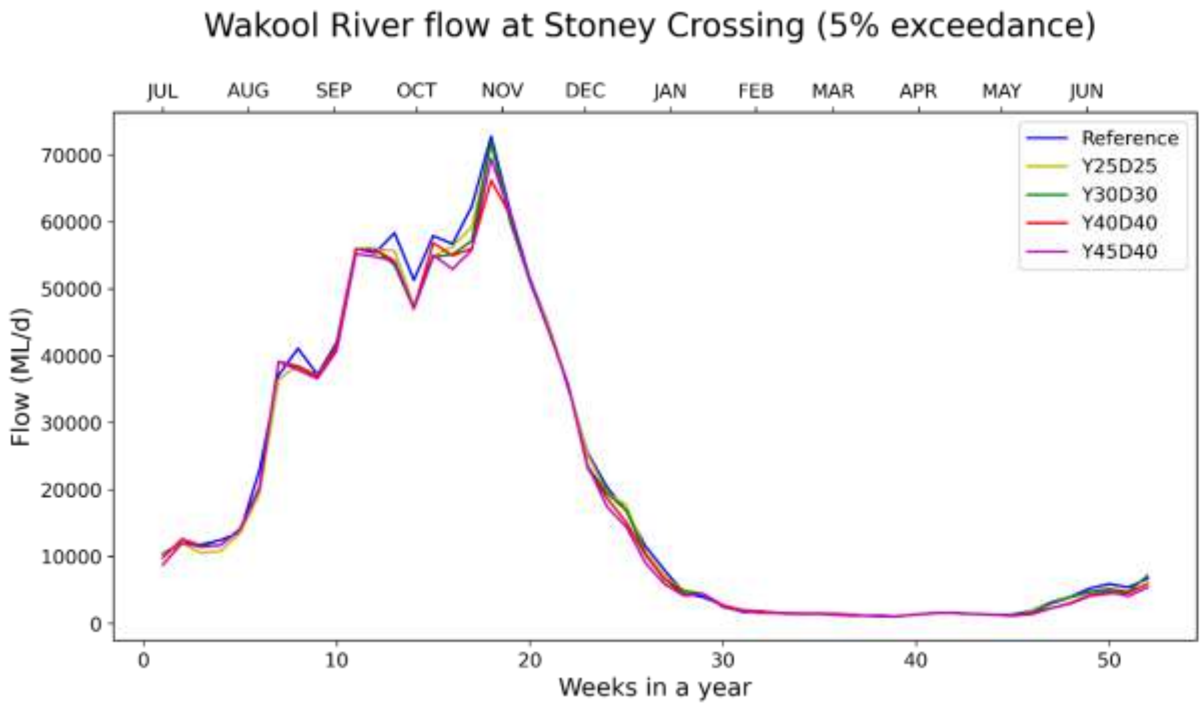

Edward River flow at Stevens Weir (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
2000
4000
6000
8000
0
10
20
30
40
50
Weeks in a year

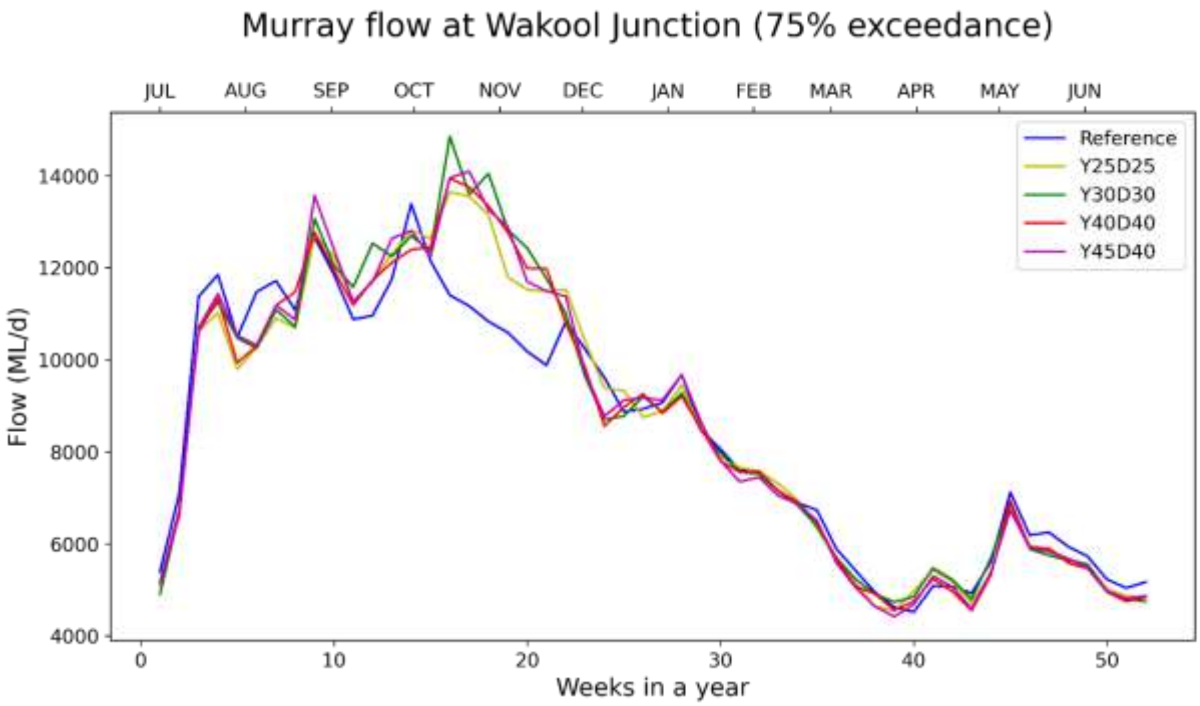

Edward River flow at Stevens Weir (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
5000
10000
15000
20000
25000
30000
0
10
20
30
40
50
Weeks in a year

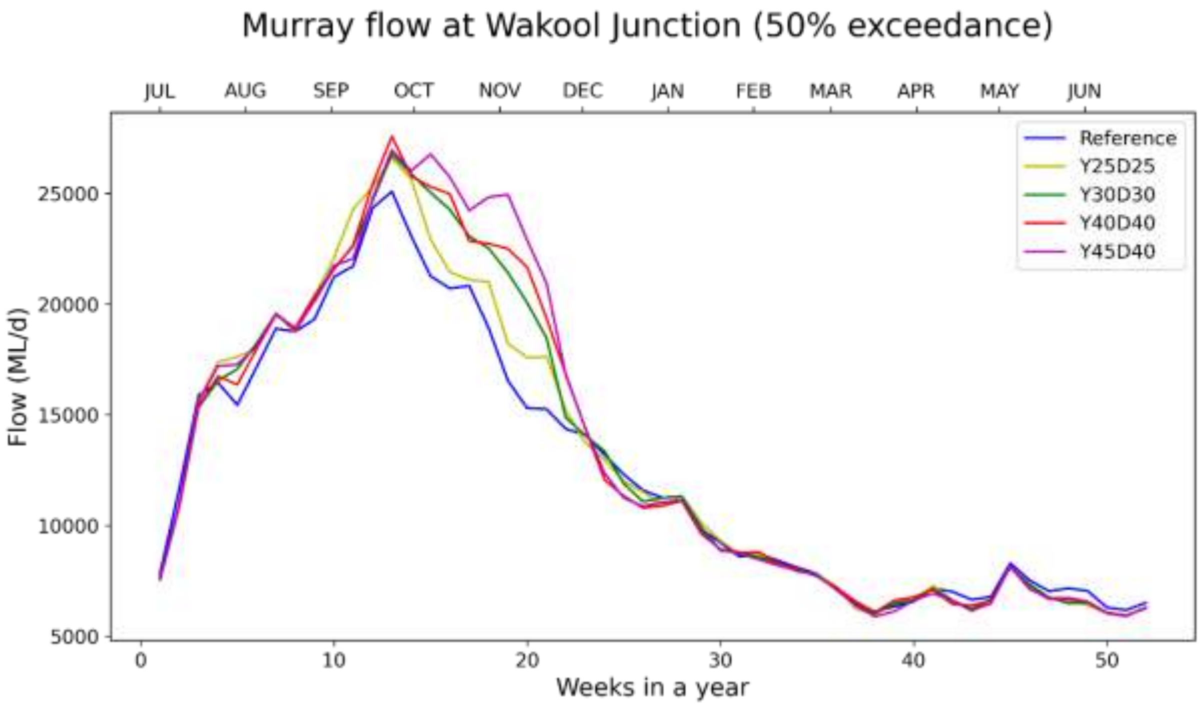

Wakool River flow at Stoney Crossing (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
Weeks in a year

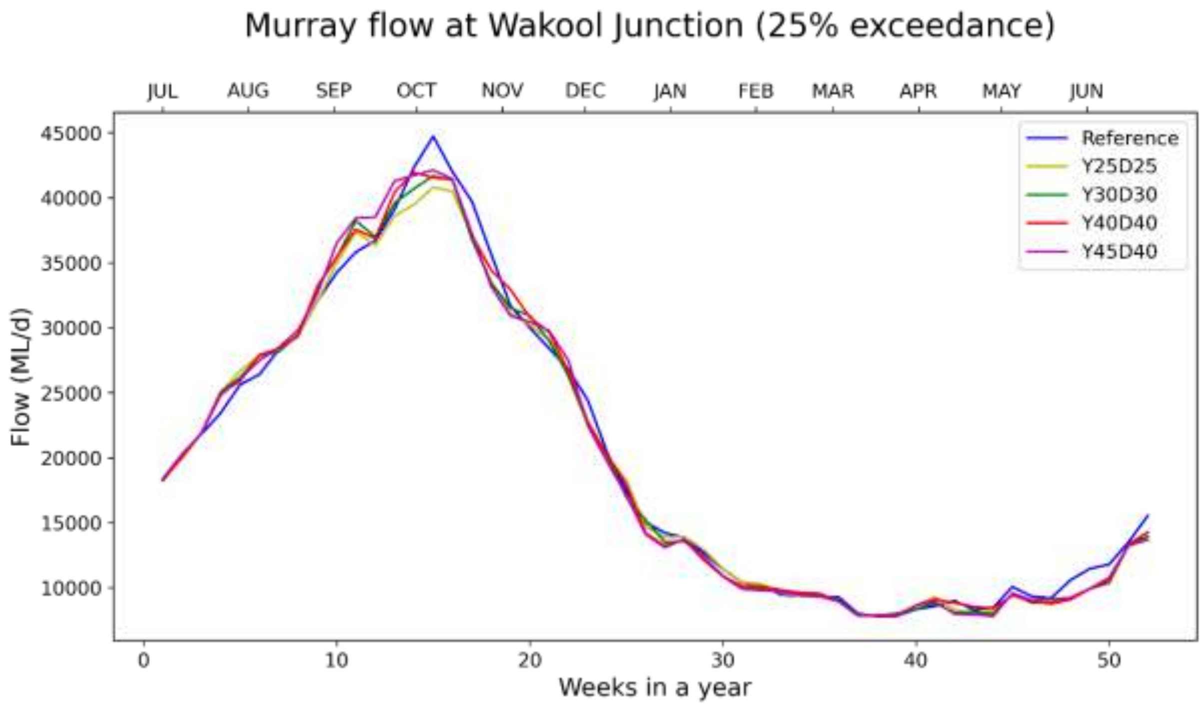

Wakool River flow at Stoney Crossing (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
Weeks in a year

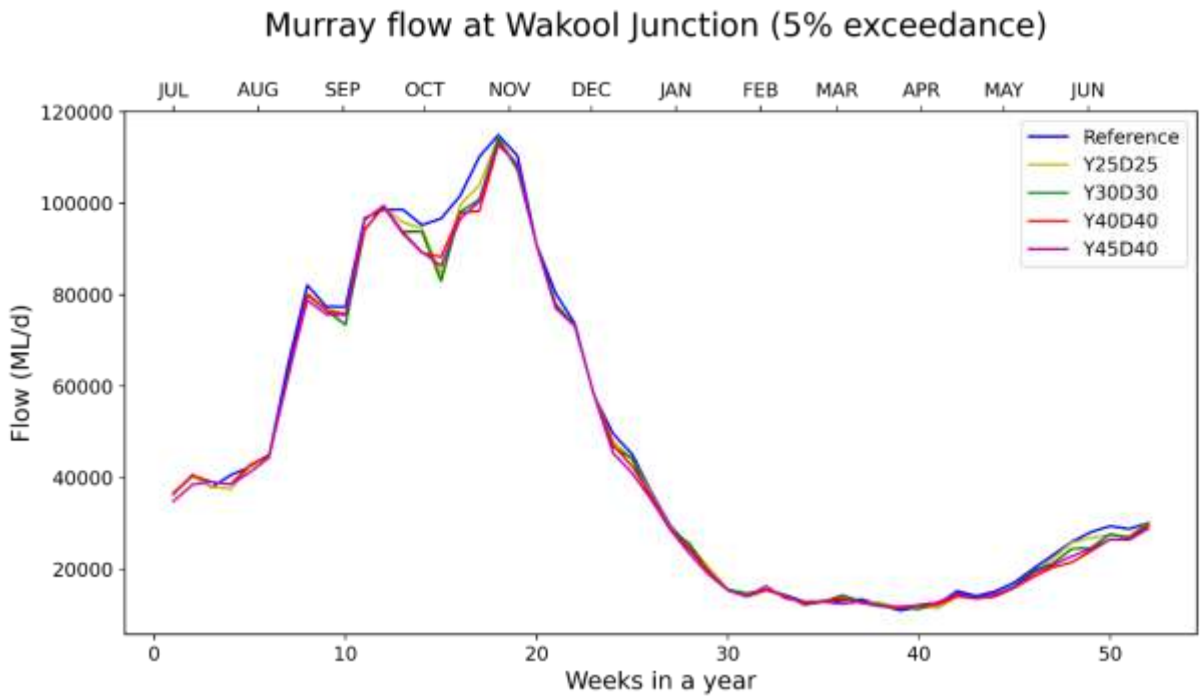

Wakool River flow at Stoney Crossing (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
0
2000
4000
6000
8000
10000
12000
14000
16000
0
10
20
30
40
50
Weeks in a year

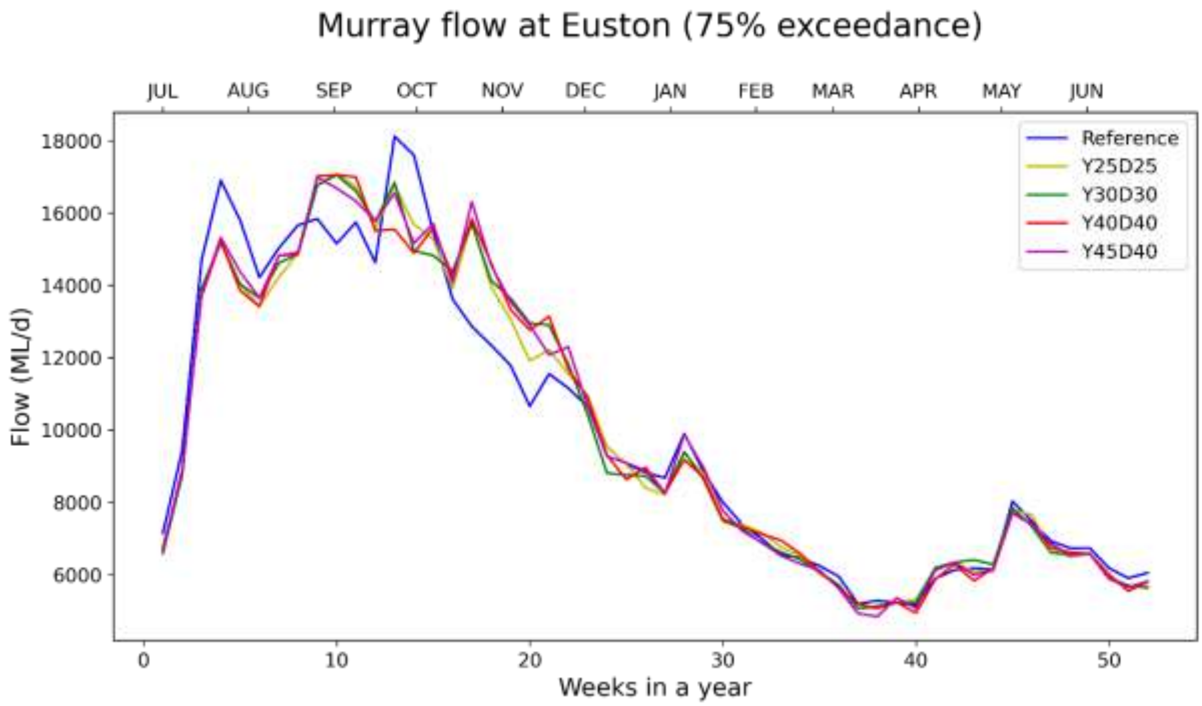

Wakool River flow at Stoney Crossing (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
0
10000
20000
30000
40000
50000
60000
70000
0
10
20
30
40
50
Weeks in a year

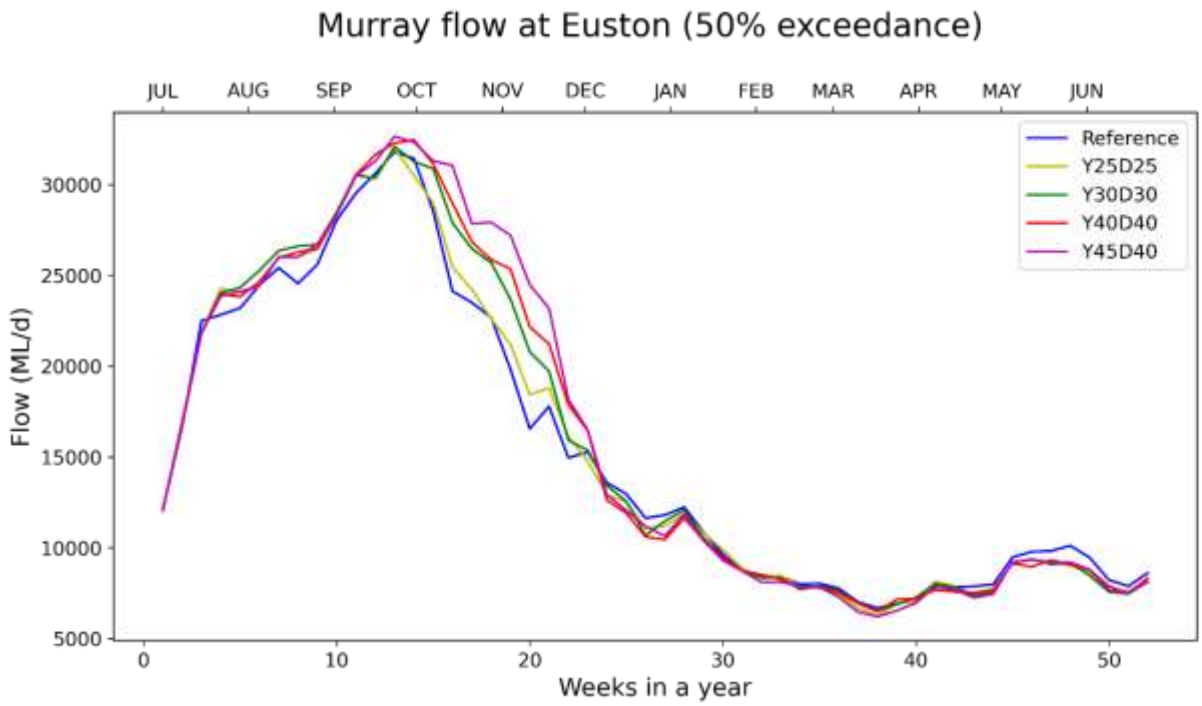

Murray flow at Wakool Junction (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
14000
12000
10000
8000
6000
4000
0
10
20
30
40
50
Weeks in a year

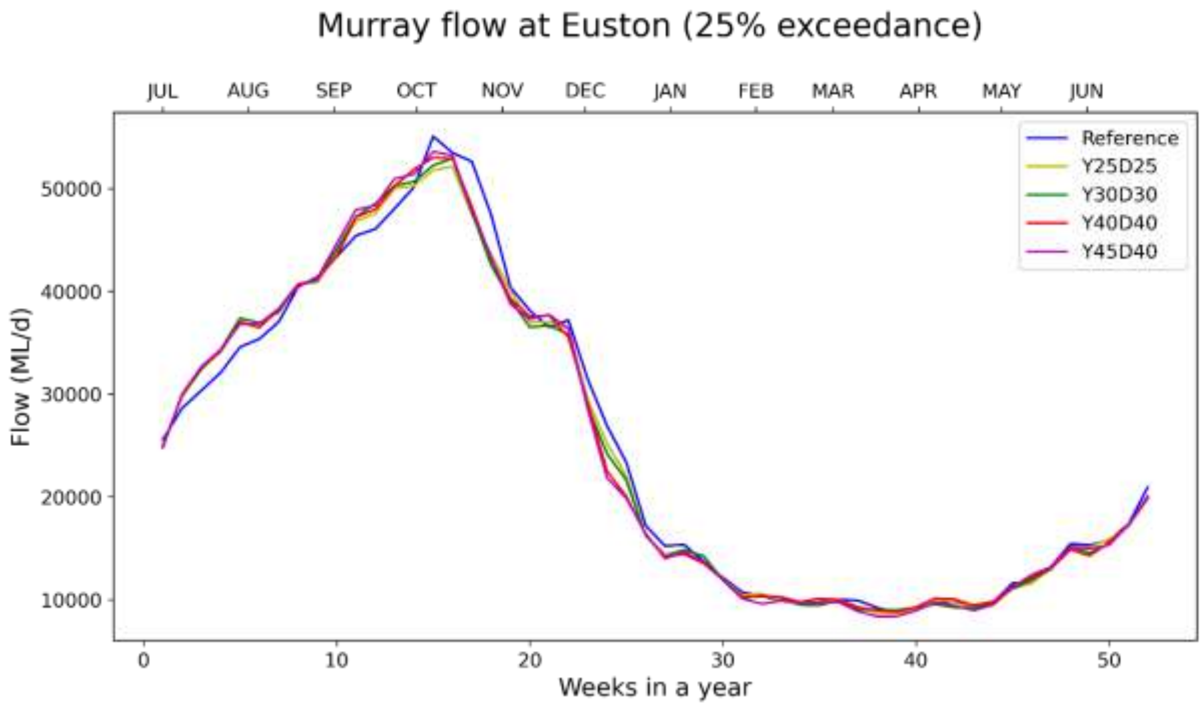

Murray flow at Wakool Junction (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
25000
20000
15000
10000
5000
0
10
20
30
40
50
Weeks in a year

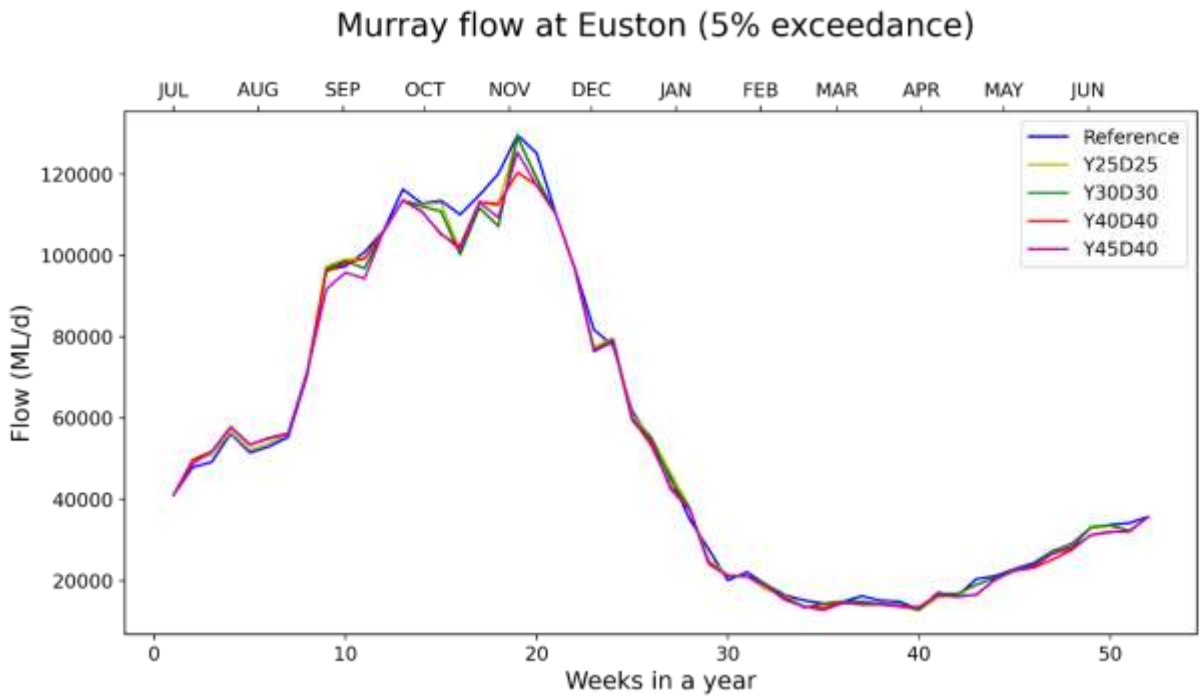

Murray flow at Wakool Junction (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
45000
40000
35000
30000
25000
20000
15000
10000
0
10
20
30
40
50
Weeks in a year
Reference
Y25D25
Y30D30
Y40D40
Y45D40

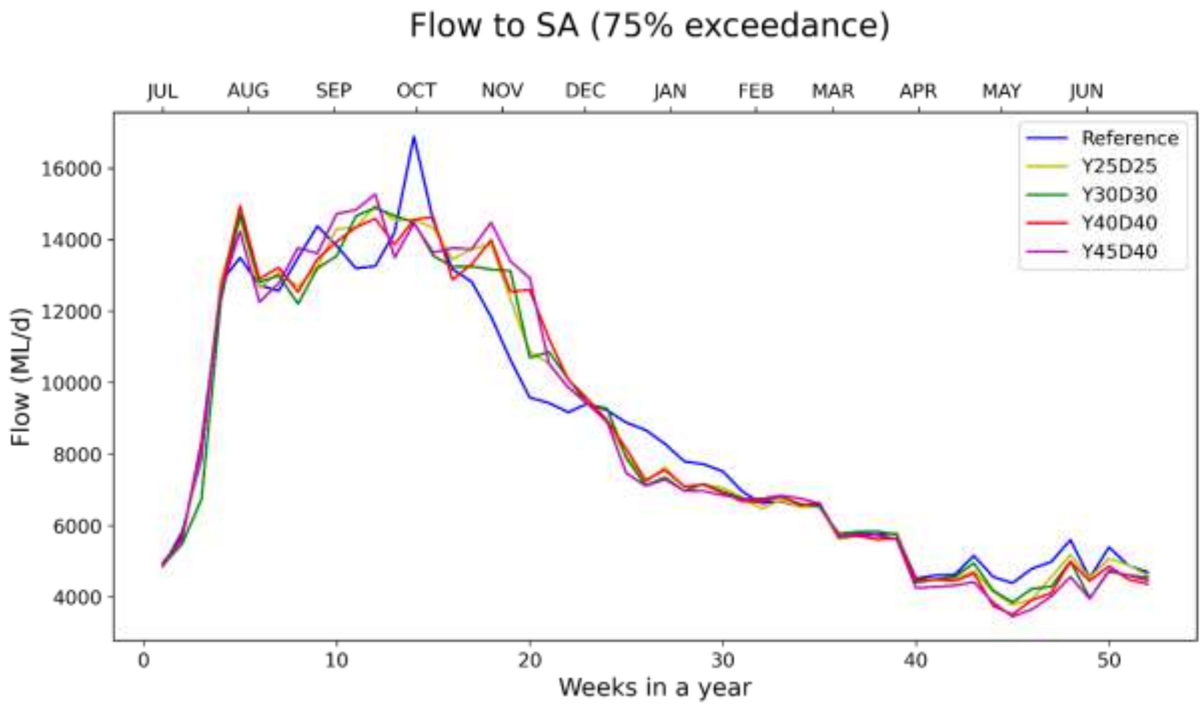

Murray flow at Wakool Junction (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
120000
100000
80000
60000
40000
20000
0
10
20
30
40
50
Weeks in a year
Reference
Y25D25
Y30D30
Y40D40
Y45D40

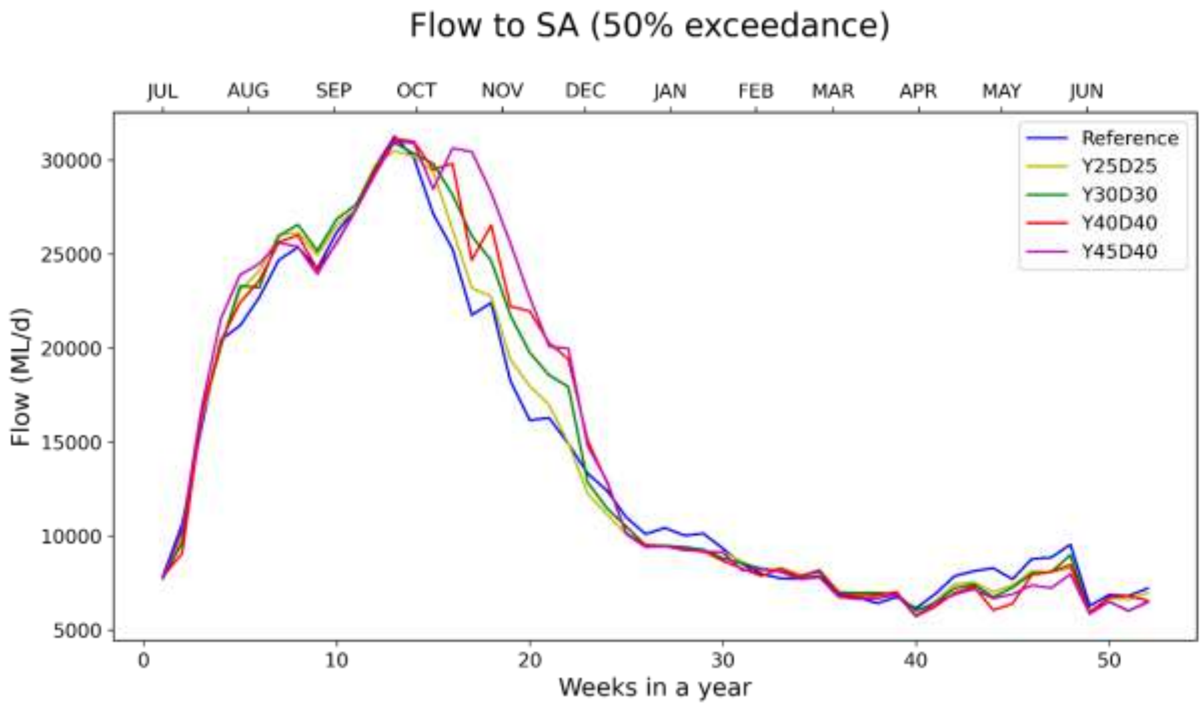

Murray flow at Euston (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
18000
16000
14000
12000
10000
8000
6000
0
10
20
30
40
50
Weeks in a year

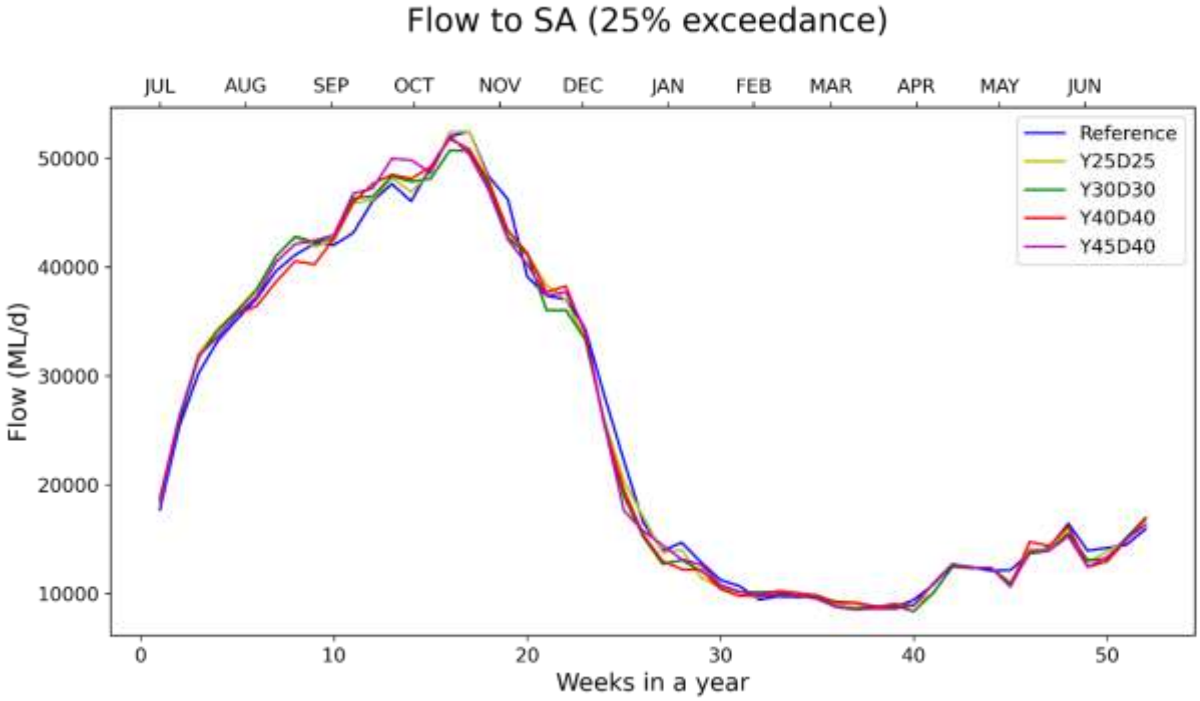

Murray flow at Euston (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
30000
25000
20000
15000
10000
5000
0
10
20
30
40
50
Weeks in a year

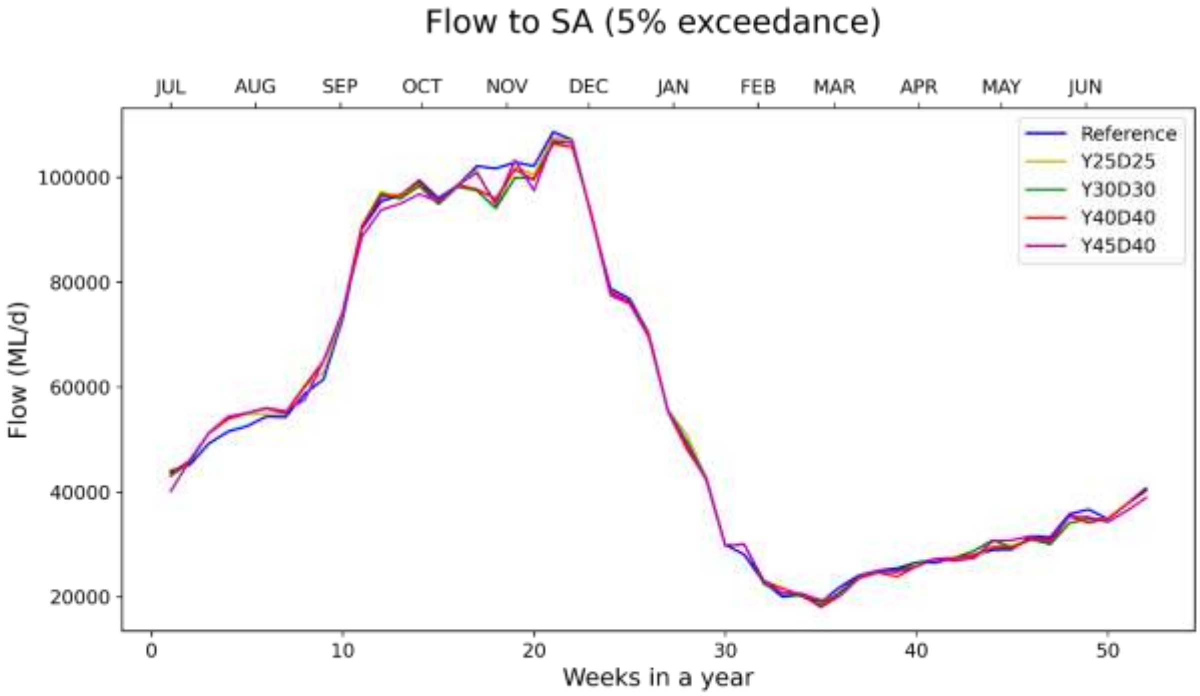

Murray flow at Euston (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
10000
20000
30000
40000
50000
0
10
20
30
40
50
Weeks in a year


Murray flow at Euston (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
20000
40000
60000
80000
100000
120000
0
10
20
30
40
50
Weeks in a year


Flow to SA (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
Weeks in a year
Reference
Y25D25
Y30D30
Y40D40
Y45D40


Flow to SA (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
Weeks in a year
Reference
Y25D25
Y30D30
Y40D40
Y45D40


Flow to SA (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
50000
40000
30000
20000
10000
0
10
20
30
40
50
Weeks in a year

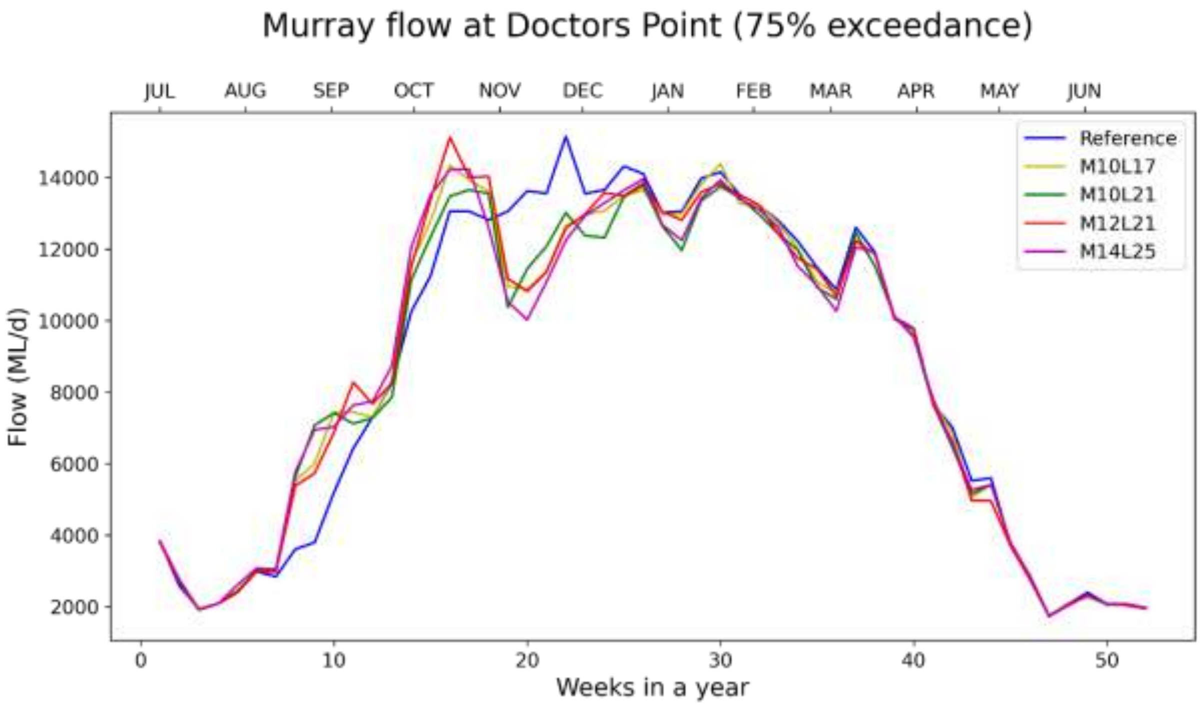

Flow to SA (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
Y25D25
Y30D30
Y40D40
Y45D40
Flow (ML/d)
100000
80000
60000
40000
20000
0
10
20
30
40
50
Weeks in a year

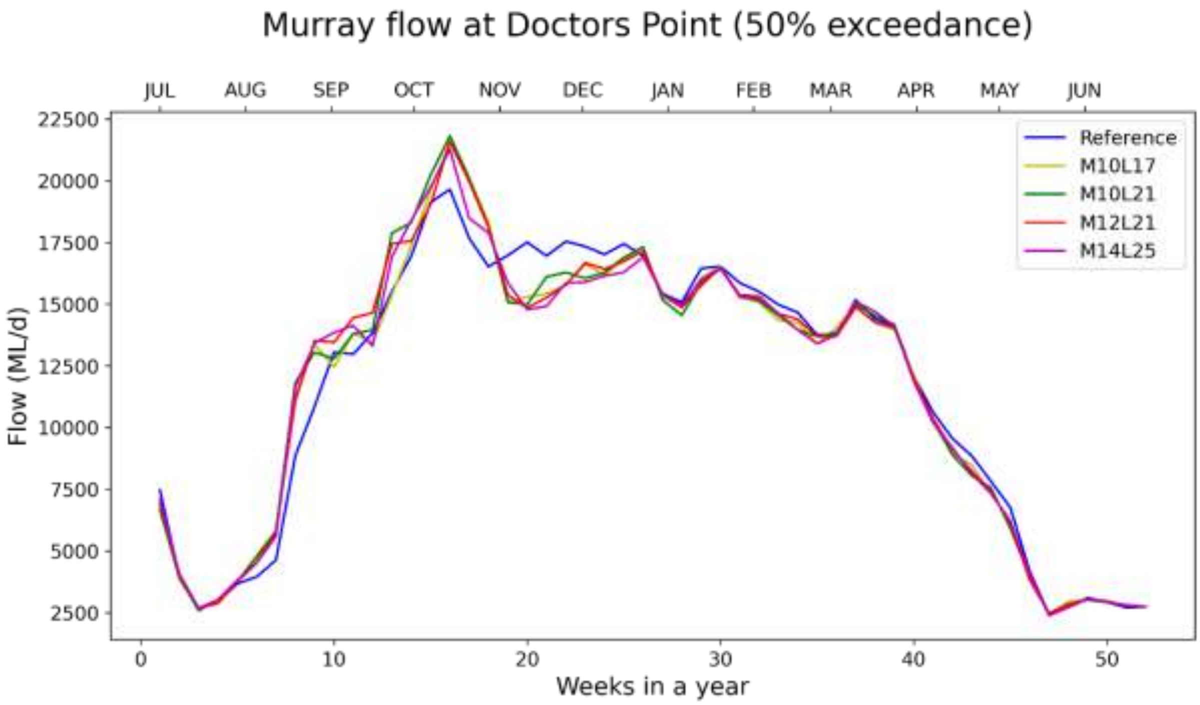
Appendix B: Typical flow behaviour under different levels of constraints relaxation scenarios in the Goulburn system

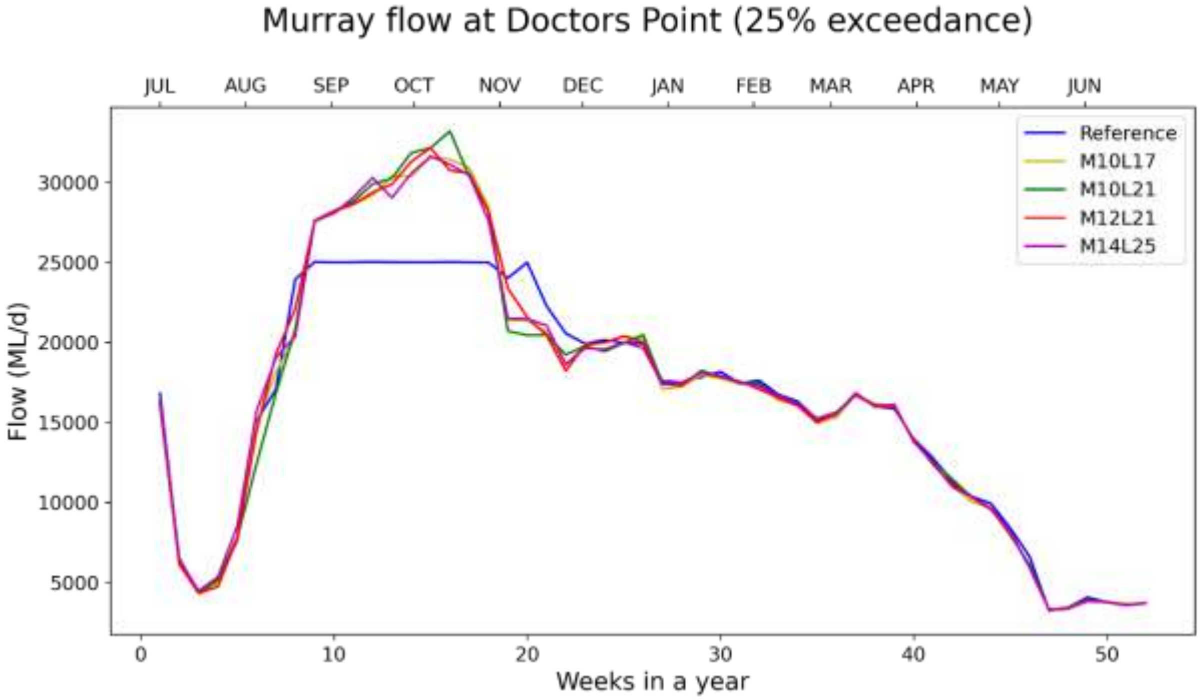
In these scenarios, different levels of constraints relaxation of the Goulburn system are tested with Murray constraints set to 40,000 ML/d at both Doctors Point and Yarrawonga downstream. Similar to what is presented at Appendix A, a series of plots are shown in the appendix at the same location and same percentage exceedance probabilities. There are four scenarios with different levels of constraints relaxation at the Goulburn system, where constraint locations are denoted by M and L indicating Mid and Lower Goulburn reaches, respectively followed by level of constraints relaxations in GL. For example, M10L17 indicates the levels of relaxations of 10,000 ML/d and 17,000 ML/d at Mid and Lower Goulburn system. It should be noted that the reference scenario is still referring to the current levels of constraints and the M10L17 scenario is exactly same to the Y40D40 scenario presented in Appendix A because all scenarios in the appendix B is based on Murray constraints managed at 40,000 ML/d and Doctors Point and Yarrawonga where Goulburn constraints are set to 10,000 ML/d and 17,000 ML/d at Mid and Lower Goulburn.

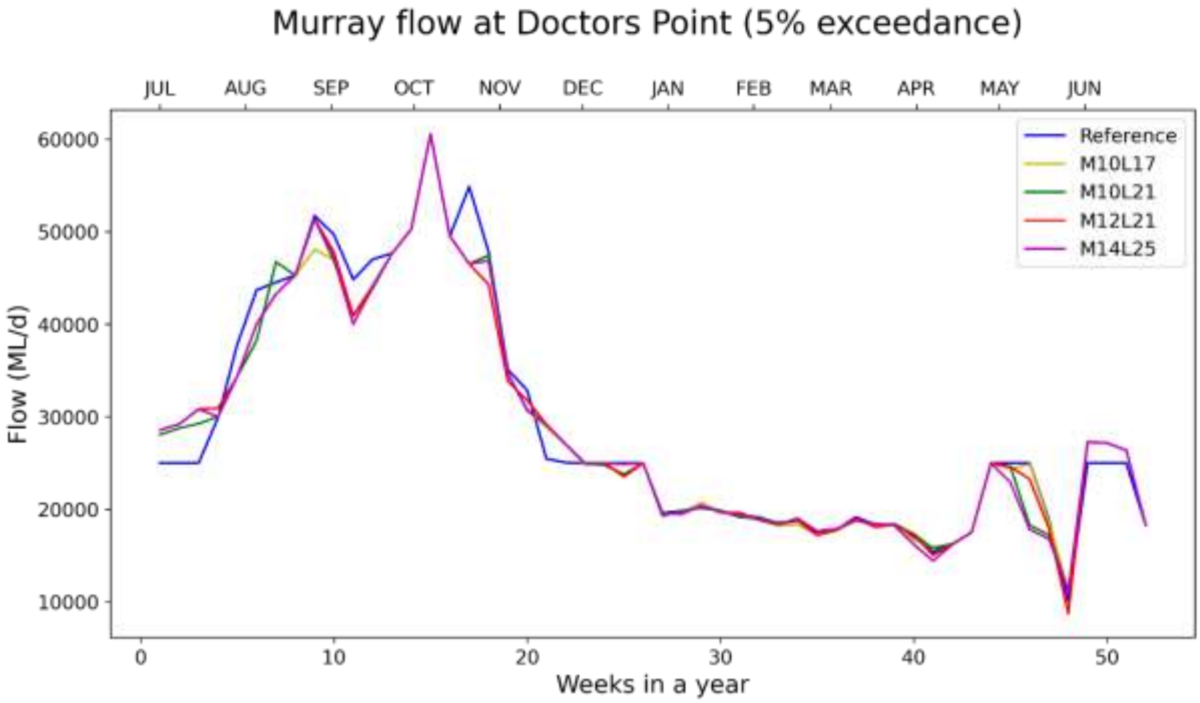
Comparison between the reference and all constraint relaxed scenarios shares key findings observed and described in Appendix A, demonstrating that environmental water holders can make use of the additional channel capacities to increase flows (thereby improving environmental outcomes) and reducing uncontrolled spill events.

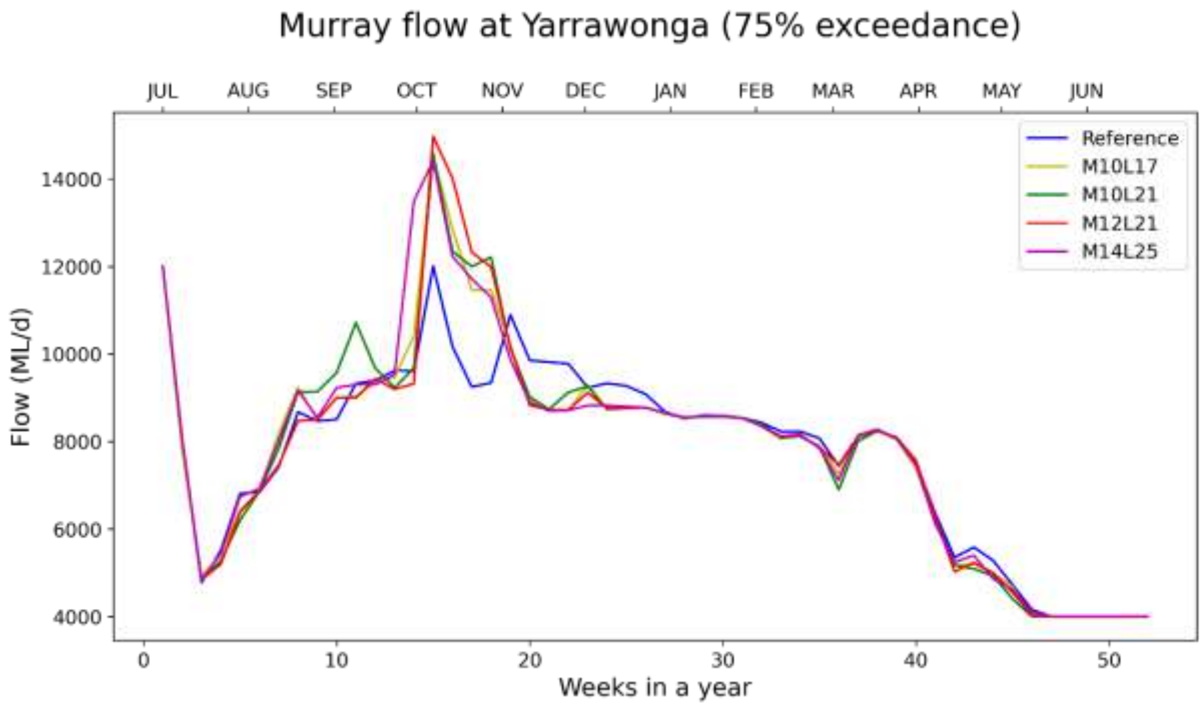
There is a mechanism built in for calculating environmental water requirements at Yarrawonga to stop demanding a large pulse of environmental water when Goulburn flow to Murray is expected to be significantly high. This is to control flows at downstream reaches of the junction within a manageable range. Therefore, it is expected to see no significant changes in the range beyond 50 percent exceedance probability and the figures in this appendix demonstrate this is the case. The biggest impact of different Goulburn constraints is shown at the low flow range at Torrumbarry where flows in a typical environmental watering season are increased from around 9,000 ML/d to 12,000 ML/d or higher as constraints in Goulburn are relaxed to higher levels. It shows that Goulburn constraints can be used to boost Murray flows at downstream of the Goulburn Junction if environmental flows from Goulburn and Murray are coordinated.

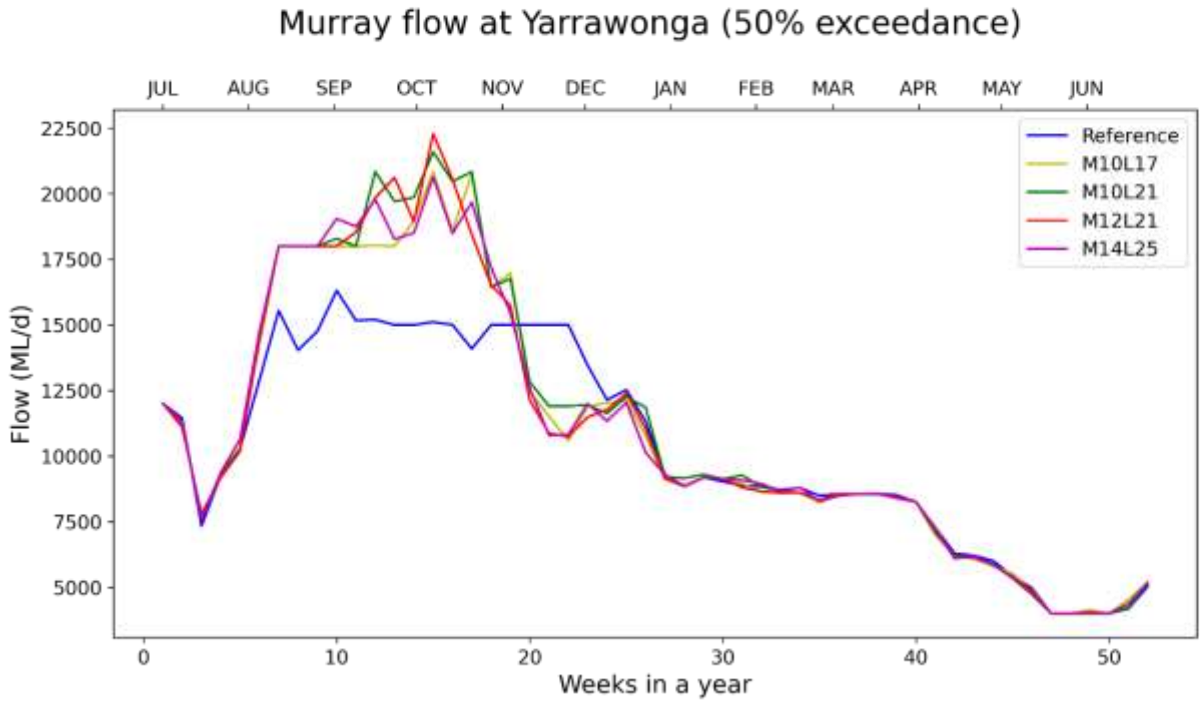

Murray flow at Doctors Point (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
Weeks in a year
Reference
M10L17
M10L21
M12L21
M14L25

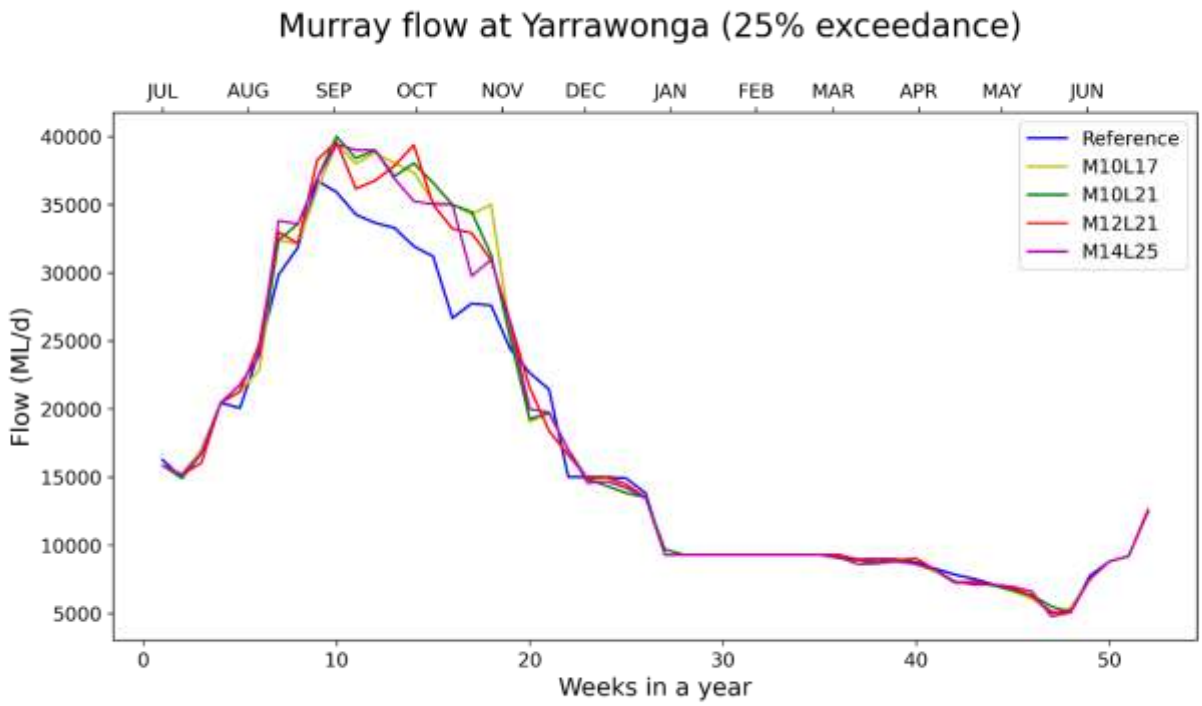

Murray flow at Doctors Point (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
Weeks in a year
Reference
M10L17
M10L21
M12L21
M14L25

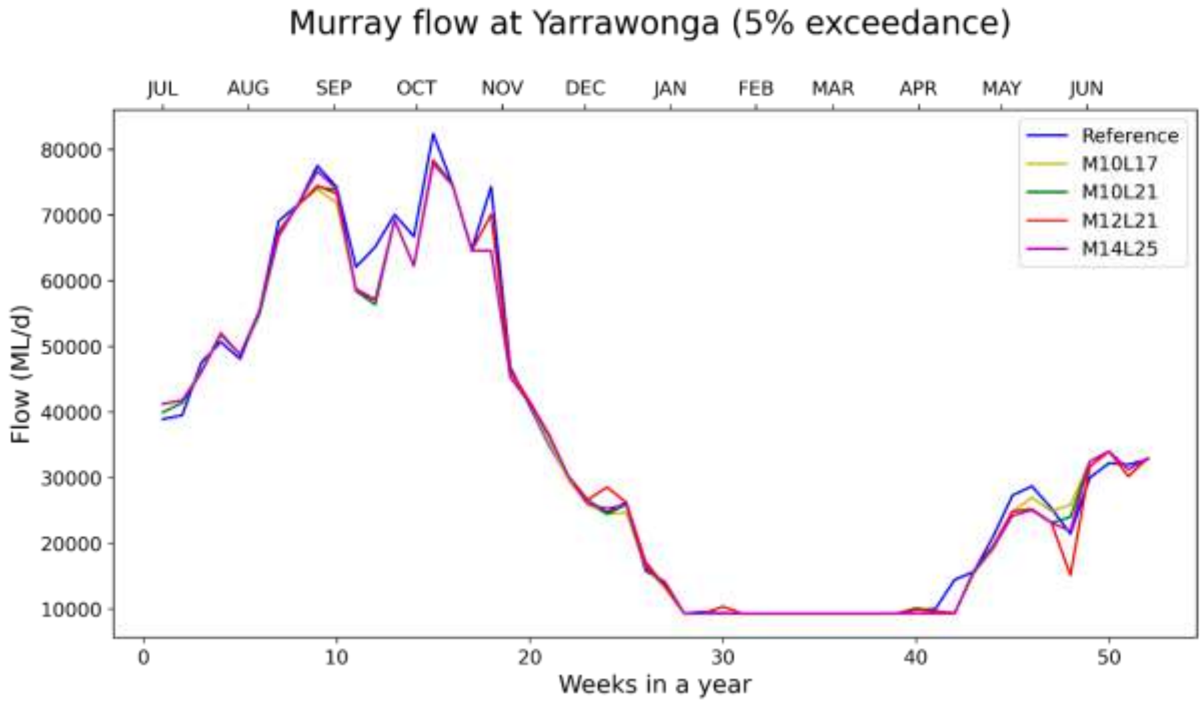

Murray flow at Doctors Point (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
5000
10000
15000
20000
25000
30000
0
10
20
30
40
50
Weeks in a year

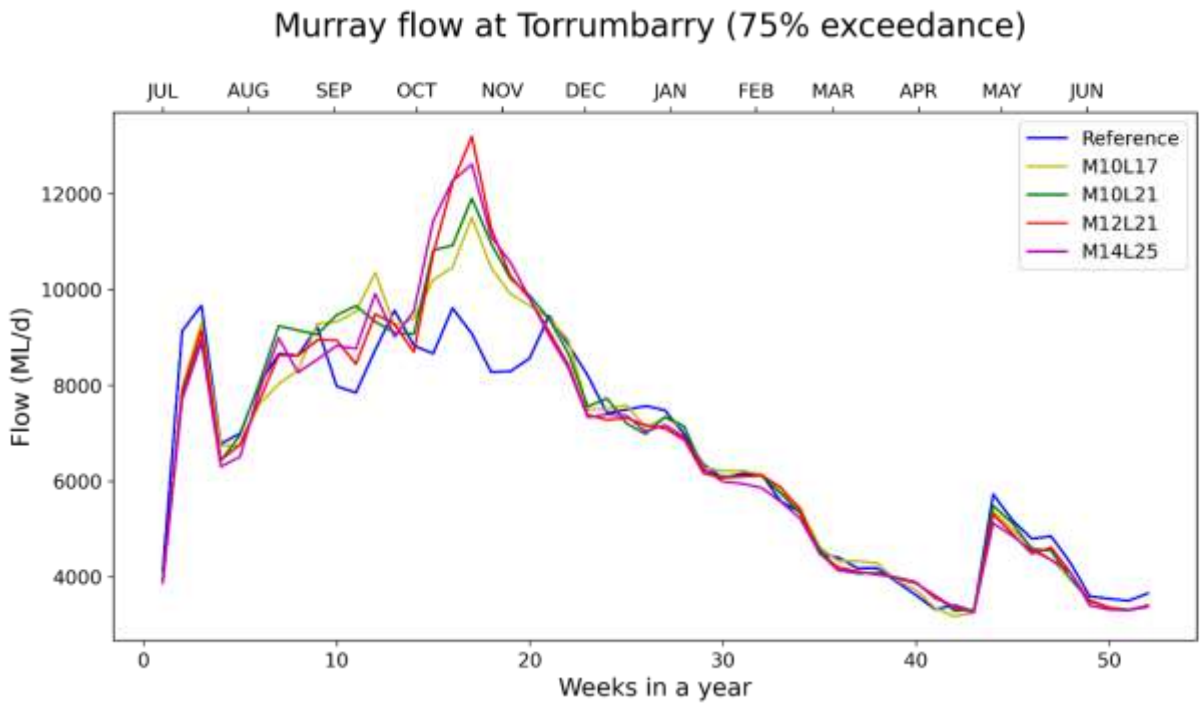

Murray flow at Doctors Point (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
10000
20000
30000
40000
50000
60000
0
10
20
30
40
50
Weeks in a year

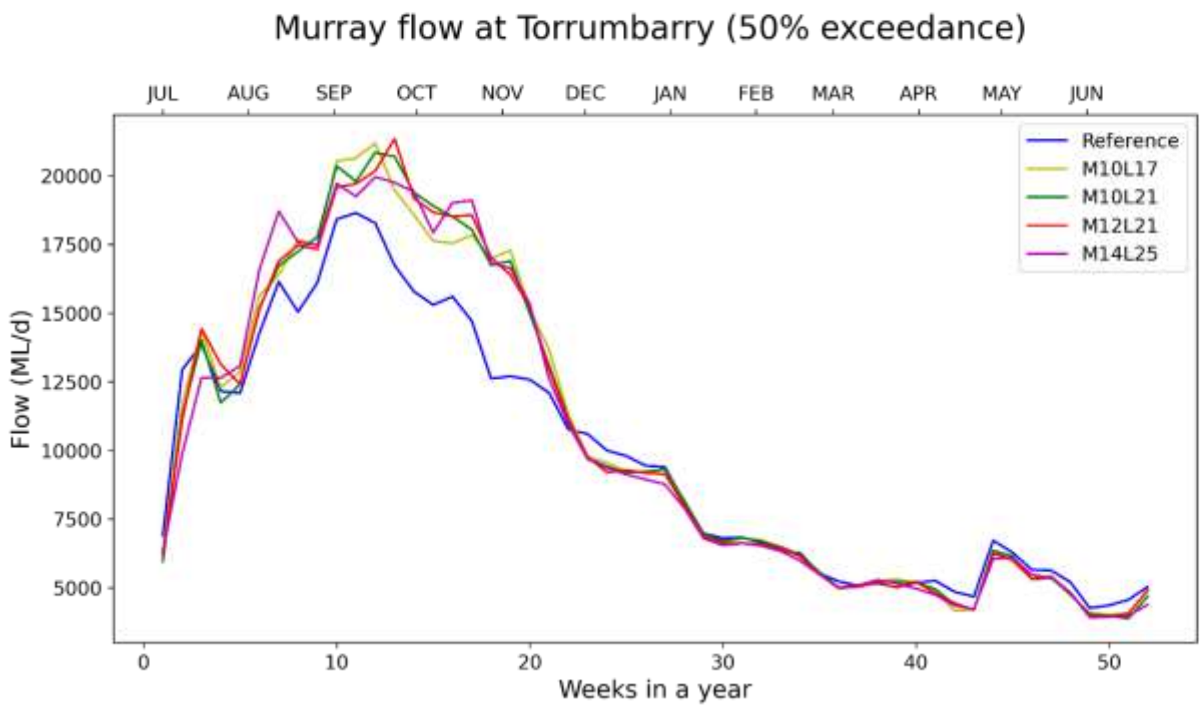

Murray flow at Yarrawonga (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
14000
12000
10000
8000
6000
4000
Flow (ML/d)
0
10
20
30
40
50
Weeks in a year

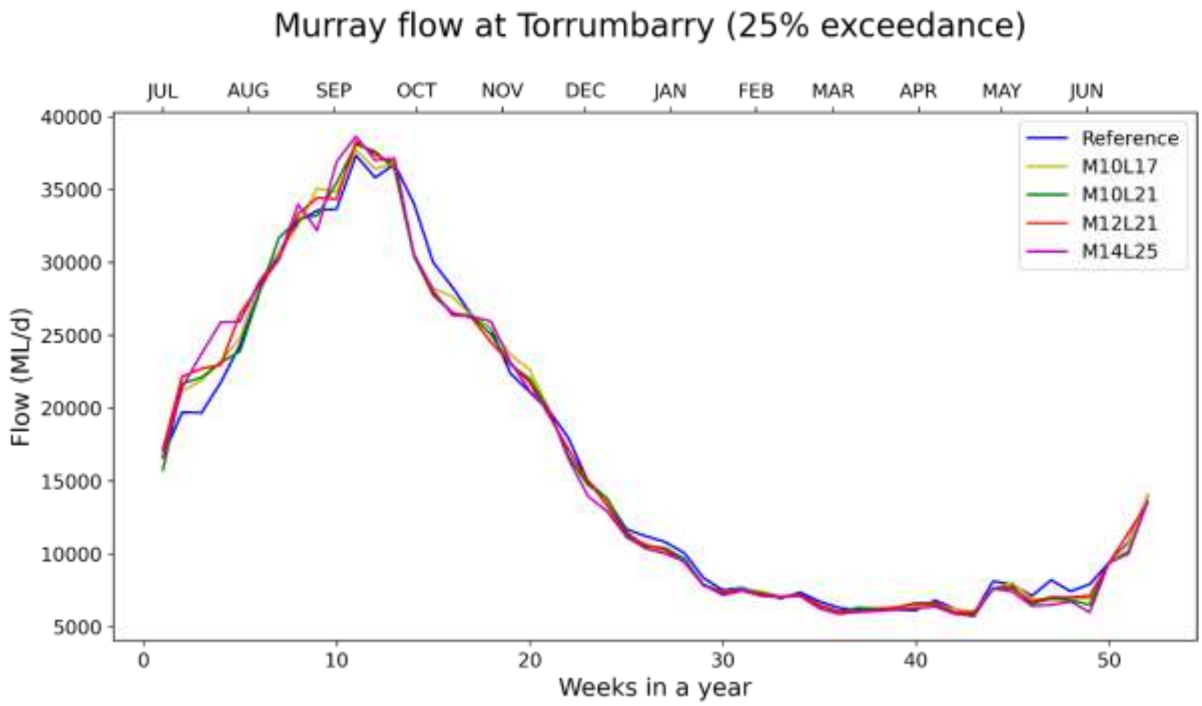

Murray flow at Yarrawonga (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
22500
20000
17500
15000
12500
10000
7500
5000
Flow (ML/d)
0
10
20
30
40
50
Weeks in a year

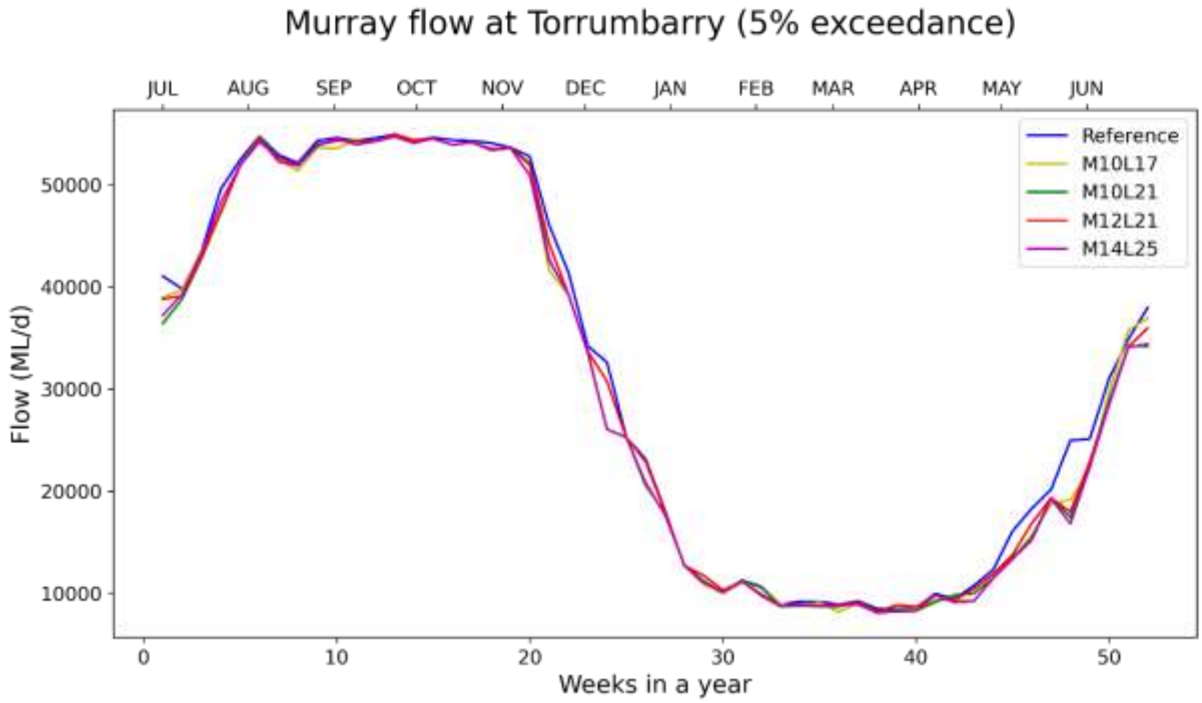

Murray flow at Yarrawonga (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
40000
35000
30000
25000
20000
15000
10000
5000
0
10
20
30
40
50
Weeks in a year

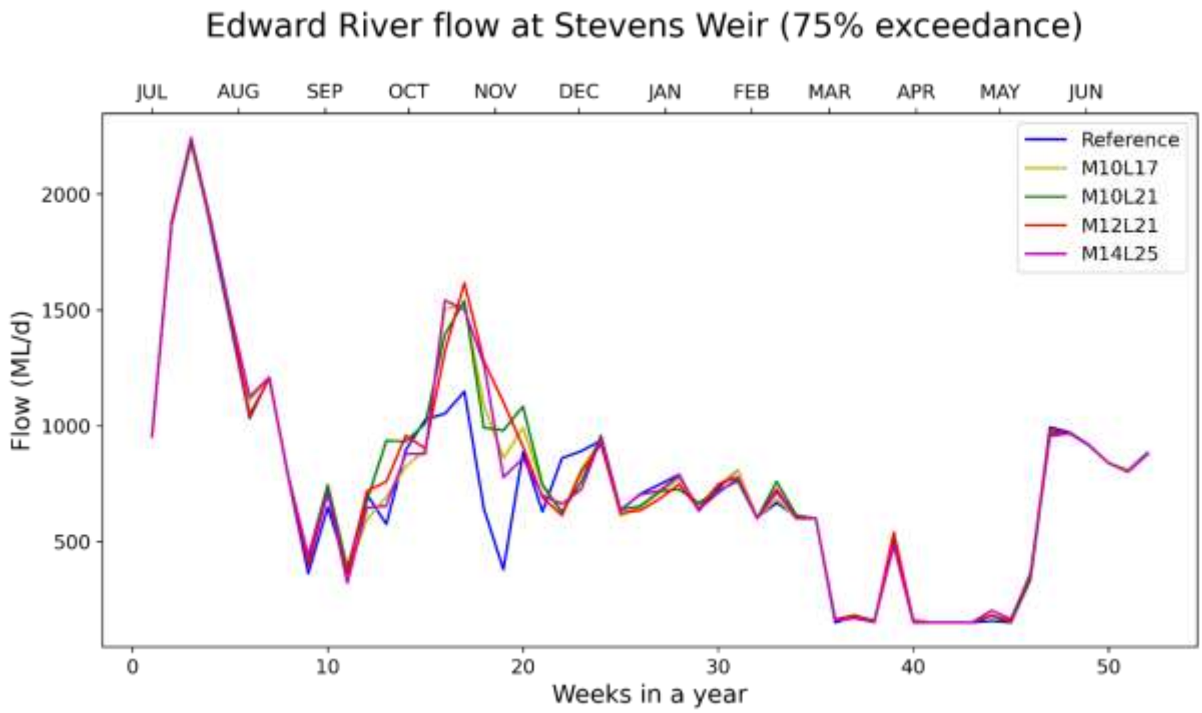

Murray flow at Yarrawonga (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
80000
70000
60000
50000
40000
30000
20000
10000
0
10
20
30
40
50
Weeks in a year

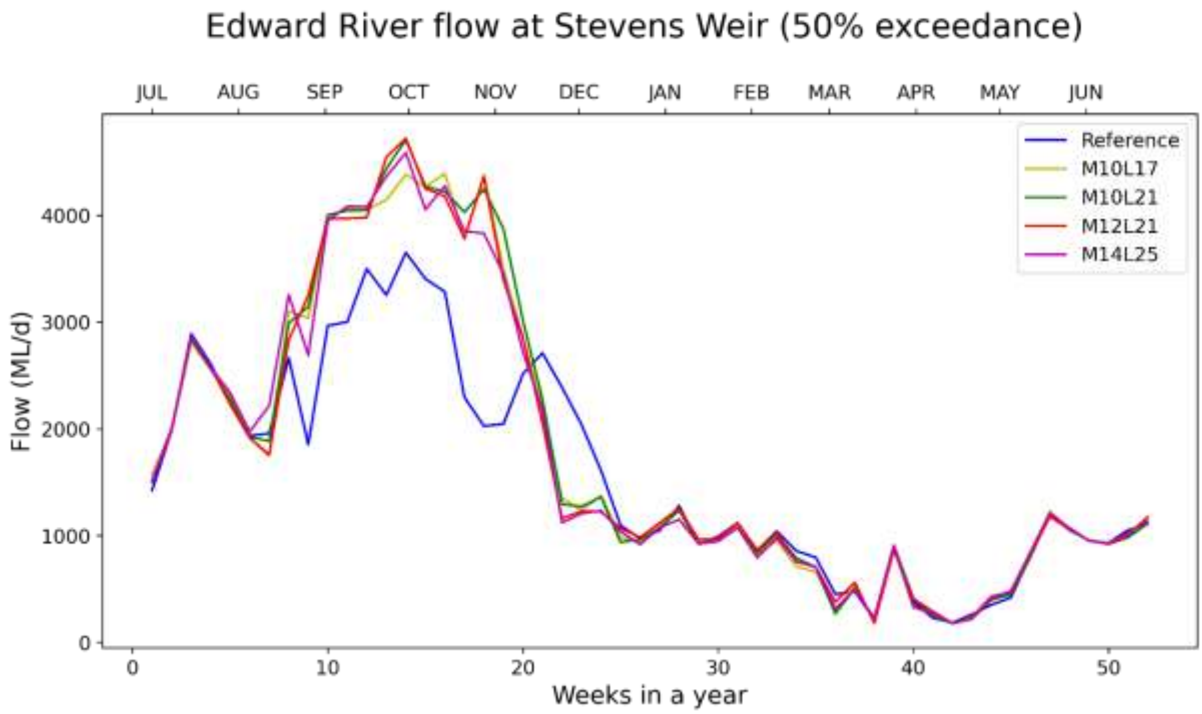

Murray flow at Torrumbarry (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
12000
10000
8000
6000
4000
0
10
20
30
40
50
Weeks in a year

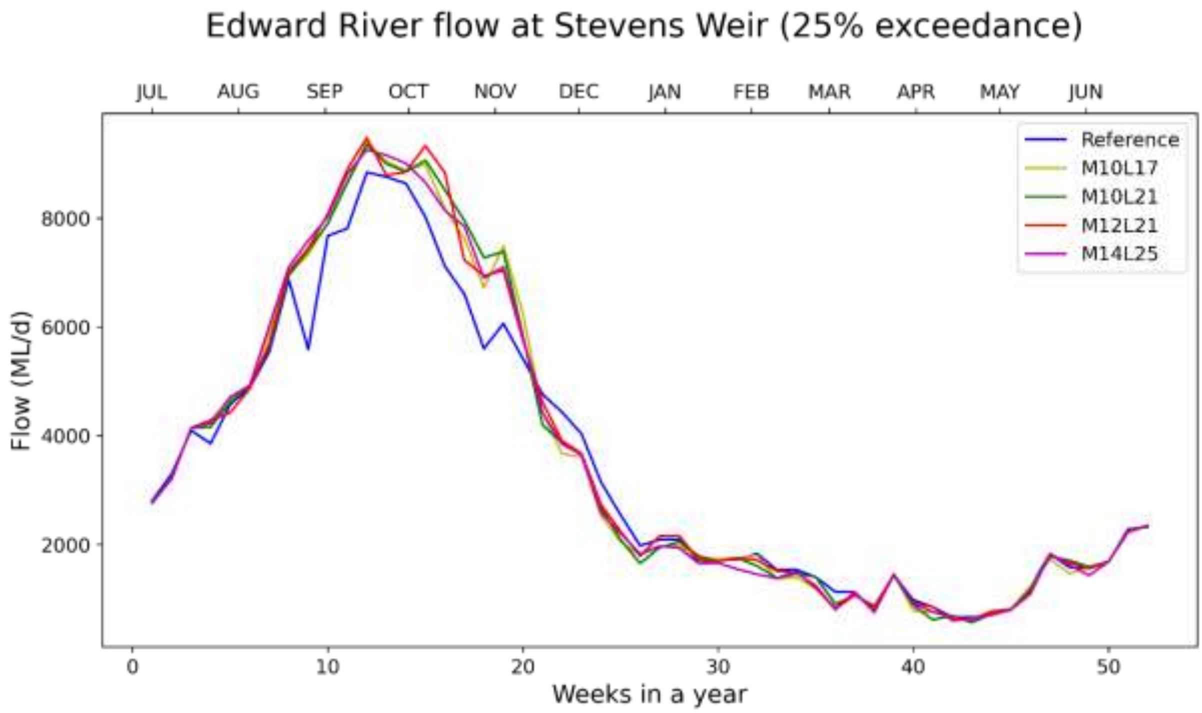

Murray flow at Torrumbarry (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
20000
17500
15000
12500
10000
7500
5000
0
10
20
30
40
50
Weeks in a year

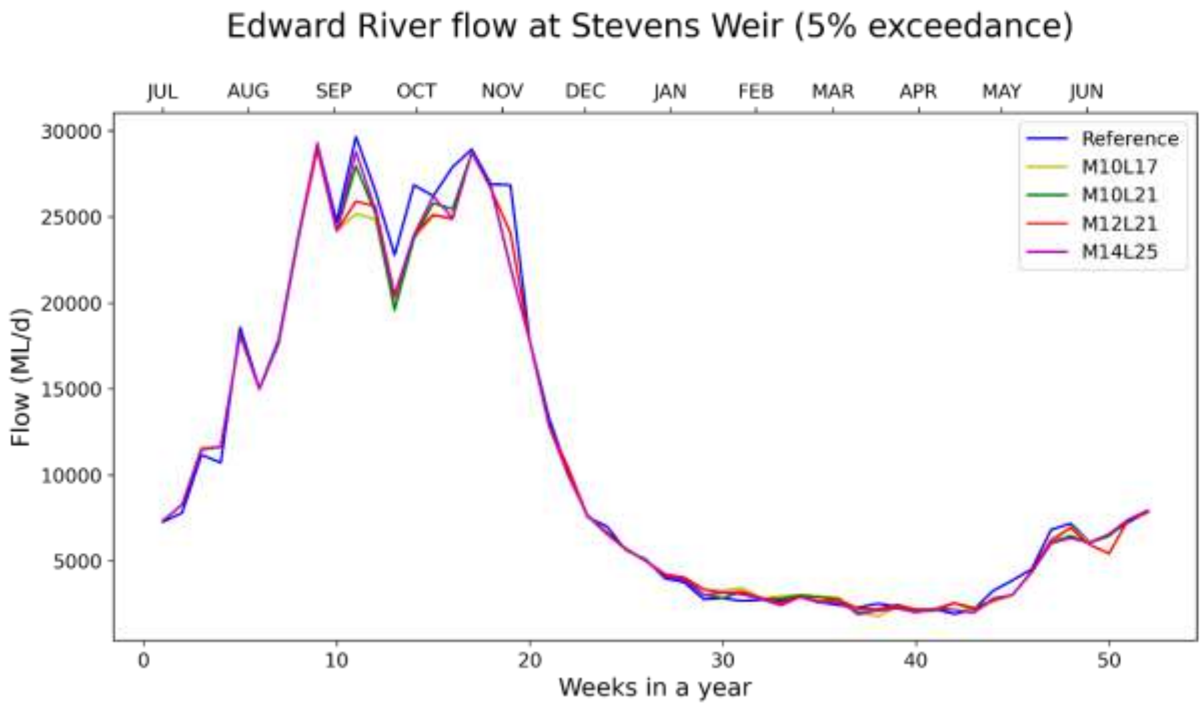

Murray flow at Torrumbarry (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
40000
35000
30000
25000
20000
15000
10000
5000
0
10
20
30
40
50
Weeks in a year
Reference
M10L17
M10L21
M12L21
M14L25

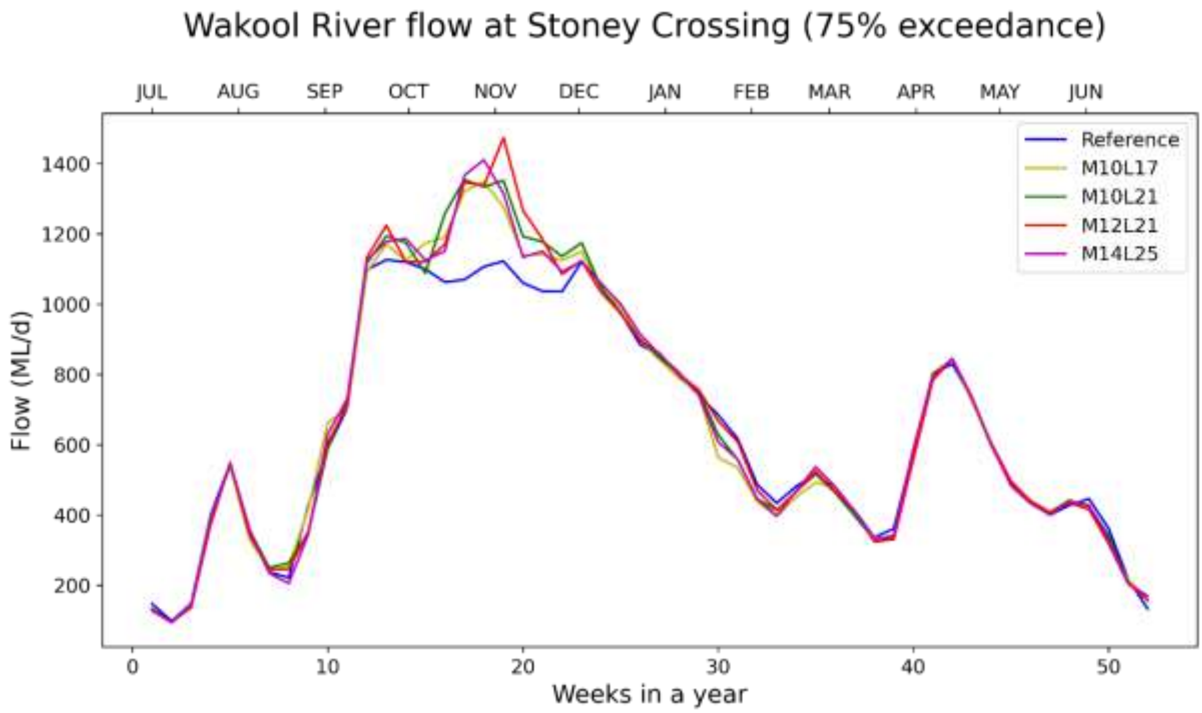

Murray flow at Torrumbarry (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
50000
40000
30000
20000
10000
0
10
20
30
40
50
Weeks in a year
Reference
M10L17
M10L21
M12L21
M14L25

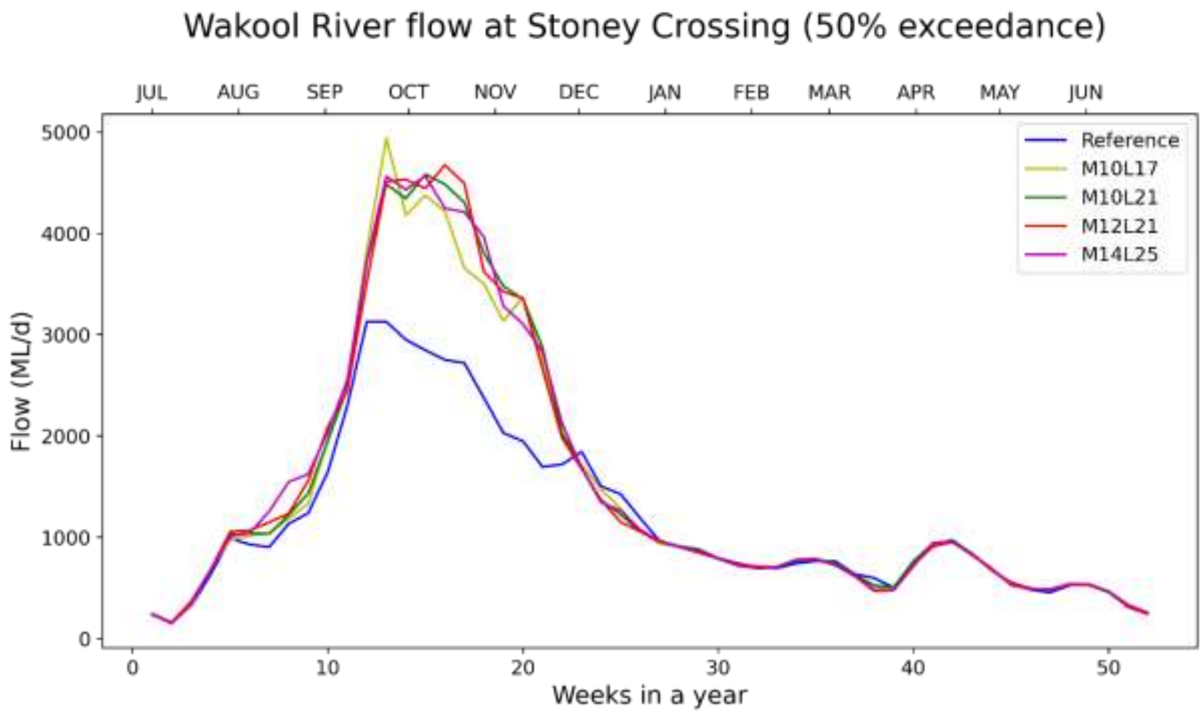

Edward River flow at Stevens Weir (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
500
1000
1500
2000
0
10
20
30
40
50
Weeks in a year

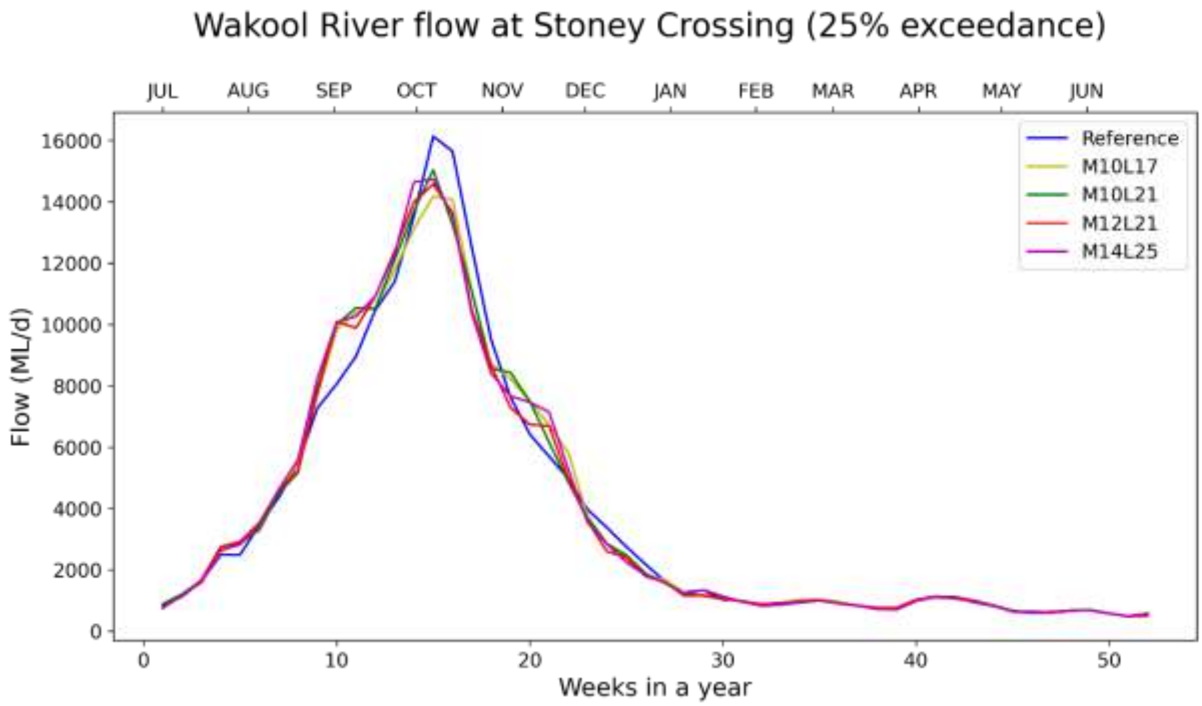

Edward River flow at Stevens Weir (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
0
1000
2000
3000
4000
0
10
20
30
40
50
Weeks in a year

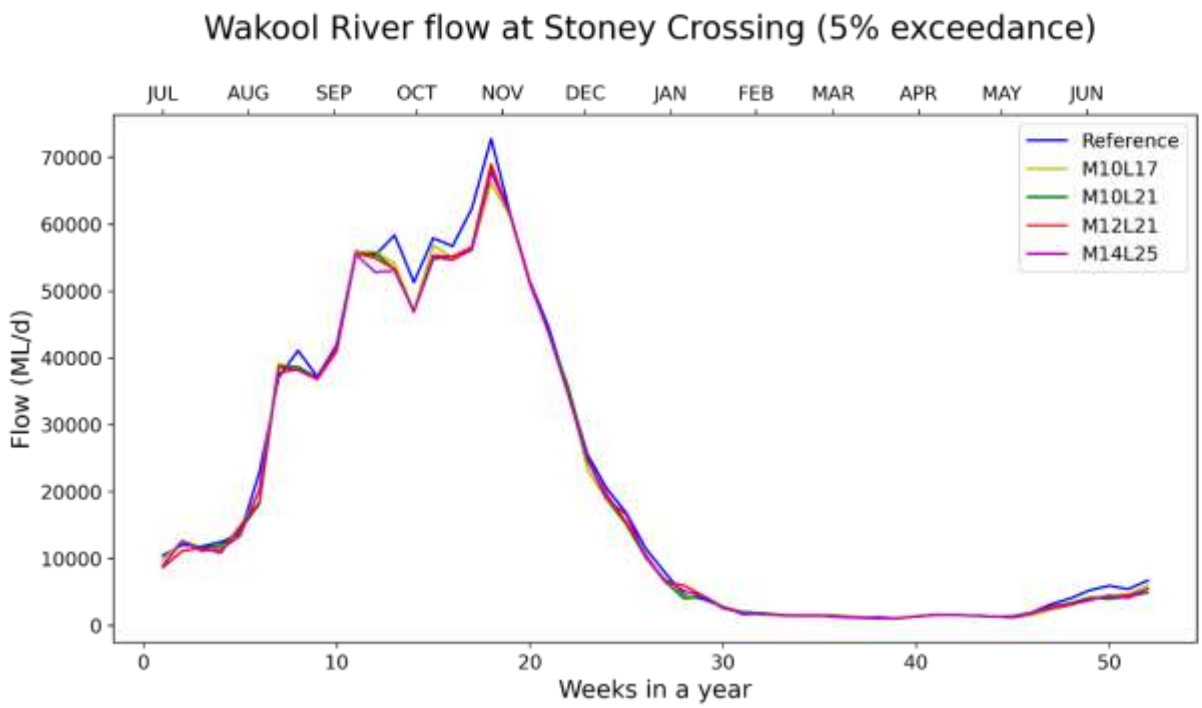

Edward River flow at Stevens Weir (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
8000
6000
4000
2000
0
10
20
30
40
50
Weeks in a year

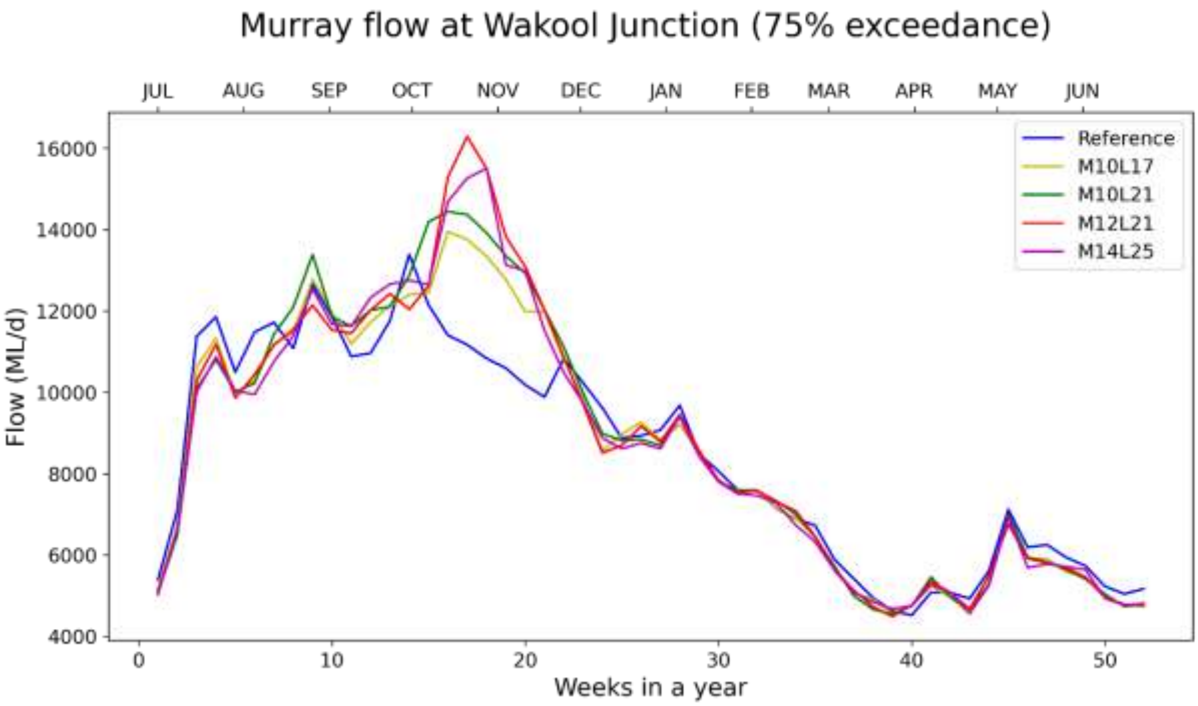

Edward River flow at Stevens Weir (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
30000
25000
20000
15000
10000
5000
0
10
20
30
40
50
Weeks in a year

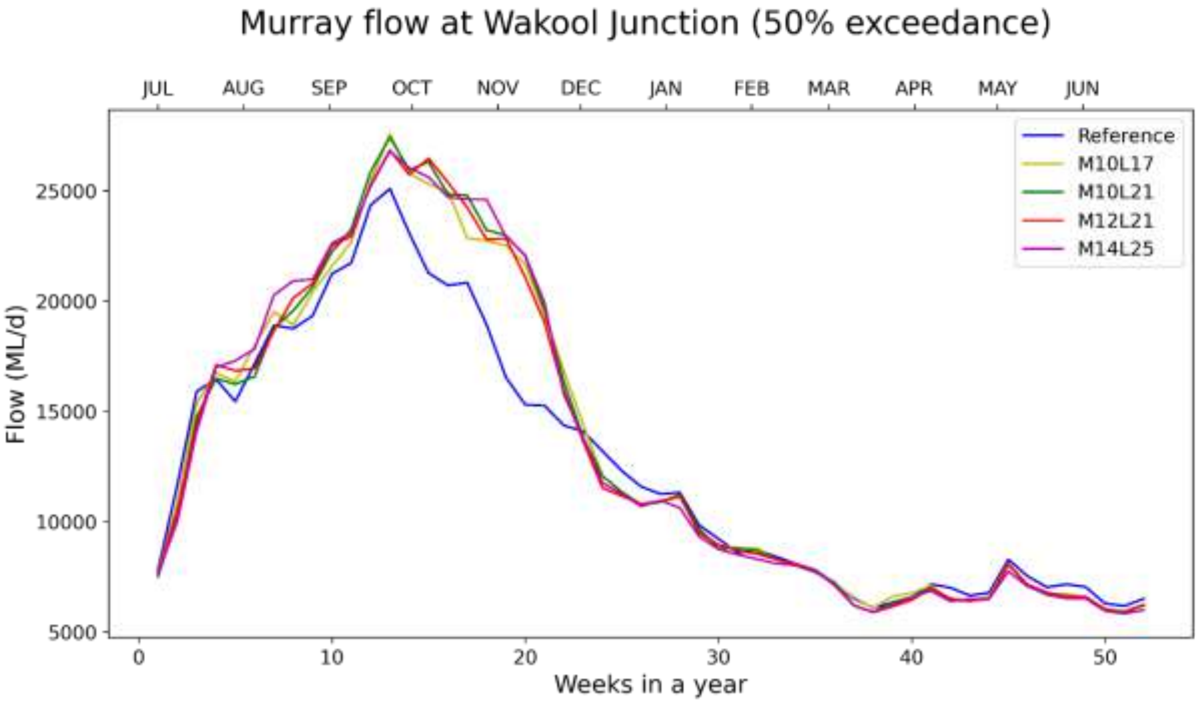

Wakool River flow at Stoney Crossing (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
Weeks in a year

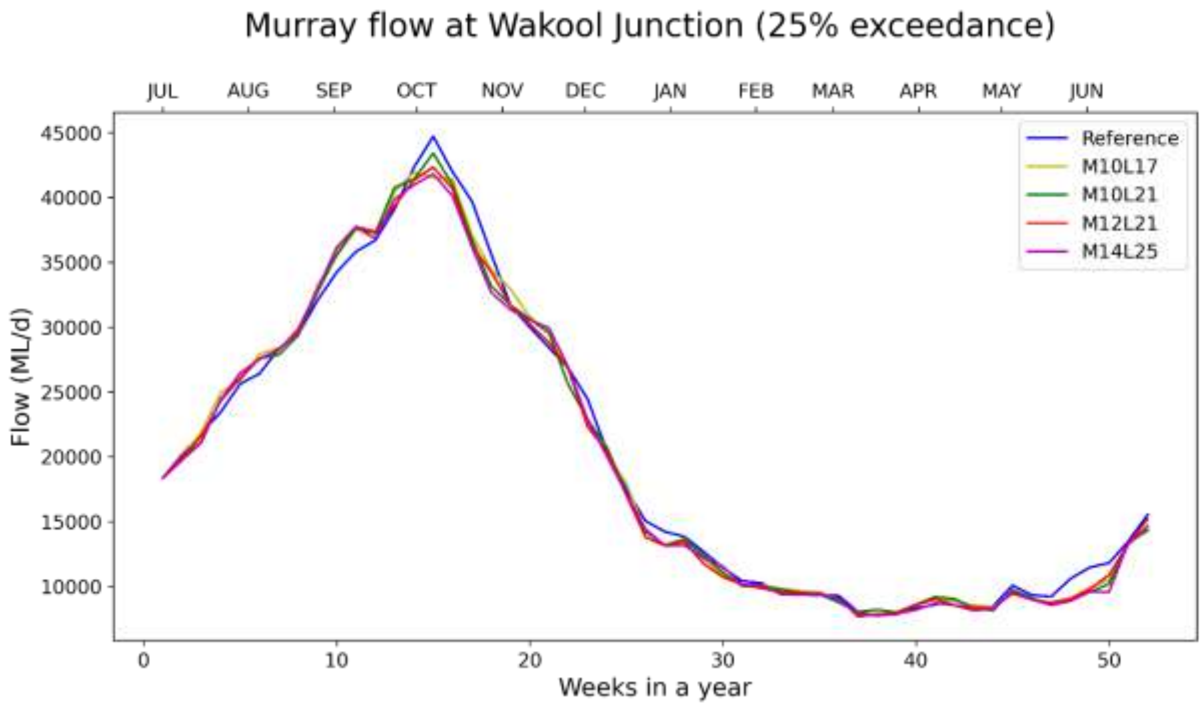

Wakool River flow at Stoney Crossing (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
Weeks in a year

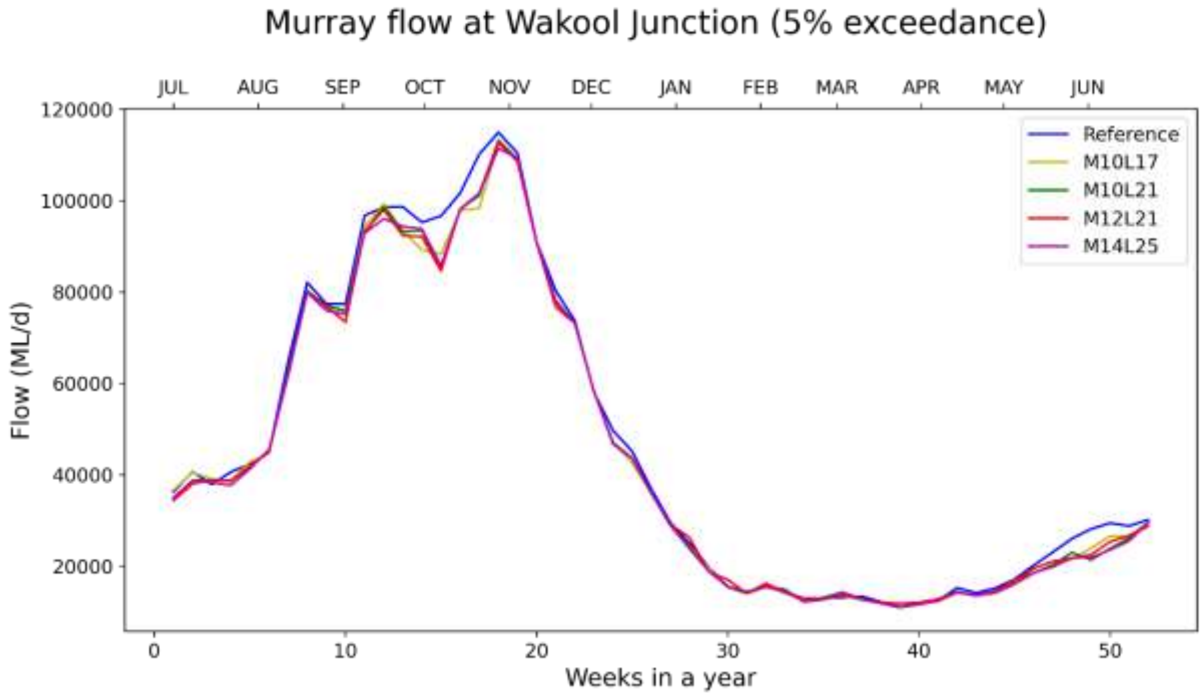

Wakool River flow at Stoney Crossing (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
Weeks in a year

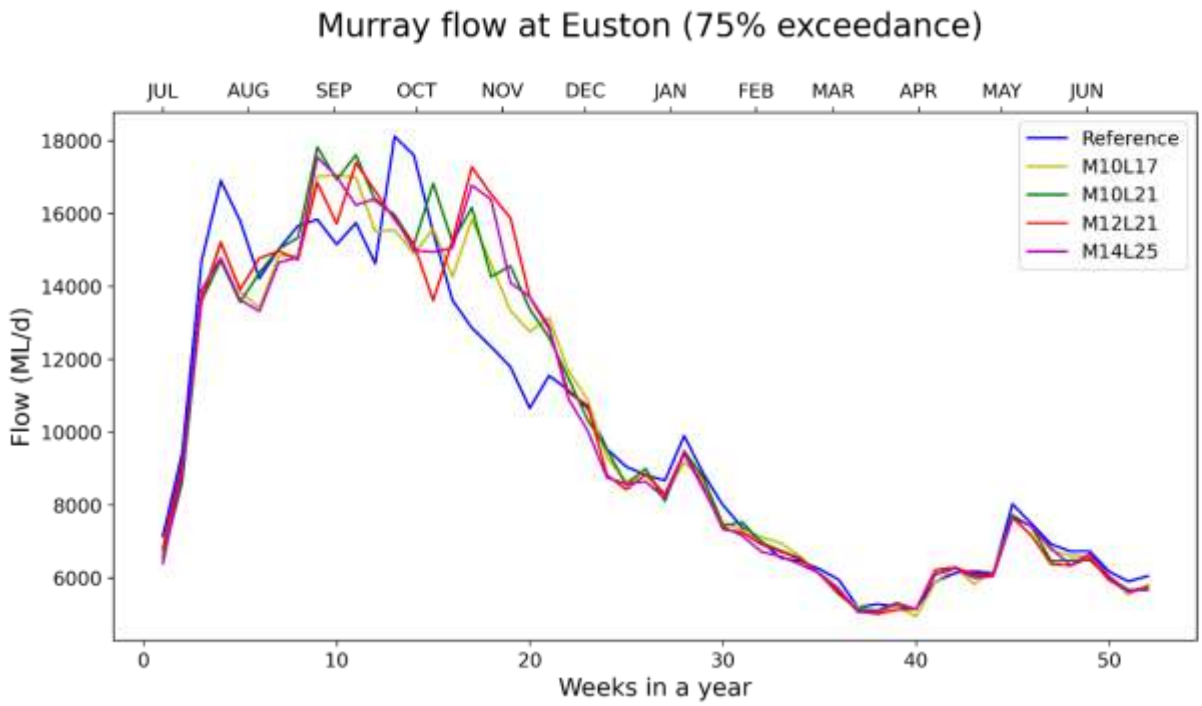

Wakool River flow at Stoney Crossing (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
Weeks in a year

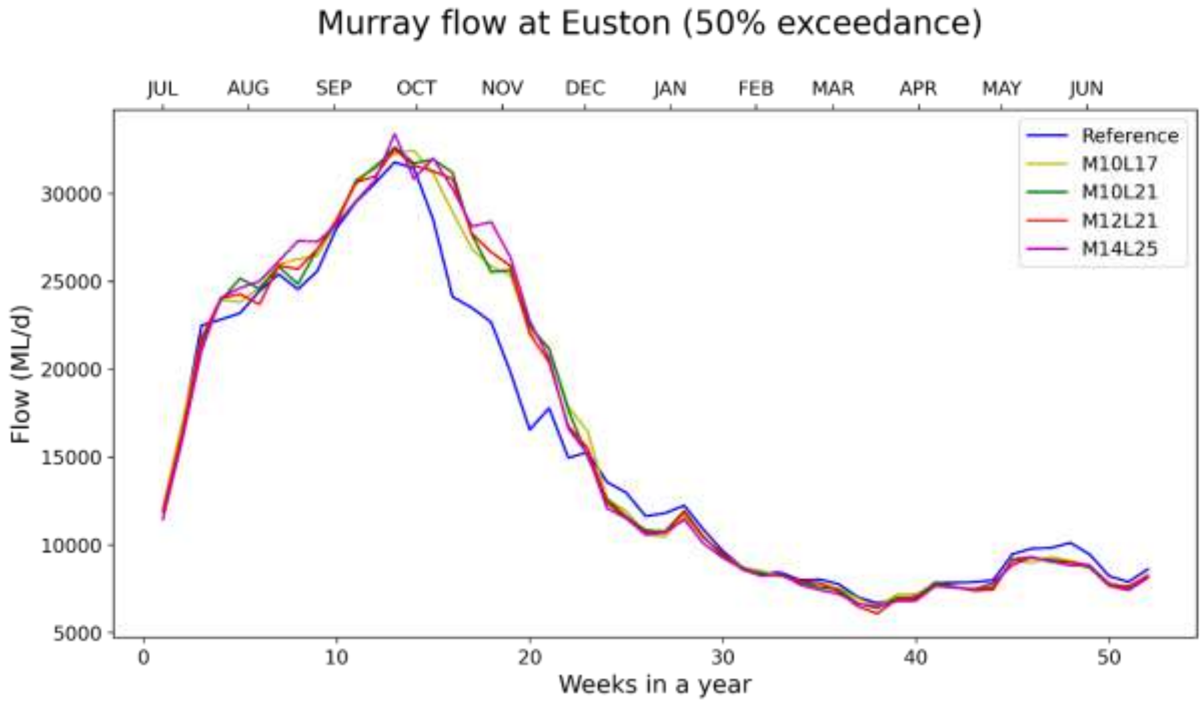

Murray flow at Wakool Junction (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
Weeks in a year
Reference
M10L17
M10L21
M12L21
M14L25

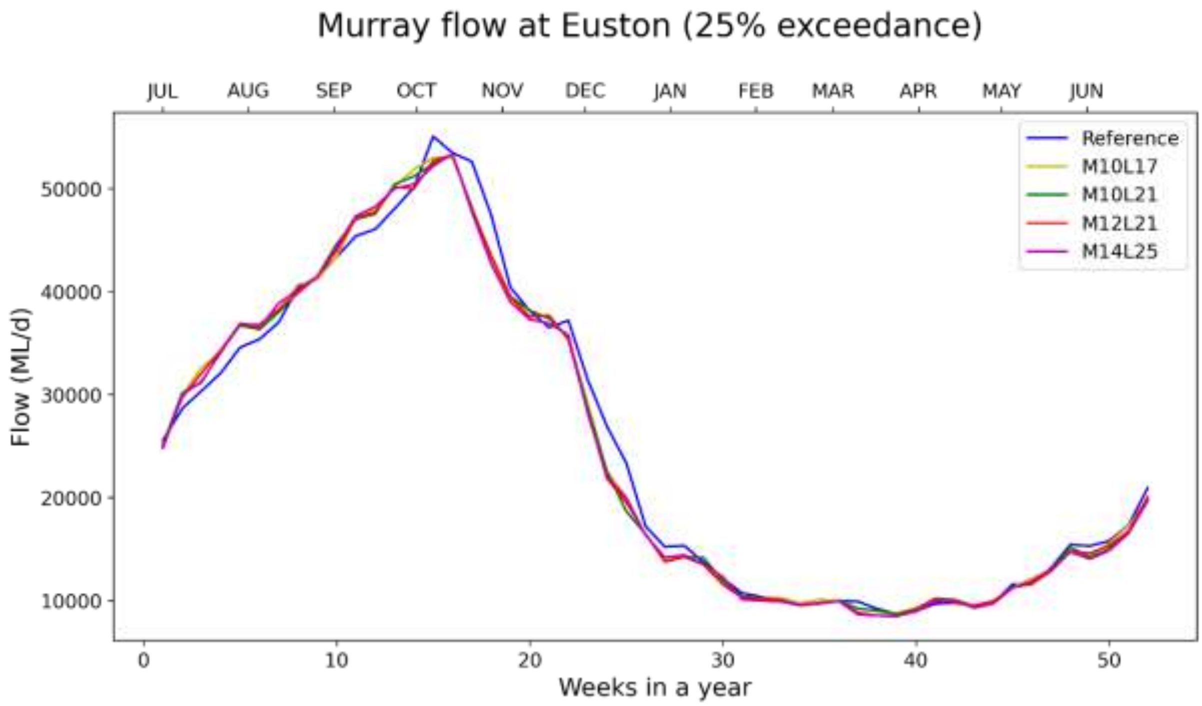

Murray flow at Wakool Junction (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
Weeks in a year
Reference
M10L17
M10L21
M12L21
M14L25

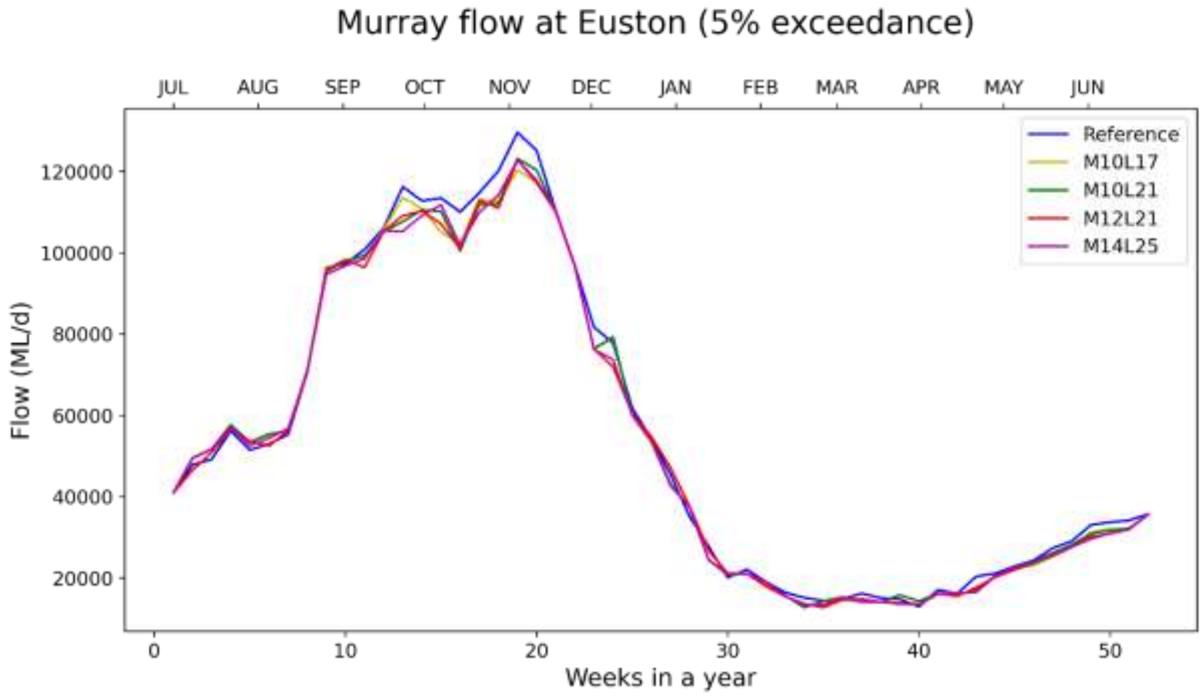

Murray flow at Wakool Junction (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
45000
40000
35000
30000
25000
20000
15000
10000
0
10
20
30
40
50
Weeks in a year

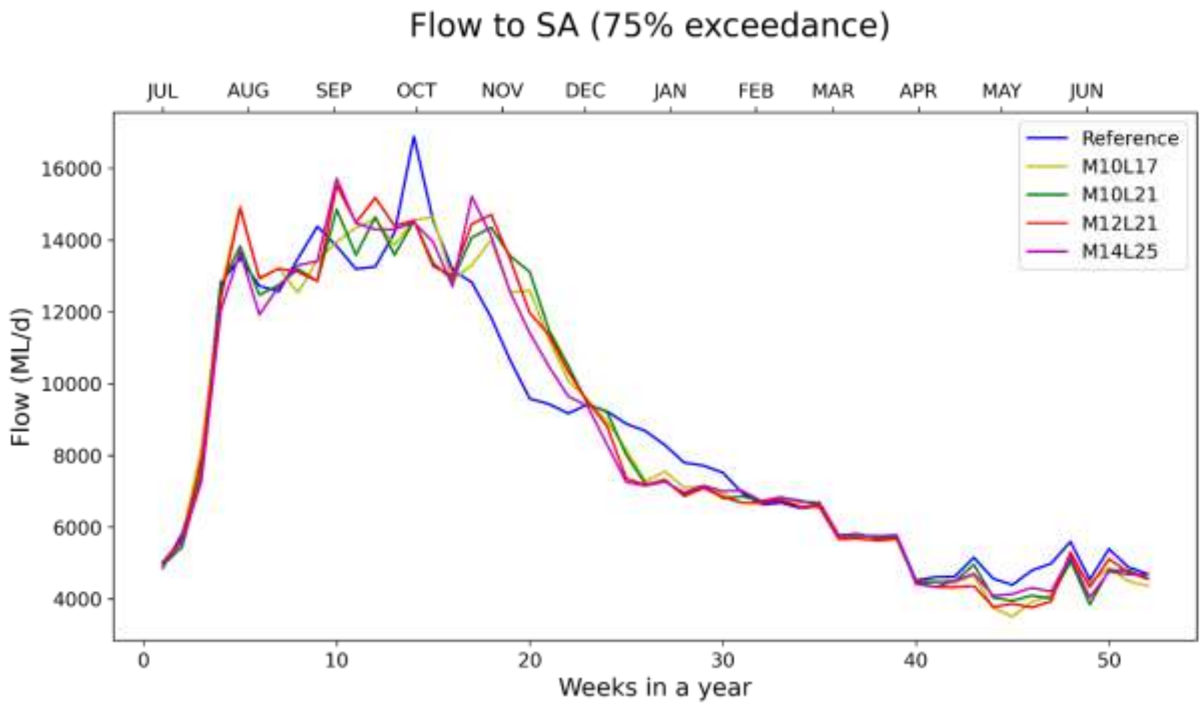

Murray flow at Wakool Junction (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
120000
100000
80000
60000
40000
20000
0
10
20
30
40
50
Weeks in a year

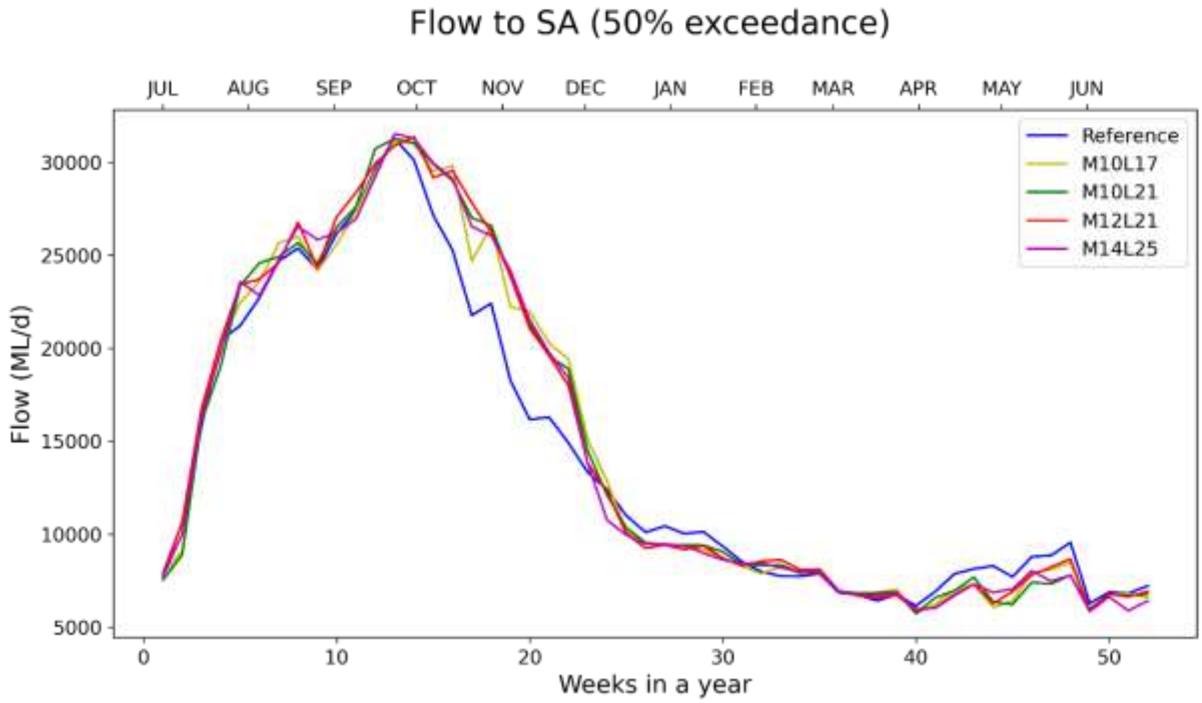

Murray flow at Euston (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
18000
16000
14000
12000
10000
8000
6000
0
10
20
30
40
50
Weeks in a year

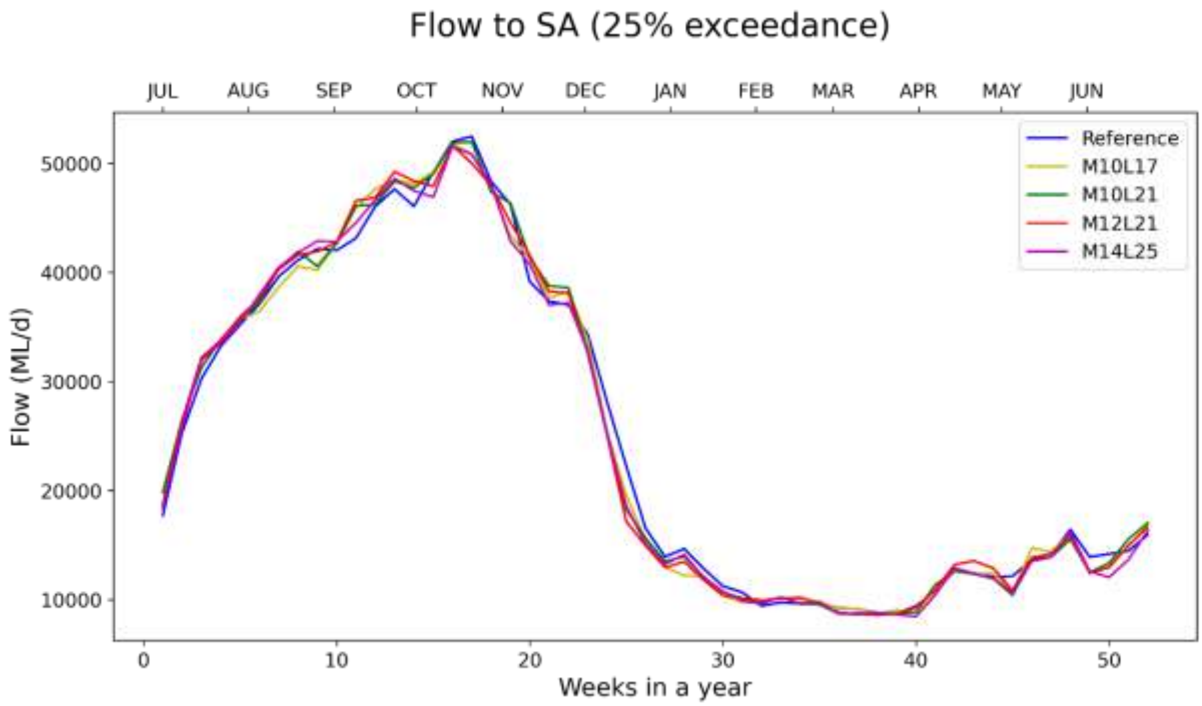

Murray flow at Euston (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
30000
25000
20000
15000
10000
5000
0
10
20
30
40
50
Weeks in a year

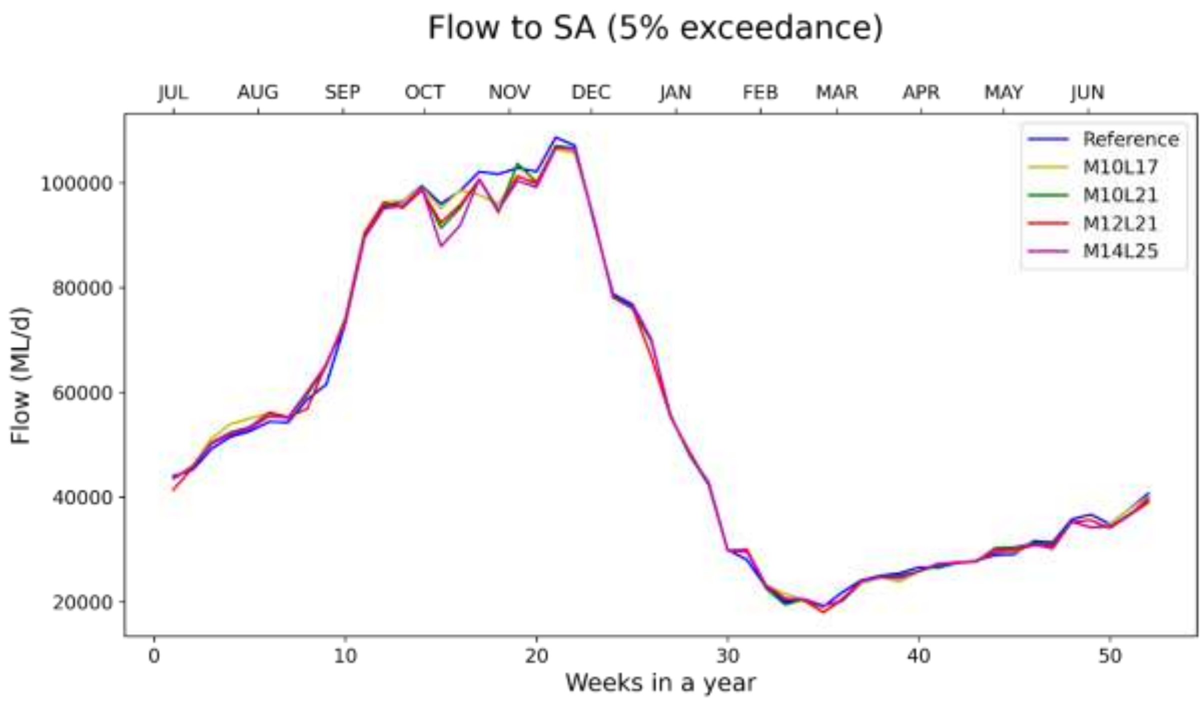

Murray flow at Euston (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
50000
40000
30000
20000
10000
0
10
20
30
40
50
Weeks in a year


Murray flow at Euston (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
120000
100000
80000
60000
40000
20000
0
10
20
30
40
50
Weeks in a year


Flow to SA (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
4000
6000
8000
10000
12000
14000
16000
0
10
20
30
40
50
Weeks in a year


Flow to SA (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
5000
10000
15000
20000
25000
30000
0
10
20
30
40
50
Weeks in a year


Flow to SA (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
50000
40000
30000
20000
10000
0
10
20
30
40
50
Weeks in a year


Flow to SA (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Reference
M10L17
M10L21
M12L21
M14L25
Flow (ML/d)
100000
80000
60000
40000
20000
0
10
20
30
40
50
Weeks in a year

Appendix C: Typical flow behaviour under future climate changes

There are three future climate changes modelled including the Post1975 and 2070 projection of medium and high climate changes. These future climate scenarios are examined under the reference scenario of the current constraints and one constraints relaxed scenario (Eildon downstream: 9,500 ML/d, Molesworth: 10,000 ML/d, Shepparton: 17,000 ML/d, Doctors Point: 40,000 ML/d and Yarrawonga downstream: 40,000 ML/d).

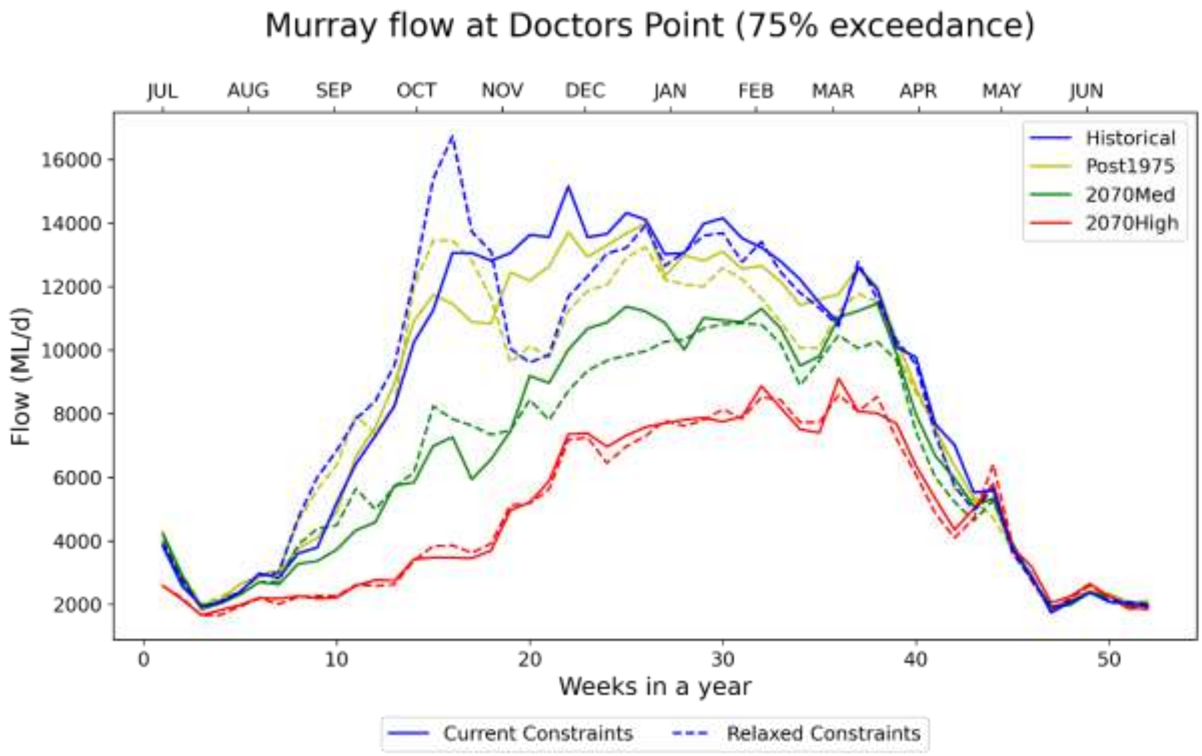
Similar to the previous appendices, results are presented at key gauging stations along Murray and Edward-Wakool systems for varying degrees of exceedance probabilities.

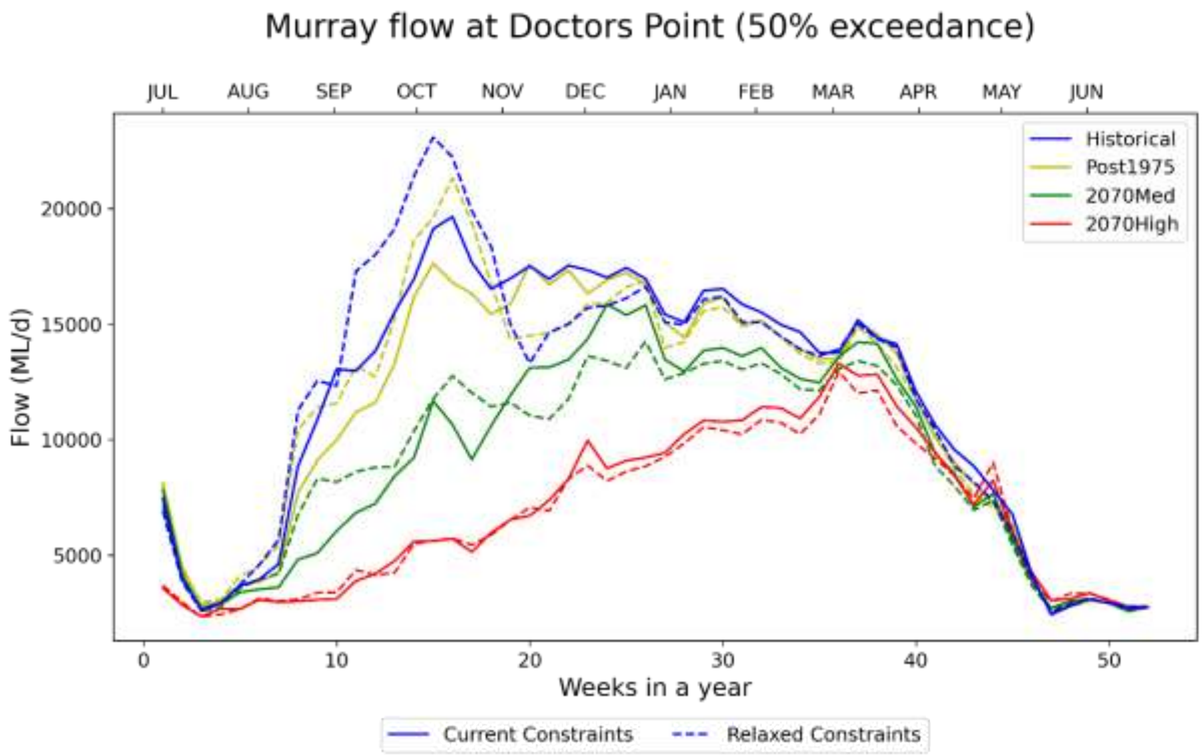
The figures presented in this appendix compare flow behaviours against different future climatic conditions (denoted by different colours) and at the same time with/without relaxing constraints (distinguished by solid and dotted lines).

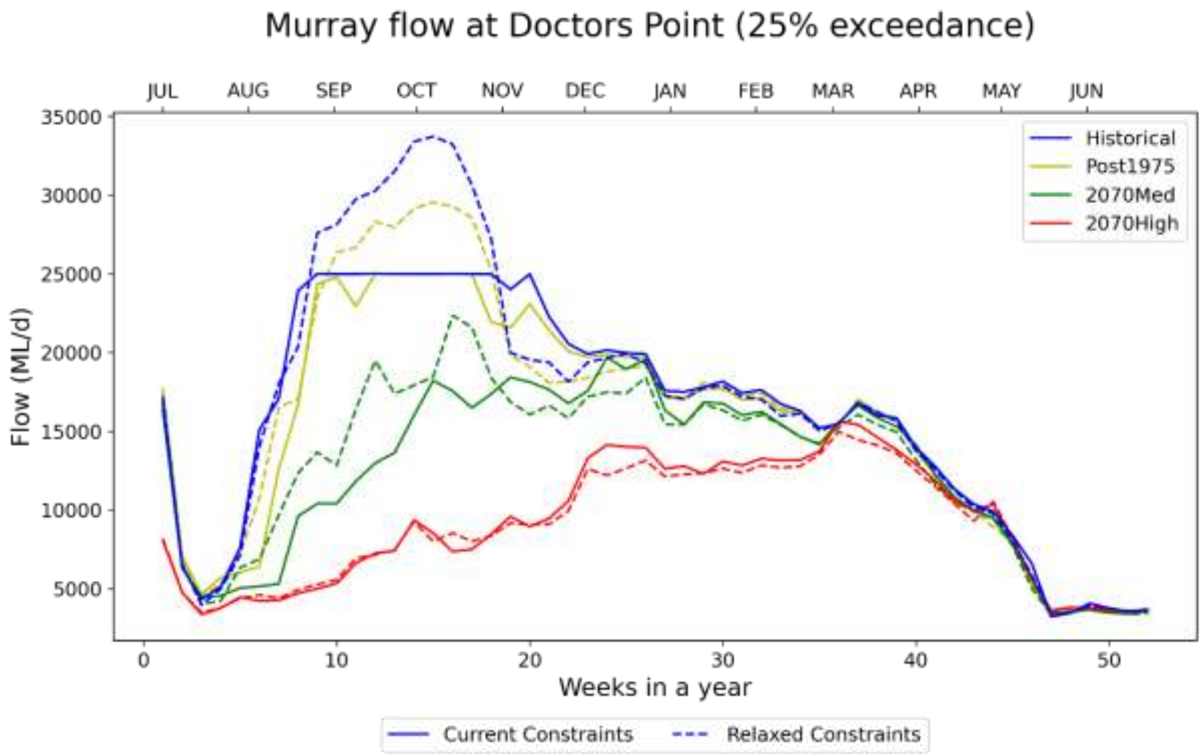
Key observations across the reported gauged stations are:

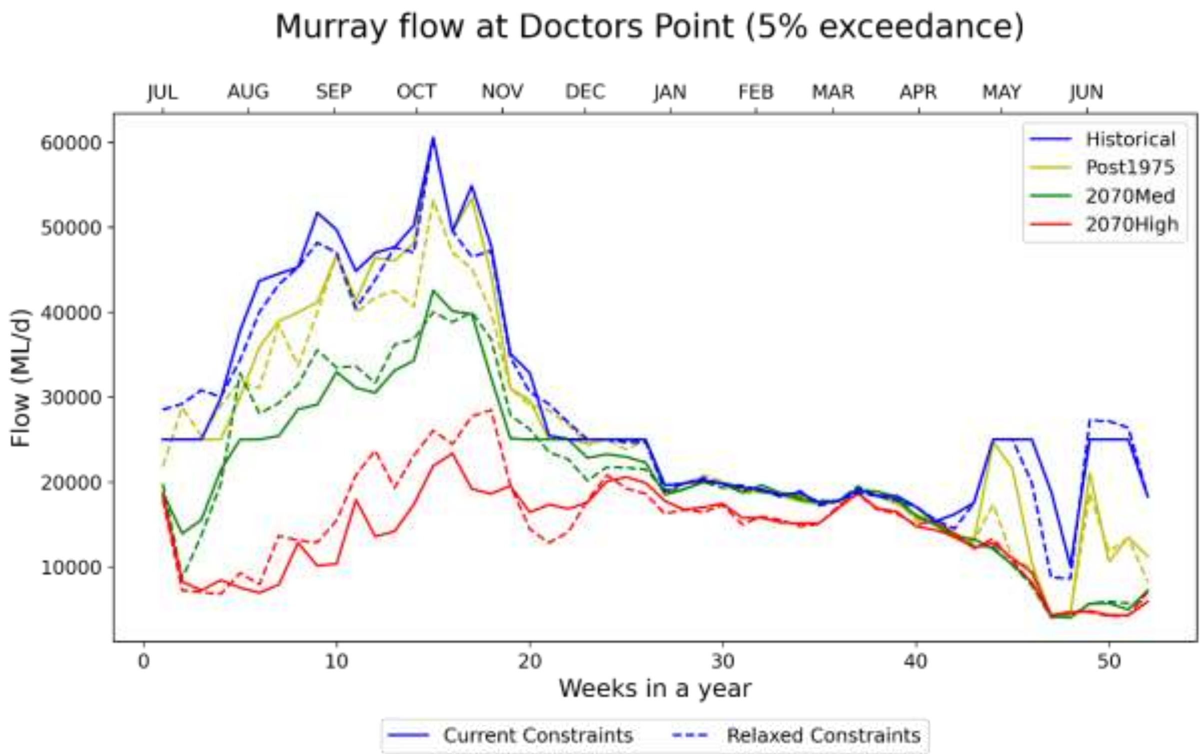
- Significant reductions in flows for the entire flow regimes as future climates become drier
- Flows during Winter-Spring seasons are more heavily affected while flows during typical irrigation season are well maintained
- At upper Murray, the constraint relaxation scenarios show significant improvements of overbank flow regimes (ie 25 percent exceedance probability) up to the 2070 medium climate and benefits tend to decrease substantially under the 2070 dry climate scenario. Relative improvements from the current constraint scenario are even greater under the 2070 medium scenario
- At mid and lower Murray, there are improved flow regimes with the relaxed constraint scenarios which are more evenly distributed across the different future climate scenarios. It indicates potential benefits of relaxing constraints and importance of coordinated water delivery under the dry climatic conditions.

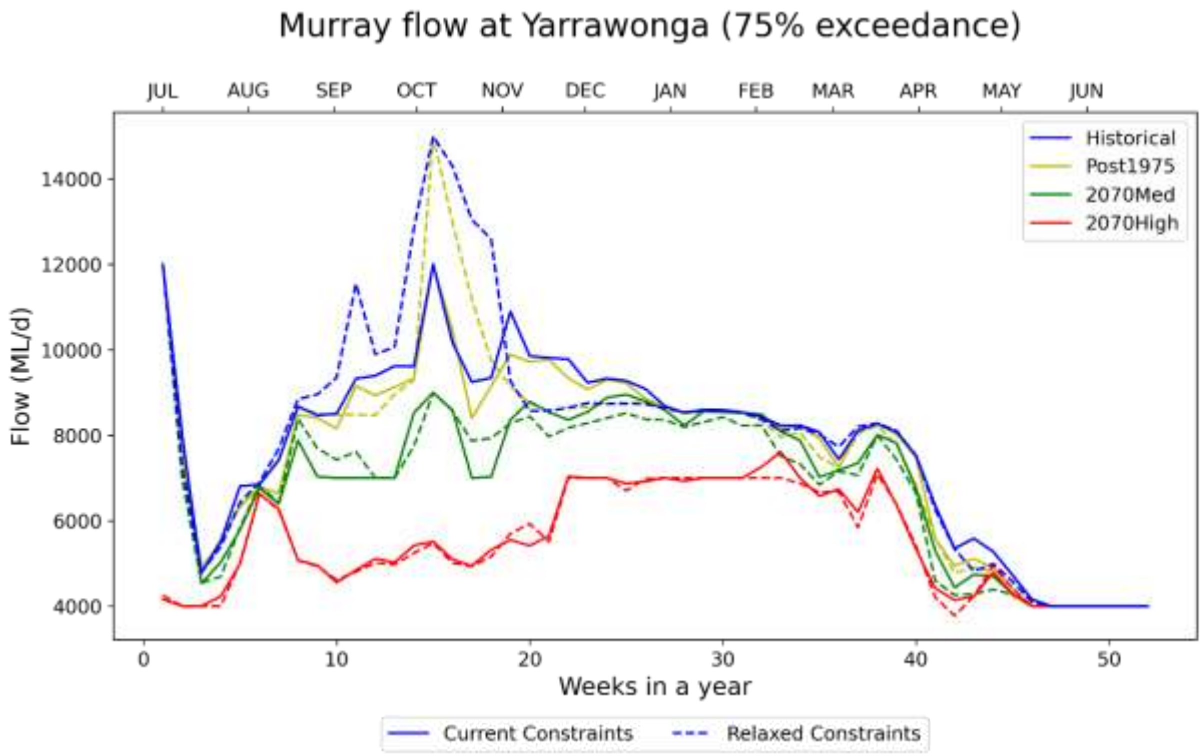
Though the results provide useful insights on what is likely to be happened under plausible future climates, there are some notes and further investigation to be considered. Model assumptions, including operation rules and key parameters deciding human behaviours around irrigation practices and environmental watering have been calibrated and validated using historical data. We have tried to incorporate recent data as much as possible. However, the calibration does not imply that the model assumptions are valid under different future climates. Operation rules and business decision processes are more likely to be adaptive to emerging drier climatic conditions in the future.

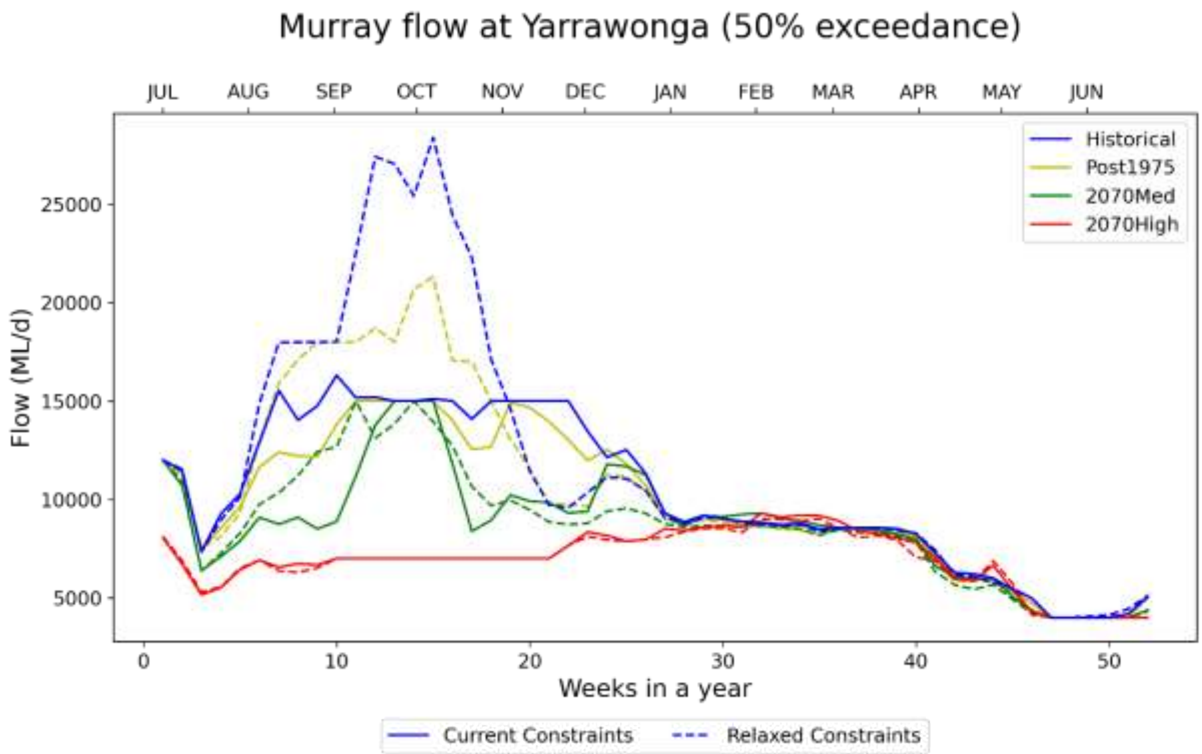

Murray flow at Doctors Point (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Historical
Post1975
2070Med
2070High
Flow (ML/d)
16000
14000
12000
10000
8000
6000
4000
2000
0
10
20
30
40
50
Weeks in a year
Current Constraints
Relaxed Constraints

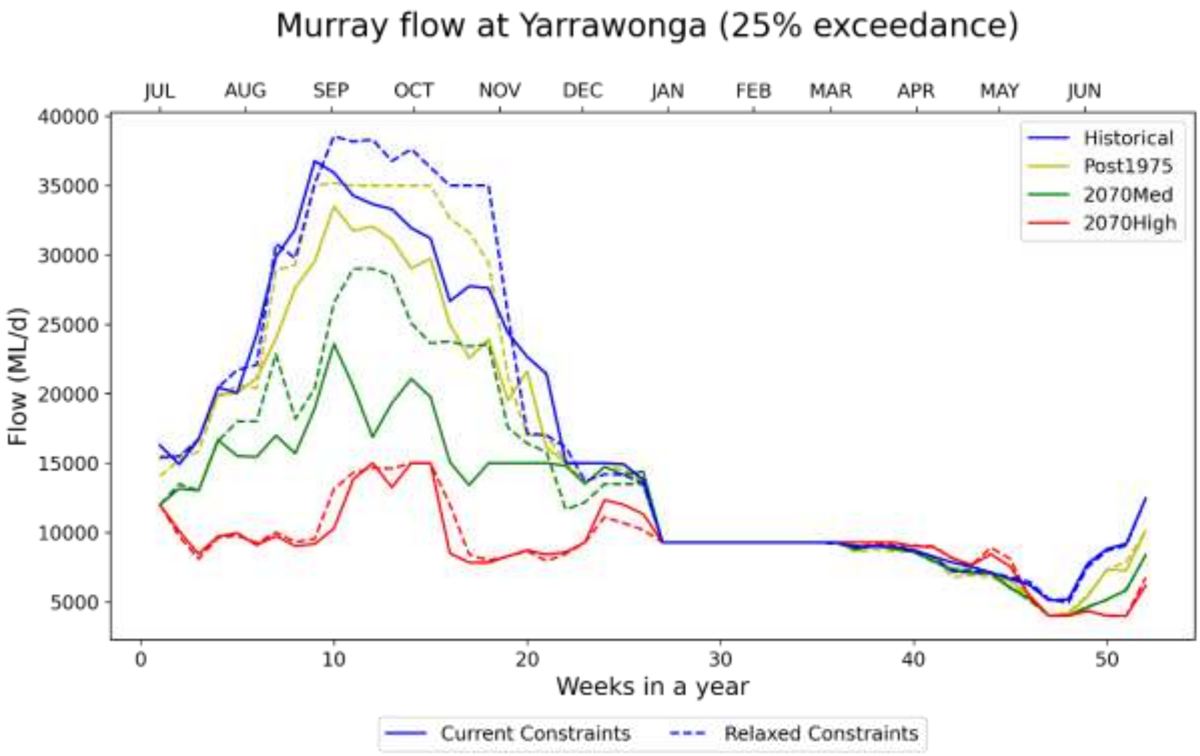

Murray flow at Doctors Point (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Historical
Post1975
2070Med
2070High
Flow (ML/d)
20000
15000
10000
5000
0
10
20
30
40
50
Weeks in a year
Current Constraints
Relaxed Constraints

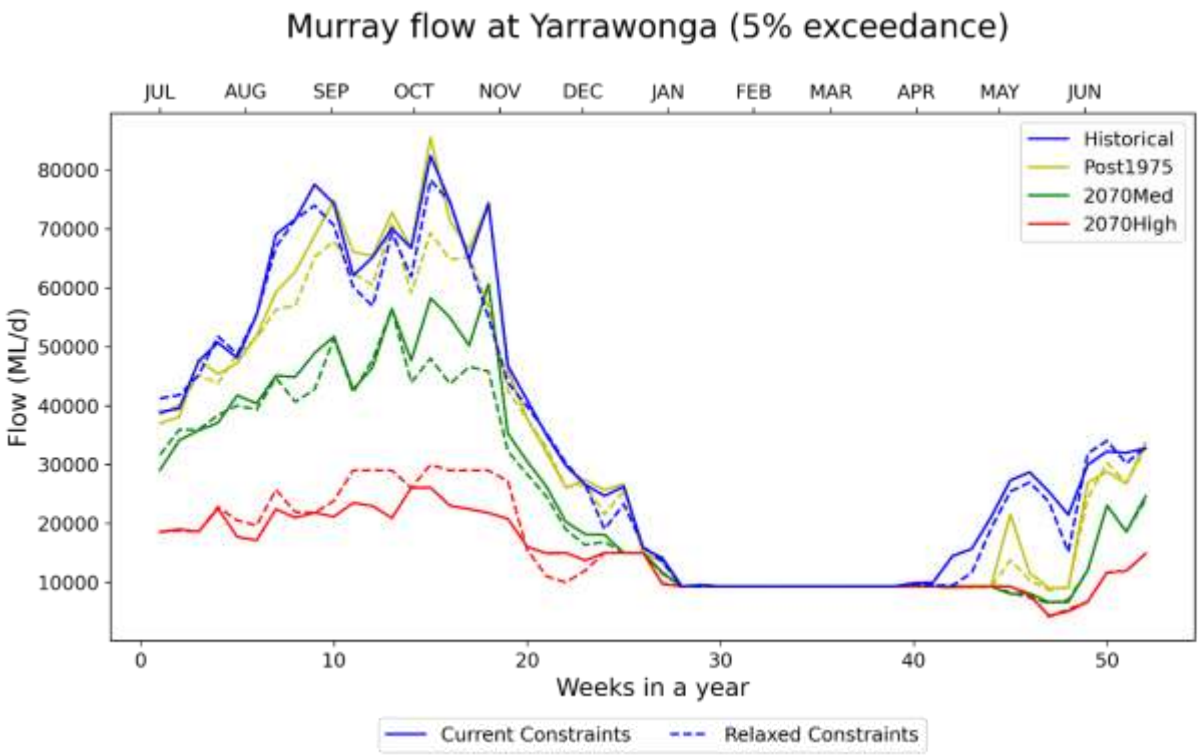

Murray flow at Doctors Point (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
35000
30000
25000
20000
15000
10000
5000
0
10
20
30
40
50
Weeks in a year
Historical
Post1975
2070Med
2070High
Current Constraints
Relaxed Constraints

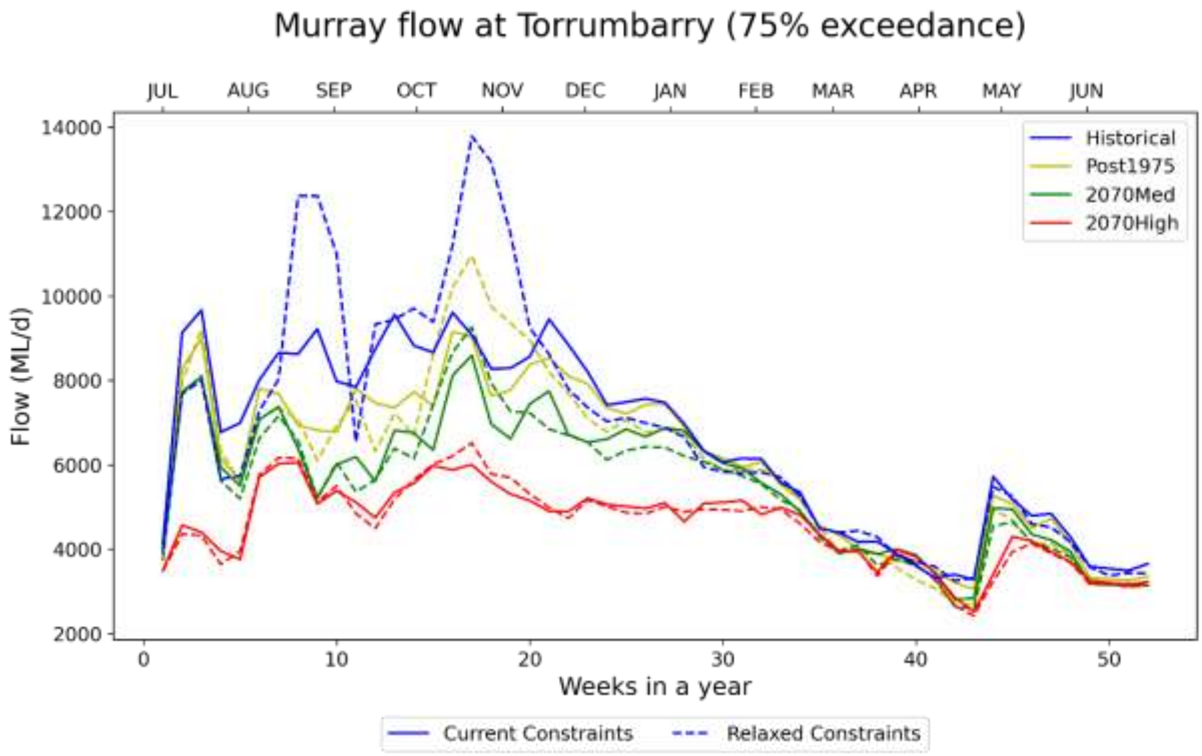

Murray flow at Doctors Point (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
60000
50000
40000
30000
20000
10000
0
10
20
30
40
50
Weeks in a year
Historical
Post1975
2070Med
2070High
Current Constraints
Relaxed Constraints

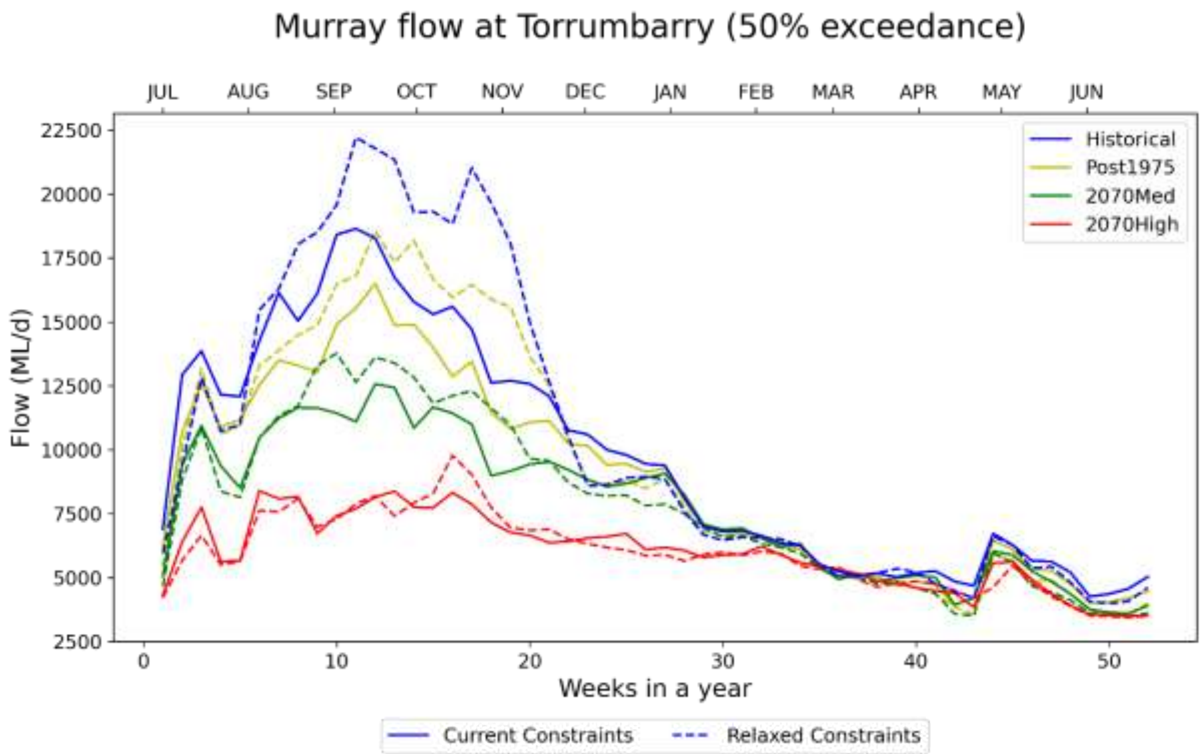

Murray flow at Yarrawonga (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
Weeks in a year
Historical
Post1975
2070Med
2070High
Current Constraints
Relaxed Constraints

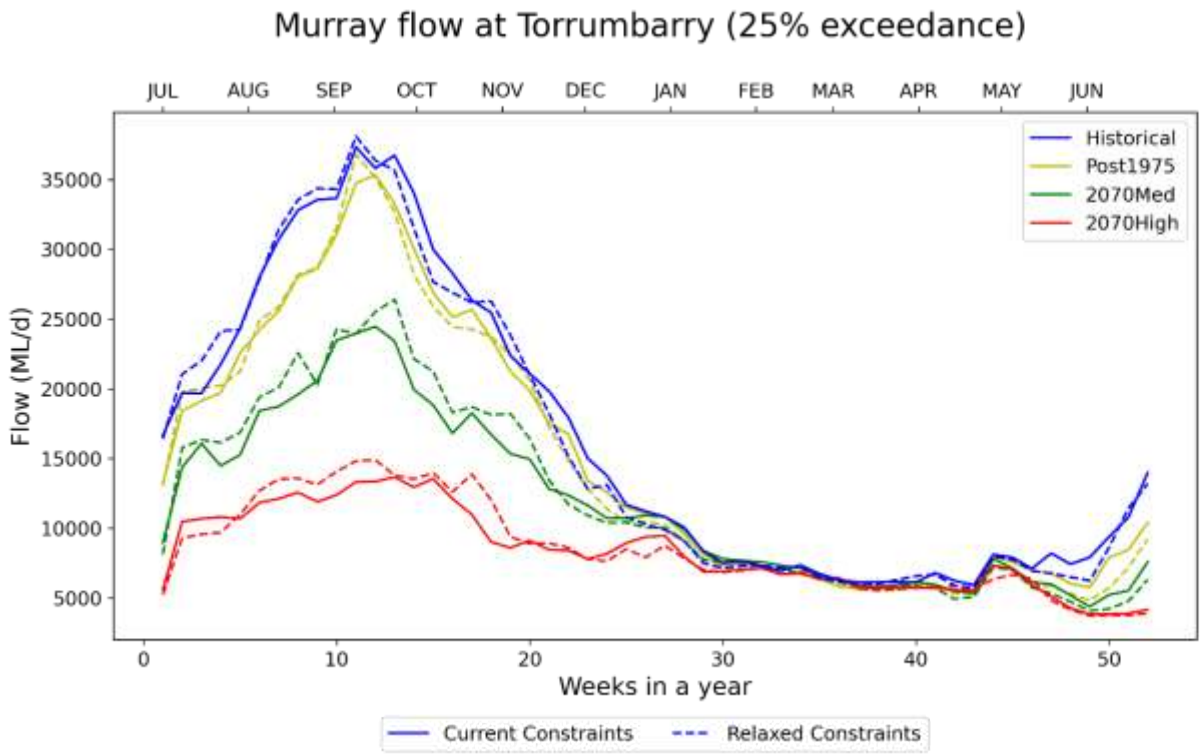

Murray flow at Yarrawonga (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
Weeks in a year
Historical
Post1975
2070Med
2070High
Current Constraints
Relaxed Constraints

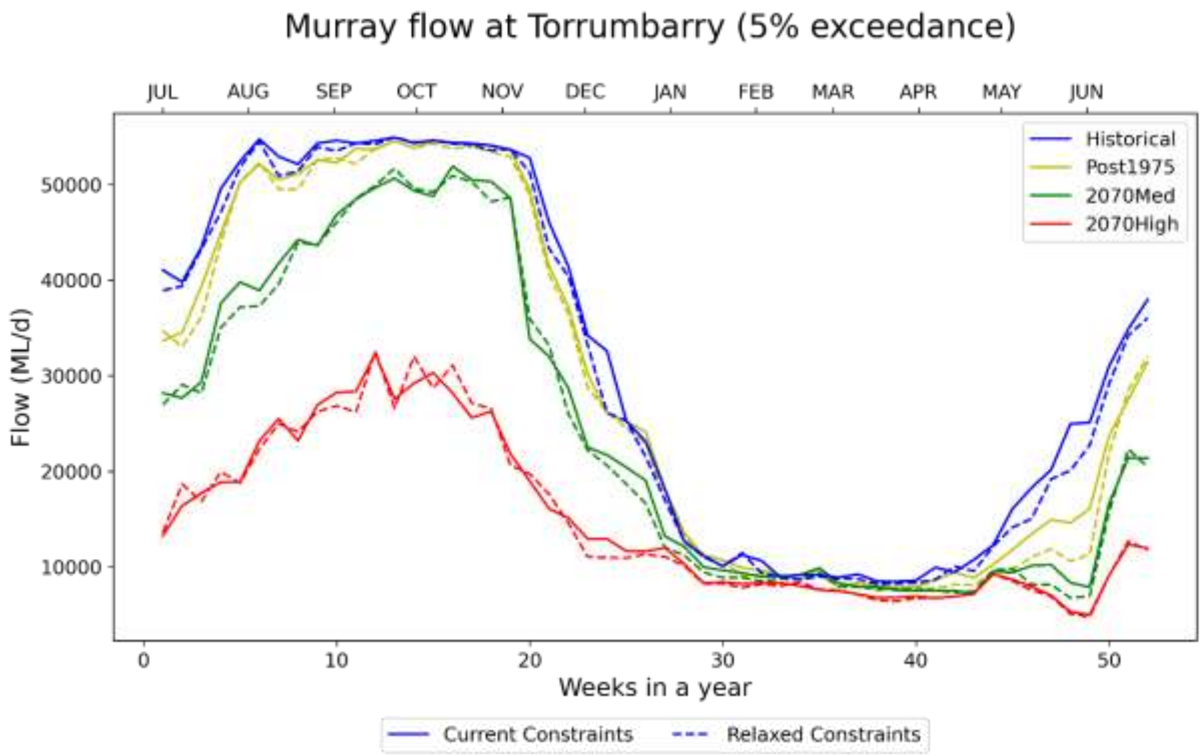

Murray flow at Yarrawonga (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
Weeks in a year
Historical
Post1975
2070Med
2070High
Current Constraints
Relaxed Constraints

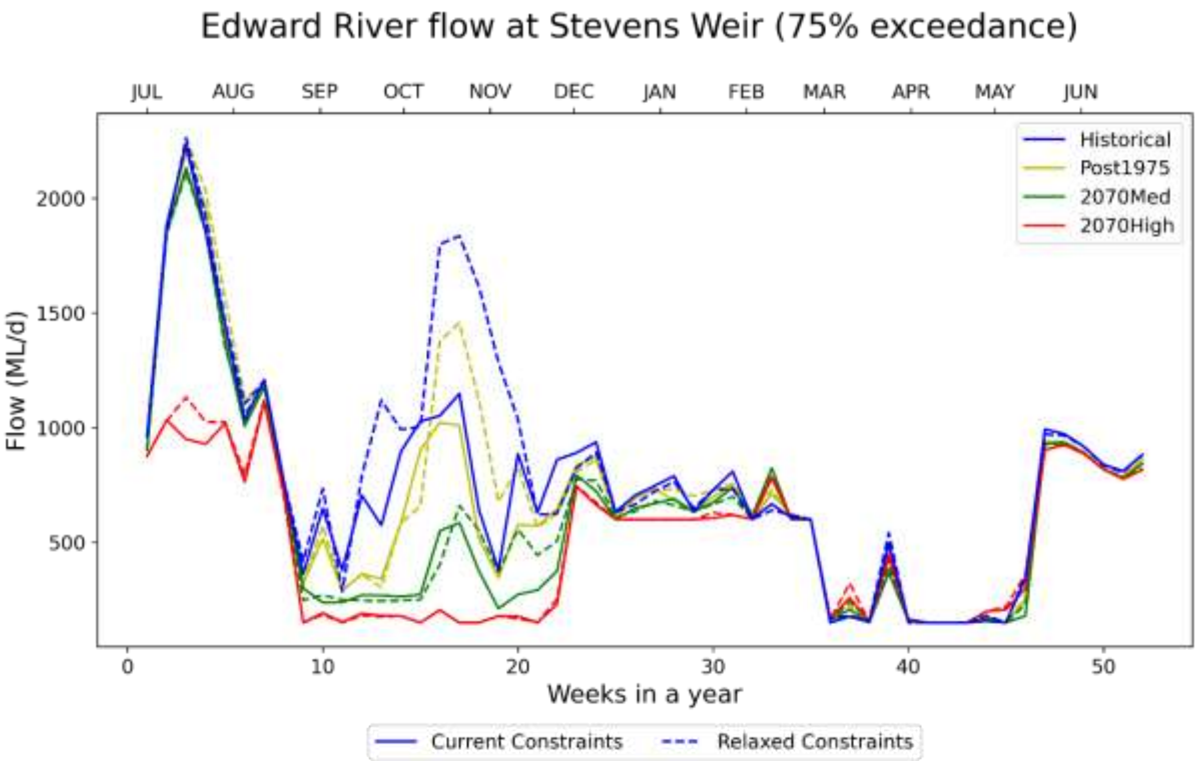

Murray flow at Yarrawonga (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
Weeks in a year
Historical
Post1975
2070Med
2070High
Current Constraints
Relaxed Constraints

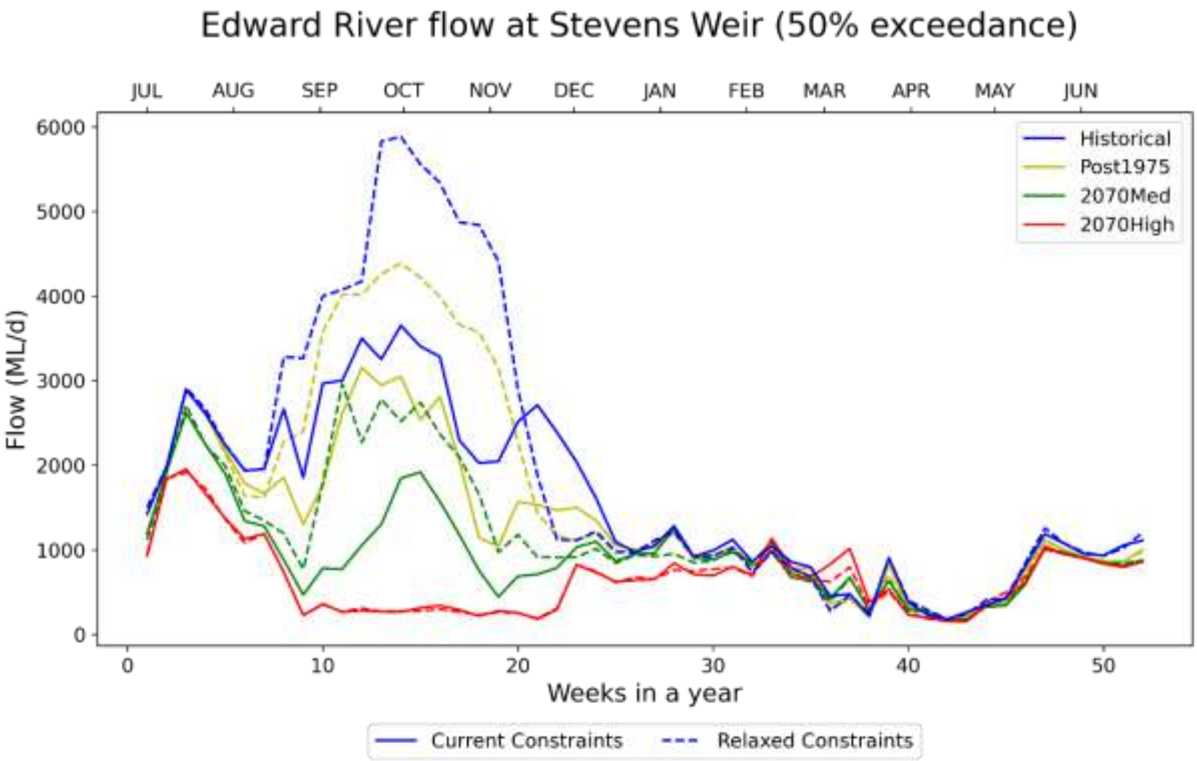

Murray flow at Torrumbarry (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
14000
12000
10000
8000
6000
4000
2000
0
10
20
30
40
50
Weeks in a year
Historical
Post1975
2070Med
2070High
Current Constraints
Relaxed Constraints

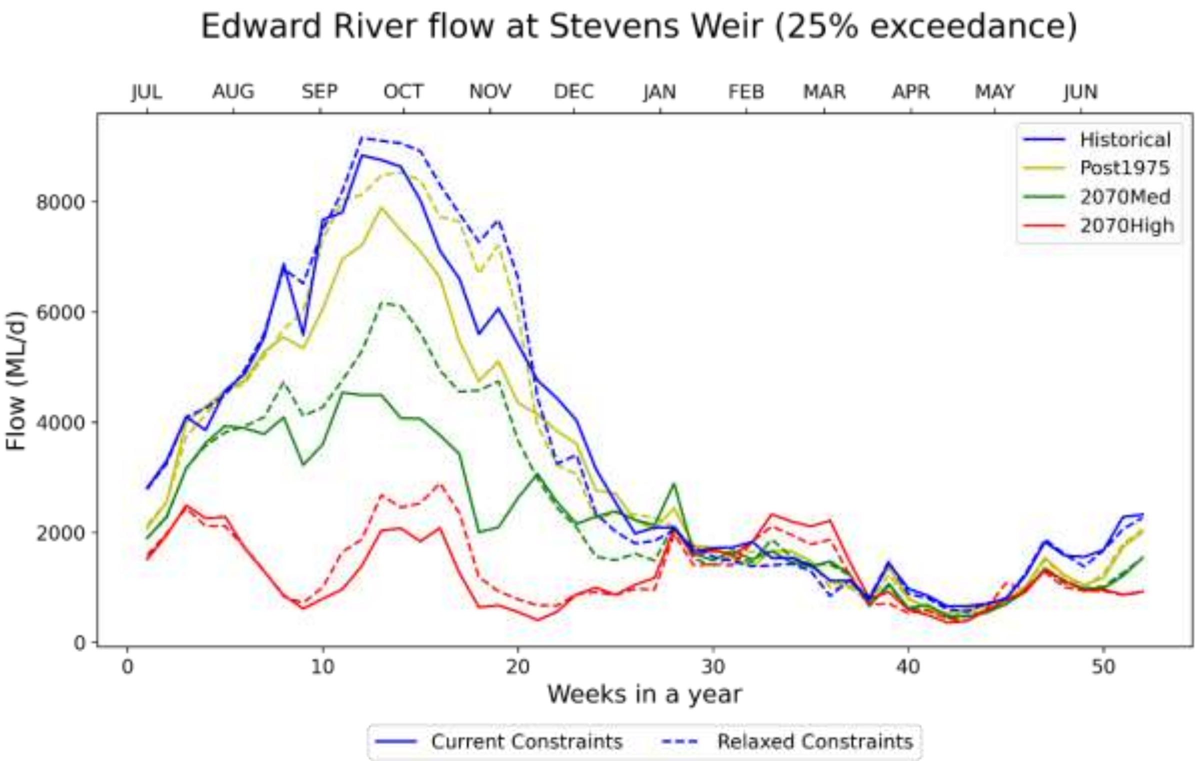

Murray flow at Torrumbarry (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
22500
20000
17500
15000
12500
10000
7500
5000
2500
0
10
20
30
40
50
Weeks in a year
Historical
Post1975
2070Med
2070High
Current Constraints
Relaxed Constraints

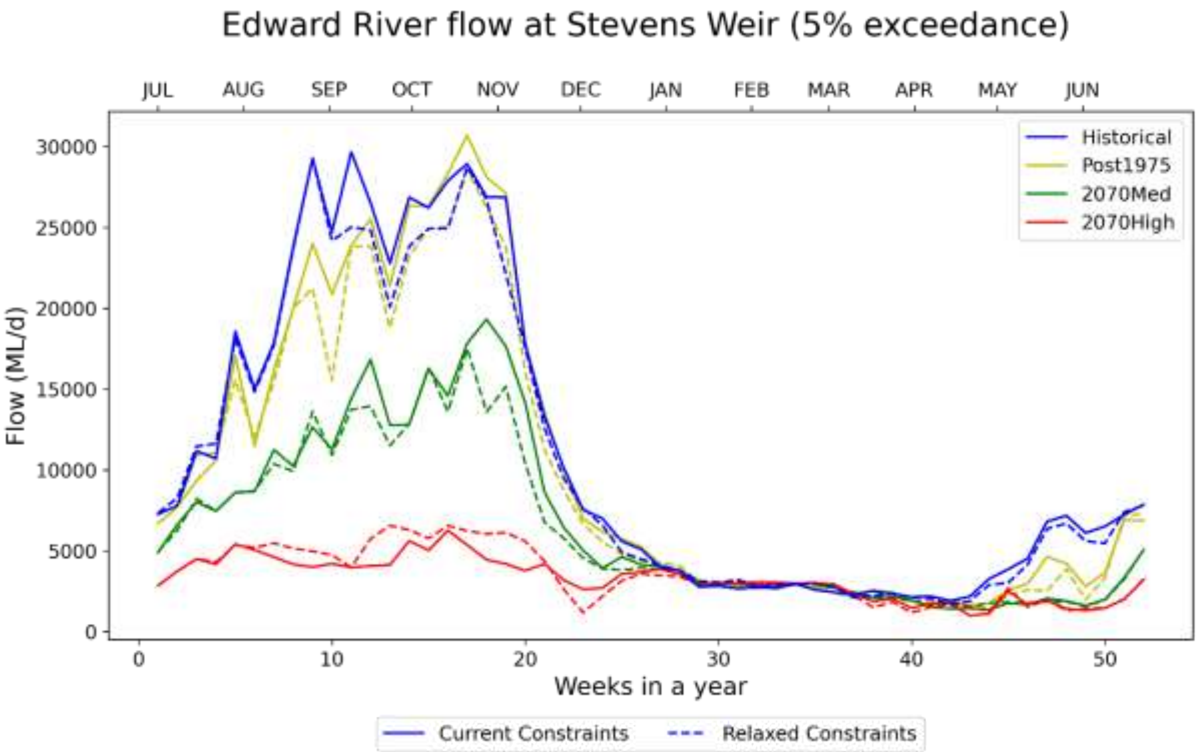

Murray flow at Torrumbarry (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Historical
Post1975
2070Med
2070High
Flow (ML/d)
Weeks in a year
Current Constraints
Relaxed Constraints

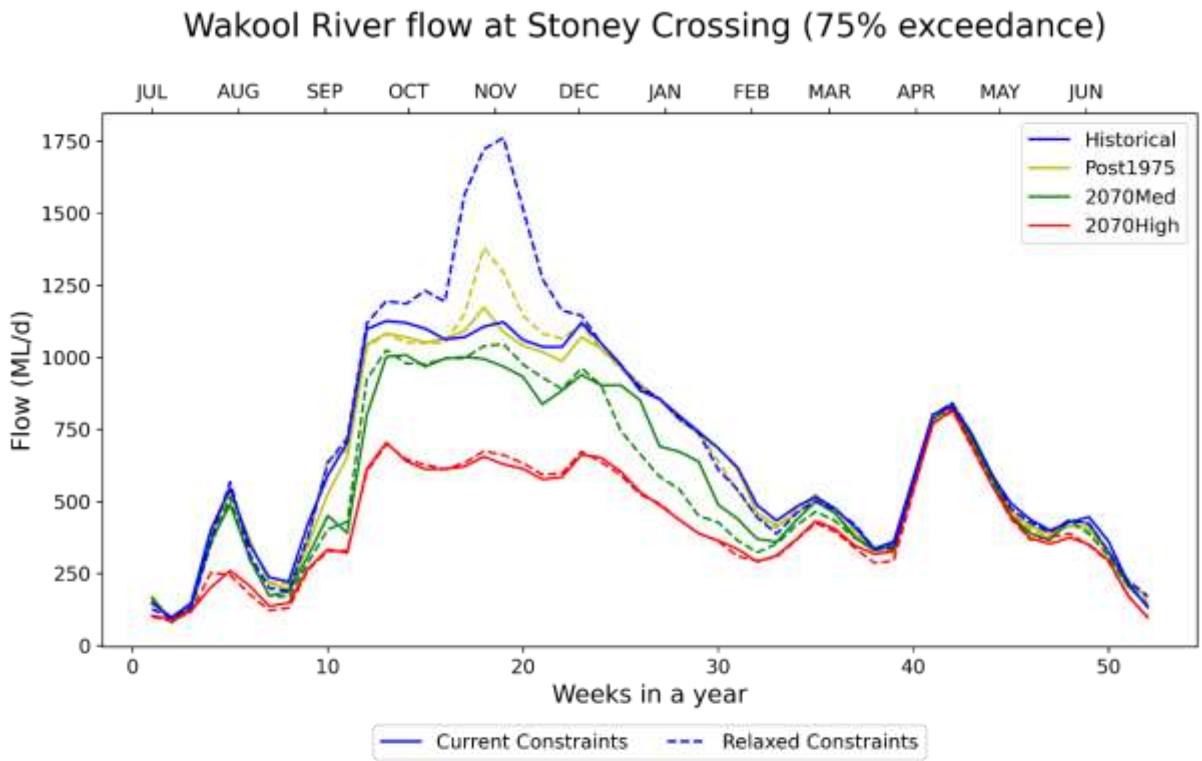

Murray flow at Torrumbarry (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Historical
Post1975
2070Med
2070High
Flow (ML/d)
Weeks in a year
Current Constraints
Relaxed Constraints

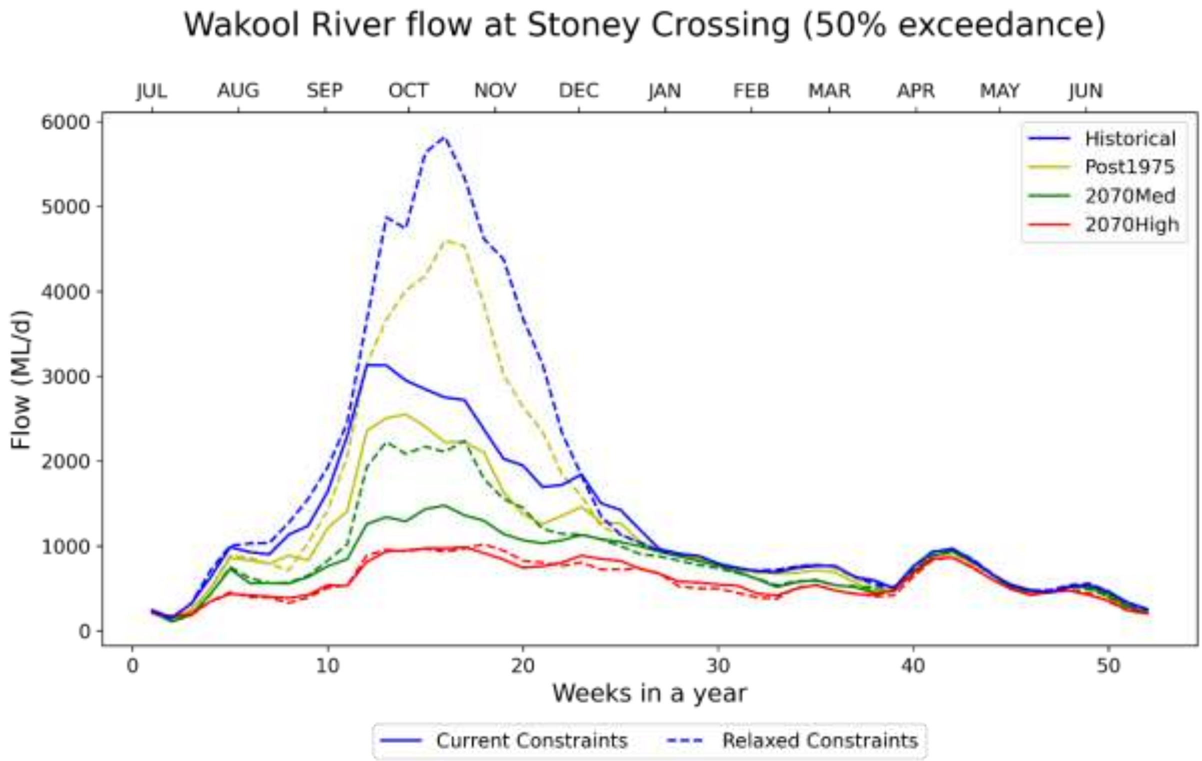

Edward River flow at Stevens Weir (75% exceedance)
JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN
Historical
Post1975
2070Med
2070High
Flow (ML/d)
Weeks in a year
Current Constraints
Relaxed Constraints

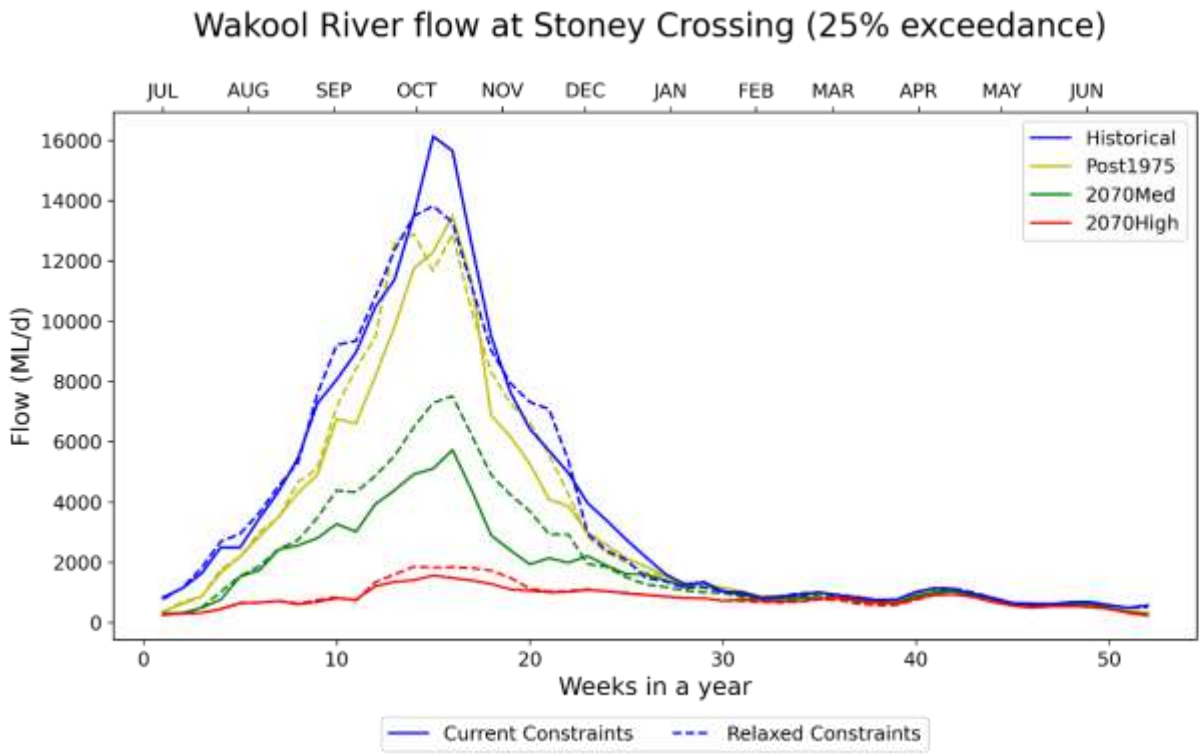

Edward River flow at Stevens Weir (50% exceedance)
JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN
Historical
Post1975
2070Med
2070High
Flow (ML/d)
Weeks in a year
Current Constraints
Relaxed Constraints

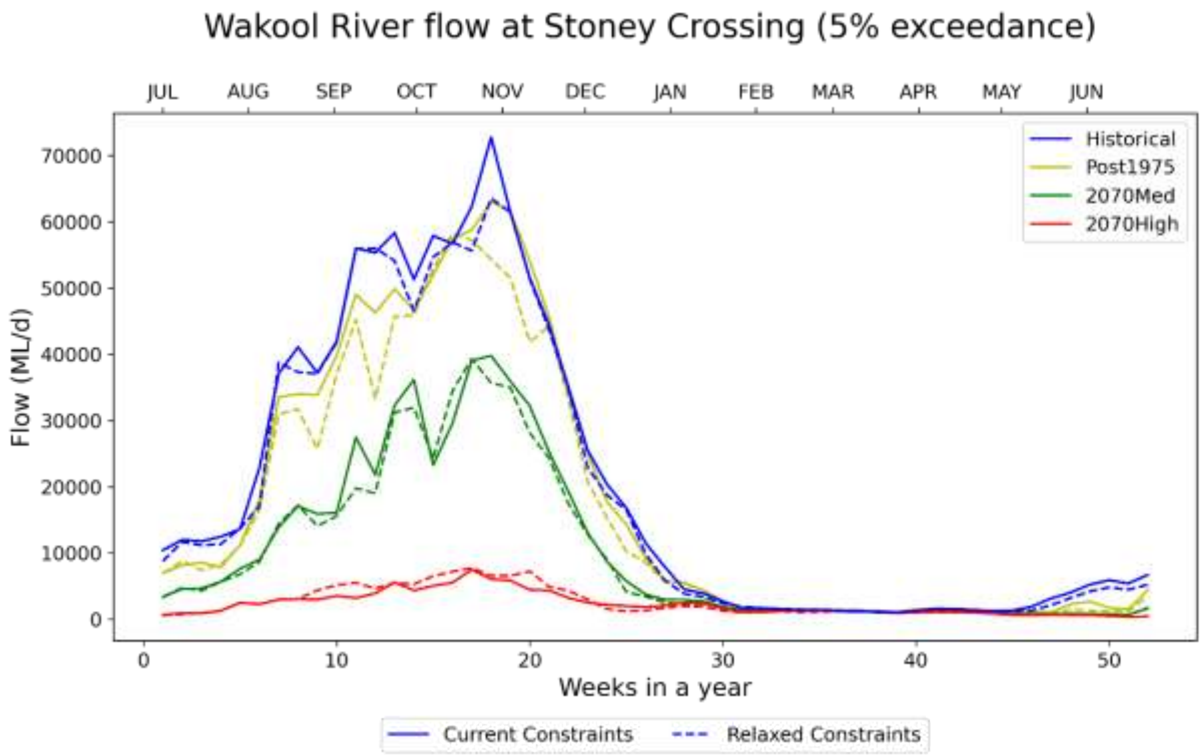

Edward River flow at Stevens Weir (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Historical
Post1975
2070Med
2070High
Flow (ML/d)
Weeks in a year
Current Constraints
Relaxed Constraints

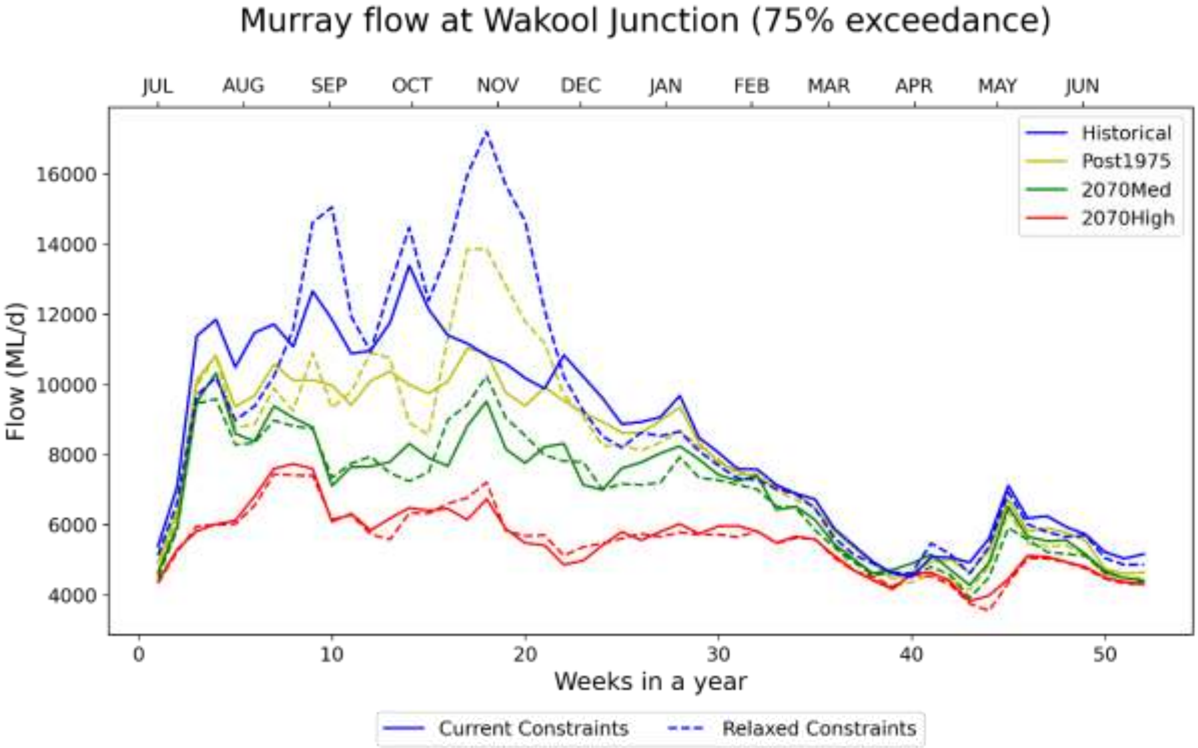

Edward River flow at Stevens Weir (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Historical
Post1975
2070Med
2070High
Flow (ML/d)
Weeks in a year
Current Constraints
Relaxed Constraints

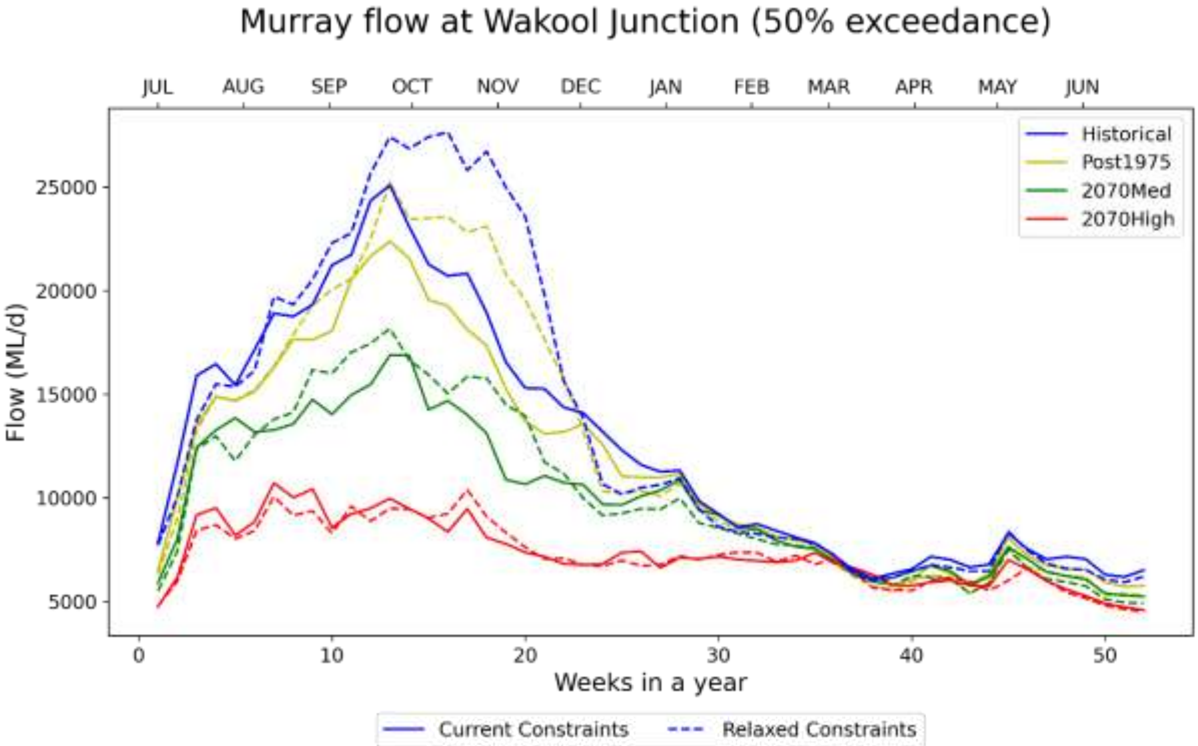

Wakool River flow at Stoney Crossing (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Historical
Post1975
2070Med
2070High
Flow (ML/d)
0
250
500
750
1000
1250
1500
1750
Weeks in a year
0
10
20
30
40
50
Current Constraints
Relaxed Constraints

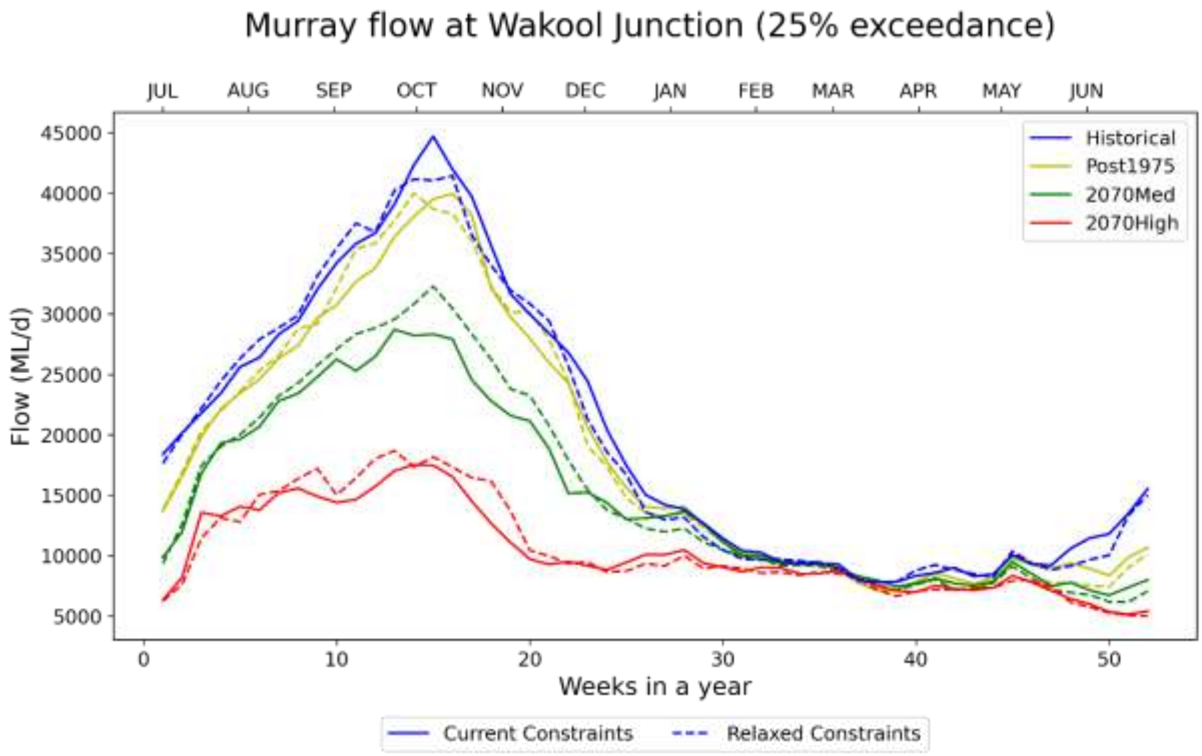

Wakool River flow at Stoney Crossing (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Historical
Post1975
2070Med
2070High
Flow (ML/d)
0
1000
2000
3000
4000
5000
6000
Weeks in a year
0
10
20
30
40
50
Current Constraints
Relaxed Constraints

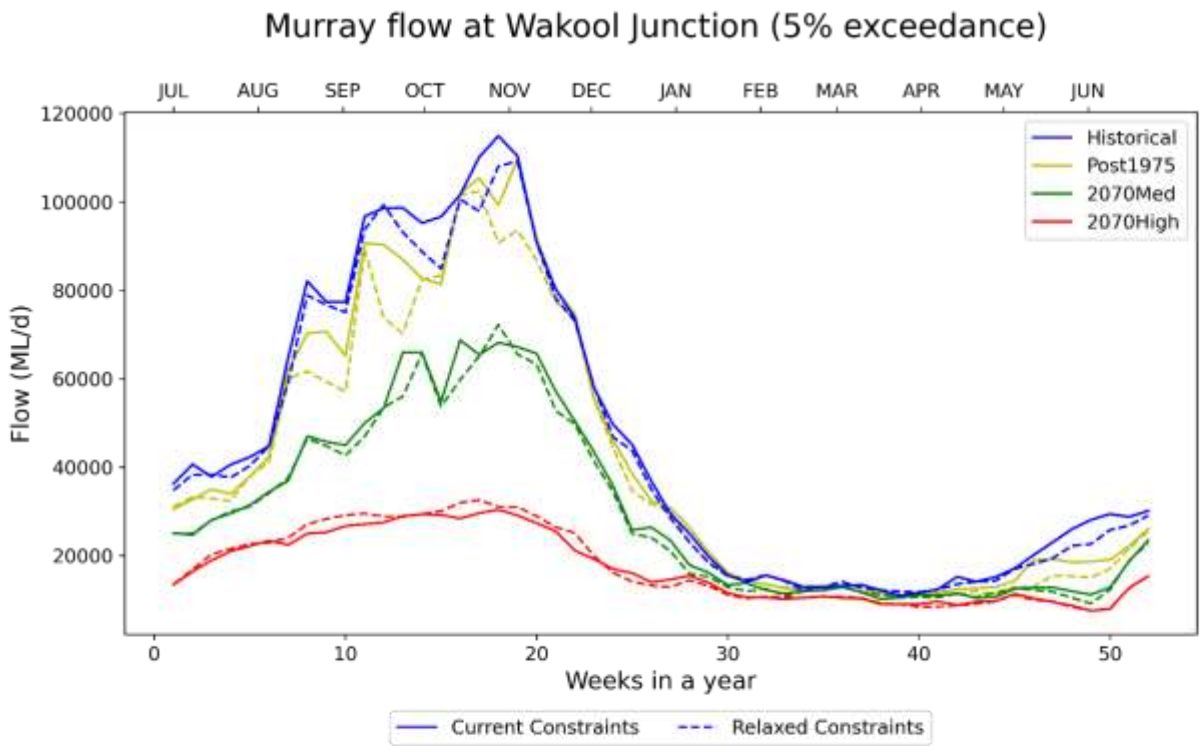

Wakool River flow at Stoney Crossing (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
16000
14000
12000
10000
8000
6000
4000
2000
0
Historical
Post1975
2070Med
2070High
0
10
20
30
40
50
Weeks in a year
Current Constraints
Relaxed Constraints

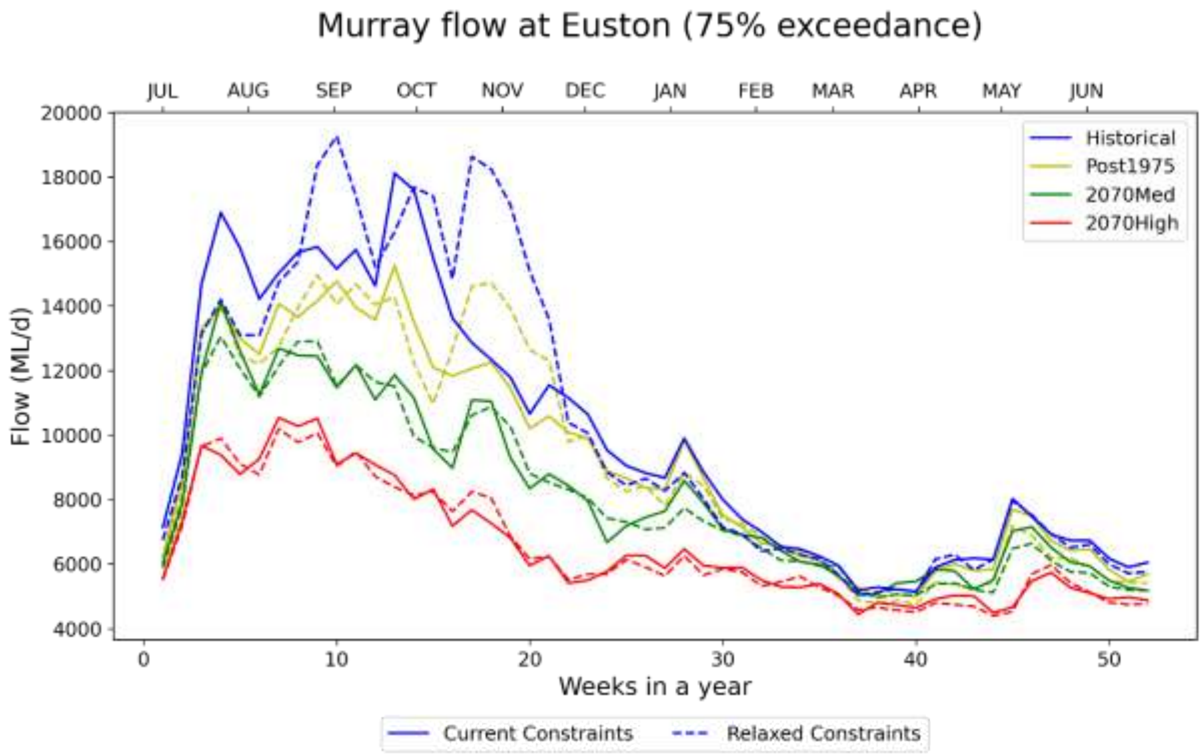

Wakool River flow at Stoney Crossing (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
70000
60000
50000
40000
30000
20000
10000
0
Historical
Post1975
2070Med
2070High
0
10
20
30
40
50
Weeks in a year
Current Constraints
Relaxed Constraints

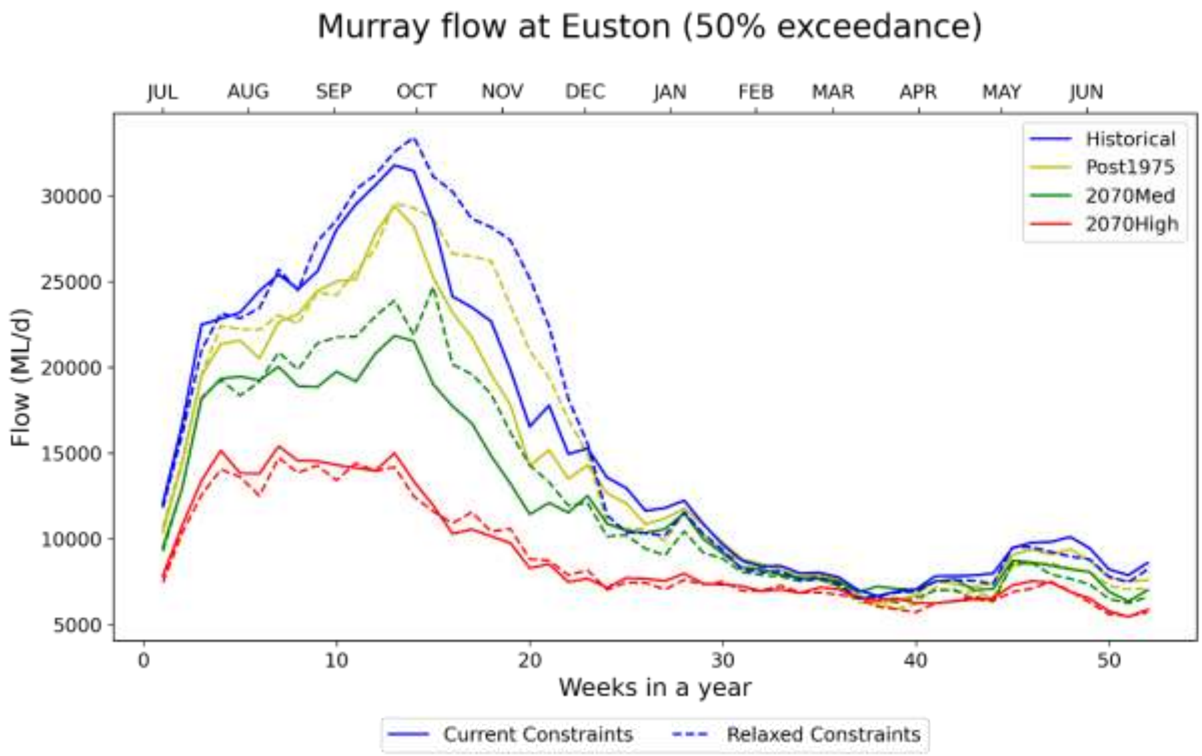

Murray flow at Wakool Junction (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Historical
Post1975
2070Med
2070High
Flow (ML/d)
16000
14000
12000
10000
8000
6000
4000
0
10
20
30
40
50
Weeks in a year
Current Constraints
Relaxed Constraints

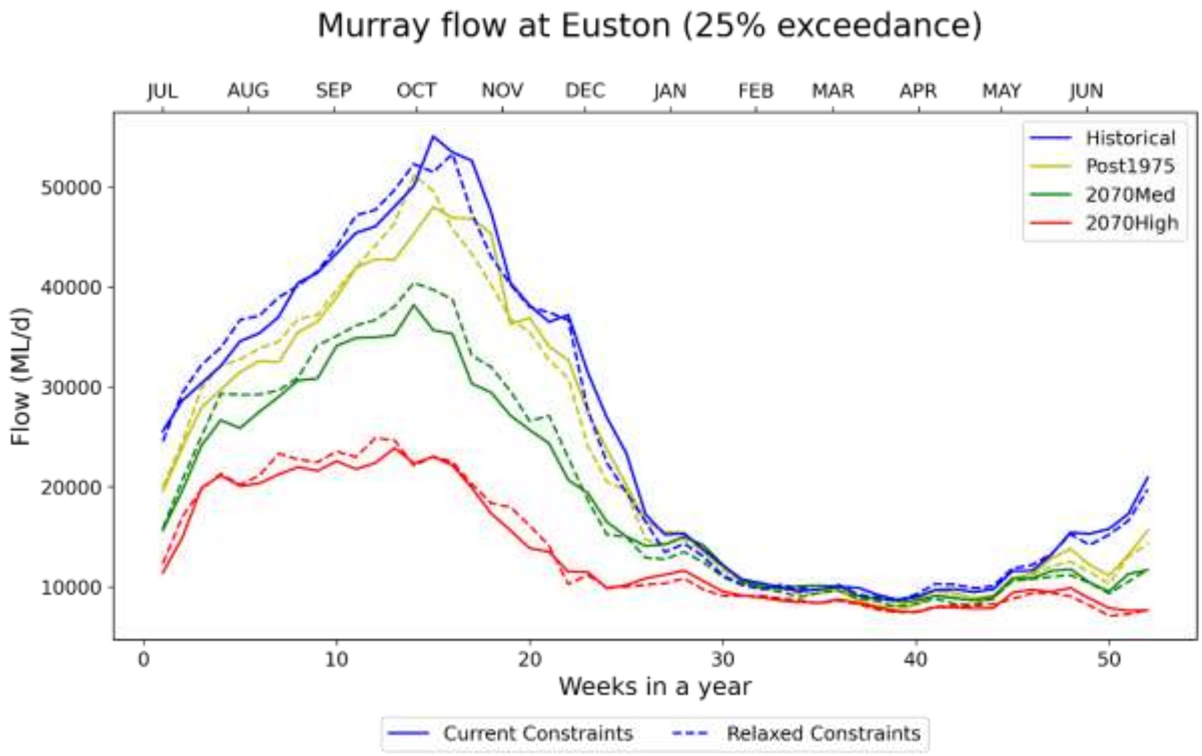

Murray flow at Wakool Junction (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Historical
Post1975
2070Med
2070High
Flow (ML/d)
25000
20000
15000
10000
5000
0
10
20
30
40
50
Weeks in a year
Current Constraints
Relaxed Constraints

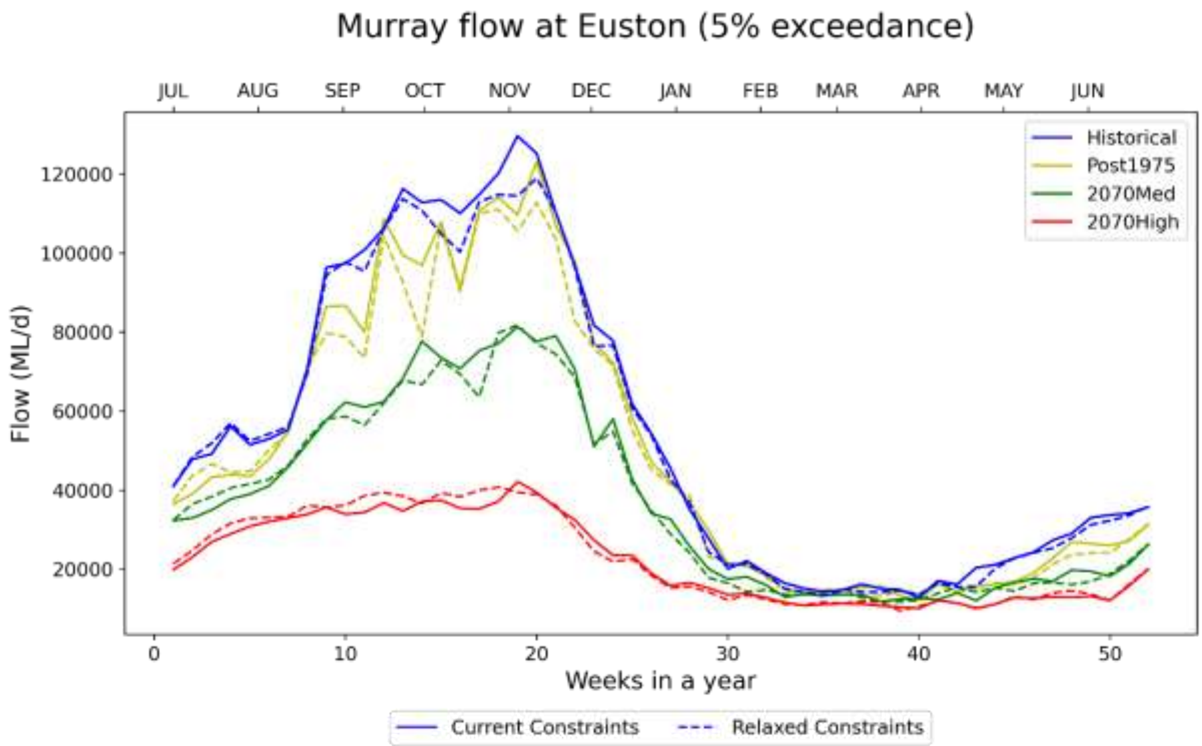

Murray flow at Wakool Junction (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
Weeks in a year
Historical
Post1975
2070Med
2070High
Current Constraints
Relaxed Constraints

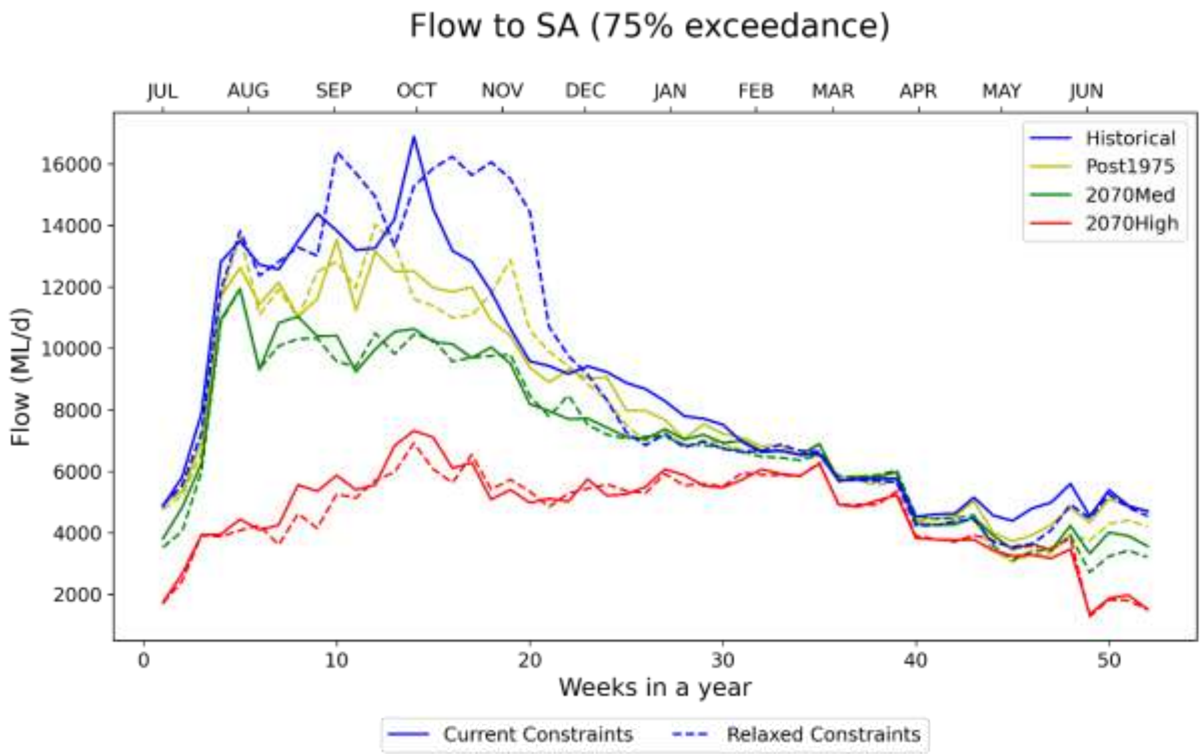

Murray flow at Wakool Junction (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
Weeks in a year
Historical
Post1975
2070Med
2070High
Current Constraints
Relaxed Constraints

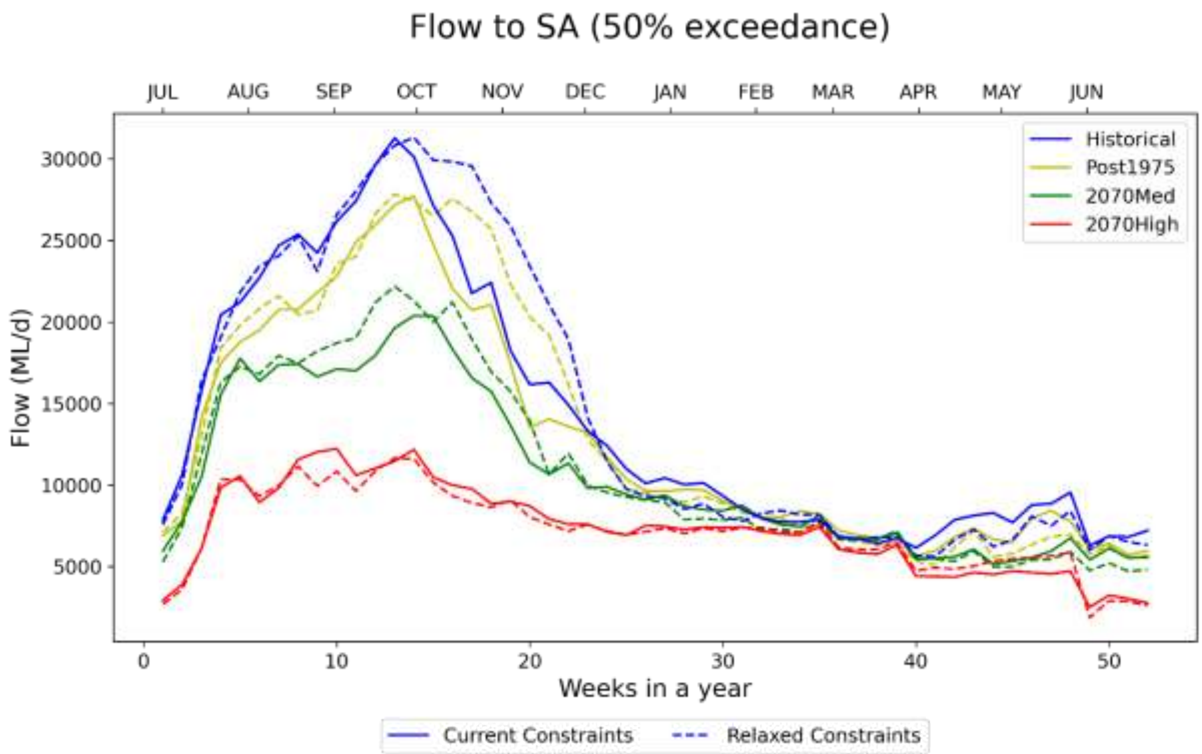

Murray flow at Euston (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
20000
18000
16000
14000
12000
10000
8000
6000
4000
0
10
20
30
40
50
Weeks in a year
Historical
Post1975
2070Med
2070High
Current Constraints
Relaxed Constraints

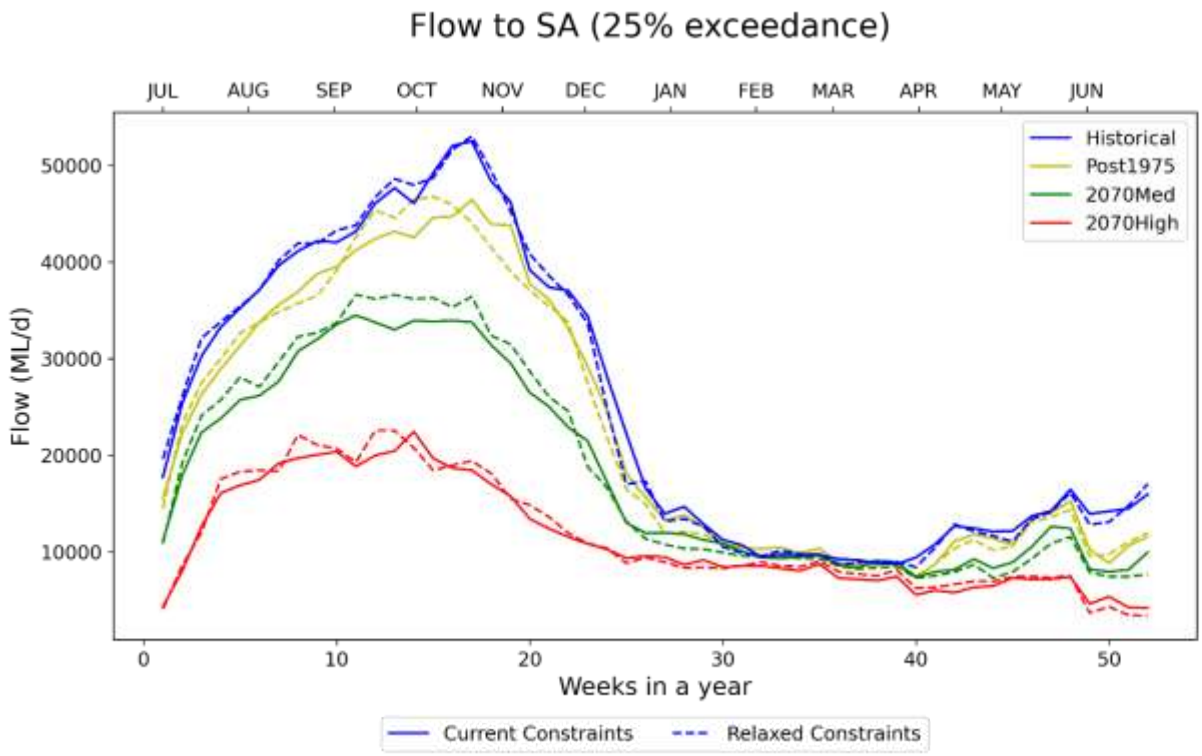

Murray flow at Euston (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
30000
25000
20000
15000
10000
5000
0
10
20
30
40
50
Weeks in a year
Historical
Post1975
2070Med
2070High
Current Constraints
Relaxed Constraints

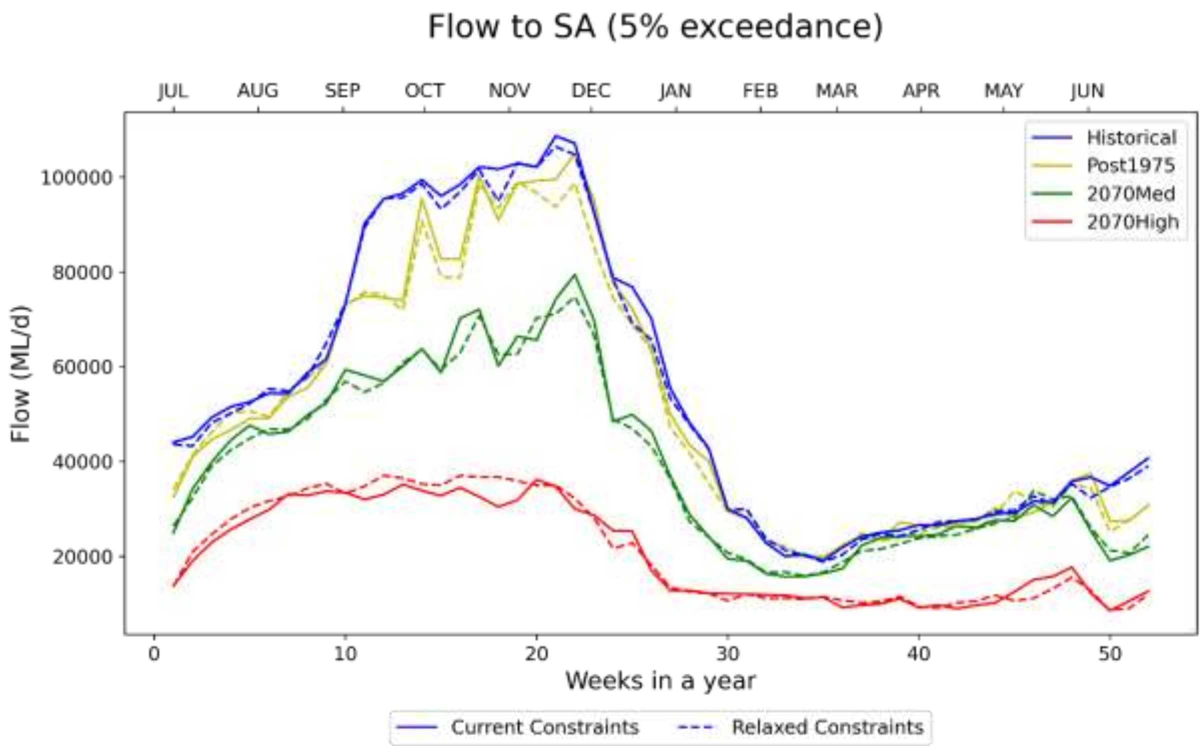

Murray flow at Euston (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Historical
Post1975
2070Med
2070High
Flow (ML/d)
50000
40000
30000
20000
10000
0
10
20
30
40
50
Weeks in a year
Current Constraints
Relaxed Constraints


Murray flow at Euston (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Historical
Post1975
2070Med
2070High
Flow (ML/d)
120000
100000
80000
60000
40000
20000
0
10
20
30
40
50
Weeks in a year
Current Constraints
Relaxed Constraints


Flow to SA (75% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Historical
Post1975
2070Med
2070High
Flow (ML/d)
Weeks in a year
Current Constraints
Relaxed Constraints


Flow to SA (50% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Historical
Post1975
2070Med
2070High
Flow (ML/d)
Weeks in a year
Current Constraints
Relaxed Constraints


Flow to SA (25% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
10000
20000
30000
40000
50000
0
10
20
30
40
50
Weeks in a year
Historical
Post1975
2070Med
2070High
Current Constraints
Relaxed Constraints


Flow to SA (5% exceedance)
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
Flow (ML/d)
20000
40000
60000
80000
100000
0
10
20
30
40
50
Weeks in a year
Historical
Post1975
2070Med
2070High
Current Constraints
Relaxed Constraints