Stage 1A of Victorian Constraints Measures Program

Synthesis report – Hydrology modelling

Final

September 2023

Document status

Client	Department of Energy, Environment and Climate Action
Project	Stage 1A of Victorian Constraints Measures Program
Report title	Synthesis report – Hydrology modelling
Version	Final
Authors	Simon Lang, Phillip Jordan
Project manager	Simon Lang
File name	VIC00092_Stage 1A Constraints Measures Program_HydrologySynthesis_Final
Project number	VIC00092

Document history

Version	Issued	Reviewed by	Approved by	Sent to	Comment
Draft	Nov. 2022	Simon Lang Phillip Jordan Andrew John (Melb. Uni.) Daniel Freitag (Sequana)	Simon Lang	DELWP SWAM, MDBA	For review by DELWP SWAM team and MDBA
Draft	Dec. 2022	Simon Lang Daniel Freitag (Sequana)	Simon Lang	DELWP	For review by DELWP Statewide Infrastructure and Rural Strategy
Final	Sep. 2023	Simon Lang	Simon Lang	Sequana, DEECA	Finalised report for Stage 1A

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ISBN 978-1-76136-667-3

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Executive Summary

Objective

An objective of Stage 1A of the Victorian Constraints Measures Program (VCMP) is to better understand how relaxing constraints may change the flow behaviour along the Goulburn and Murray rivers, under a range of climate conditions. The outputs from the hydrological modelling, in combination with the inundation extents predicted by hydraulic models, will be used to assess the expected environmental, cultural, social and economic outcomes of constraints relaxation. These outcomes will be compared with current conditions so that stakeholders can appreciate the scale of the potential changes and provide informed input as to the feasibility of this project.

The purpose of this report is to provide a concise synthesis of the outcomes from hydrological modelling undertaken during Stage 1A of the VCMP.

Relaxation of constraints may produce some or all of the following outcomes:

- Increase the ability of environmental water managers to provide higher priority flow components, such as winter/spring fresh flows, which produce greater environmental benefits compared with lower priority flow components.
- Reduce shortfalls[1] in meeting environmental water demands, which occur when environmental water allocations cannot be fully utilised[2] because of constraints.
- Reduce the duration, volume and peak flow in flood events associated with spills, particularly from Lake Eildon.

Models used

Hydrological models of the Goulburn and Murray systems were used to run 100+ year simulations of hydrological conditions, assuming current demands, infrastructure and operational rules, to quantify the extent to which the above three outcomes would be influenced by constraint relaxation.

The three models used for Stage 1A of the VCMP were:

1. The University of Melbourne's Stochastic Goulburn Environmental Flow Model (SGEFM), which was used for a high-level analysis of the hydrological and ecological outcomes of relaxed constraints on the mid-Goulburn and lower Goulburn (John *et al.*, 2021, 2022; University of Melbourne, 2022).
2. The DELWP's daily time-step Goulburn Broken Campaspe Coliban Loddon (GBCCL) Source Model, which was used to analyse in more detail the hydrological outcomes of relaxed constraints on the mid-Goulburn and lower Goulburn (DEECA, 2023).

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[1] Shortfalls are the difference between environmental water demands and total flow, calculated on a daily time-step and summed to annual volumes

[2] Utilisation is the proportion of water available via environmental water entitlements that is used on average

3. The MDBA's daily time-step Source Murray Model (SMM), which was used to analyse the hydrological outcomes for the River Murray if constraints are relaxed at Doctors Point, Yarrawonga Weir and in the mid-Goulburn and lower Goulburn (MDBA, 2022a).

The first two models simulate the Goulburn system using differing but complementary approaches. The SGEFM represents a higher-level view of the Goulburn system, and has a short run-time, which makes it useful for simulating hydrological and ecological outcomes for a wide range of potential constraint relaxation and future climate scenarios. The GBCCL Source model builds in the finer spatial and temporal complexity of water management in the Goulburn system. Therefore, the SGEFM was applied for "range finding" to understand the sensitivity of hydrological and ecological outcomes[3] to incremental changes in flow constraints and/or climate projections. The GBCCL Source model was run for selected flow constraint relaxation options in the mid- and lower Goulburn to assess the expected hydrological outcomes in more detail.

The SMM simulates the hydrology of the southern connected Murray-Darling Basin, and was run for selected flow constraint relaxation options at Doctors Point, downstream of Yarrawonga Weir, and in the mid- and lower Goulburn. This work built on the scenario modelling for the NSW Reconnecting River Country Program, which was also done using the SMM. Linkage between the Goulburn and Murray models was achieved by running a sequence of simulations with the GBCCL Source model and SMM and feeding input and output data between the two models.

Conclusions

The hydrology modelling for the Goulburn system, using both the SGEFM and the GBCCL Source model, has shown that it is important to relax the lower Goulburn constraint to at least 17,000 ML/d – 21,000 ML/d, in order to deliver winter/spring freshes to the Kaiela (lower Goulburn). Relaxation of the mid-Goulburn constraint, for example to 12,000 or 14,000 ML/d, is also required to most effectively deliver environmental water to the lower Goulburn. The rate of improvement for both the annual volume of environmental water shortfalls and constrained environmental water delivery declined once the mid-Goulburn constraint was relaxed beyond 14,000 ML/d and the lower Goulburn constraint was relaxed beyond 17,000 ML/d – 21,000 ML/d. This is because regulated releases from Lake Eildon are constrained to be below the minor flood level of 13,700 ML/d at Eildon. There may also be some benefits for the mid-Goulburn associated with delivering larger flows through that reach in winter/spring, which have not yet been assessed.

Relaxation of constraints also slightly reduces the occurrences of spills from storage because there is greater capacity for regulated releases to proactively meet environmental flow requirements. For example, the proportion of years with 5+ days of winter/spring flow exceeding 17,000 ML/d at Molesworth – which is downstream of Lake Eildon – would be expected to reduce from 25% to 19% if current constraints were relaxed to 14,000 ML/d in the mid-Goulburn and 25,000 ML/d in the lower Goulburn.

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[3] The modelled ecological outcomes are summarised in the Alluvium (2022) report about the environmental benefits and risks of constraint relaxation

For the River Murray upstream of Barmah Choke, the relaxation of constraints at Doctors Point and Yarrawonga increases the number of winter/spring days when flows are greater than current constraints but less than or equal to the relaxed constraint threshold. For example, the days per year of winter/spring flow greater than 25,000 ML/d or 35,000 ML/d increases at Doctors Point, Yarrawonga Weir and Tocumwal if constraints are relaxed to 35,000 ML/d or 40,000 ML/d. This increase is most likely to be observed in August, September and October. Once the flow of interest is above the relaxed constraint, the pattern changes. For example, downstream of Yarrawonga Weir the number of days of winter/spring flow above 45,000 ML/d reduces if the constraint is relaxed to 25,000 ML/d – 40,000 ML/d. The degree of difference in hydrological modelling outcomes between current and relaxed constraint scenarios tends to decrease with increasing distance downstream of the Barmah Choke.

Climate change simulations undertaken with the SGEFM showed that for climate change projections that were both moderately drier (~5% to 15% drier) and hotter (~1°C to 4°C hotter) than baseline conditions, there were net benefits to hydrologic metrics from relaxing constraints along the Goulburn River. The benefits increased as constraints were relaxed and were therefore largest for the scenario that simulated constraints of 14,000 ML/d in the mid-Goulburn and 25,000 ML/d in the lower Goulburn. If average annual rainfall decreases by more than 20%, the predicted benefits from constraint relaxation are significantly reduced. Climate change simulations with the GBCCL Source model and SMM also predicted hydrological benefits from constraint relaxation under moderately drier conditions, and reduced benefits under significantly drier conditions.

Recommended further work

Further improvements in hydrological modelling have been recommended by DEECA (2023) and the MDBA (2022a) for potential future stages of the VCMP. These include:

- Including more realistic tributary inflow forecasts in the hydrological models, to better reflect forecast uncertainties and how these influence the release decisions made by storage managers.
- Updating the simulated accounting of the transmission losses associated with environmental water deliveries along the Goulburn River, particularly for near-bankfull and out-of-bank flows.
- Assessing whether environmental water deliveries from the Goulburn River to the River Murray can be better aligned with environmental water deliveries downstream of Yarrawonga Weir.
- Further investigating the potential flow triggers for releasing environmental water from storage, and the trade-off between carrying water over to meet future winter/spring fresh environmental flow targets versus releasing water sooner to meet lower priority targets.
- Modelling more constraint relaxation options under potential future climate conditions using the GBCCL Source model and SMM.

Improving the representation of flow routing in the environmental water deliveries modelled by the SGEFM will also be important if the SGEFM is used to refine the assessment of the environmental costs and benefits of constraint relaxation in the mid- and lower Goulburn.

1. Introduction

1.1 Workstream objective

Hydrological modelling is used to simulate how water will flow through a river system under different climate sequences and operating conditions. The modelling generally considers a range of factors such as inflow seasonality and patterns (rainfall-runoff), river operating rules (such as how dams are managed to supply water and mitigate flood impacts) and water demands (such as irrigation, environmental and trade volumes). This modelling can be used to test how flow behaviour is expected to change based on adjustments to these factors.

An objective of Stage 1A of the Victorian Constraints Measures Program (VCMP) is to better understand how relaxing constraints may change the flow behaviour in the subject reaches of the Goulburn and Murray rivers, under a range of climate conditions. The outputs from the hydrological modelling, in combination with the inundation extents predicted by hydraulic models, will be used to assess the expected environmental, cultural, social and economic outcomes of constraints relaxation. These outcomes will be compared with current conditions so that stakeholders can appreciate the scale of the potential changes and provide informed input as to the feasibility of this project.

Hydraulic modelling seeks to explain and understand the extent, depth and velocity of flow along the river system, for various flow rates. Hydraulic analysis does not attempt to explain how often those flow rates would eventuate or the duration of inundation. Instead, hydrological analyses are used to explore the frequency, duration and timing of various flow rates. In particular this report considers for various constraint relaxation options:

- The modelled ability to utilise the environmental water held in storage, particularly for the Goulburn system.
- The predicted changes to the frequency, duration, and seasonality of flows at various key locations along the Goulburn and Murray rivers.
- The robustness of the expected outcomes to a range of climate change projections.

A simplified schematic of the Murray, Goulburn and Murrumbidgee rivers is shown in Figure 1. The figure also shows the locations of the existing operational constraints along the River Murray and Goulburn River that have been the subject of the constraints relaxation investigations discussed in this report. These constraints are:

- 9,500 ML/d on the Goulburn River at Eildon
- 10,000 ML/d on the Goulburn River at Molesworth (mid-Goulburn)
- 9,500 ML/d on the Goulburn River at Murchison and Shepparton (lower Goulburn)
- 25,000 ML/d on the River Murray at Doctors Point
- 15,000 ML/d – 18,000 ML/d on the River Murray downstream of Yarrawonga Weir

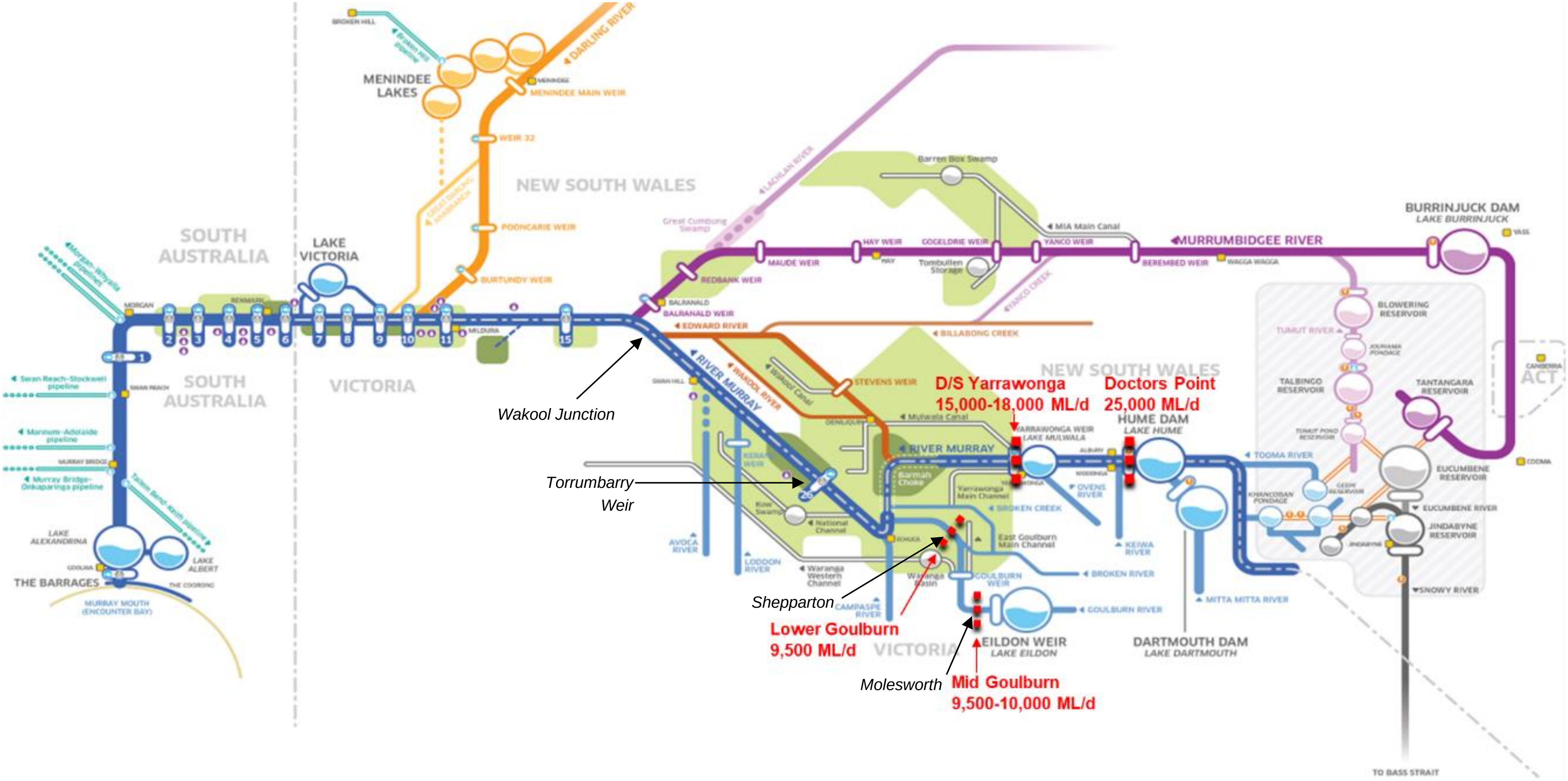

Figure 1: Schematic of the operational constraints on the River Murray and Goulburn River systems that were investigated in Stage 1A of the VCMP. Other place names often referred to in this report are shown in italics.

Relaxation of constraints may produce some or all of the following outcomes:

- Increase the ability of environmental water managers to provide higher priority flow components, such as winter/spring fresh flows, which produce greater environmental benefits compared with lower priority flow components.
- Reduce shortfalls in meeting environmental water demands which occur when environmental water allocations cannot be fully utilised because of constraints.
- Reduce the duration, volume and peak flow in flood events associated with spills, particularly from Lake Eildon.

Hydrological models of the Goulburn and Murray systems were used to run 100+ year simulations of hydrological conditions, assuming current demands, infrastructure and operational rules, to quantify the extent to which the above three outcomes would be influenced by constraint relaxation.

1.2 Stage 1A scope

1.2.1 Hydrological models used

Three hydrological models were used for Stage 1A of the VCMP:

1. The University of Melbourne's Stochastic Goulburn Environmental Flow Model (SGEFM) was used for a high-level analysis of the hydrological and ecological outcomes of relaxed constraints on the mid-Goulburn and lower Goulburn (John *et al.*, 2021, 2022; University of Melbourne, 2022).
2. The DELWP's Goulburn Broken Campaspe Coliban Loddon (GBCCL) Source Model was used to analyse in more detail the hydrological outcomes of relaxed constraints on the mid-Goulburn and lower Goulburn (DEECA, 2023).
3. The MDBA's Source Murray Model (SMM) was used to analyse the hydrological outcomes for the River Murray if constraints are relaxed at Doctors Point, Yarrawonga Weir and in the mid-Goulburn and lower Goulburn (MDBA, 2022a).

One of the models (SGEFM) was specifically designed to be run with stochastic input data, to test the robustness of hydrological and ecological outcomes to a wide range of hydro-climatic variability and potential future climate change. The remaining two models (GBCCL Source and SMM) could be run with stochastic data in future but stochastic simulations were not undertaken with these models during Stage 1A of the VCMP.

The SGEFM represents a higher-level view of the Goulburn system and runs at a monthly timestep (with flows then disaggregated to a daily time-step). The GBCCL Source model runs on a daily time step and builds in the finer spatial and temporal complexity of water management in the Goulburn system. Because the SGEFM could be quickly run thousands of times, it was applied for "range finding" to understand the sensitivity of hydrological and ecological outcomes[4] to incremental changes in flow constraints and/or climate projections.

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[4] The modelled ecological outcomes are summarised in the Alluvium (2022) report about the environmental benefits and risks of constraint relaxation

The GBCCL Source model was then run for selected flow constraint relaxation options in the mid- and lower Goulburn, to assess the expected hydrological outcomes in more detail.

The SMM simulates the hydrology of the southern connected Murray-Darling Basin at a daily time-step, and was run for selected flow constraint relaxation options at Doctors Point, downstream of Yarrawonga Weir, and in the mid- and lower Goulburn. This work built on the hydrological modelling done for the NSW Reconnecting River Country Program, which was also done using the SMM. Linkage between the Goulburn and Murray models was achieved via running a sequence of simulations with the GBCCL Source model and SMM and feeding input and output data between the two models.

Technical reports on the use of the SGEFM, GBCCL Source model and SMM for Stage 1A of the VCMP have been written by John *et al.* (2022), DEECA (2023) and the MDBA (2022a) respectively.

1.2.2 Linkage of hydrological models

The hydrology models for the Goulburn and Murray systems are not dynamically linked. For example, the SMM cannot interactively “call out” water from the GBCCL Source model to meet environmental or irrigator demands (that come about due to inter-valley trade). However, given they have been developed in the same software (Source), outputs from the GBCCL Source model can be easily converted to SMM input files that simulate the end of system flows from the Goulburn to the Murray.

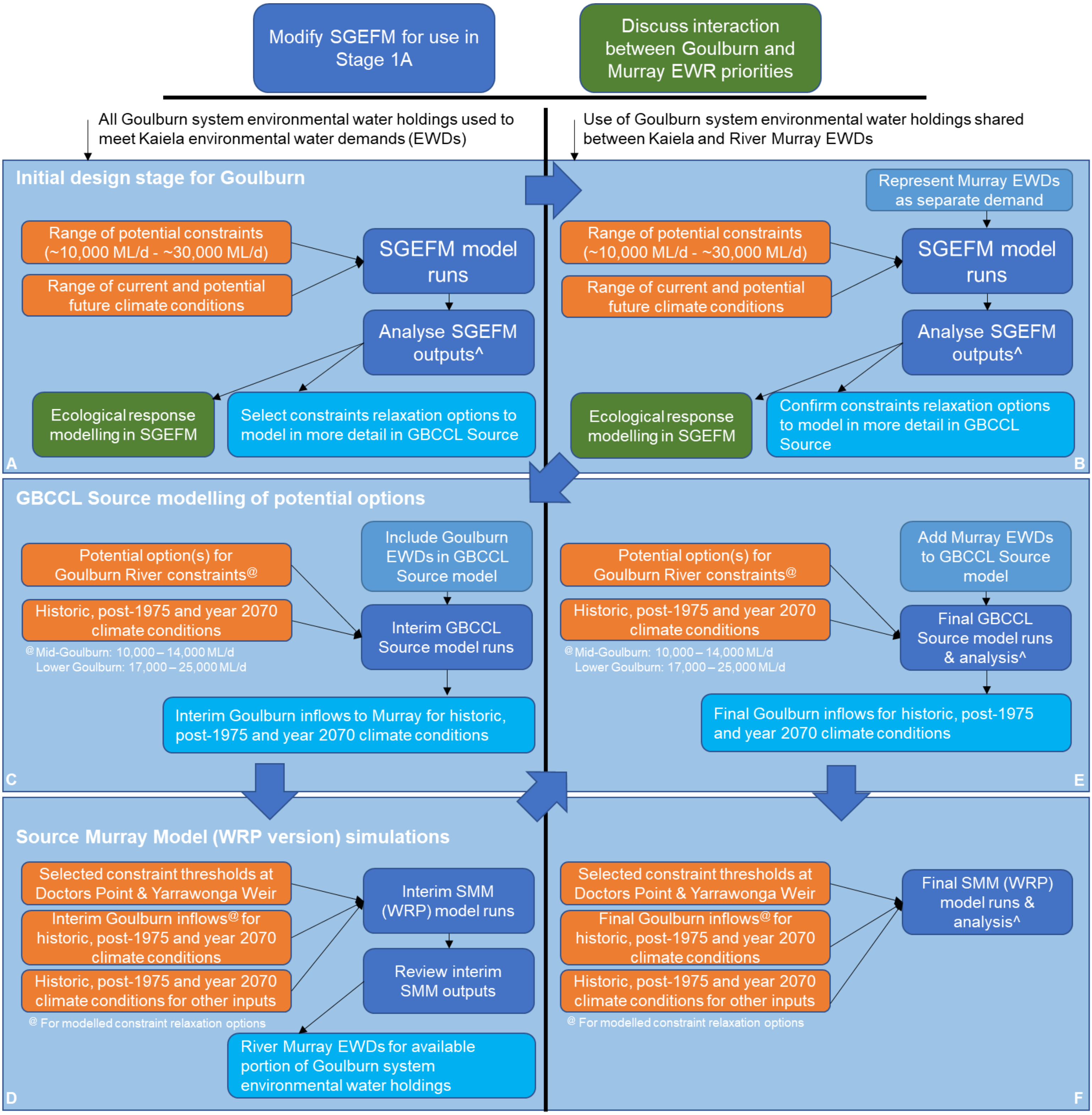
Figure 2 shows how the models were linked for the hydrological modelling that was undertaken in Stage 1A of the VCMP:

- Some modifications were made to the SGEFM (see Section 2.1), as recommended in the Stage 1A Stocktake Review report (Sequana Partners, 2022). The SGEFM was then run for initial design of constraint relaxation, with all Goulburn system environmental water holdings used to meet Kaiela (lower Goulburn River) environmental demands (box A in Figure 2).
- The SGEFM was then re-run to test the sensitivity of outcomes to using held environmental water in the Goulburn to meet environmental water demands in both the Kaiela and River Murray (box B in Figure 2).
- The results from the SGEFM were used to inform the constraint relaxation scenarios that were tested in the GBCCL Source model. The GBCCL Source model was then run, with all Goulburn system environmental water holdings used to meet Kaiela environmental demands (box C in Figure 2).
- End of system flows from the GBCCL Source were provided as a daily time series of inputs to the SMM, for the current constraint scenario and each constraint relaxation scenario. The SMM was then run to produce outcomes on the assumption that all Goulburn system environmental water holdings were used to meet Kaiela environmental demands (box D in Figure 2).

- Results from the SMM were used to identify periods when Murray environmental water demands could be supplied with ‘unused’ held environmental water in the Goulburn system. The GBCCL Source model was then run, with environmental water holdings used to meet a combination of environmental water demands in the Murray and Kaiela (box E in Figure 2).
- The outputs from the second iteration of the GBCCL Source model runs were used as inputs to the second iteration of the SMM runs to produce final modelled outputs for the River Murray system (box F in Figure 2).

The SGEFM was run for a wide range of current and potential future climate conditions. The current constraint scenario and all constraint relaxation options investigated using the GBCCL Source model and SMM were simulated using historic climate conditions representing the period from the 1890s to June 2020. The current constraint scenario and one constraint relaxation option were also run in the GBCCL Source mode and SMM for post-1975 conditions and projected climate conditions for the year 2070.

This synthesis report refers to hydrology modelling results from boxes A, C/E and F.



^ compared with base case

Figure 2: Linkage of hydrological models used for Stage 1A of the VCMP.

1.2.3 Environmental water holdings

The hydrological modelling completed for Stage 1A of the VCMP was based on existing environmental water holdings. That is, the modelling did not assume any further water recovery for the environment in either the Goulburn River or River Murray systems.

In the Goulburn system, environmental water entitlements are held by the Victorian Environmental Water Holder (VEWH) and the Commonwealth of Australia, via the Commonwealth Environmental Water Office (CEWO) and under The Living Murray (TLM) program. In total, there is approximately 390 GL of high-reliability water shares and 200 GL of low-reliability water shares in the Goulburn River system held for environmental use. The breakdown of holdings by organisation and entitlement type is included in the DEECA (2023) report.

In the River Murray system (Commonwealth Environmental Water Office, 2020; Victorian Environmental Water Holder, 2022; NSW Department of Planning and Environment, 2017):

- The CEWO holds a total of approximately 420 GL of entitlements upstream of the Barmah Choke, mainly comprised of NSW general security licences and Victorian high reliability licenses.
- The CEWO holds approximately 380 GL of entitlements downstream of the Barmah Choke, mainly comprised of Victorian high reliability licenses and NSW general security licenses.
- The VEWH has about 390 GL of entitlements, made up of Victorian high reliability, low reliability and unregulated water shares.
- The NSW Department of Planning and Environment (DPE) has about 220 GL of entitlements, mainly comprised of NSW general security and supplementary licenses.

Section 3 of the MDBA (2022a) report includes further information on the CEWO water holdings upstream and downstream of the Barmah Choke.

The environmental water demands included in the SGEFM, GBCCL Source model and SMM, and the triggers used to call out of storage the water allocated to these environmental water entitlements, are summarised in the modelling reports by John *et al.* (2022), DEECA (2023) and the MDBA (2022a).

1.3 Structure of this report

The purpose of this report is to provide a concise synthesis of the outcomes from hydrological modelling undertaken during Stage 1A of the VCMP:

- Section 2 discusses the scenarios that were simulated using each of the three models (SGEFM, GBCCL Source model and SMM)
- Section 0 summarises the hydrological modelling outcomes for the Goulburn River, based on results from the SGEFM and GBCCL Source model
- Section 4 summarises the hydrological modelling outcomes for the River Murray, based on results from the SMM

- Section 5 considers the potential impacts of projected future climate change on the expected hydrological outcomes from constraint relaxation, using the Goulburn River as a case study.
- Section 6 summarises the key conclusions from the modelling, and
- Section 7 recommends further work to be considered if the VCMP proceeds beyond Stage 1A.

2. Scenarios modelled

2.1 Stochastic Goulburn Environmental Flow Model

A schematic of the SGEFM is included in Figure 3.

The Stocktake Report for Stage 1A of the VCMP (Sequana Partners, 2022) recommended several enhancements to the SGEFM be undertaken prior to scenario modelling. These were:

- Updates to the disaggregation algorithm to enable:
    - Daily outputs at multiple locations along the river.
    - Better representation of environmental flow release patterns and pulses of summer inter-valley trade, as per the updated Goulburn River Operating Plan (Department of Environment Land Water and Planning, 2021a).
- Updates to the annual and seasonal inter-valley trade delivery relationships, to reflect recent reviews of the trading rules and Goulburn Operating Plan.
- Refinement of how water harvesting from Goulburn Weir to Waranga Bain was represented, to simulate delivery of higher daily environmental flow rates to the lower Goulburn.
- Inclusion of an alternate set of environmental demands that included potential use of environmental water holdings in the Goulburn system to meet River Murray needs (see box B in Figure 2).

These changes were made during Stage 1A of the VCMP and are described by John *et al.* (2022).

The SGEFM was then run to test many potential combinations of flow constraints for the:

- mid-Goulburn (i.e. Molesworth), between **10,000 ML/d** and **21,800 ML/d** and
- lower Goulburn (i.e. Murchison and Shepparton), between **9,500 ML/d** and **30,800 ML/d**

but, in all cases subject to:

- regulated releases from Eildon remaining below minor flood level (13,700 ML/d) and
- flows at Trawool and Seymour remaining below minor flood level (21,800 ML/d).

The outcomes were assessed using three key hydrologic metrics: allocation reliability, shortfalls between environmental water demands and the flows delivered (environmental water shortfalls), and the volume of allocated environmental water that could not be delivered due to constraints (constrained delivery volume). In addition, scenarios were assessed based on the outputs of twelve ecological models that represent environmental watering objectives in the lower Goulburn River. The range-finding exercise did not assess potential benefits for the mid Goulburn River.

The performance of selected constraint relaxation options were then simulated for a large range of plausible future climates, i.e. temperature increases from ranging from 0 to 4°C, and annual rainfall changes from -30% to +15% (both relative to a 1980-2009 baseline period; University of Melbourne (2022)).

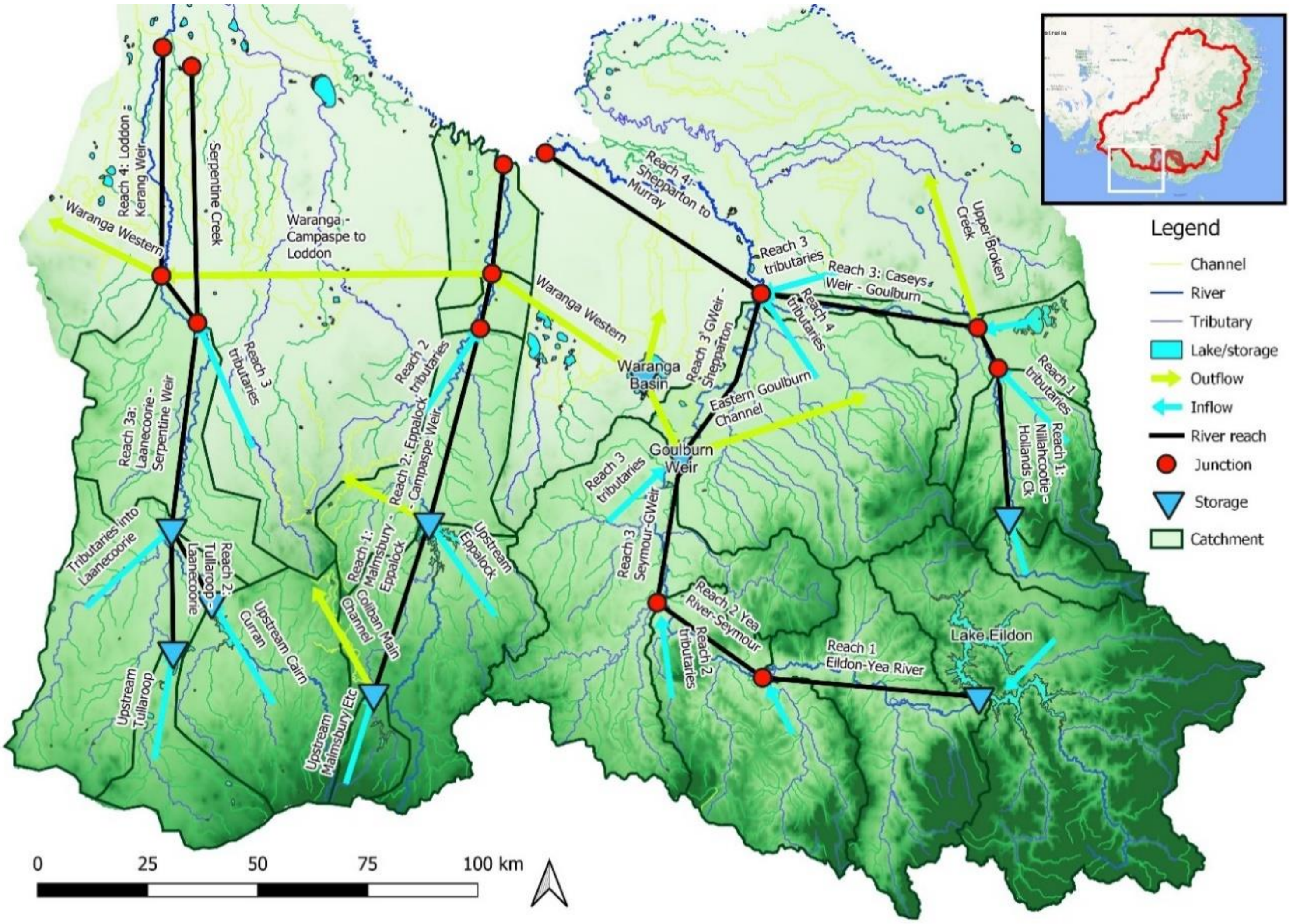


Figure 3: SGEFM scope and spatial representation (reproduced from Figure 1 of John *et al.*, 2022). Note that the model was updated to include outputs at Molesworth and Trawool in the mid-Goulburn.

2.2 Goulburn Broken Campaspe Coliban Loddon Source model

Figure 4 provides a schematic of the GBCCL Source model.

Based on the outcomes of the SGEFM modelling (Section 3.1), the GBCCL Source model was run using historic climate conditions (1890 to 2020) for the current constraint and constraint relaxation scenarios listed in Table 1. Appendix A shows how the constraint relaxation thresholds relate to gauged water levels at Eildon, Murchison and Shepparton.

The scenarios that represent current constraints, and a mid-Goulburn constraint of 10,000 ML/d and a lower Goulburn constraint of 17,000 ML/d (M10L17) were also run for post-1975 climate conditions, and climate conditions projected for the year 2070.

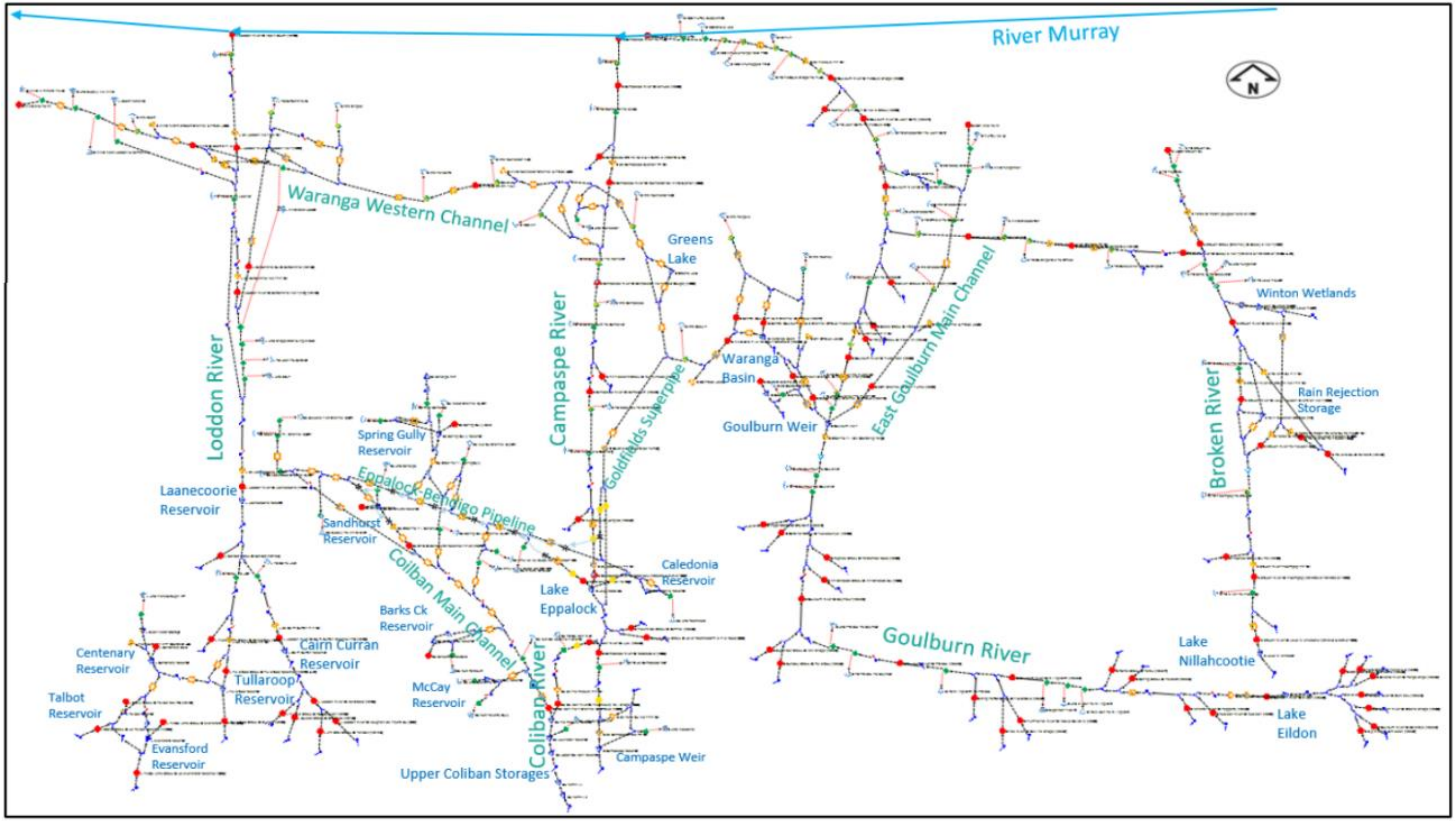


Figure 4: GBCCL Source model scope and spatial representation (Li *et al.*, 2019).

Table 1: Current and relaxed constraint scenarios modelled using the GBCCL Source model assuming historic climate conditions. The M10L9.5 and M10L17 scenarios were also modelled for post-1975 climate conditions, and conditions projected for the year 2070.

Location (gauge number)	**Constraint at given location for simulated scenario**				
	Current (M10L9.5)	**Scenario 1 (M10L17)**	**Scenario 2 (M10L21)**	**Scenario 3 (M12L21)**	**Scenario 4 (M14L25)**
Eildon (405203)	9,500 ML/d	9,500 ML/d	9,500 ML/d	12,000 ML/d	13,700 ML/d
Molesworth	10,000 ML/d	10,000 ML/d	10,000 ML/d	Jul-Oct*: 12,000 ML/d Nov-Jun: 10,000 ML/d	Jul-Oct*: 14,000 ML/d Nov-Jun: 10,000 ML/d
Murchison (405200)	9,500 ML/d	17,000 ML/d	21,000 ML/d	21,000 ML/d	25,000 ML/d
Shepparton (405204)	9,500 ML/d	17,000 ML/d	21,000 ML/d	21,000 ML/d	25,000 ML/d

* Relaxed mid-Goulburn constraint not used to meet environmental water orders from River Murray

Towards the end of Stage 1A, a fifth scenario was also modelled in the GBCCL Source model (DEECA, 2023), to simulate a mid-Goulburn constraint of 12,000 ML/d and a lower Goulburn constraint of 25,000 ML/d (M12L25). Results for this scenario are not included in this hydrology synthesis report, but are compared with Scenario 4 (M14L25) in a standalone memo (HARC, 2023).

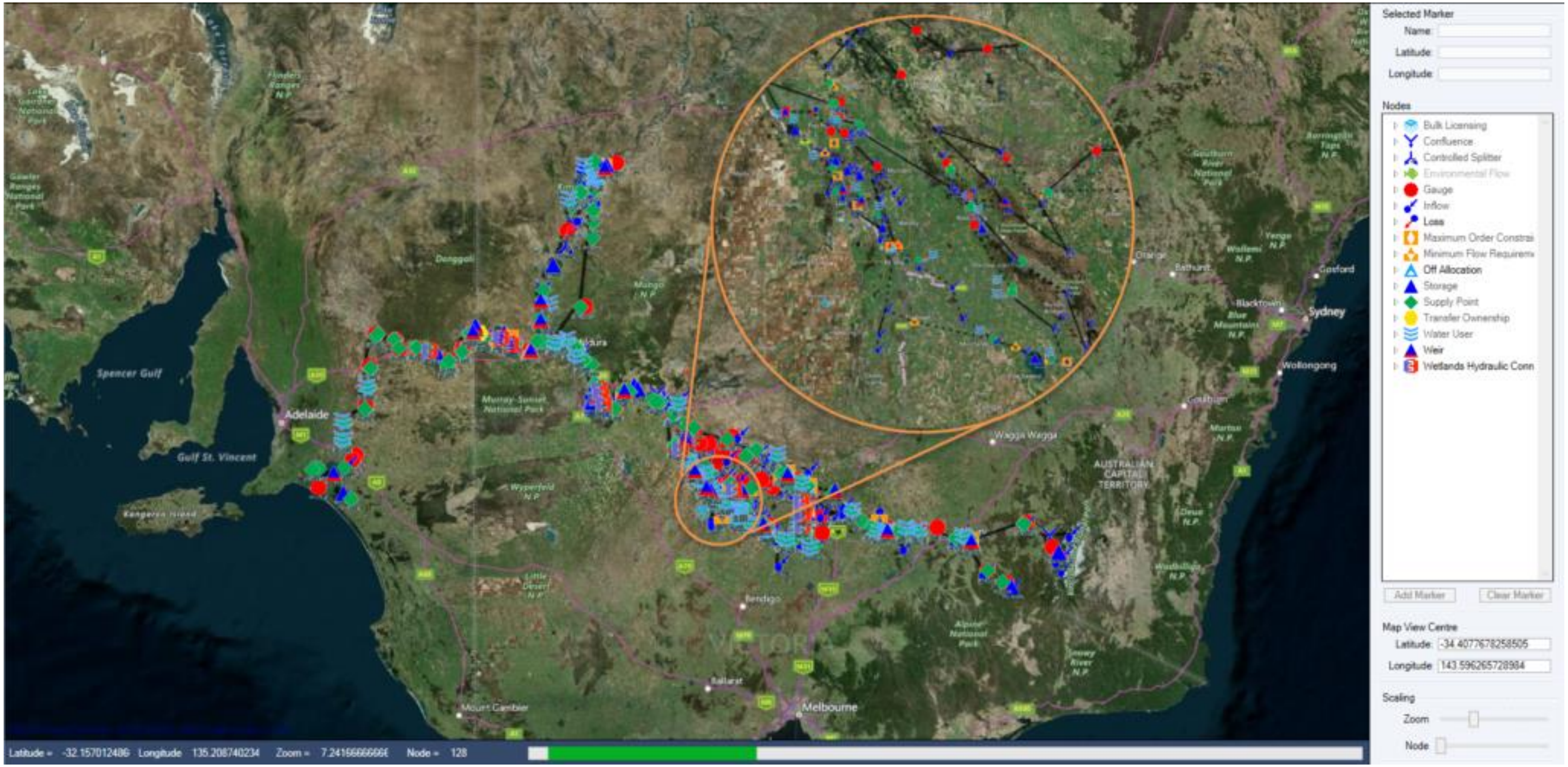
2.3 Source Murray Model

The conceptual layout of the SMM is shown in Figure 5.

The SMM was run to test outcomes for the ten scenarios listed in Table 2. The first scenario represents the current constraints.

The next group of five scenarios simulate the expected change in River Murray hydrology if constraints are relaxed at Doctors Point and/or downstream of Yarrawonga Weir, assuming the mid-Goulburn constraint is 10,000 ML/d and the lower Goulburn constraint is 17,000 ML/d. The range of constraint relaxation tested was based on the hydrology modelling investigations first begun by the NSW Reconnecting River Country (https://www.dpie.nsw.gov.au/water/water-infrastructure-nsw/sdlam/reconnecting-river-country-program). Appendix A shows how the constraint relaxation thresholds relate to gauged water levels at Albury (near Doctors Point) and downstream of Yarrawonga Weir.

The next group of four scenarios simulate the expected change in River Murray hydrology if the Doctors Point and Yarrawonga Weir constraint is 40,000 ML/d, and the mid- and lower Goulburn constraints vary as per the four relaxation scenarios listed in Table 1.



Map View Centre
Latitude: -34.4077678258505
Longitude: 143.596265728984

Latitude = -32.157012486 Longitude 135.208740234 Zoom = 7.24166666666€ Node = 128

Figure 5: SMM layout and geographic representation (eWater, 2020).

Table 2: Flow constraint scenarios run in the Source Murray Model for Stage 1A (MDBA, 2022a)

Scenario Label	Scenario category	Flow constraint (ML/d) at location			
		Doctors Point	Yarrawonga Weir	Mid-Goulburn	Lower Goulburn
Y15D25	Current	15,000	25,000	10,000	9,500
Y25D25	G17 set	25,000	25,000	10,000	17,000
Y30D30		30,000	30,000	10,000	17,000
Y35D35		35,000	35,000	10,000	17,000
Y40D40		40,000	40,000	10,000	17,000
Y45D40		40,000	45,000	10,000	17,000
M10L17 - Y40D40	Y40D40 set	40,000	40,000	10,000	17,000
M10L21 - Y40D40		40,000	40,000	10,000	21,000
M12L21 - Y40D40		40,000	40,000	12,000	21,000
M14L25 - Y40D40		40,000	40,000	14,000	25,000

3. Hydrological outcomes – Goulburn River

This section of the report summarises key outcomes from the hydrological modelling done for the Goulburn River using the SGEFM and GBCCL Source model. More detailed information on the modelling approach and results is provided in reports by John *et al.* (2022) and DEECA (2023) for the SGEFM and GBCCL Source model respectively.

3.1 Stochastic Goulburn Environmental Flow Model

Figure 6 summarises the range of outcomes expected for three key hydrological indicators in the Goulburn River system under current climate conditions if constraints are relaxed in the mid-Goulburn and/or lower Goulburn. Figure 7 shows selected results from Figure 6 for discrete constraint thresholds in the mid- and lower Goulburn. These modelled outcomes are for the scenario where all environmental water holdings in the Goulburn system are used to meet environmental water demands in the lower Goulburn (box A of Figure 2). Figure 6 and Figure 7 show that:

- The reliability of allocations to water share holders is expected to be virtually unchanged by constraint relaxation (see left panel of Figure 6).
- Shortfalls in meeting environmental water demands would decline as the mid-Goulburn constraint is relaxed from 10,000 to 14,000 ML/d and the lower Goulburn constraint is relaxed from 9,500 ML/d to about 21,000 ML/d However, environmental water shortfall reductions would plateau for constraint relaxation beyond about 14,000 ML/d in the mid-Goulburn and 21,000 ML/d in the lower Goulburn.
- The degree to which use of environmental water holdings is constrained reduces as constraints are relaxed in a similar manner observed for environmental water shortfalls. That is, the degree to which environmental water deliveries are constrained reduces as the mid-Goulburn constraint is relaxed from 10,000 ML/d to 14,000 ML/d and the lower Goulburn constraint is relaxed from 9,500 ML/d to about 25,000 ML/d. The rate of reduction plateaus for constraint relaxation beyond 14,000 ML/d in the mid-Goulburn and about 25,000 ML/d in the lower Goulburn.

These patterns suggest that if regulated releases from Lake Eildon are capped below minor flood level (13,700 ML/d at the time of writing) the change in environmental water shortfalls and delivery constraints will be minimal if mid-Goulburn constraints are relaxed beyond 14,000 ML/d. The results also suggest that if the mid-Goulburn constraint is 14,000 ML/d, the patterns of tributary inflows under current climate conditions are such that the change in environmental water shortfalls and delivery constraints will be minimal if lower Goulburn constraints are relaxed beyond 21,000 – 25,000 ML/d.

John *et al.* (2022) found that these patterns were very similar regardless of whether all environmental water holdings in the Goulburn system were used to meet lower Goulburn environmental water demands, or a combination environmental water demands in the lower Goulburn and River Murray.

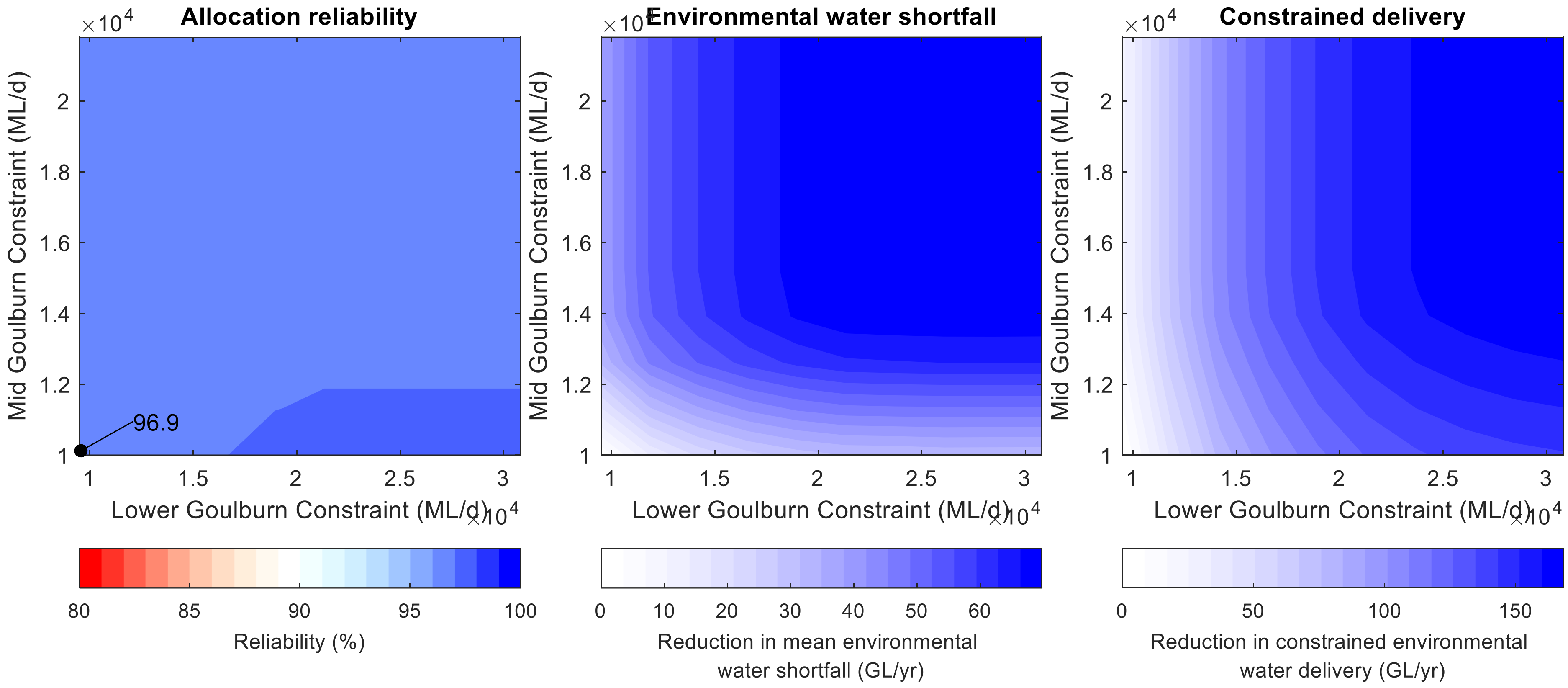


Figure 6: Reliability of high reliability water share allocations in the Goulburn (left panel), reduction in mean annual environmental water shortfalls (centre) and reduction in mean annual volumes of constrained environmental water delivery (right), for different options of mid- and lower Goulburn constraints (reproduced from Figure 6 of John *et al.*, 2022). For current constraints (10,000 ML/d in the mid-Goulburn and 9,500 ML/d in the lower Goulburn), mean environmental water shortfalls are 130 GL/year and the mean volume of constrained environmental flow delivery is 178 GL/year.

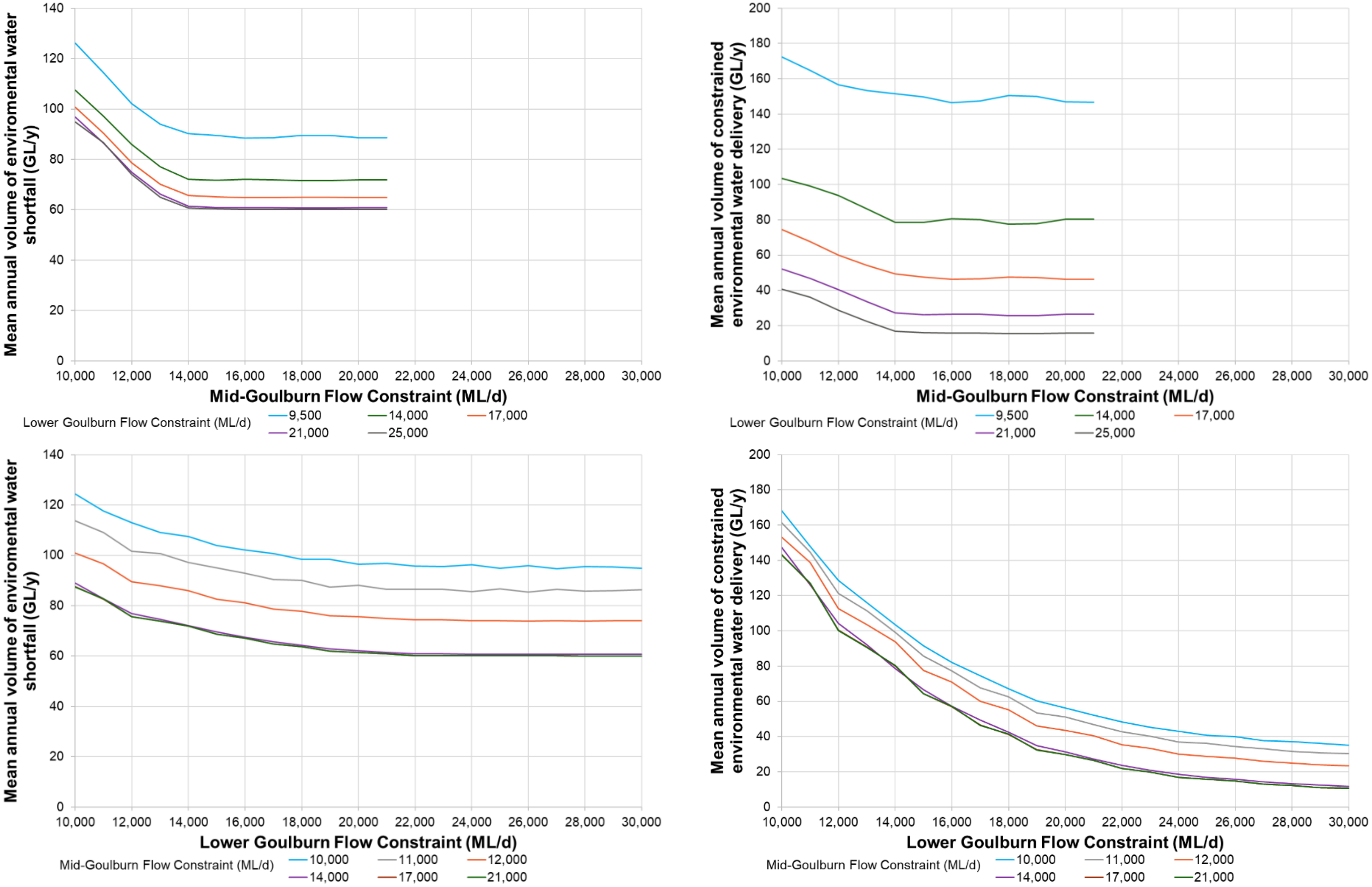


Figure 7: Results from the centre and right-hand panel of Figure 6, showing variation in the mean annual environmental water shortfall and volume of constrained environmental water delivery for either a given mid-Goulburn constraint and varied lower Goulburn constraint or vice-versa.

Based on these observations, the scenarios in Table 1 were chosen for further investigation using the GBCCL Source model. The rationale for choosing these scenarios is summarised in Table 3.

Table 3: Rationale for selecting scenarios from the combinations modelled in SGEFM for further exploration in the GBCCL Source model.

Scenario	Mid-Goulburn constraint	Lower Goulburn constraint	Rationale for selection
Scenario 1	10,000 ML/d	17,000 ML/d	Generally the lowest constraint option that still provided overall ecological benefits; avoids constraint relaxation in the mid-Goulburn
Scenario 2	10,000 ML/d	21,000 ML/d	For the scenario that avoids constraint relaxation in the mid-Goulburn, there is minimal change in the hydrologic metrics if the lower Goulburn constraint is relaxed beyond 21,000 ML/d
Scenario 3	12,000 ML/d	21,000 ML/d	Mid-point between Scenario 1/2 and Scenario 4.
Scenario 4	14,000 ML/d	25,000 ML/d	A likely upper bound on the ecological benefits and degree of hydrological change expected from constraint relaxation assuming flows are managed within known minor flood levels.

3.2 Goulburn Broken Campaspe Coliban Loddon Source model

Based on the observations made with the SGEFM (Section 3.1), the GBCCL Source model was run for the scenarios listed in Table 1. This step of the hydrology modelling produced daily times-series (from 1891 to 2020) of modelled flow along the Goulburn River for each constraint relaxation scenario simulated, assuming historic climate conditions. An example of these outputs is shown in Figure 8 for the period from June to September 2007.

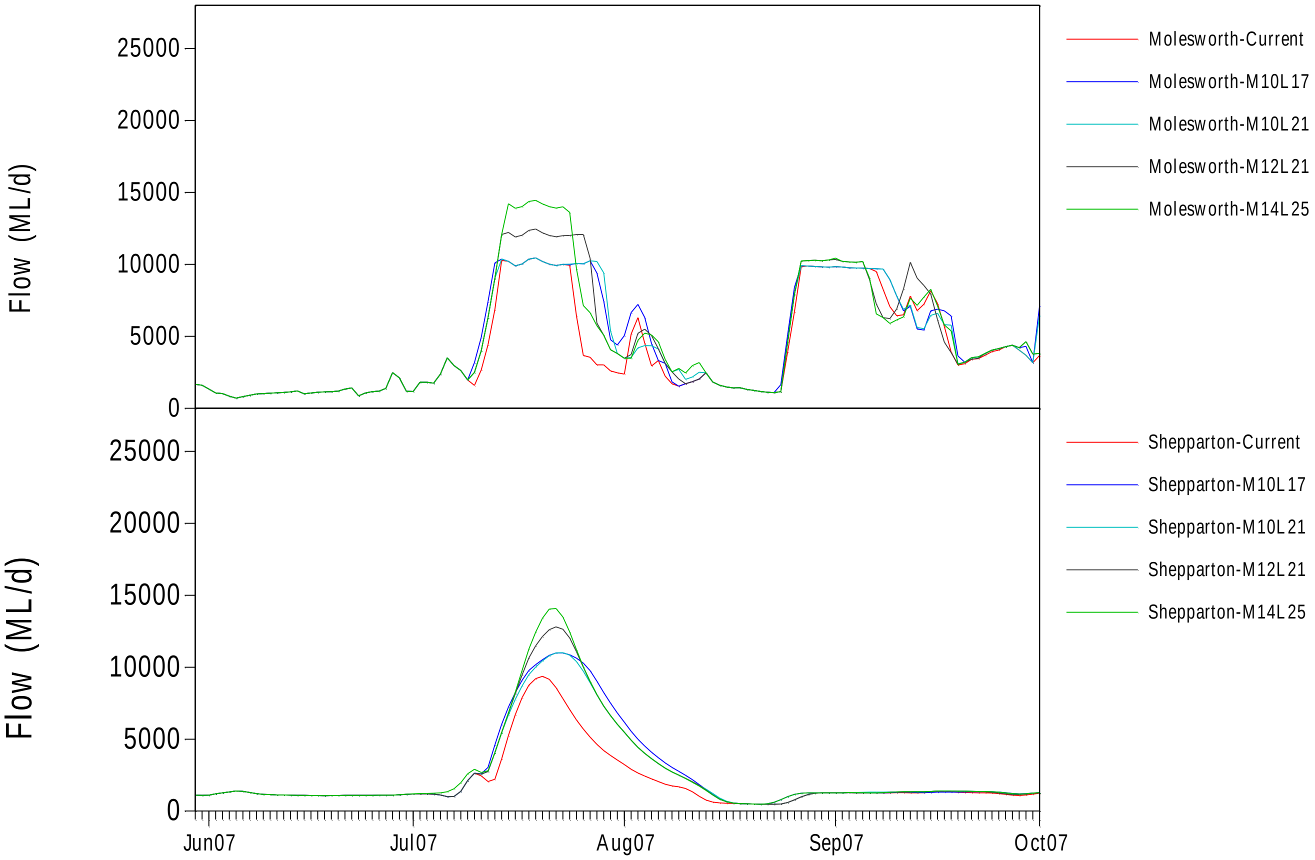


Figure 8: Example outputs from the GBCCL Source model showing daily flow modelled for Molesworth (top) and Shepparton (bottom) under current constraints and four constraint relaxation scenarios. The legend entry shows the constraint relaxation scenario. For example M14L25 is the case where the mid-Goulburn constraint is 14,000 ML/d and the lower Goulburn constraint is 25,000 ML/d.

The GBCCL Source model was also used to track modelled use of the environmental water holdings in the Goulburn system, and Figure 9 shows that relaxation of constraints allows much greater use of environmental water over the July to October period compared with current conditions. For example, relaxing the lower Goulburn constraint from 9,500 ML/d to 21,000 ML/d increases the modelled utilisation of environmental water holdings to meet Goulburn River environmental water demands from <50% to >75%. Further relaxation of the lower Goulburn constraint results in further increases in modelled utilisation, but at a decreased rate.

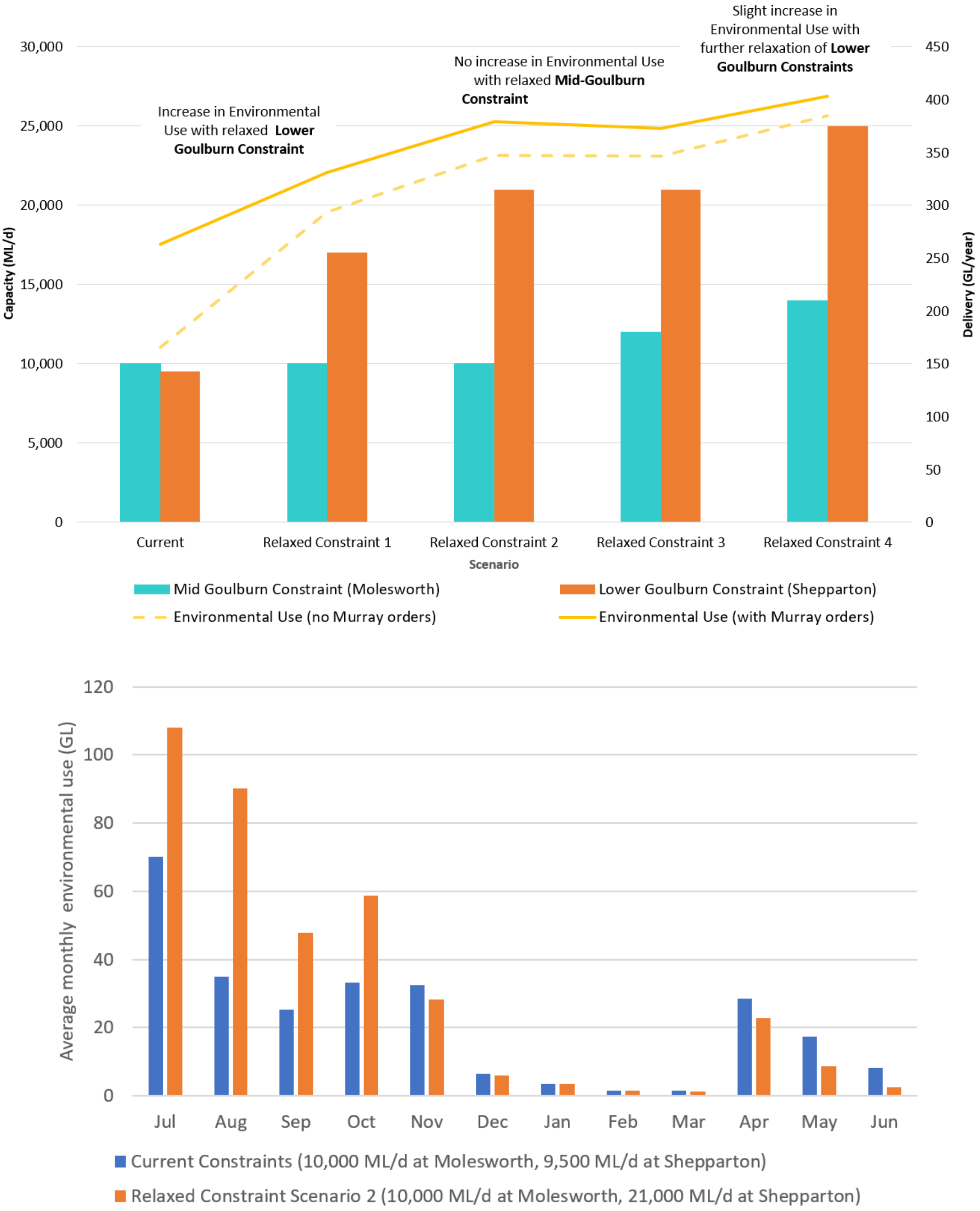


Figure 9: Modelled utilisation of Goulburn system environmental water holdings versus constraint relaxation in the mid- and lower Goulburn (top), and modelled within year use of environmental water for Scenario 2 (mid-Goulburn constraint of 10,000 ML/d and lower Goulburn constraint relaxed to 21,000 ML/d; as reproduced from the DELWP (2022a) report. The modelled current utilisation will be different to historical utilisation because environmental water demands and the management of water holdings have evolved over time.

Figure 9 also demonstrates that as constraints are relaxed along the Goulburn River, the incremental use of environmental water holdings in the Goulburn River system to meet River Murray demands decreases (i.e. the gap between the yellow-dashed and yellow-solid line becomes smaller).

Using the outputs available from the GBCCL Source model, several representations of the hydrological outcomes were prepared using the results from box E of Figure 2. These were:

- Time-series of the maximum flow within each month at Eildon, Molesworth, Trawool, Murchison, Shepparton and McCoys Bridge (e.g. Figure 10).
- Box plots of the number of days per year above thresholds of interest at the same locations listed above (e.g. Figure 11), either considering all seasons, winter/spring only, or winter/spring divided into seasons when Lake Eildon is or is not spilling in the current constraints scenario.
- Spell plots showing the timing and duration of flows at or above key thresholds at Molesworth and Shepparton (e.g. Figure 12).

The full set of plots prepared are included in the report appendices.

- The time-series of the maximum flow within each month (Appendix B) shows the expected change in the magnitude and timing of peak flows[5] because of constraints relaxation.
- The box plots of the number of days per year above flow thresholds (Appendix C) show the expected change in how often per year flows of a given magnitude would be exceeded.
- The spell plots (Appendix D) show the expected timing and duration of flows at or above key thresholds at Molesworth and Shepparton.

The modelled time-series of daily flow data were also used to inform the Alluvium (2022) assessment of the environmental benefits and risks of constraints relaxation.

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[5] Within day flow peaks may be slightly larger than the mean daily flow peaks simulated by the GBCCL Source model

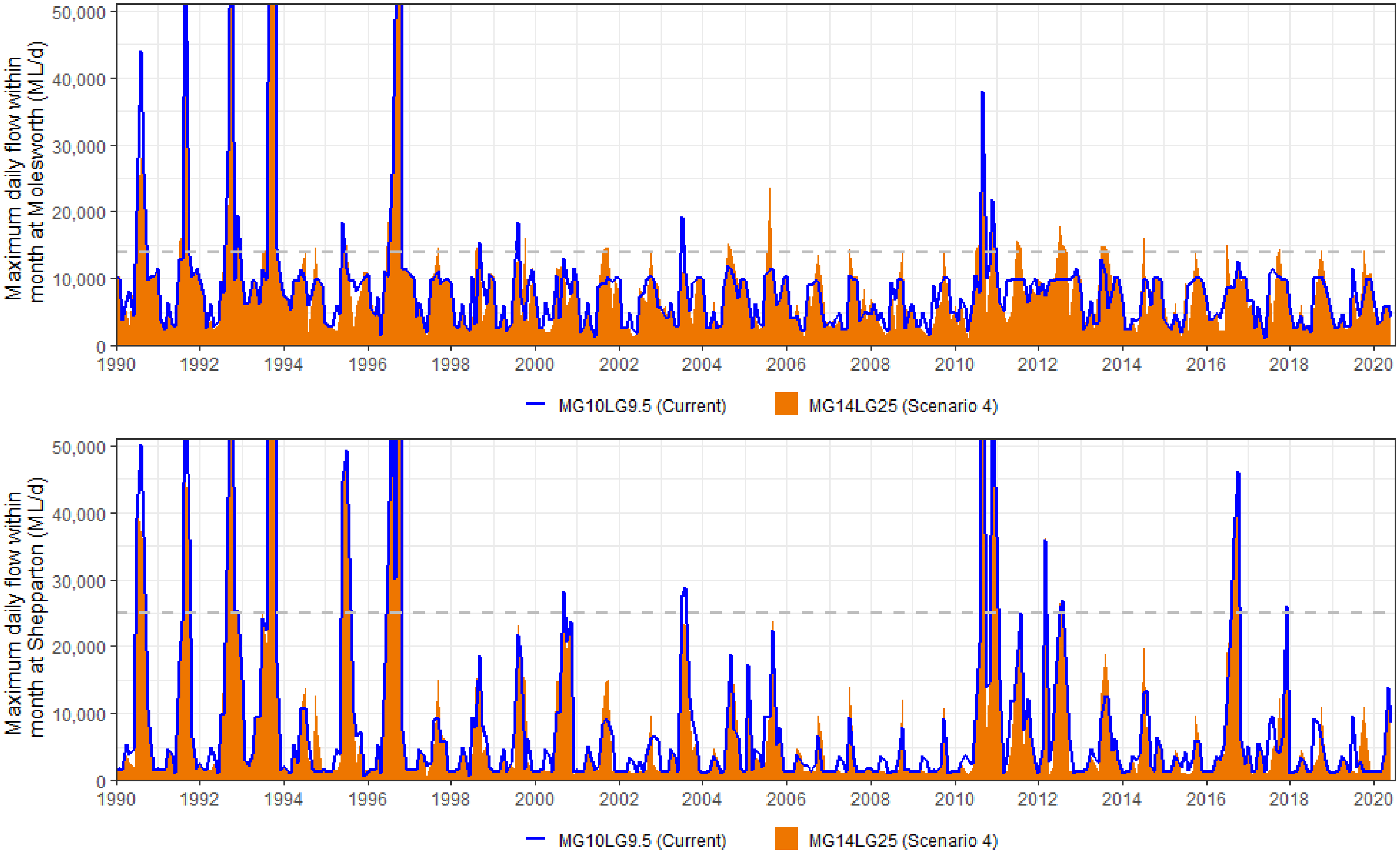
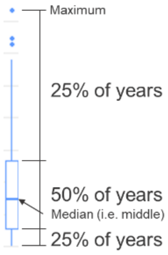


Figure 10: Maximum modelled daily flow at Molesworth (top) and Shepparton (bottom) within each month from 1990 to 2020 under current constraints and with constraints relaxed to 14,000 ML/d in the mid-Goulburn and 25,000 ML/d in the lower Goulburn.



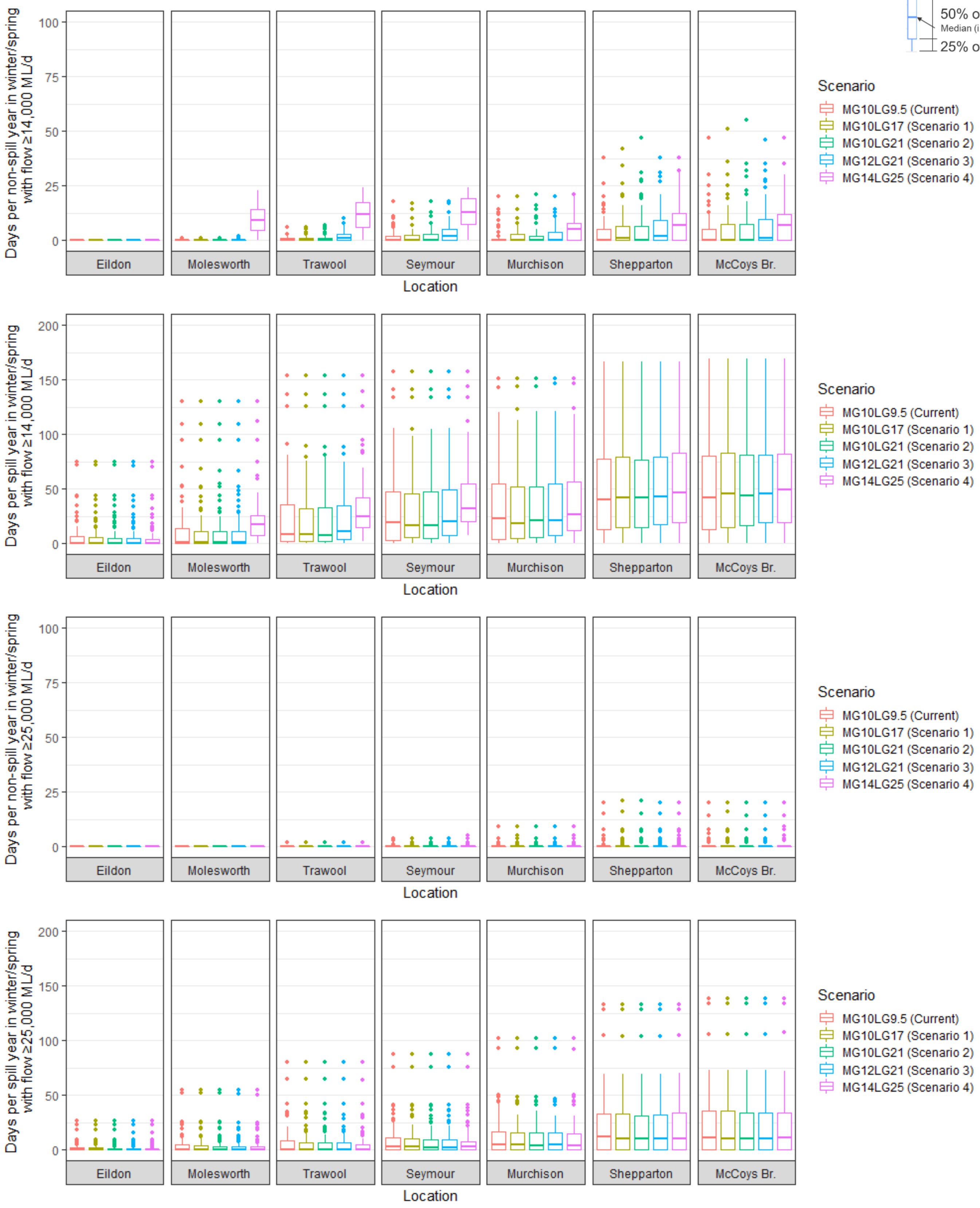
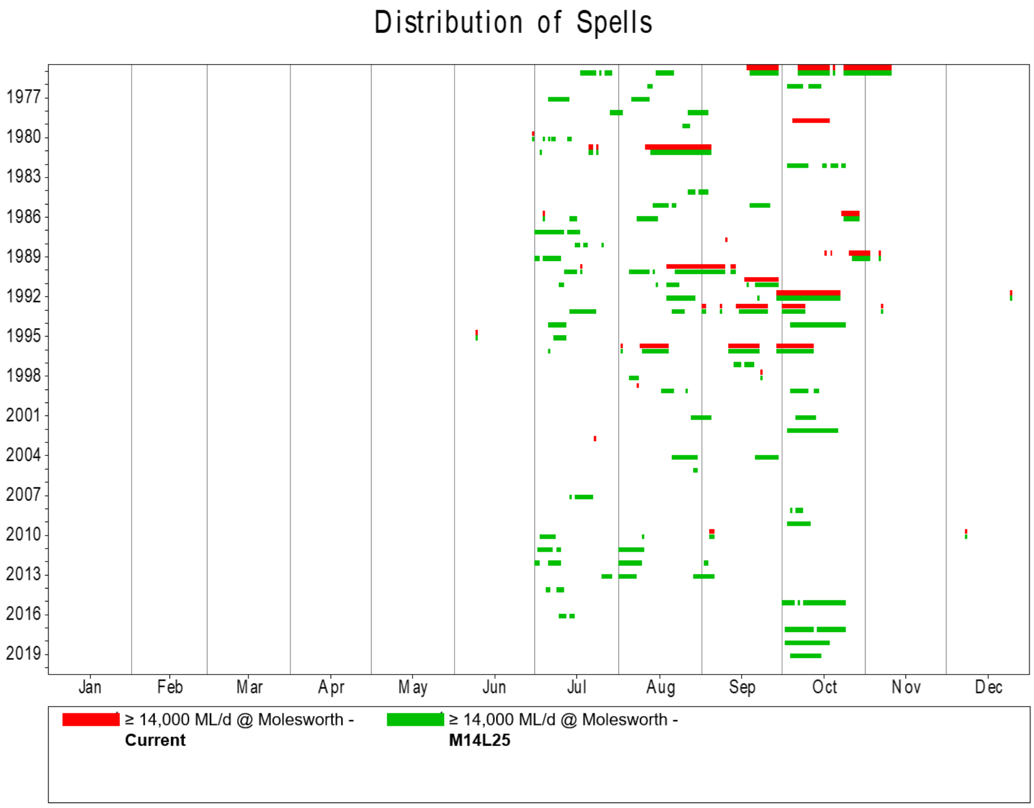


Figure 11: Box plots of winter/spring days in each year when flows of 14,000 ML/d (top two) or 25,000 ML/d (bottom two) would be achieved or exceeded at each location, under current and relaxed constraint scenarios, divided into years when Lake Eildon is or is not spilling under current constraints.



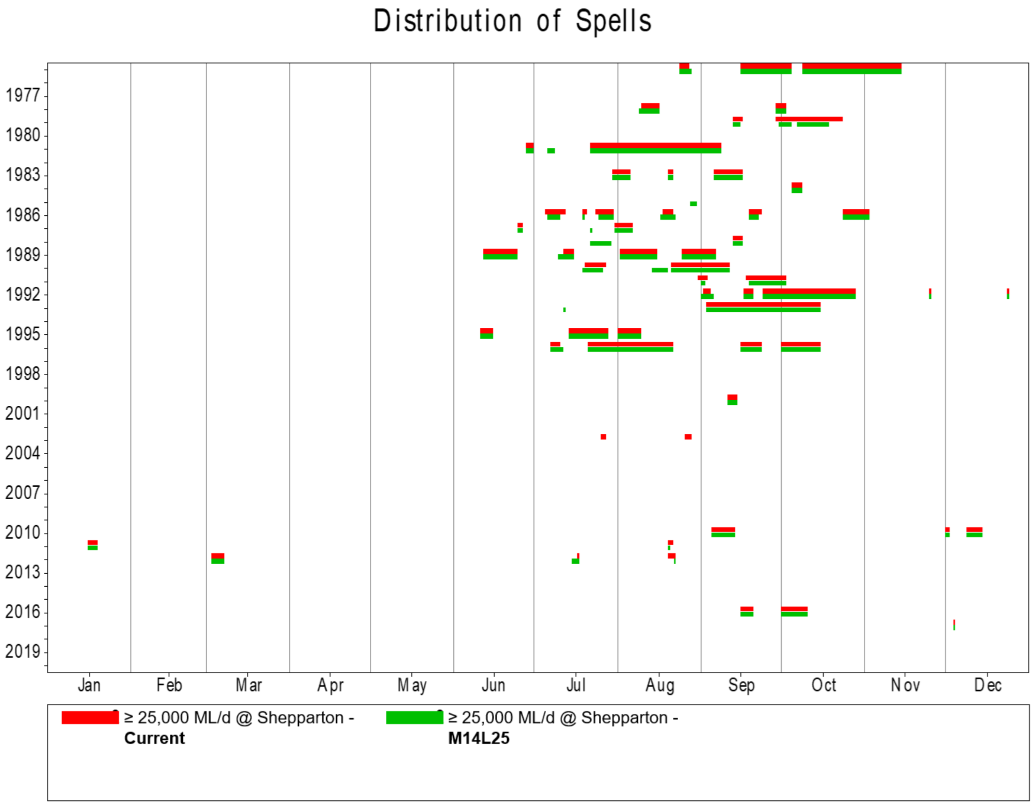


Figure 12: 1975 – 2020 spells of flow at or above 14,000 ML/d at Molesworth (top) and 25,000 ML/d at Shepparton (bottom) under current constraints and with constraints relaxed to 14,000 ML/d in the mid-Goulburn and 25,000 ML/d in the lower Goulburn.

Based on these figures (i.e. Figure 10 to Figure 12 and Appendix B to Appendix D), the following observations can be made:

The peak flow at Molesworth is expected to reach the mid-Goulburn constraint in most years. In contrast, the peak flow at Shepparton will only approach the lower Goulburn constraint if water released from Lake Eildon to the mid-Goulburn coincides with tributary inflows between Eildon and Shepparton (Figure 10). This observation is confirmed by the spell plots in Figure 12. This means that although utilisation of the available environmental water holdings may not increase significantly if the mid-Goulburn constraint is relaxed (Figure 9), the mid-Goulburn constraint has a strong influence on the peak flow that can be delivered to the lower Goulburn particularly during average or dry conditions.

Constraint relaxation will make most difference to how often flows will be near mid-Goulburn operational constraints in years when Lake Eildon is not spilling under current constraints (see top panel of Figure 11). The difference in the hydrologic regime is less noticeable in years when Lake Eildon is spilling under current constraints (second and fourth panel of Figure 11) and at thresholds above the mid-Goulburn constraint (third panel of Figure 11).

Figure 13 presents the information in Figure 11 and from Appendix C in a different way to further reinforce some of these points. In Figure 13, the proportion of years with at least 5 days of winter/spring flow above a range of thresholds at Molesworth (top) and Shepparton (bottom) is shown for current constraints and the four constraint relaxation scenarios simulated in the GBCCL Source model. This demonstrates that relaxing constraints increases the proportion of years with 5+ days of winter/spring flow at Molesworth for thresholds below or at the relaxed constraint. The frequency of flows at thresholds above the relaxed constraint reduces slightly. At Shepparton the consequence of relaxing constraints up to 14,000 ML/d in the mid-Goulburn is noticeable for flow thresholds up to 17,000 ML/d. The proportion of years with 5+ days of winter/spring flow at 21,000 ML/d is essentially unchanged and reduces slightly at 25,000 ML/d. This means that the GBCCL predicts that changes to the lower Goulburn hydrology begin plateauing once the lower Goulburn constraint is relaxed beyond ~17,000 ML/d, whereas the SGEFM predicted this plateauing to occur if the constraint is relaxed beyond ~21,000 ML/d.

The frequency with which winter/spring flows are expected to reach constraint thresholds in the lower Goulburn is influenced in part by how triggers for environmental water releases and inflow forecasts are represented in the GBCCL Source model. The existing GBCCL Source model assumes a particular flow is required before environmental water releases are made, and that tributary inflows will be 90% of the previous day's inflow. This approach is probably under-estimating the ability of storage managers to adjust releases in response to weather forecasts. There is potential therefore that different hydrological outcomes in the lower Goulburn could be simulated in the GBCCL Source model if a wider range of triggers for environmental water releases and a more realistic representation of inflow forecasts were modelled in future stages of the VCMP. Improving the representation of inflow forecasts in the GBCCL Source model would also potentially reduce the frequency with which modelled peak flows exceed the simulated mid-Goulburn constraint (e.g. as shown in Figure 10). The investigation of the buffers required to avoid flows exceeding relaxed operational constraints is scheduled for Stage 1B of the VCMP.

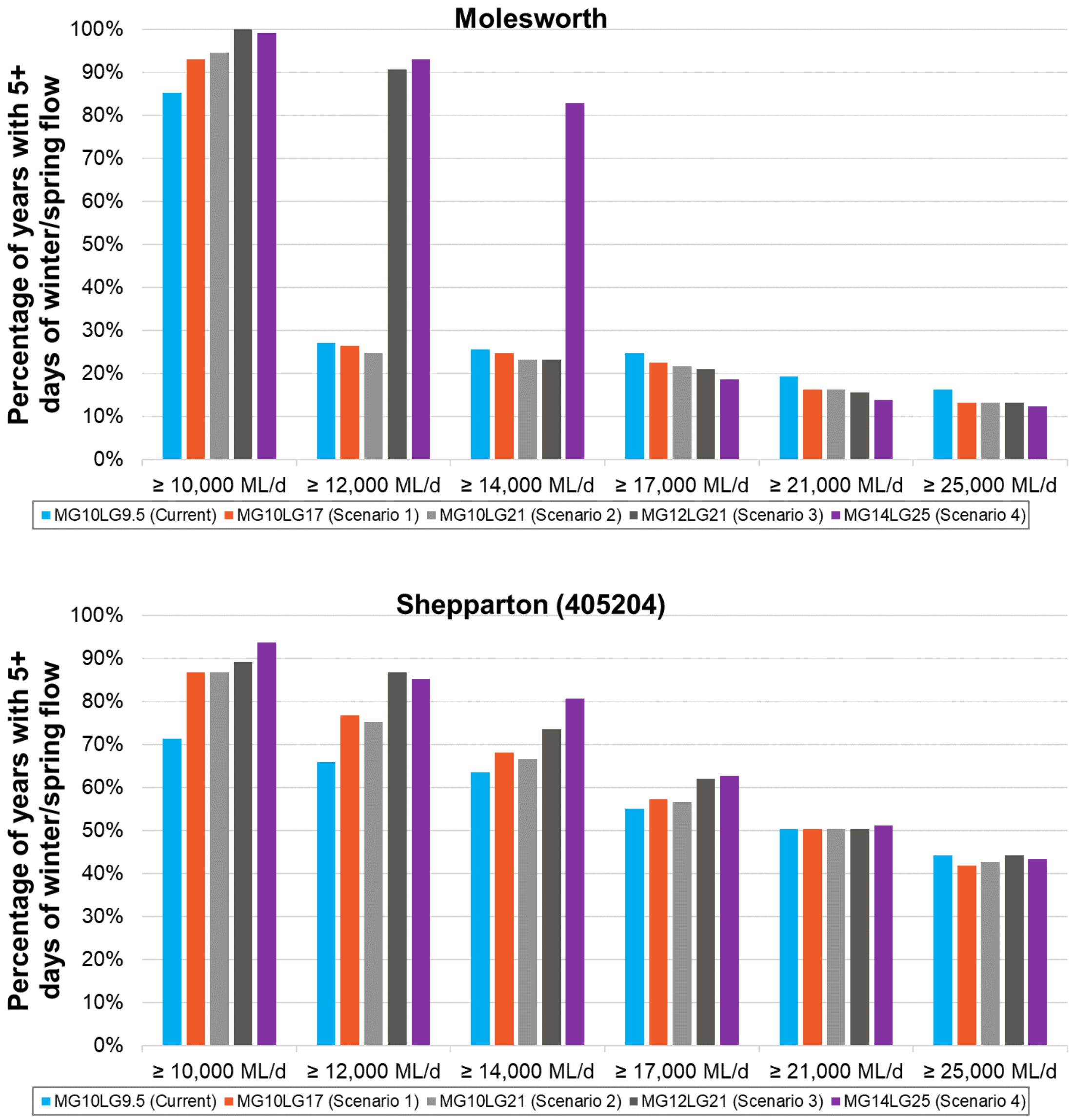


Figure 13: Proportion of years (1891-2020), with at least five days of winter/spring flow exceeding defined flow rates, for different mid- and lower Goulburn constraints: Molesworth (top panel) and Shepparton (bottom panel).

4. Hydrological outcomes – River Murray – Source Murray Model

This section of the report summarises key outcomes from the hydrological modelling done for the River Murray using the SMM. More detailed information on the modelling approach and results is provided in the MDBA (2022a) report. This work builds on the scenario modelling also completed for the NSW Reconnecting River Country Project using the SMM.

4.1 With a single set of Goulburn River constraints

Using the final outputs available from the SMM (box F in Figure 2) for the 'G17 set' of scenarios listed in Table 2, the same representations of the hydrological outcomes as used for the Goulburn were prepared. These were:

- Time-series of the maximum flow within each month at Doctors Point, downstream of Yarrawonga Weir, Tocumwal, Barmah, downstream of Torrumbarry Weir, Barham, downstream of Wakool Junction, Wentworth and the SA border (e.g. Figure 14).
- Box plots of the number of days per year above thresholds of interest at the same locations listed above (e.g. Figure 15), either considering all seasons or winter/spring only. The winter/spring results were also divided into seasons when Lake Hume is or is not spilling, but the outcomes were similar and are therefore not presented here.
- Spell plots showing the timing and duration of flows at or above key thresholds at Doctors Point and downstream of Yarrawonga Weir (e.g. Figure 16).

The full set of plots prepared are included in the report appendices.

- The time-series of the maximum flow within each month (Appendix E) shows the expected change in the magnitude and timing of peak flows[6] because of constraints relaxation.
- The box plots of the number of days per year above flow thresholds (Appendix F) show the expected change in how often per year flows of a given magnitude would be exceeded.
- The spell plots (Appendix G) show the expected timing and duration of flows at or above key thresholds at Doctors Point and downstream of Yarrawonga Weir.

The modelled time-series of daily flow data were also used to inform the Alluvium (2022) assessment of the environmental benefits and risks of constraints relaxation.

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[6] Within day flow peaks may be slightly larger than the mean daily flow peaks simulated by the GBCCL Source model

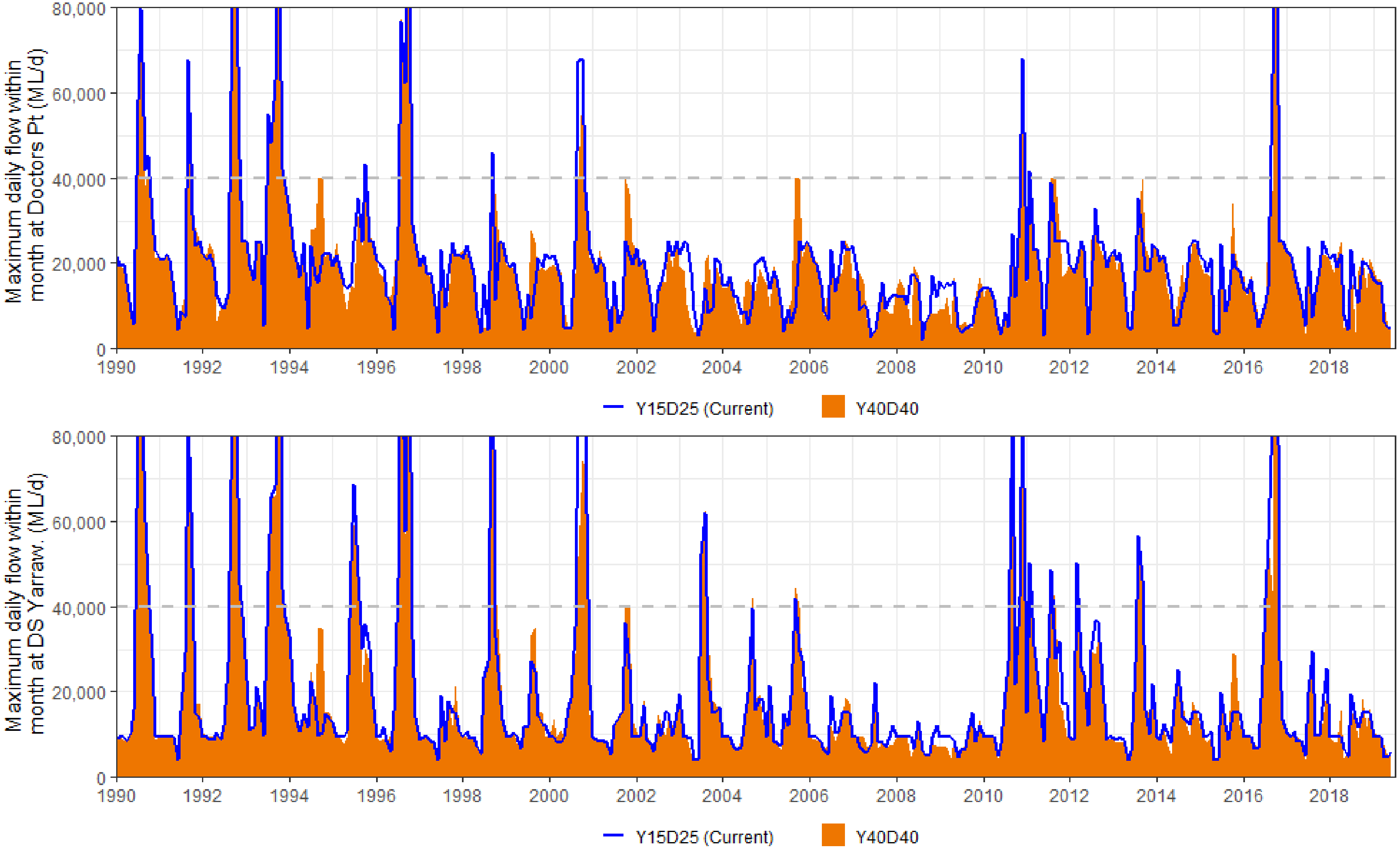
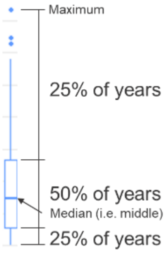


Figure 14: Maximum modelled daily flow at Doctors Point (top) and downstream of Yarrawonga Weir (bottom) within each month from 1990 to 2019 under current constraints and with constraints relaxed to 40,000 ML/d at both locations.



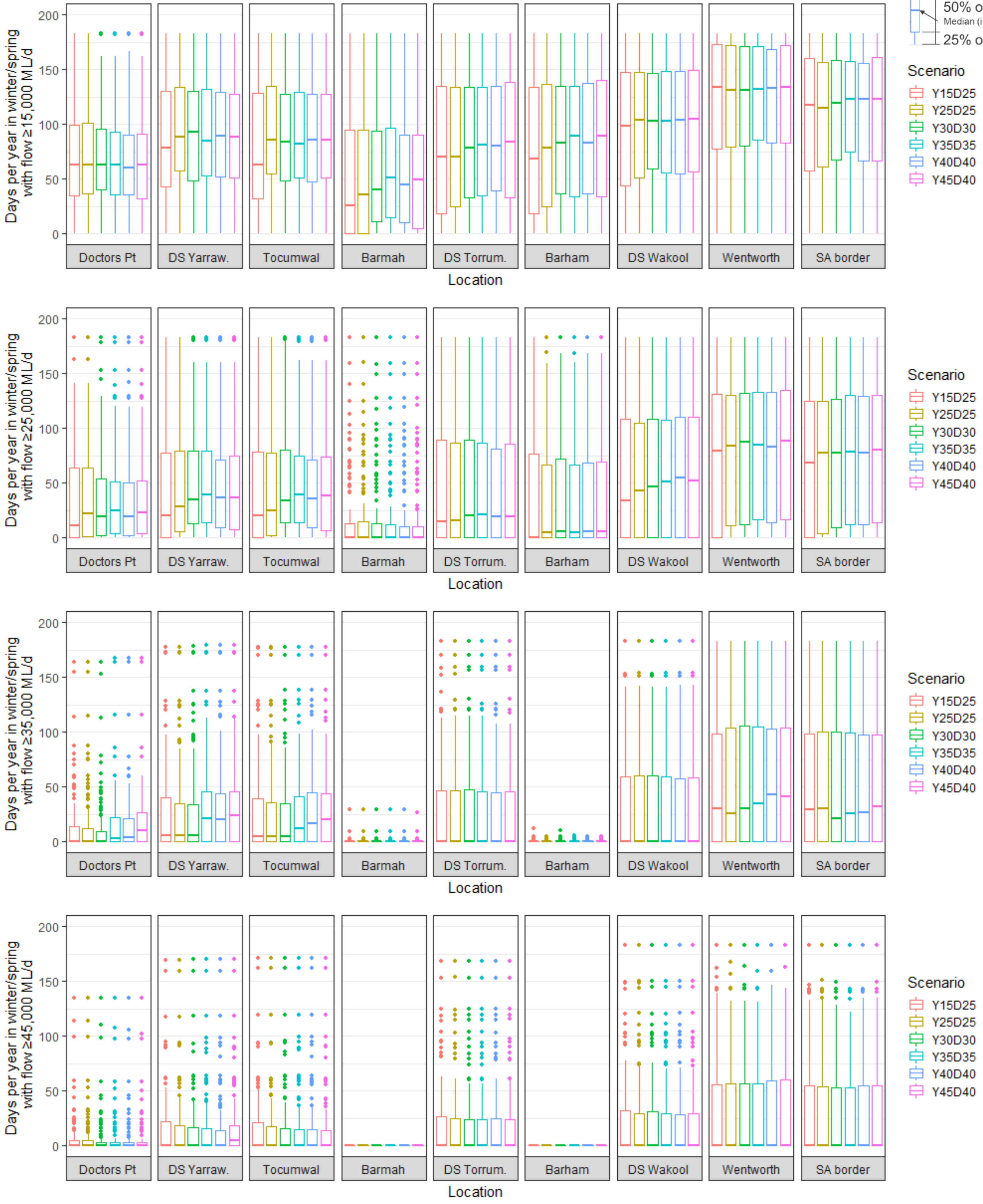


Figure 15: Box plots of the number of days in winter/spring where flows are equal to or greater than 15,000 ML/d, 25,000 ML/d, 35,000 ML/d and 45,000 ML/d depending on the location and constraint relaxation scenario modelled.

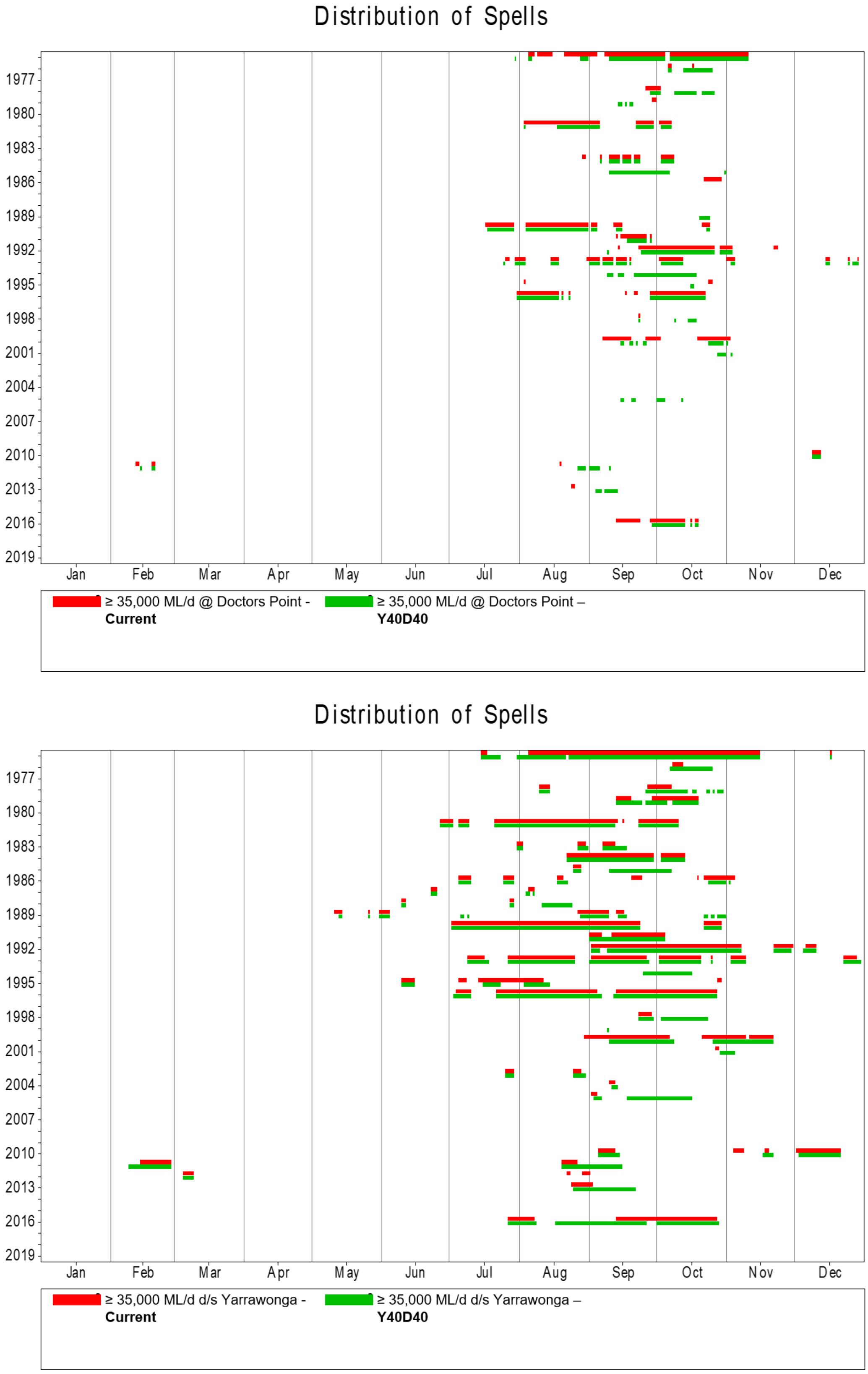


Figure 16: 1975 – 2019 spells of flow at or above 35,000 ML/d at Doctors Point (top) and downstream of Yarrawonga Weir (bottom) under current constraints and with constraints relaxed to 40,000 ML/d at both locations.

Based on these plots (Figure 14 to Figure 16 and Appendix E to Appendix G), the following observations can be made:

Regulated releases at the relaxed operational constraint at Doctors Point or downstream of Yarrawonga Weir are not expected to occur every year (Figure 14). Rather they are more likely to occur in years that are not very dry or not very wet.

For the River Murray upstream of Barmah Choke, the relaxation of constraints at Doctors Point and Yarrawonga increases the number of winter/spring days when flows are greater than current constraints but less than or equal to the relaxed constraint threshold. For example, Figure 15 shows that days per year of winter/spring flow greater than 25,000 ML/d or 35,000 ML/d increases at Doctors Point, Yarrawonga Weir and Tocumwal if constraints are relaxed to 35,000 ML/d or 40,000 ML/d at both locations. Figure 16 shows that this increase is most likely to be observed in August, September and October. Downstream of Barmah Choke the change in the number of days of winter/spring flow above 25,000 ML/d and 35,000 ML/d depends on the combination of location and constraint relaxation.

Once the flow of interest is above the relaxed constraint, the pattern changes. This is most apparent in the bottom panel of Figure 15 which shows the number of winter/spring days with flow greater or equal to 45,000 ML/d. For example, downstream of Yarrawonga Weir the number of days of winter/spring flow with flow greater or equal to 45,000 ML/d reduces if the constraint is relaxed to 25,000 ML/d – 40,000 ML/d, but increases if the constraint is relaxed to 45,000 ML/d. As the flow threshold of interest increases, the observed differences between current and relaxed constraint scenarios downstream of the Barmah Choke also decrease.

These observations are similar to those made about the hydrological modelling outcomes for the Goulburn River (Section 3.2) and are reinforced by Figure 17, which shows the proportion of years with at least 5 days of winter/spring flow above a range of thresholds at Doctors Point (top left) and downstream of Yarrawonga Weir (top right), Torrumbarry Weir (bottom left) and Wakool Junction (bottom right). This plot demonstrates that relaxing constraints increases the proportion of years with 5+ days of winter/spring flow at Doctors Point and Torrumbarry Weir for thresholds below or at the relaxed constraint. The frequency of flows at thresholds above the relaxed constraints reduces slightly. The observed difference between the current and relaxed constraint scenarios decreases with distance downstream, and shown by the results in Figure 17 for locations downstream of Torrumbarry Weir and the Wakool Junction.

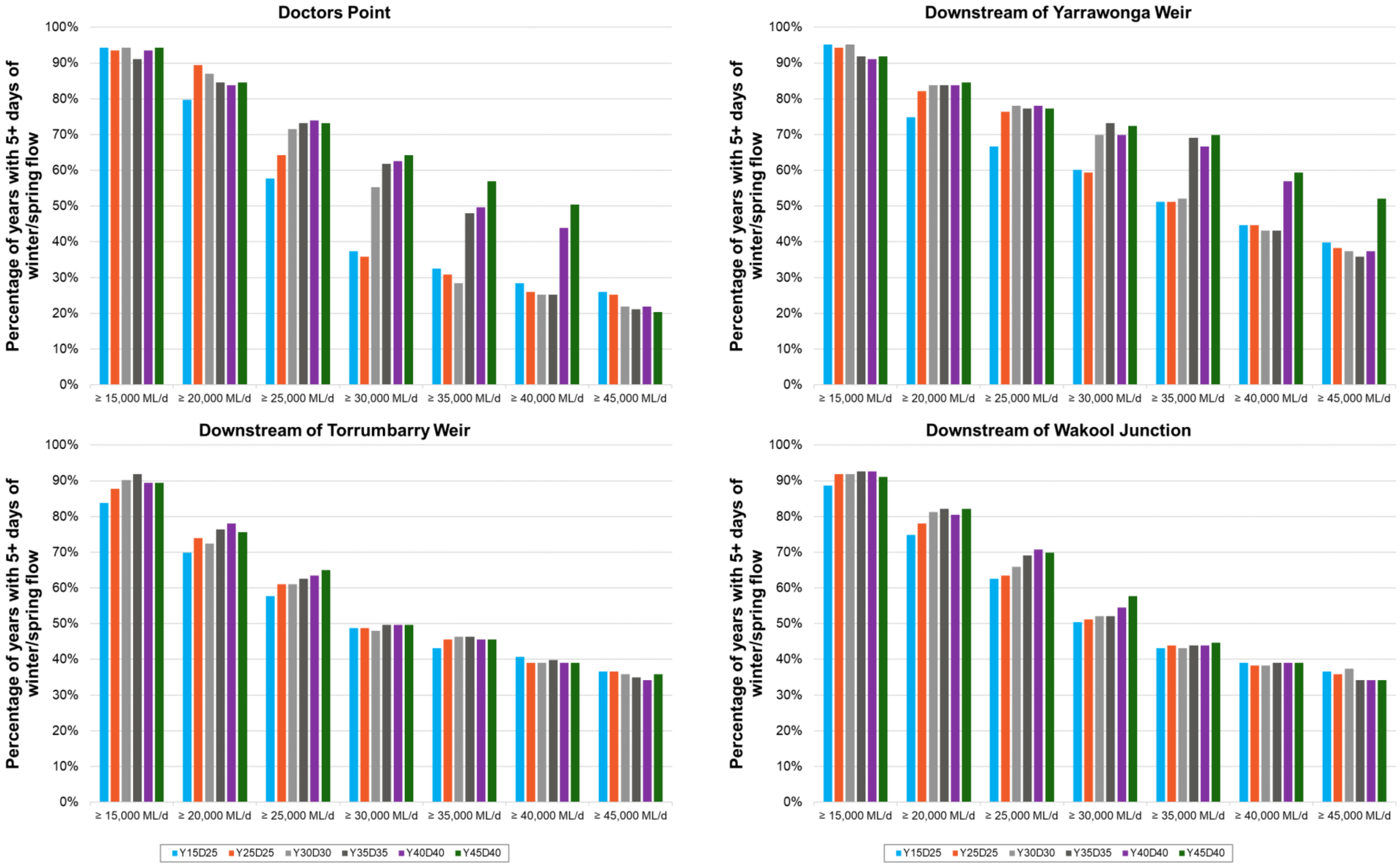


Figure 17: Proportion of years (1895-2019), with 5+ days of winter/spring flow exceeding defined flow rates, for different Doctors Point and Yarrawonga Weir constraints: Doctors Point (top left), and downstream of Yarrawonga Weir (top right), Torrumbarry Weir (bottom left) and Wakool Junction (bottom right).

4.2 With varied Goulburn River constraints

To test how the potential variation in mid- and lower Goulburn constraint thresholds is expected to influence the hydrology of the River Murray, the calculations used to create Figure 17 were repeated for the Y40D40 set of scenarios listed in Table 2. The results are shown in Figure 19. This figure suggests – based on the SMM methodology described by the MDBA (2022a) – that as the degree of constraint relaxation on the Goulburn River is increased:

- *Upstream of the Goulburn River confluence*: The number of years with 5+ days of winter/spring flow greater than thresholds of 15,000 ML/d to 45,000 ML/d will generally be unchanged or slightly reduce.
- *Downstream of the Goulburn River confluence (to Wakool Junction)*: The number of years with 5+ days of winter/spring flow greater than thresholds of 15,000 ML/d to 45,000 ML/d will generally be unchanged or slightly increase. An example of how relaxing constraints in the Goulburn River can change flow downstream of Yarrawonga Weir is provided in Figure 18.

In summary, the results in Figure 19 compared with those in Figure 17 indicate that hydrological outcomes for the River Murray are more sensitive to constraint relaxation options considered for Doctors Point and downstream of Yarrawonga Weir compared with constraint relaxation options considered for the Goulburn River. For example Figure 18 shows that in October 1994 the difference between the blue and green lines (M10L17 with Y40D40 versus M10L17 with Y25D25) is bigger than the difference between the green and black lines (M10L17 with Y40D40 versus M14L25 with Y40D40).

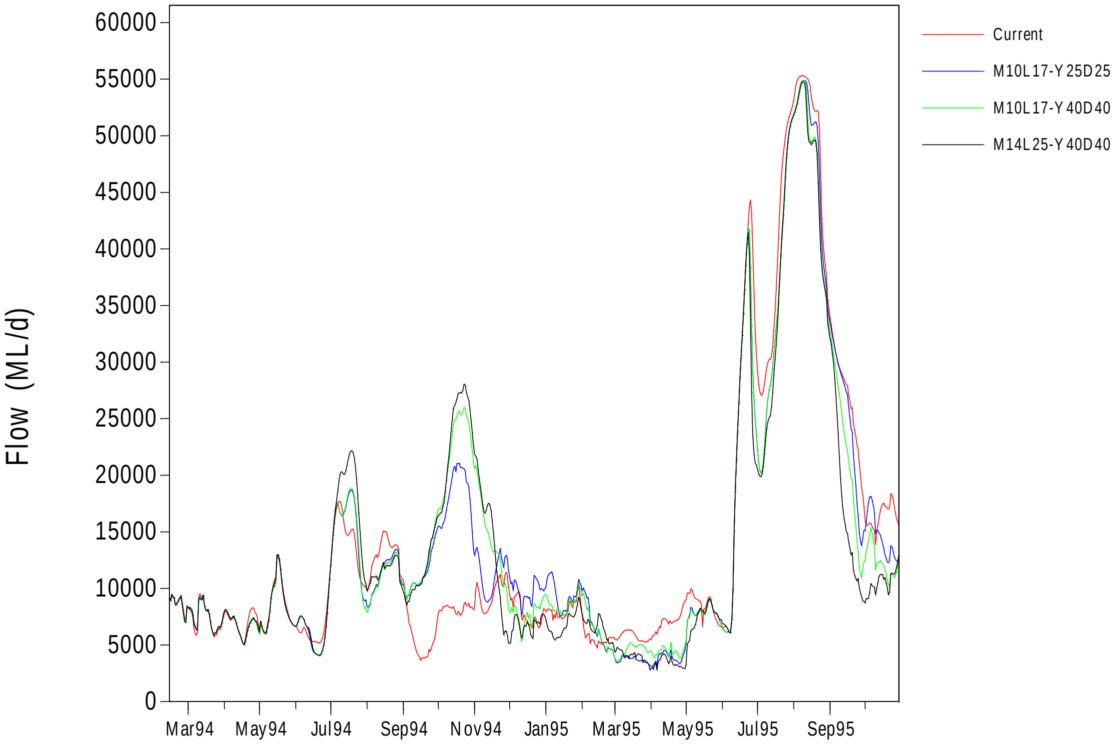


Figure 18: Daily time-series of modelled flow downstream of Torrumbarry Weir for current constraints and three combinations of constraint relaxation at Doctors Point, Yarrawonga Weir, the mid-Goulburn and lower Goulburn.

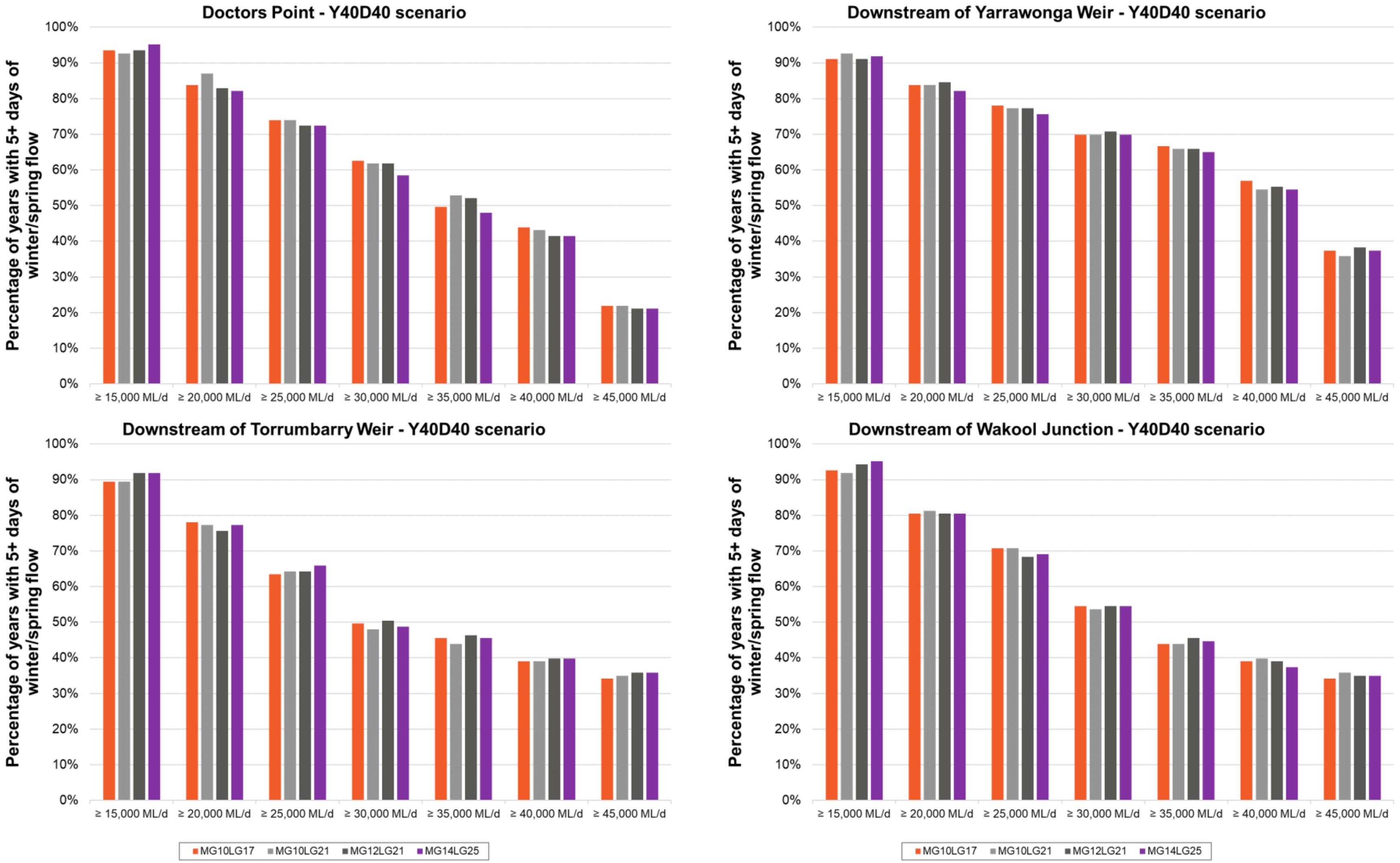


Figure 19: Proportion of years (1895-2019), with 5+ days of winter/spring flow exceeding defined flow rates, for the Y40D40 scenario and different Goulburn River constraints: Doctors Point (top left), and downstream of Yarrawonga Weir (top right), Torrumbarry Weir (bottom left) and Wakool Junction (bottom right).

It also needs to be noted that the SMM simulations completed for Stage 1A of the VCMP do not attempt to coincide environmental water deliveries along the River Murray with environmental water deliveries from the Goulburn to the Murray. An example of the typical differences in the timing of environmental water deliveries from the Goulburn to the River Murray and from Hume Dam / Yarrawonga Weir to Torrumbarry Weir is shown in Figure 20, as reproduced from Section 8.1 of the MDBA (2022a) report.

The potential benefits and impacts of more closely aligning the use of environmental water in the rivers that comprise the southern connected Murray-Darling Basin is being considered as part of the Enhanced Environmental Water Delivery (EEWD) project (www.water.vic.gov.au/__data/assets/pdf_file/0021/325083/31-Enhanced-Environmental-Water-Delivery-EEWD-Current-notification-Amendment-2-Redactions-applied.pdf).

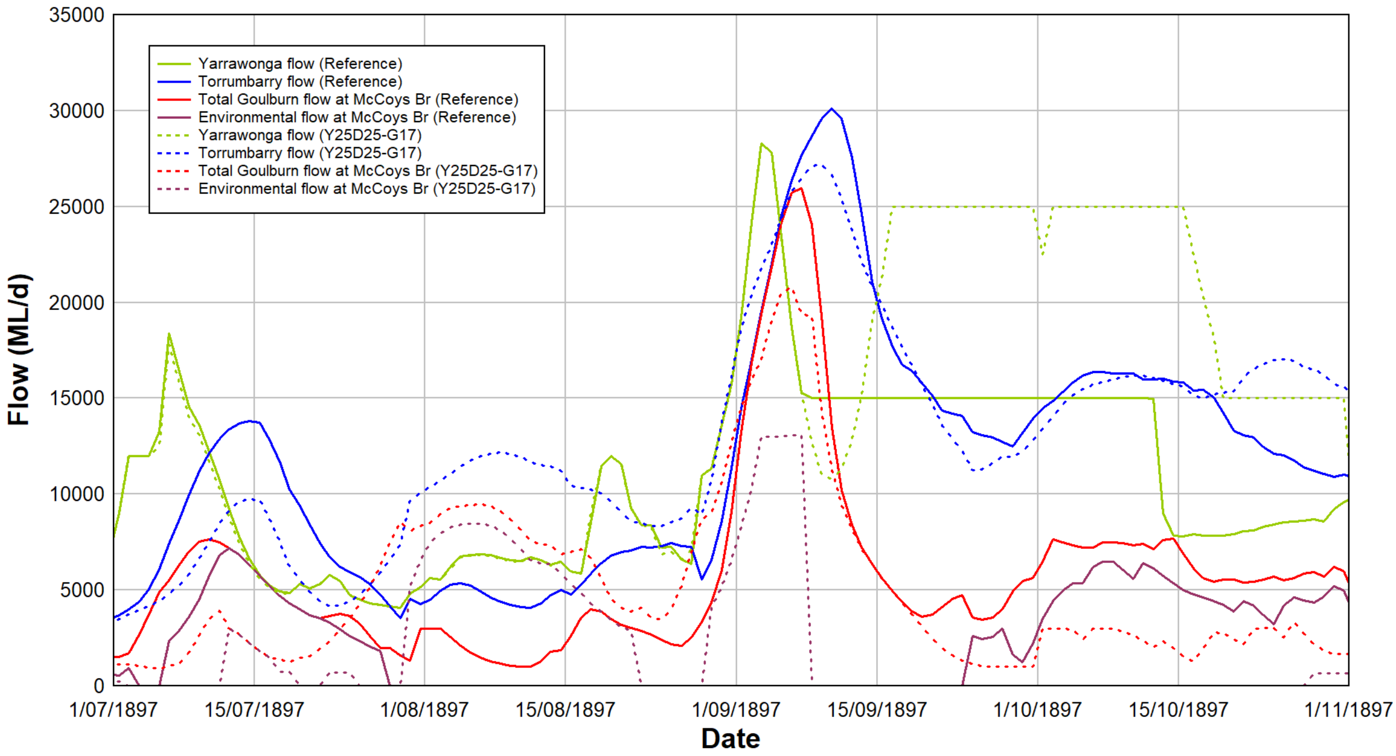


Figure 20: Example time-series of daily flows simulated in the SMM showing the peak of Goulburn River flows to the River Murray for the Y25D25 scenario (dotted red line) arrives before the peak of River Murray flows downstream of Yarrawonga Weir (dotted green line). Modelled flows downstream of Torrumbarry (blue dotted line) peak shortly after the Goulburn River inflows peak, but before the flows peak downstream of Yarrawonga Weir. This figure is reproduced from the MDBA (2022a) report.

5. Potential climate change impacts

5.1 Goulburn River

The potential for future climate change to influence the expected changes to the hydrological outcomes attributable to constraints relaxation was first tested using the SGEFM simulations of the Goulburn River system. The outcomes are described in detail by John *et al.* (2022).

In summary, "all constraint relaxation options [for the mid- and lower Goulburn] deliver benefits across a relatively wide range of plausible climates consistent with climate model projections. Hence, constraint relaxation is likely to offer robust climate change adaptation benefits" (John *et al.*, 2022). In other words:

- The improvements to important hydrologic metrics attributable to constraint relaxation are not expected to be significantly diminished if climate change is within a relatively wide range of potential future conditions.
- Constraint relaxation is therefore expected to be a useful strategy for mitigating the impacts of hydrological changes if the climate change that occurs is within a relatively wide range of potential future conditions.

This conclusion is based – in part – on the patterns of hydrologic metrics shown in Figure 21. This figure demonstrates that relative to the 'do nothing' baseline (i.e. maintaining current constraints), the relaxation of constraints will reduce environmental water shortfalls and the volume of constrained environmental water deliveries, even as the climate becomes drier and hotter. The degree of improvement relative to the baseline depends on the degree of constraint relaxation and change in annual rainfalls. The modelled outcomes are less sensitive to changes in temperature.

For example, if the climate does not change, the SGEFM simulated reduction in environmental water shortfalls compared with the current constraints scenario is 21%, 43% and 53% for the M10L17, M12L21 and M14L25 scenarios respectively. These percentages reduce as the projected climate becomes drier (i.e. the shading on the left side of Figure 21 becomes whiter as the change in mean precipitation becomes more negative). However, the percentage are still well above 0% for changes in average annual rainfall of up to -20%, and increase as the degree of constraint relaxation increases (i.e. the bottom left panel is much bluer than the top left panel).

If average annual rainfall decreases by more than 20%, the predicted benefits from constraint relaxation are significantly reduced. This is confirmed by the right side of Figure 21, which shows that there will be minimal constraints on environmental water deliveries if average annual rainfall reduces by more than 20%. This is because such a large decrease in rainfall would significantly reduce inflows to the Goulburn River system, and hence the water allocated to environmental water holders for use in the mid- and lower Goulburn.

These observations were also tested using the ecological models in the SGEFM, and the outcomes are described by John *et al.* (2022) and in the Alluvium (2022) assessment of the environmental benefits and risks of constraints relaxation.

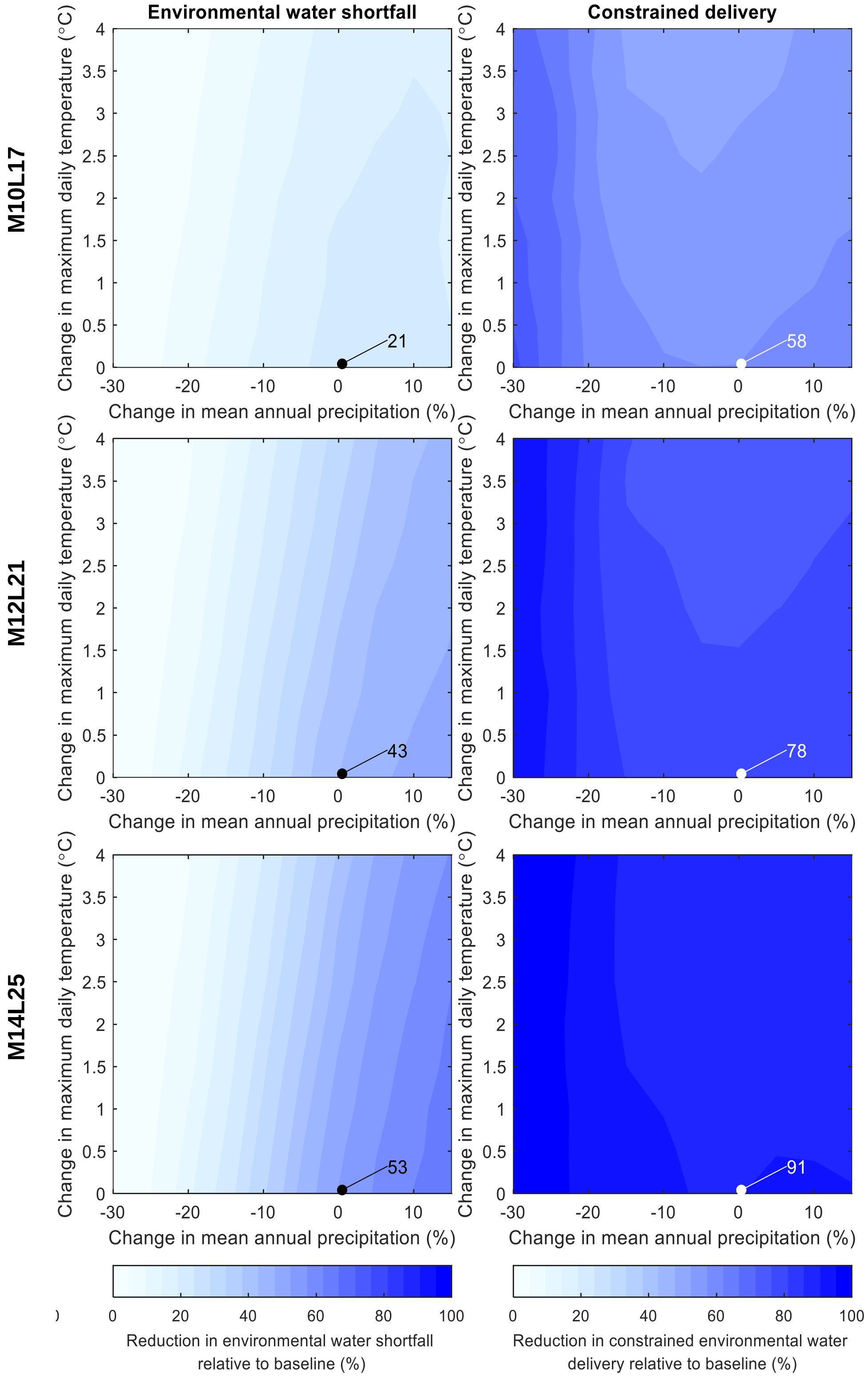


Figure 21: Percentage reduction in environmental water shortfalls and constrained environmental flow delivery for three constraint relaxation scenarios under a range of future climates (reproduced from University of Melbourne, 2022). The percentage reduction is relative to current constraints of 10,000 ML/d in the mid-Goulburn (M) and 9,500 ML/d in the lower Goulburn (L).

The GBCCL Source model was also used to simulate the current constraints scenario and the M10L17 constraint relaxation scenario for the Goulburn River system under post-1975 conditions, and projected conditions for the year 2070 with medium or high climate change. An example of the GBCCL Source model outputs for these simulations is provided in Figure 22.

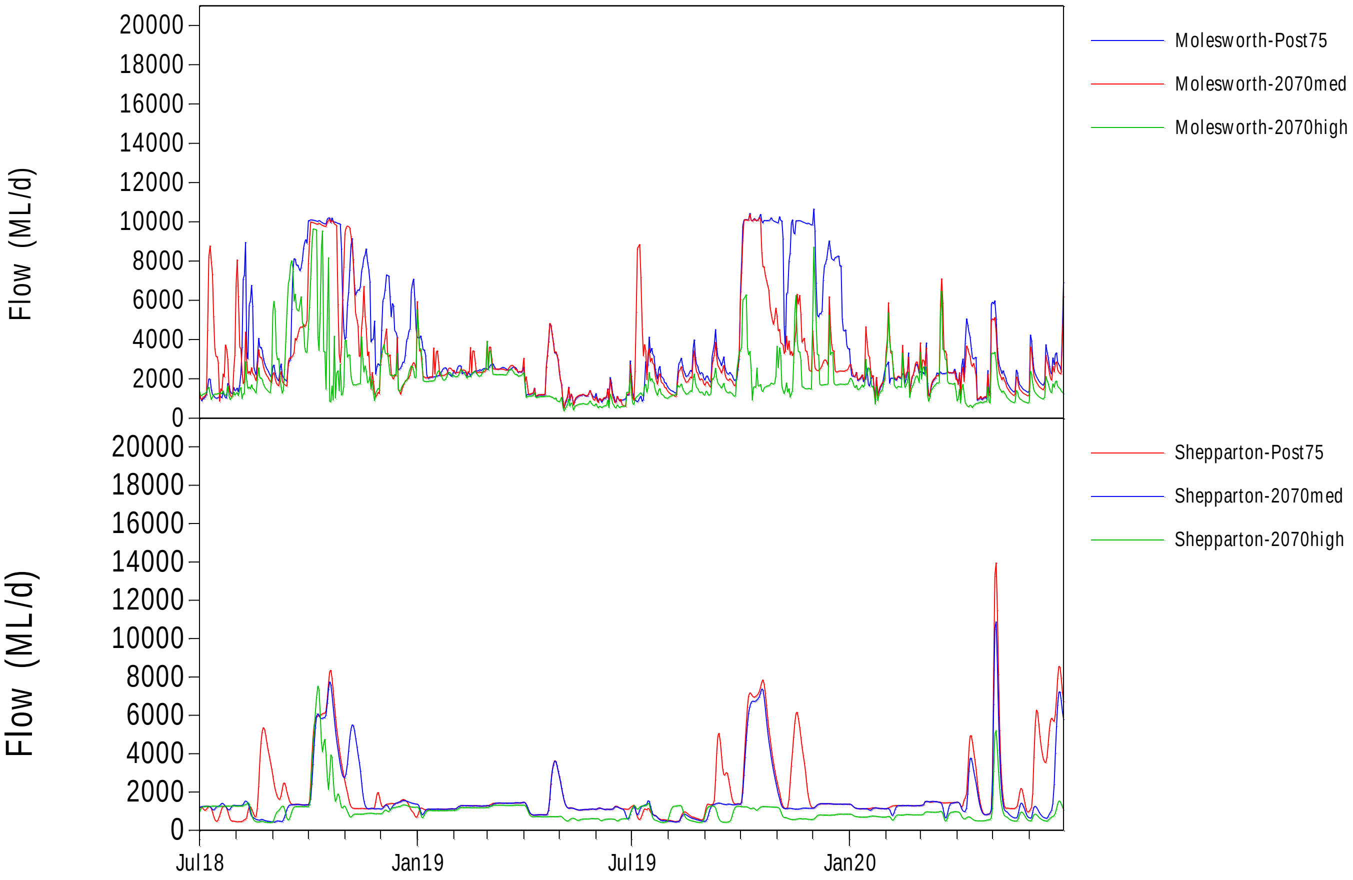


Figure 22: Example time-series of daily flow modelled for Molesworth and Shepparton from July 2018 to June 2020 for post-1975 conditions and year 2070 conditions under medium and high climate change. Historic conditions are the same as post-1975 conditions for these three years.

The GBCCL Source modelling results for these climate change scenarios tested are described in the DEECA (2023) report, but the outcomes are consistent with observations made using the SGEFM. For example, the GBCCL Source modelling results show that under post-1975 and 2070 medium climate change conditions relaxing constraints will increase the utilisation of environmental water holdings, but under the severe 2070 high climate change conditions constraint relaxation will make much less difference to environmental water use.

The figures on the following pages use GBCCL Source modelling results to provide further demonstration of how the interplay between constraints relaxation and potential future climate change is anticipated to influence the hydrology of the Goulburn River. Figure 23 compares difference in peak flows between the current constraint and M10L17 scenario at Molesworth and Shepparton for historic, post-1975 and year 2070 conditions (medium and high climate change). This figure shows that compared to the 'do nothing' case, the *difference* in peak flows after constraint relaxation is similar across the simulated climate conditions.

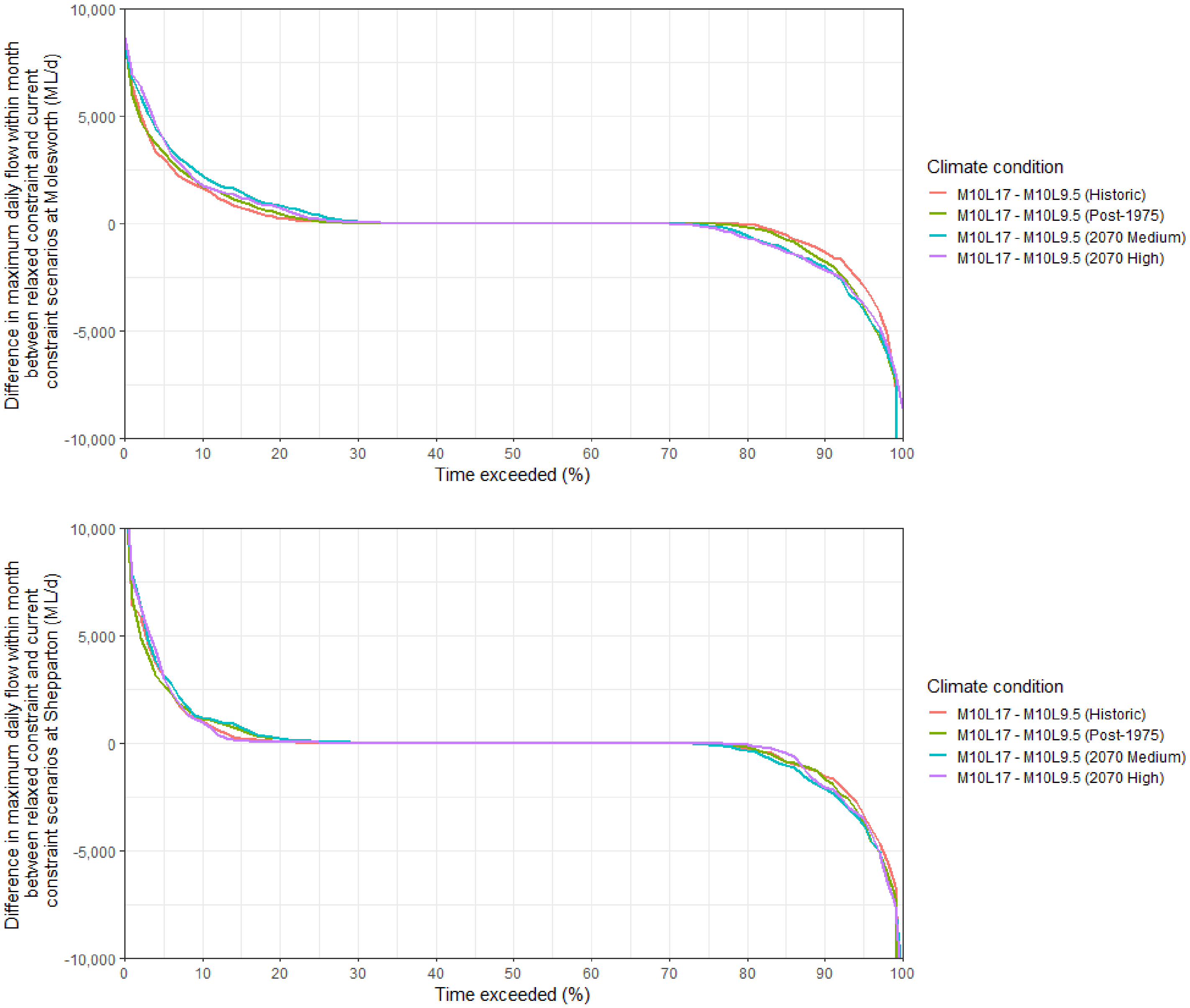
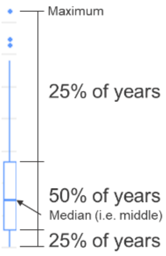


Figure 23: Modelled differences in the peak daily flows when current constraints (M10L9.5) are relaxed to 17,000 ML/d in the lower Goulburn (M10L17) under historic conditions and three representations of potential future climate conditions.

In contrast to Figure 23, Figure 24 shows a noticeable difference between the four simulated climate conditions. Figure 24 contains box plots of the number of winter/spring days in each year when flows of 10,000 ML/d (top) or 17,000 ML/d (bottom) would be achieved or exceeded at various Goulburn River locations, under the current and M10L17 constraint scenarios. This demonstrates that while the *differences* between the current and M10L17 constraint scenarios are still apparent – particularly at the 10,000 ML/d threshold – the *total* number of winter/spring days with flows of 10,000 ML/d / 17,000 ML/d or greater reduces as the climate conditions become drier.



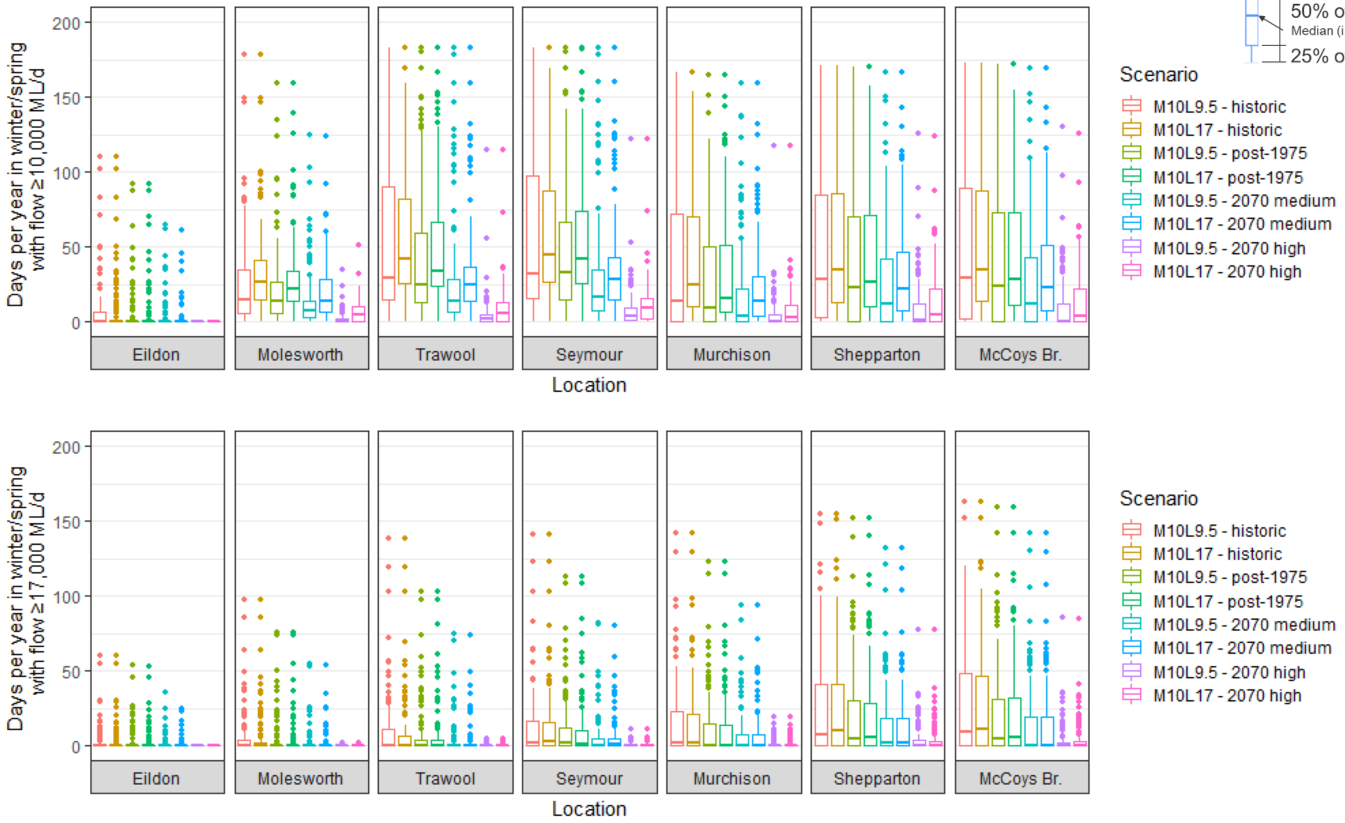
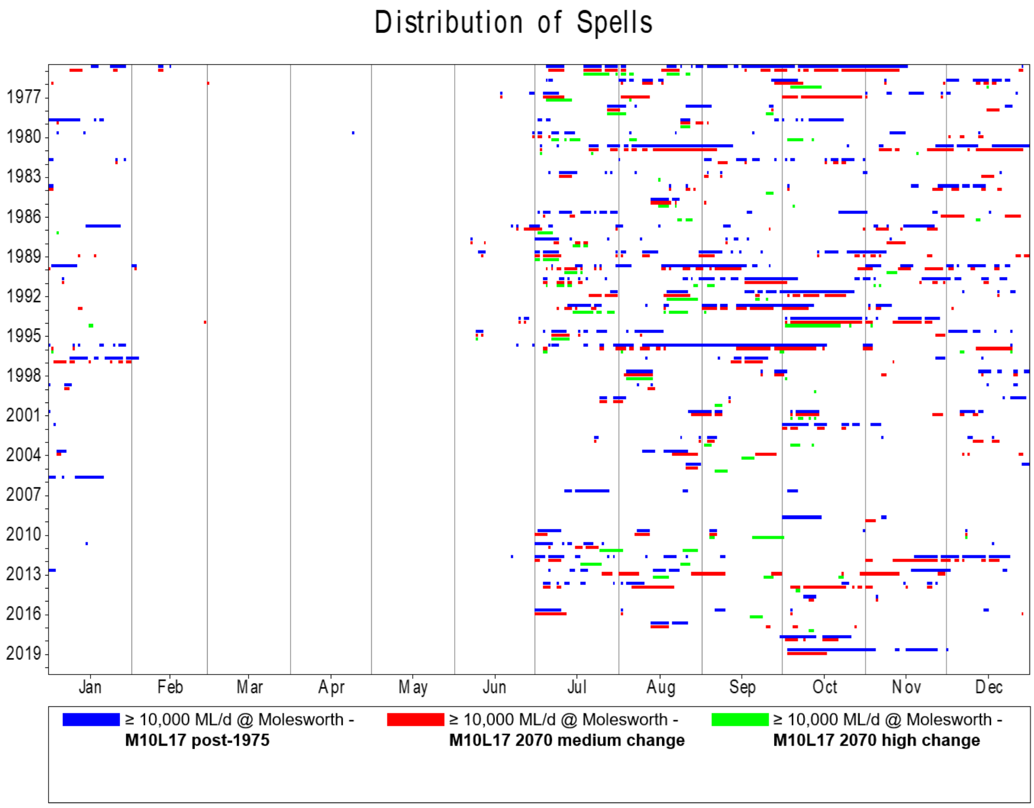


Figure 24: Box plots of winter/spring days in each year when flows of 10,000 ML/d (top) or 17,000 ML/d (bottom) would be achieved or exceeded at each location, under the current and M10L17 constraint scenarios.

Figure 25 plots spells of flow at or exceeding 10,000 ML/d at Molesworth (top) or 17,000 ML/d at Shepparton (bottom) for the M10L17 scenario under post-1975 conditions or year 2070 climate conditions with medium and high climate change. Historic conditions are not shown because for the years plotted the GBCCL Source modelling results are essentially the same as for post-1975 conditions. Figure 25 explains some of the trends seen in Figure 24, in that the duration of spells with flow at or above 10,000 ML/d and 17,000 ML/d reduces as the climate conditions become drier. The intervals between flows of these magnitudes also increases.

Figure 25 also shows that under post-1975 (blue) and year 2070 with medium climate change (red) conditions, flows are still regularly at or above the simulated constraints (10,000 ML/d in the mid-Goulburn; 17,000 ML/d in the lower Goulburn) but under year 2070 with high climate change conditions (green) flows are rarely at or exceeding these constraints. This suggests that – as observed with the SGEFM – there would be additional benefit from relaxing constraints beyond 10,000 ML/d in the mid-Goulburn and 17,000 ML/d in the lower Goulburn under somewhat drier conditions (post-1975 and year 2070 with medium climate change) but not under much drier conditions (year 2070 with high climate change). In future stages of the VCMP, this observation could be tested further by using the GBCCL Source model to simulate the other constraint relaxation scenarios (M10L21, M12L21 and M1425) under potential future climate conditions.



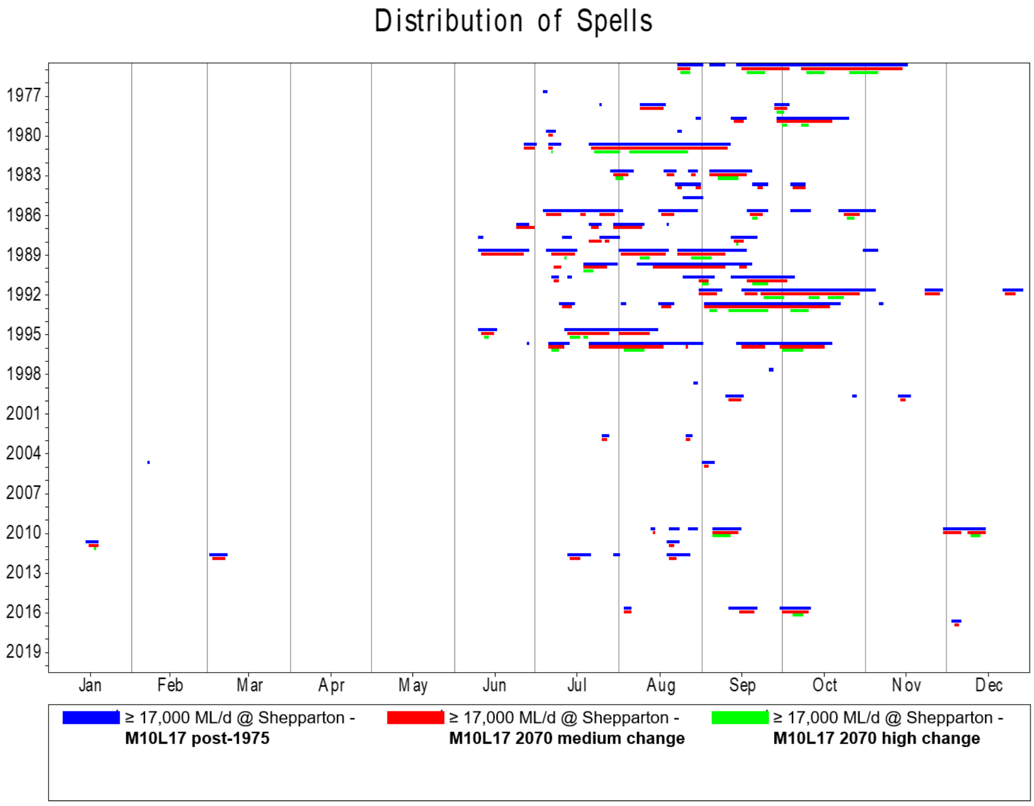


Figure 25: 1975 – 2020 spells of flow at or above 10,000 ML/d at Molesworth (top) and 17,000 ML/d at Shepparton (bottom) for the M10L17 scenario and post-1975 conditions or year 2070 climate conditions with medium and high climate change.

5.2 River Murray

The SMM was used to simulate the current constraints scenario and the Y40D40 constraint relaxation scenario for the River Murray system under post-1975 conditions, and projected conditions for the year 2070 with medium or high climate change. Examples of the SMM outputs for these simulations are included in Appendix C of the MDBA (2022a) report.

The key outcomes from the SMM modelling for potential future climate conditions are very similar to those observed using the GBCCL Source model. That is:

- Utilisation of the available environmental water holdings increases if constraints are relaxed under post-1975 and year 2070 medium climate change conditions, but constraint relaxation makes little difference to the average annual volumes of modelled environmental water use under year 2070 high climate change conditions.
- The *difference* in peak flows after constraint relaxation is similar across the simulated climate conditions (Figure 26), albeit that for the River Murray the 2070 high climate change case departs more from the other cases compared with what was observed for the Goulburn River.
- When the number of winter/spring days per year above various flow thresholds is considered (Figure 27), the difference between the current and relaxed constraint scenario is still apparent. What is particularly noticeable though is how the *total* number of days above the flow thresholds reduces as the climate condition becomes drier.
- As the climate condition becomes drier, the duration of flows at or near relaxed constraints is expected to reduce, and the intervals between flows of this magnitude will lengthen (Figure 28).

In future stages of the VCMP, these observations would ideally be tested further by using the SMM to simulate other constraint relaxation scenarios (e.g. Y25D25, Y30D30, Y35D35) under potential future climate conditions.

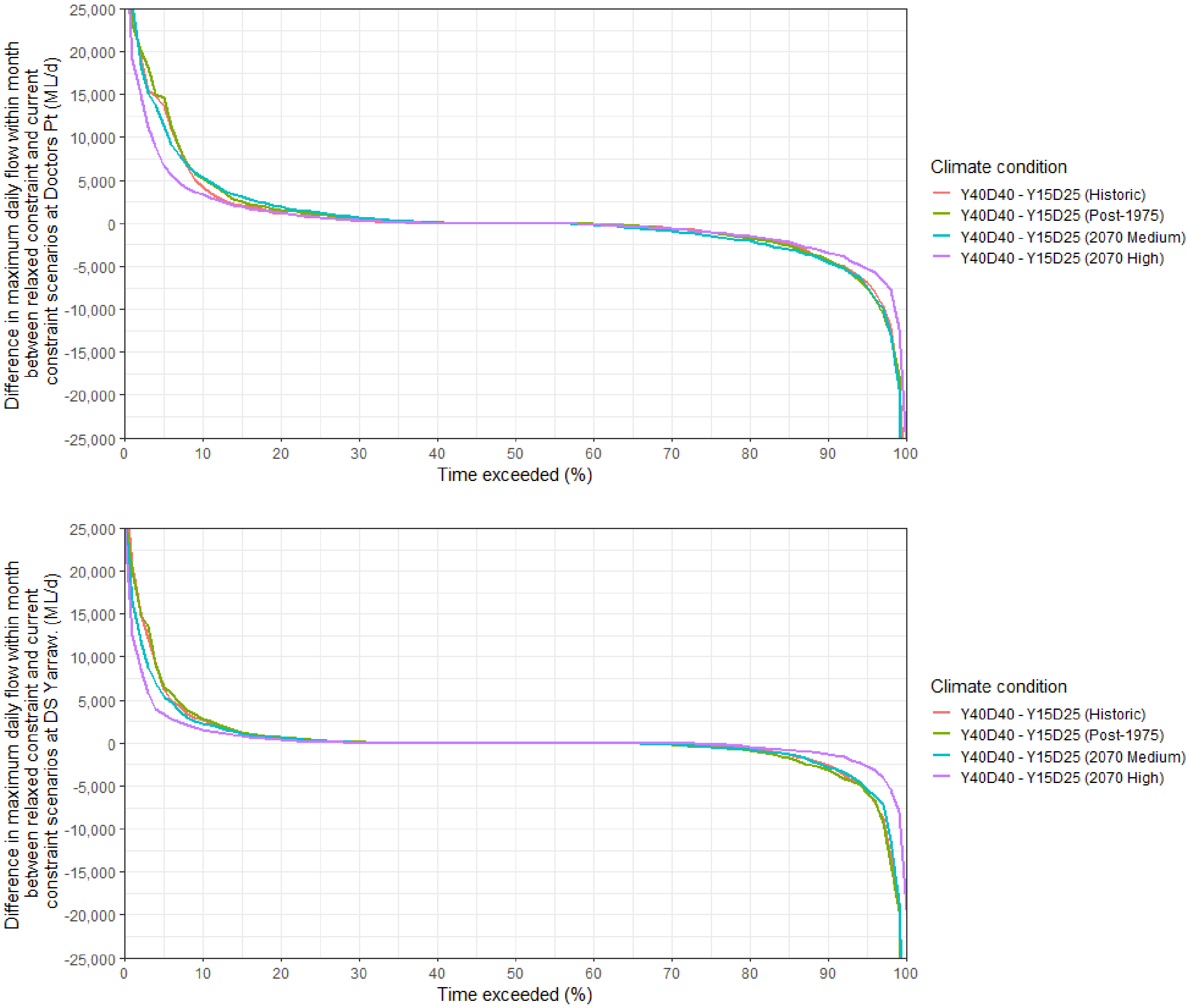
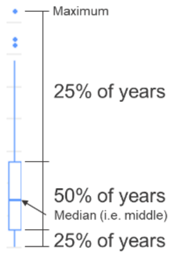


Figure 26: Modelled differences in the peak daily flows when current constraints (Y15D25) are relaxed to 40,000 ML/d at Doctors Point and downstream of Yarrawonga Weir (Y40D40) under historic conditions and three representations of potential future climate conditions.



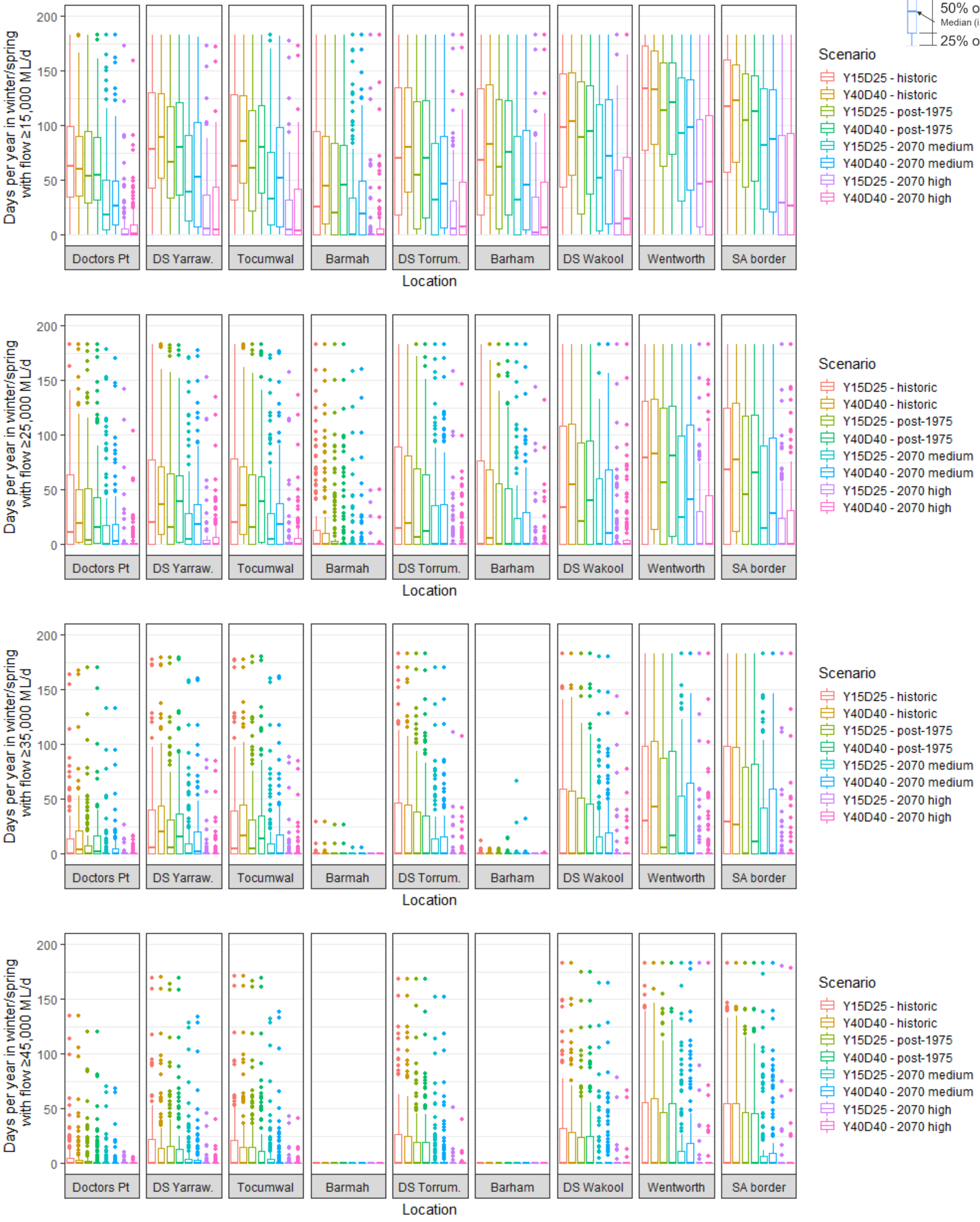
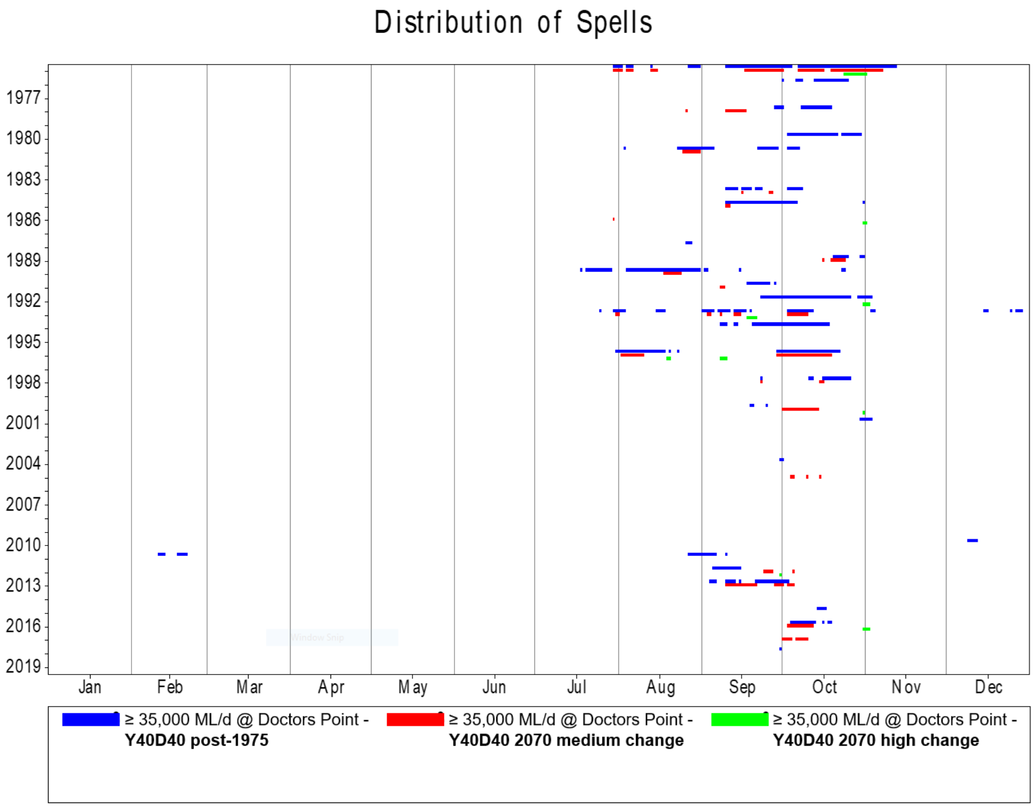


Figure 27: Box plots of winter/spring days in each year when flows of equal to or greater than 15,000 ML/d, 25,000 ML/d, 35,000 ML/d and 45,000 ML/d would be achieved or exceeded at various River Murray locations, under the current and Y40D40 constraint scenarios.



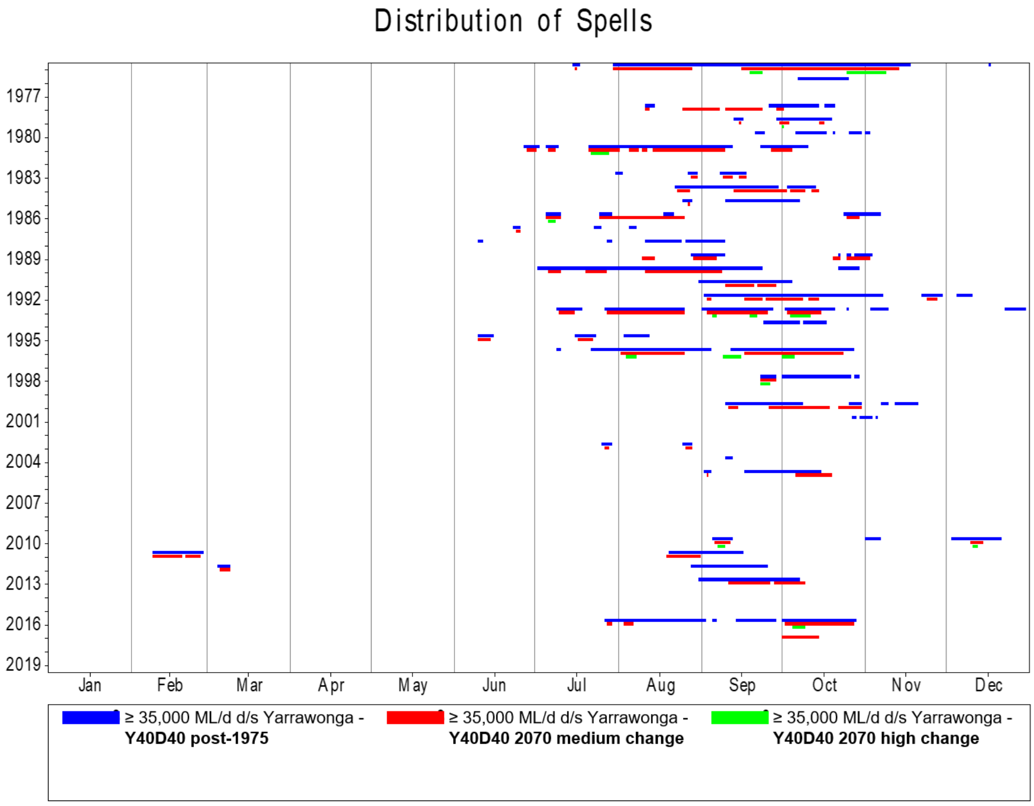


Figure 28: 1975 – 2019 spells of flow at or above 35,000 ML/d at Doctors Point (top) and downstream of Yarrawonga Weir (bottom) for the Y40D40 scenario and post-1975 conditions or year 2070 climate conditions with medium and high climate change.

6. Summary

Hydrology modelling using both the SGEFM and GBCCL Source model has demonstrated that relaxing constraints in the mid- and lower Goulburn will reduce environmental water shortfalls in the lower Goulburn, and reduce the degree to which environmental water holders are constrained in delivering higher priority environmental flow components. However, the rate of improvement in both of these hydrologic metrics reduces once the mid-Goulburn constraint is relaxed beyond 14,000 ML/d and the lower Goulburn constraint is relaxed beyond 17,000 ML/d – 21,000 ML/d. This plateauing occurs because modelled regulated releases from Lake Eildon are held below minor flood level (i.e. 13,700 ML/d at the time of writing), and the rate of improvement in the metrics diminishes as the difference between the mid- and lower Goulburn constraint widens.

Relaxation of the Goulburn River constraints also increases the extent to which existing environmental water holdings can be used to meet Goulburn River environmental water demands, rather than being held in storage or called out to the River Murray. For example, relaxing the lower Goulburn constraint from 9,500 ML/d to 17,000 ML/d increases the modelled utilisation of environmental water holdings to meet Goulburn River environmental water demands from <50% to >75%. Further relaxation of the lower Goulburn constraint results in further increases in utilisation, but at a decreased rate.

The degree of constraint relaxation in the mid-Goulburn does not influence modelled utilisation of environmental water holdings in the Goulburn River system, but the peak of environmental water deliveries to the lower Goulburn is sensitive to the constraint in the mid-Goulburn, particularly during average or dry conditions. For example, if the mid-Goulburn constraint is relaxed to 14,000 ML/d, the frequency of lower Goulburn flows ≥14,000 ML/d as simulated in the GBCCL Source model increases noticeably. However, the difference for lower Goulburn flows ≥17,000 ML/d is less significant, and is almost negligible for flows ≥21,000 ML/d. This may be in part because of how flow release triggers and inflow forecasts are modelled in the GBCCL Source model, and therefore the modelled alignment of environmental water deliveries with tributary flow patterns is a recommended area of further work in future stages of the VCMP.

For the River Murray upstream of Barmah Choke, the relaxation of constraints at Doctors Point and Yarrawonga increases the number of winter/spring days when flows are greater than current constraints but less than or equal to the relaxed constraint threshold. For example, the days per year of winter/spring flow greater than 25,000 ML/d or 35,000 ML/d increases at Doctors Point, Yarrawonga Weir and Tocumwal if constraints are relaxed to 35,000 ML/d or 40,000 ML/d at both locations. This increase is most likely to be observed in August, September and October. Once the flow of interest is above the relaxed constraint, the pattern changes. For example, downstream of Yarrawonga Weir the number of days of winter/spring flow above 45,000 ML/d reduces if the constraint is relaxed to 25,000 ML/d – 40,000 ML/d. The degree of difference in hydrological modelling outcomes between current and relaxed constraint scenarios tends to decrease with increasing distance downstream of the Barmah Choke.

Some of these patterns are observable in Figure 29, which shows flow duration curves for modelled outcomes in winter/spring at Doctors Point (top) and downstream of Torrumbarry Weir (bottom) under historic climate, and current or two potential constraint relaxation scenarios. For example, a flow of 35,000 ML/d at Doctors Point would be expected to occur less often if constraints were relaxed to 30,000 ML/d at Doctors Point, and more often if constraints were relaxed to 40,000 ML/d. Further downstream at Torrumbarry Weir the differences in the flow duration curves between the current and relaxed constraint scenarios is less marked.

A similar outcome can be seen in Figure 30, which shows flow duration curves for modelled outcomes in winter/spring at Molesworth (top) and Shepparton (bottom) under historic climate, and current or three potential constraint relaxation scenarios. The change in the flow duration curves at Molesworth corresponding with flow rates of 10,000 ML/d – 14,000 ML/d are noticeable, and there is small reduction in the modelled frequency of flow rates above the relaxed constraint. Further downstream at Shepparton, the differences in the flow duration curves between the current and relaxed constraint scenarios is again less marked.

Part of the observed hydrological changes caused by relaxing constraints is attributable to reduced spills from storage, which are modelled to happen if there is increased capacity to make environmental water releases. For example, the proportion of years with 5+ days of winter/spring flow exceeding 17,000 ML/d at Molesworth – which is downstream of Lake Eildon – would be expected to reduce from 25% to 19% if current constraints were relaxed to 14,000 ML/d in the mid-Goulburn and 25,000 ML/d in the lower Goulburn.

The sensitivity of the expected hydrological outcomes from constraints relaxation to potential future climate change was primarily tested using SGEFM simulations of the Goulburn River. In summary, “all constraint relaxation options [for the mid- and lower Goulburn] deliver benefits across a relatively wide range plausible climates consistent with climate model projections. Hence, constraint relaxation is likely to offer robust climate change adaptation benefits” (John *et al.*, 2022). If however, average annual rainfall decreases by more than 20%, the predicted benefits from constraint relaxation are significantly reduced. This is because such a large decrease in rainfall would significantly reduce inflows to the Goulburn River system, and hence the water allocated to environmental water holders for use in the mid- and lower Goulburn. Climate change simulations with the GBCCL Source model and SMM also predicted hydrological benefits from constraint relaxation under moderately drier conditions, and reduced benefits under significantly drier conditions.

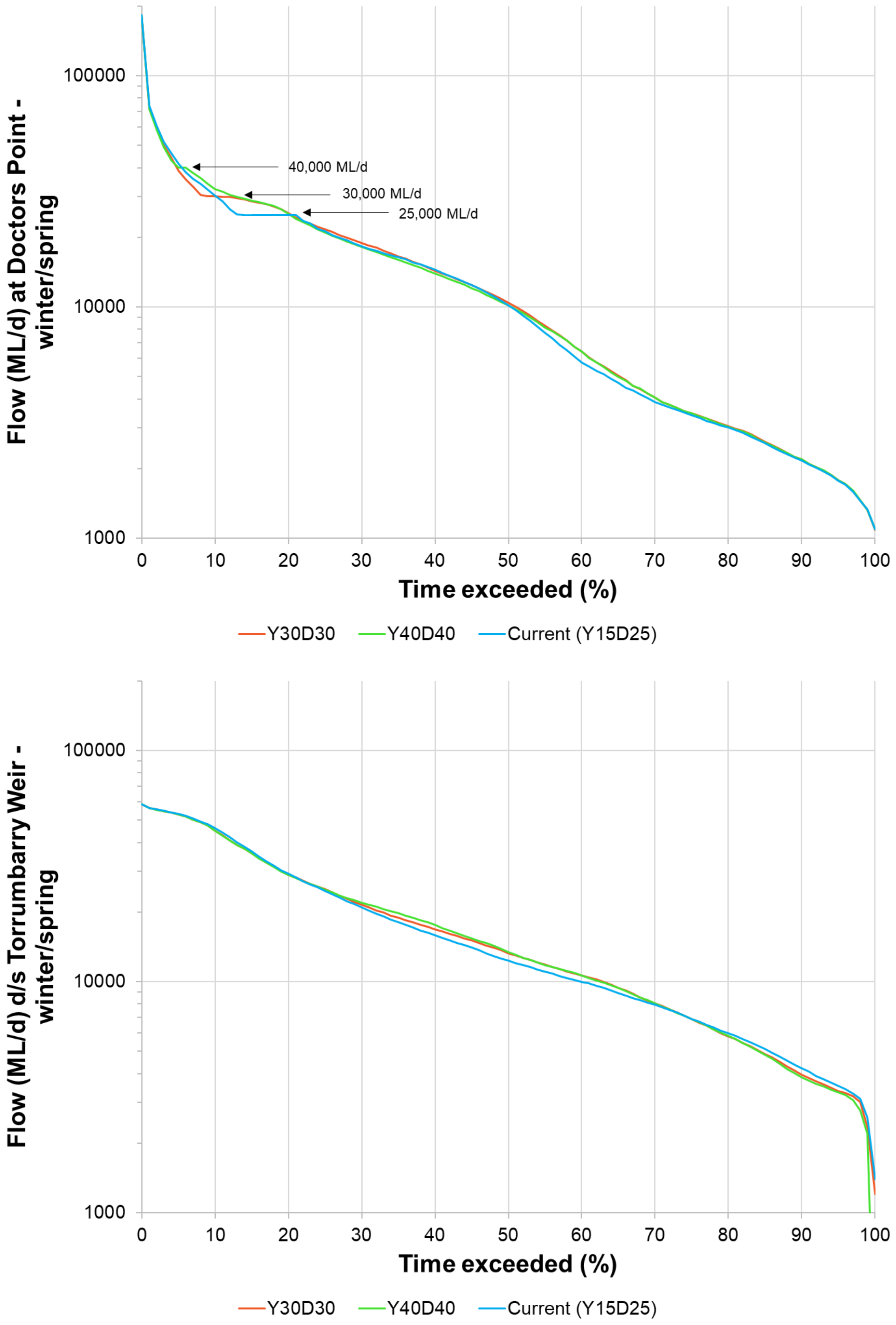


Figure 29: Flow durations curves of daily modelled flows during winter/spring at Doctors Point (top) and downstream of Torrumbarry Weir (bottom) for historic climate conditions and current or relaxed constraints.

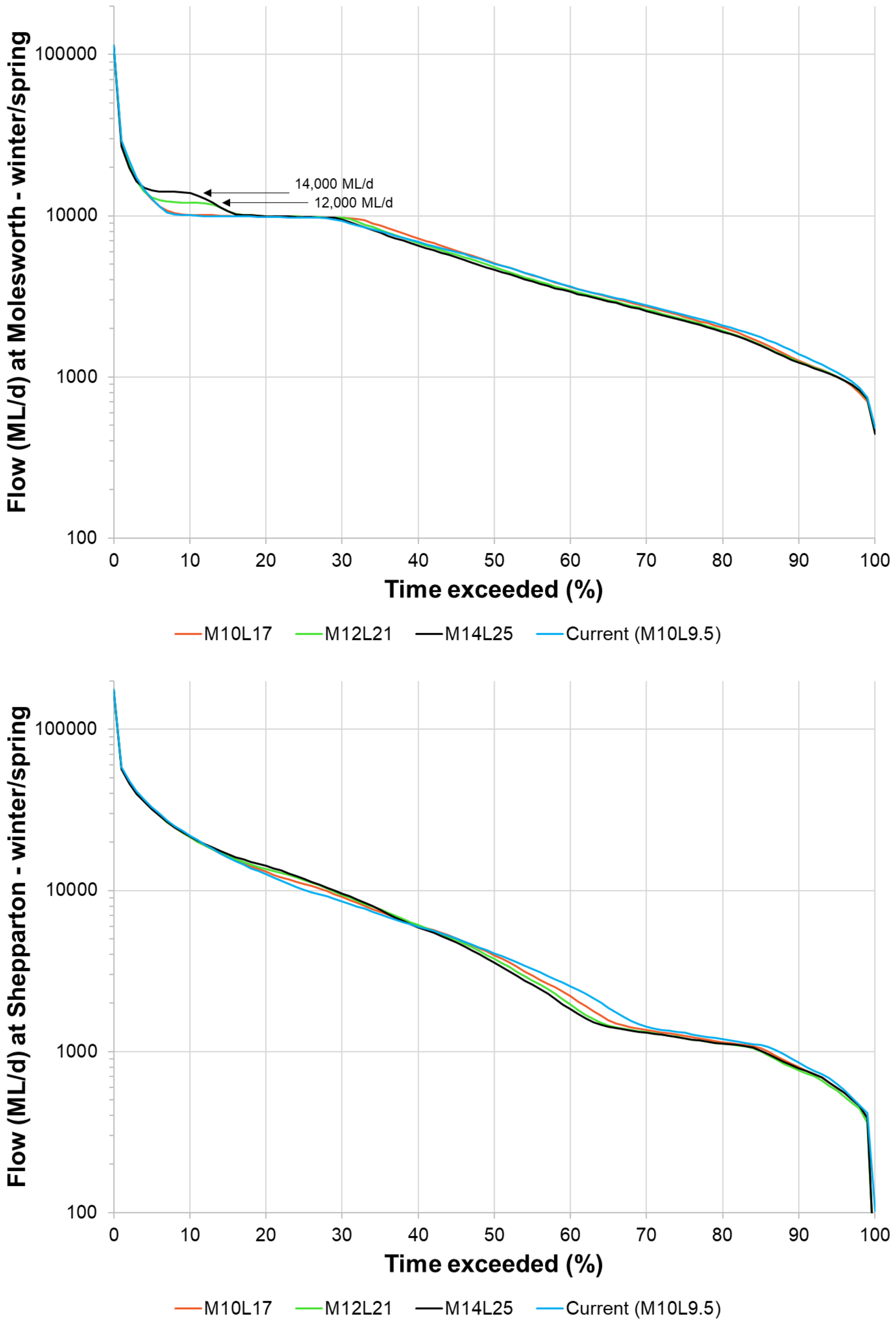


Figure 30: Flow durations curves of daily modelled flows during winter/spring at Molesworth (top) and Shepparton (bottom) for historic climate conditions and current or relaxed constraints.

7. Future modelling improvements

The DEECA (2023) and MDBA (2022a) reports include details of future hydrological modelling improvements that are either underway or planned for the future. This section of the report summarises five of these potential modelling improvements that would benefit future stages of the VCMP if it proceeds past Stage 1A. Comment is also included about a potential refinement to the modelling of Waranga Basin transfers in the GBCCL Source model, and a recommended change to the modelled routing of environmental water deliveries in the SGEFM.

7.1 Analysis of climate change impacts

The GBCCL Source model and SMM were used to simulate the current constraints scenario and one relaxed constraint scenario for the Goulburn River and River Murray systems under post-1975 conditions, and conditions projected for the year 2070 assuming medium or high climate change. It is recommended that future stages of the VCMP use these Source models to simulate several constraint relaxation scenarios under potential future climate conditions, to further test that the outcomes are consistent with observations made using the SGEFM.

More work could also be done on assessing whether the changes to complex rainfall characteristics – such as intensification of rainfall bursts and changes to seasonal patterns – that are likely to occur as the climate warms, will influence the timing of water allocations and environmental water demands, and how readily environmental water deliveries can be piggy-backed on tributary inflows. This type of investigation, given the uncertainties involved, would be best suited to a detailed design phase of the VCMP (i.e. if the project proceeds past feasibility stage).

7.2 Tributary inflow forecasts

The hydrology models used for Stage 1A of the VCMP represent all tributary inflows, but the simulated forecasting of these inflows is simplistic. For example, the GBCCL Source model assumes that tributary inflows tomorrow will be 90% of the tributary inflows today. Increasing the realism of tributary inflow forecasts in the hydrological models will be an important pre-cursor to future refinement of strategies for releasing environmental water from storage to meet environmental water demands while keeping total flows within operational constraints.

The Activity 7 report from Stage 1A of the EEWD project (MDBA, 2022b) includes an option including better streamflow forecasts in the GBCCL Source model and SMM. It would involve the Bureau of Meteorology generating hindcasts – back to at least 1900 – of 7-day to 21-day flow forecasts that would have been available with today’s technology. These hindcasts could then be used in place of the simplistic inflow forecasts currently included in the hydrology models applied during Stage 1A of the VCMP.

7.3 Transmission loss accounting

The current version of the GBCCL Source model does not account against the simulated environmental water holdings the additional transmission losses that may occur when environmental water deliveries are near-bankfull or out-of-bank. DELWP (2022b) estimates that modelled utilisation of the environmental water holdings in the Goulburn River system could increase by approximately 20 GL/year once the potential for these additional losses at higher flows is considered in more detail and included in the GBCCL Source model. Any changes to loss accounting as represented in the GBCCL Source model would also need to be considered for inclusion in the SGEFM if it is used in future stages of the VCMP.

7.4 Representation of environmental water demands

Flow targets representing environmental water demands in the lower Goulburn and downstream of Yarrawonga Weir are included in the GBCCL Source model and SMM respectively. As noted in Stage 1A of the EEWD project (MDBA, 2022b), the SMM could be improved by including environment-related flow targets at other sites beyond Yarrawonga Weir. The potential benefits of including mid-Goulburn environmental water demands in the GBCCL Source model should also be considered in future stages of the VCMP.

7.5 Use versus carryover of held environmental water

If operational constraints are relaxed, the rate at which water can be delivered to environmental assets and therefore the volume of environmental water holdings that could be used in a given year will increase. This will heighten the importance of the decisions made by environmental water managers about whether to use water holdings in the short-term to meet flow recommendation a), or carryover water and accrue more in storage until there is sufficient holdings to meet flow recommendation b). The choice of when to release environmental water from storage will also become important if constraints are relaxed, because there is likely to be more times when the holdings in storage will be less than needed to deliver events with peaks near operational constraints, unless releases are aligned with tributary inflows. The best strategies for use versus carryover of environmental water holdings and/or triggers for releasing water from storage will be developed over time; however, there is the opportunity in future stages of the VCMP to test some potential strategies using the capabilities of the GBCCL Source model and SMM. For example, in Stage 1A of the VCMP, the GBCCL Source model was configured so that pre-existing flows needed to be 30%-40% of the target peak flow before environmental water was released to deliver fresh events. It may be that other trigger values will result in better simulated hydrologic and environmental outcomes, and therefore further investigation of release trigger and carryover strategies is recommended for future stages of the VCMP.

7.6 Transfers to Waranga Basin

During a community consultative committee meeting, it was noted that in the M14L25 scenario there were periods where modelled flows at Molesworth were at or above the mid-Goulburn constraint for ~3 weeks, even though the duration of the peak winter / spring environmental fresh demand in the lower Goulburn is 5 days. There are two reasons this may be occurring. Firstly, the rate of rise and fall associated with the winter / spring fresh environmental flow recommendation may be contributing to the extended time flows are at the mid-Goulburn constraint in years when delivery of the fresh is ‘forced’ at the end of the season. Secondly, in some years, transfers from Lake Eildon to Waranga Basin may be occurring adjacent to environmental water deliveries to the lower Goulburn, thus extending the period when flows are at the mid-Goulburn constraint.

Given the community interest in how often flows will be at the mid-Goulburn constraint, it is recommended that the contributing factors to this simulated behaviour be investigated further using the GBCCL Source model. The results of this investigation may show that the modelling of the lower Goulburn environmental water demand and/or transfers from Lake Eildon to Waranga Basin can be refined if the VCMP continues past Stage 1A. For example, potential refinements could include keeping the mid-Goulburn constraint at the current 10,000 ML/d during periods when Eildon-Waranga transfers are occurring, and/or adding a spell of low flow between delivery of the winter / spring fresh and Eildon-Waranga transfers

7.7 Environmental water delivery routing in SGEFM

The simplistic but different tributary inflow forecasts used in the SGEFM and GBCCL Source model is one reason why they provide slightly different estimates of when the benefits of constraint relaxation begin plateauing in the lower Goulburn (e.g. ~21,000 ML/d versus ~17,000 ML/d if the mid-Goulburn constraint is 14,000 ML/d). Another reason is that the SGEFM simulated routing of environmental water deliveries from Goulburn Weir to Shepparton is likely to be underestimating the attenuation of flow peaks between these locations. Therefore, if the SGEFM is used in future stages of the VCMP, it is recommended that this element of the model be refined.

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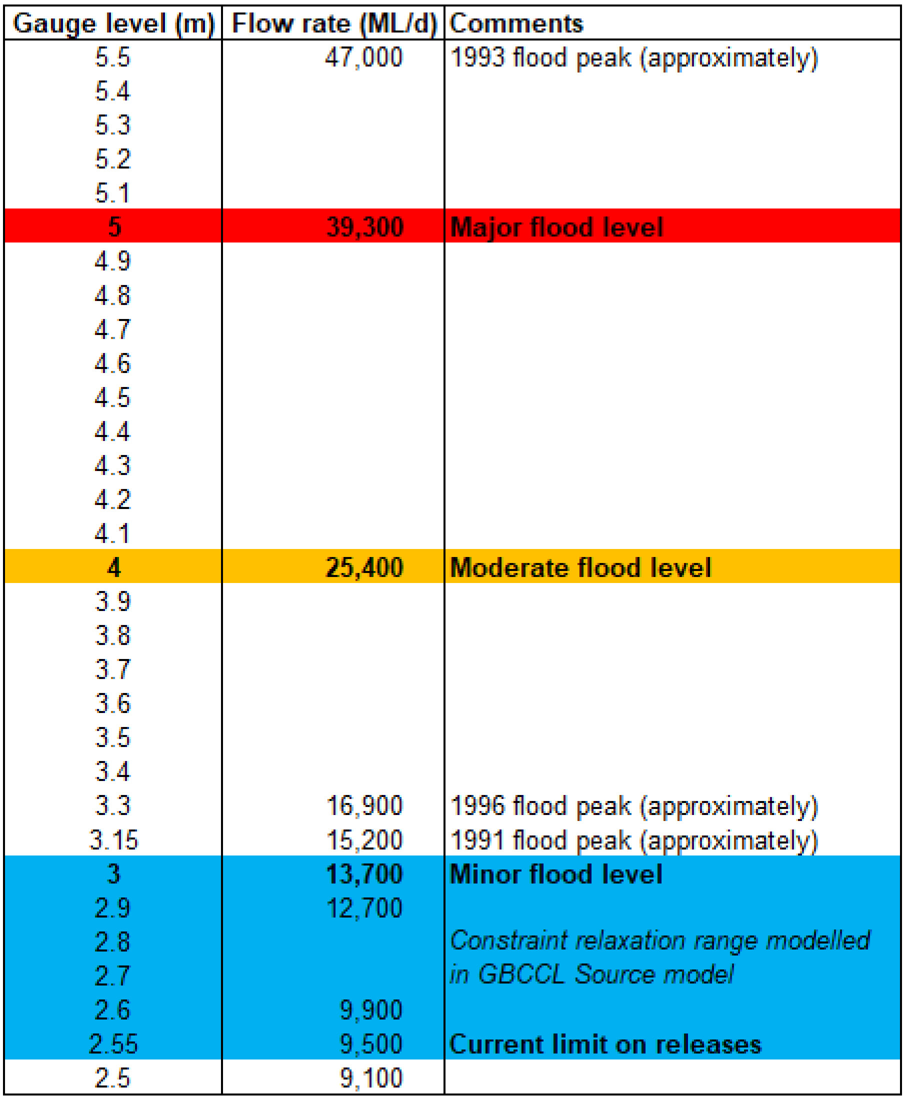
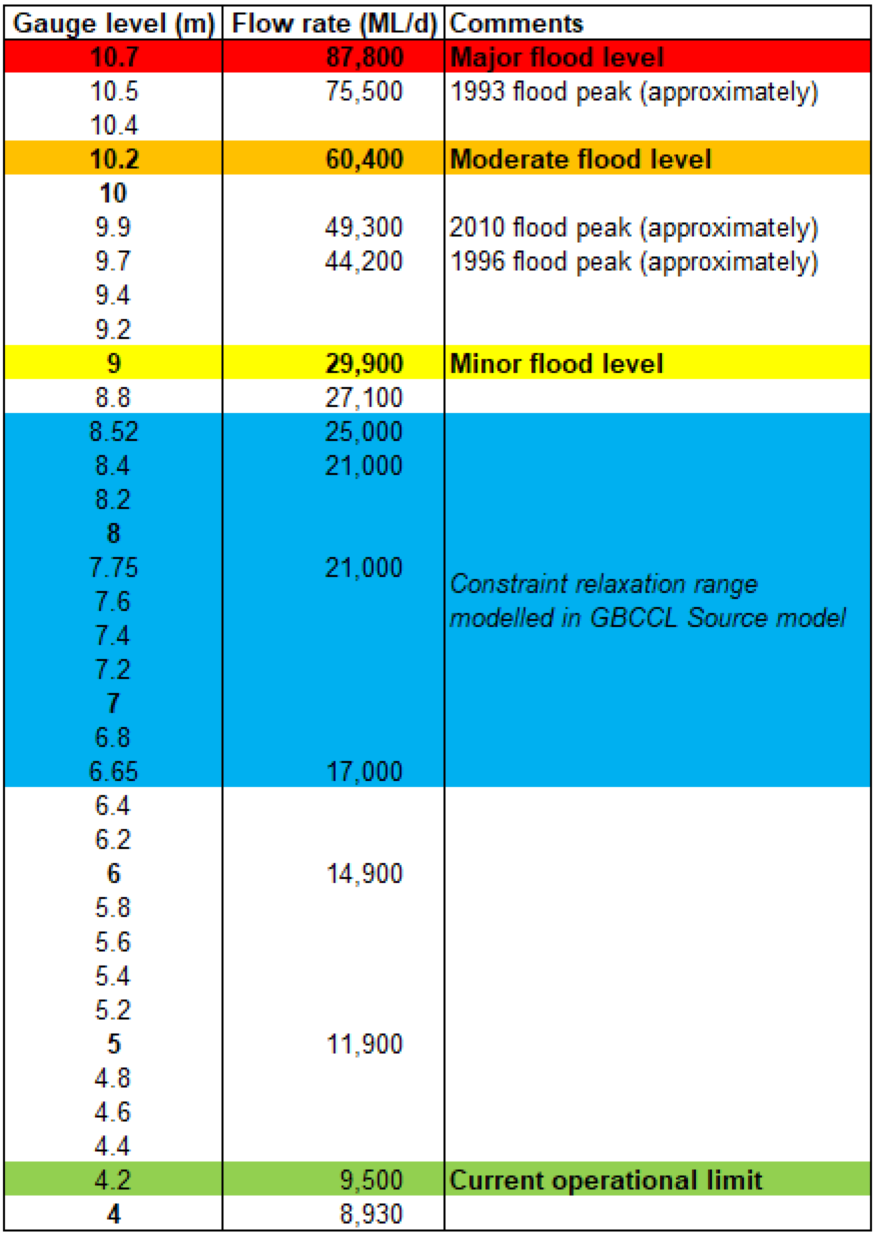
Appendix A Gauge board representation of scenarios modelled in Source

A.1 Goulburn River at Eildon (405203)



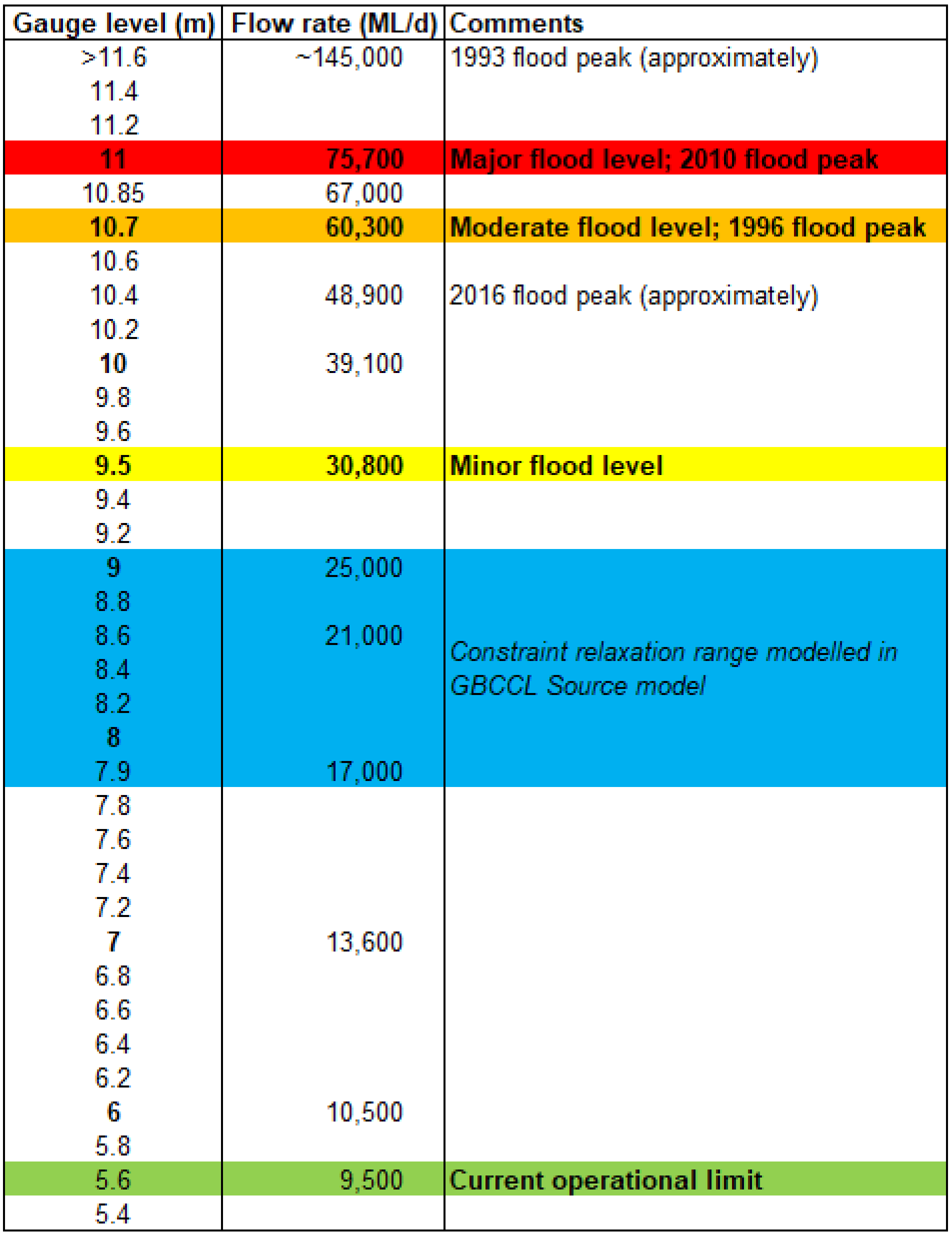
Gauge level (m)	Flow rate (ML/d)	Comments
5.5	47,000	1993 flood peak (approximately)
5.4		
5.3		
5.2		
5.1		
5	**39,300**	**Major flood level**
4.9		
4.8		
4.7		
4.6		
4.5		
4.4		
4.3		
4.2		
4.1		
4	**25,400**	**Moderate flood level**
3.9		
3.8		
3.7		
3.6		
3.5		
3.4		
3.3	16,900	1996 flood peak (approximately)
3.15	15,200	1991 flood peak (approximately)
3	**13,700**	**Minor flood level**
2.9	12,700	
2.8		*Constraint relaxation range modelled in GBCCL Source model*
2.7		
2.6	9,900	
2.55	9,500	**Current limit on releases**
2.5	9,100	

A.2 Goulburn River at Murchison (405200)



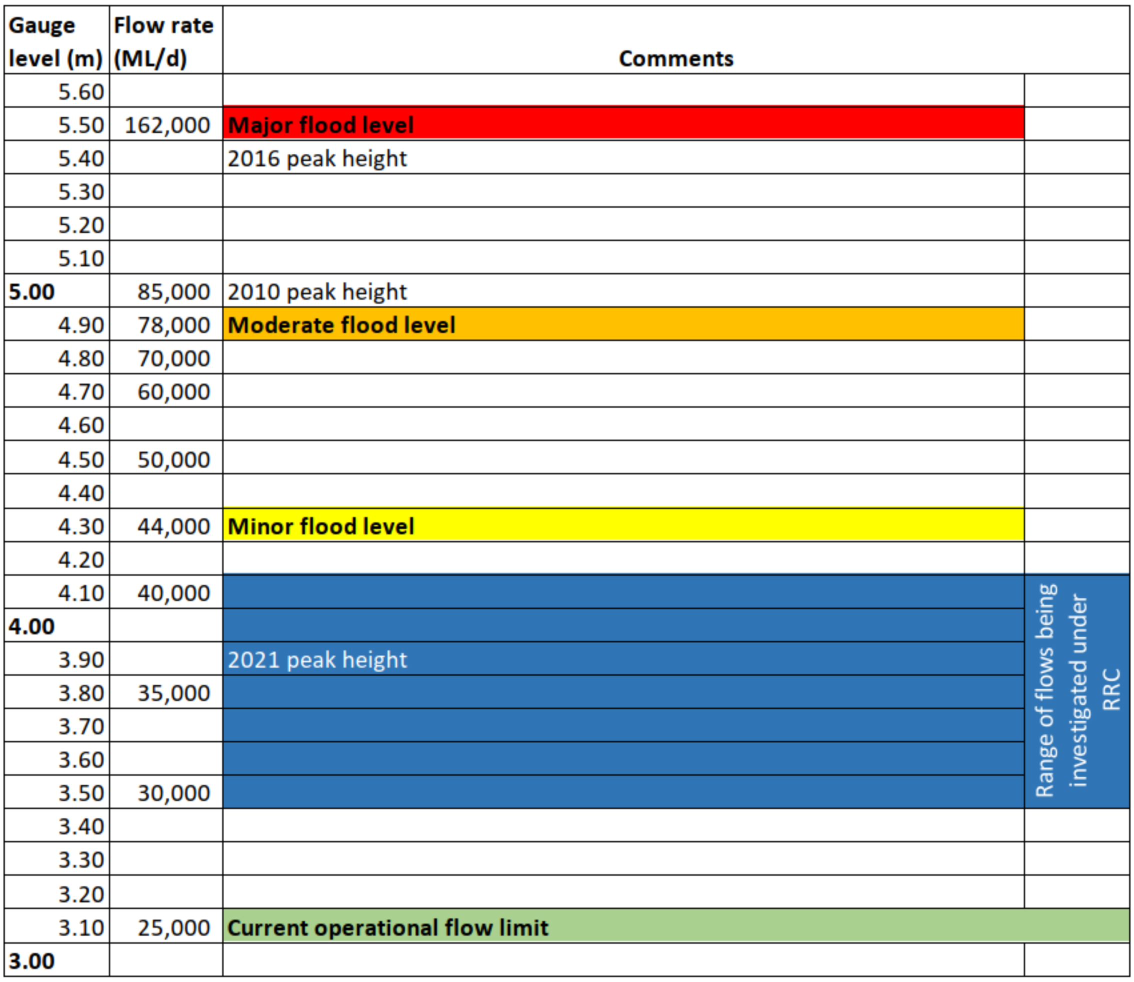
Gauge level (m)	Flow rate (ML/d)	Comments
10.7	**87,800**	**Major flood level**
10.5	75,500	1993 flood peak (approximately)
10.4		
10.2	**60,400**	**Moderate flood level**
10		
9.9	49,300	2010 flood peak (approximately)
9.7	44,200	1996 flood peak (approximately)
9.4		
9.2		
9	**29,900**	**Minor flood level**
8.8	27,100	
8.52	25,000	*Constraint relaxation range modelled in GBCCL Source model*
8.4	21,000	
8.2		
8		
7.75	21,000	
7.6		
7.4		
7.2		
7		
6.8		
6.65	17,000	
6.4		
6.2		
6	14,900	
5.8		
5.6		
5.4		
5.2		
5	11,900	
4.8		
4.6		
4.4		
4.2	9,500	**Current operational limit**
4	8,930	

A.3 Goulburn River at Shepparton (405204)



Gauge level (m)	Flow rate (ML/d)	Comments
>11.6	~145,000	1993 flood peak (approximately)
11.4		
11.2		
11	**75,700**	**Major flood level; 2010 flood peak**
10.85	67,000	
10.7	**60,300**	**Moderate flood level; 1996 flood peak**
10.6		
10.4	48,900	2016 flood peak (approximately)
10.2		
10	39,100	
9.8		
9.6		
9.5	**30,800**	**Minor flood level**
9.4		
9.2		
9	25,000	*Constraint relaxation range modelled in GBCCL Source model*
8.8		
8.6	21,000	
8.4		
8.2		
8		
7.9	17,000	
7.8		
7.6		
7.4		
7.2		
7	13,600	
6.8		
6.6		
6.4		
6.2		
6	10,500	
5.8		
5.6	9,500	**Current operational limit**
5.4		

A.4 River Murray at Doctors Point (409017)

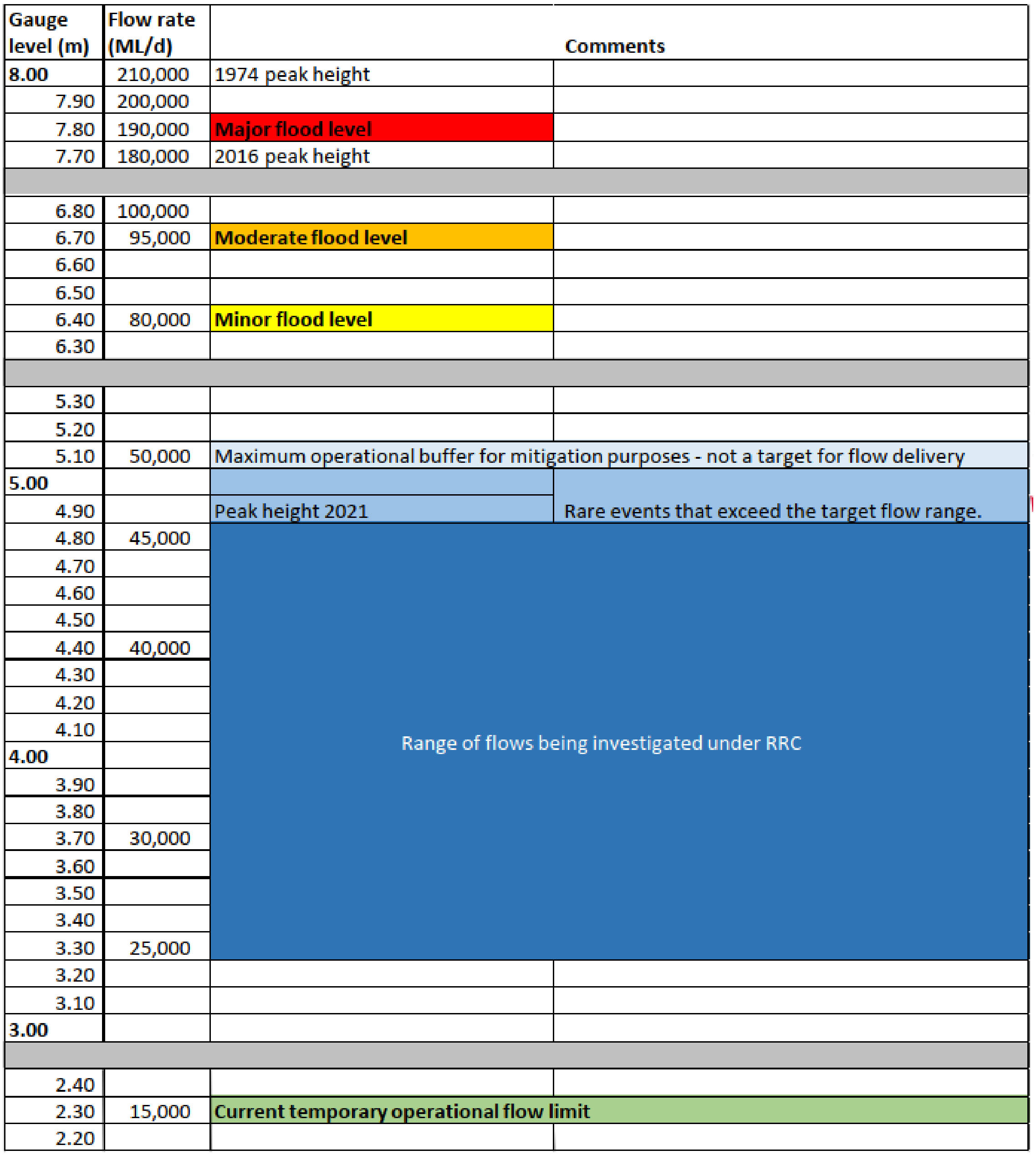


Gauge level (m)	Flow rate (ML/d)	Comments	
5.60			
5.50	162,000	**Major flood level**	
5.40		2016 peak height	
5.30			
5.20			
5.10			
5.00	85,000	2010 peak height	
4.90	78,000	**Moderate flood level**	
4.80	70,000		
4.70	60,000		
4.60			
4.50	50,000		
4.40			
4.30	44,000	**Minor flood level**	
4.20			
4.10	40,000		Range of flows being investigated under RRC
4.00			
3.90		2021 peak height	
3.80	35,000		
3.70			
3.60			
3.50	30,000		
3.40			
3.30			
3.20			
3.10	25,000	**Current operational flow limit**	
3.00			

This gauge board is for the River Murray at Albury (Union Bridge), which is a short distance downstream of the Doctors Point gauge.

Reproduced from Reconnecting River Country (RRC) program stakeholder engagement materials for Murray flow options (FINAL v2.0 July 2022).

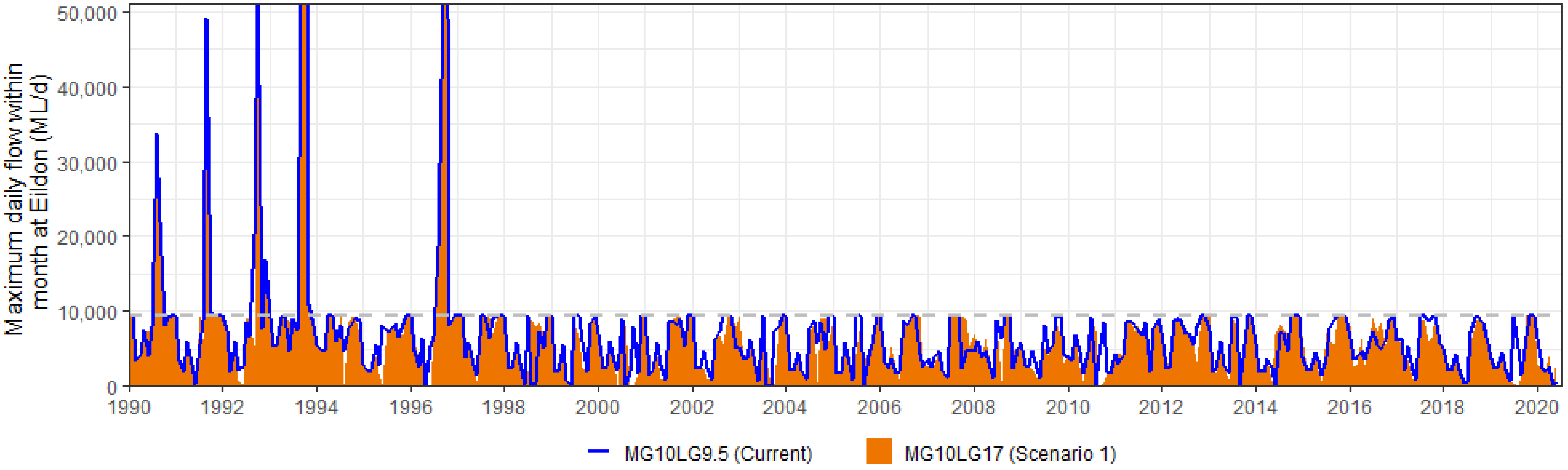
A.5 River Murray downstream of Yarrawonga Weir (409025)

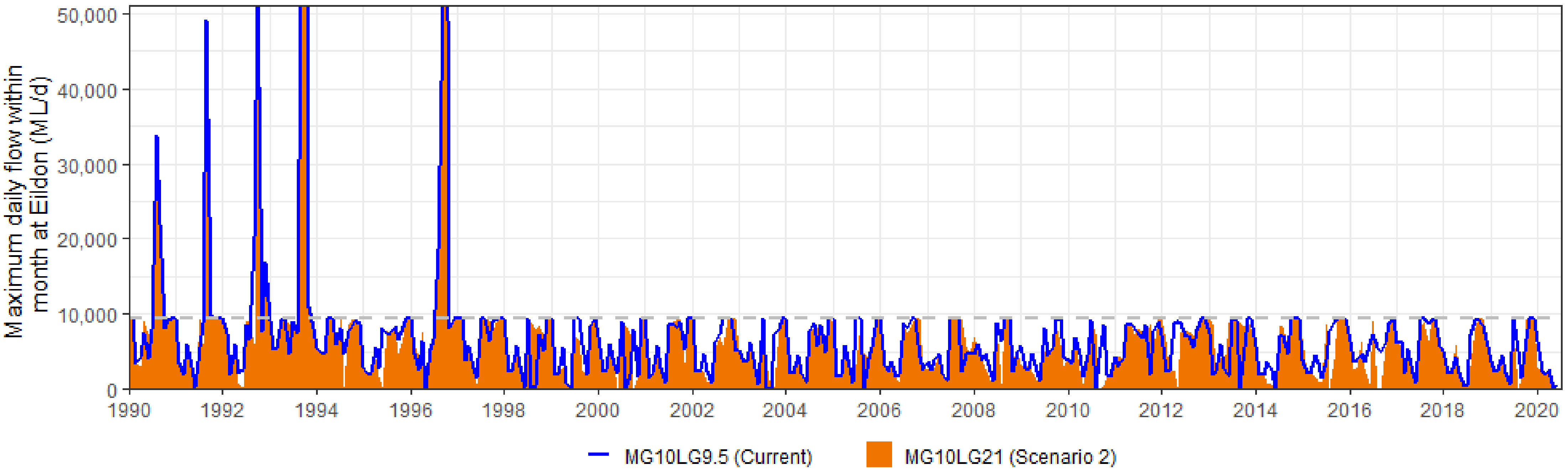


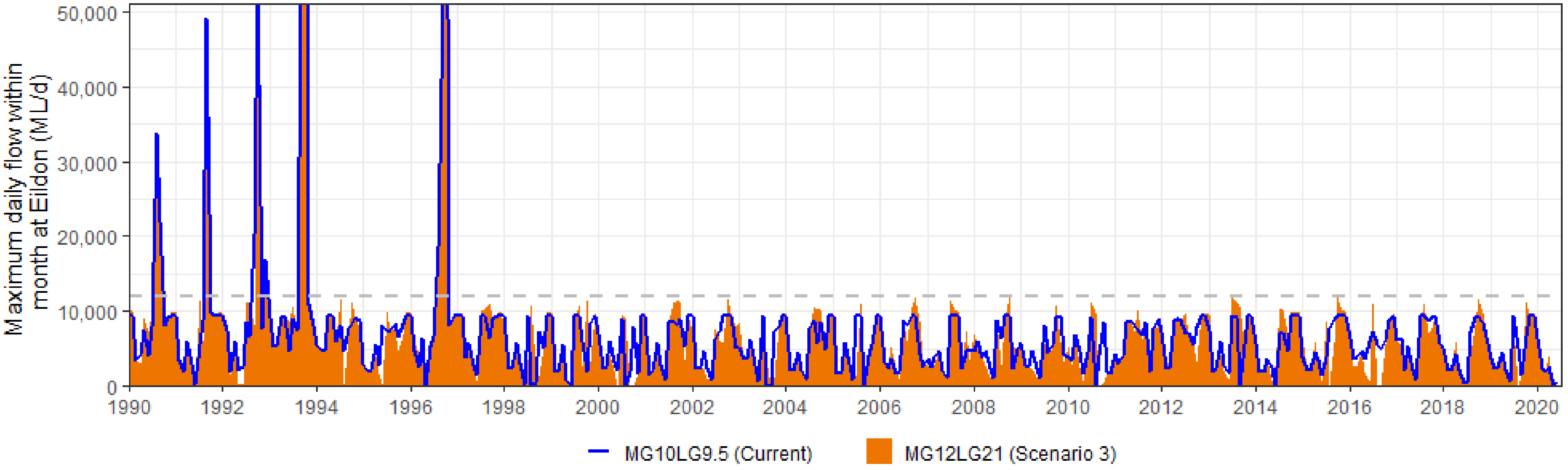
Gauge level (m)	**Flow rate (ML/d)**	**Comments**	
8.00	210,000	1974 peak height	
7.90	200,000		
7.80	190,000	**Major flood level**	
7.70	180,000	2016 peak height	
6.80	100,000		
6.70	95,000	**Moderate flood level**	
6.60			
6.50			
6.40	80,000	**Minor flood level**	
6.30			
5.30			
5.20			
5.10	50,000	Maximum operational buffer for mitigation purposes - not a target for flow delivery	
5.00			Rare events that exceed the target flow range.
4.90		Peak height 2021	
4.80	45,000	Range of flows being investigated under RRC	
4.70			
4.60			
4.50			
4.40	40,000		
4.30			
4.20			
4.10			
4.00			
3.90			
3.80			
3.70	30,000		
3.60			
3.50			
3.40			
3.30	25,000		
3.20			
3.10			
3.00			
2.40			
2.30	15,000	**Current temporary operational flow limit**	
2.20			

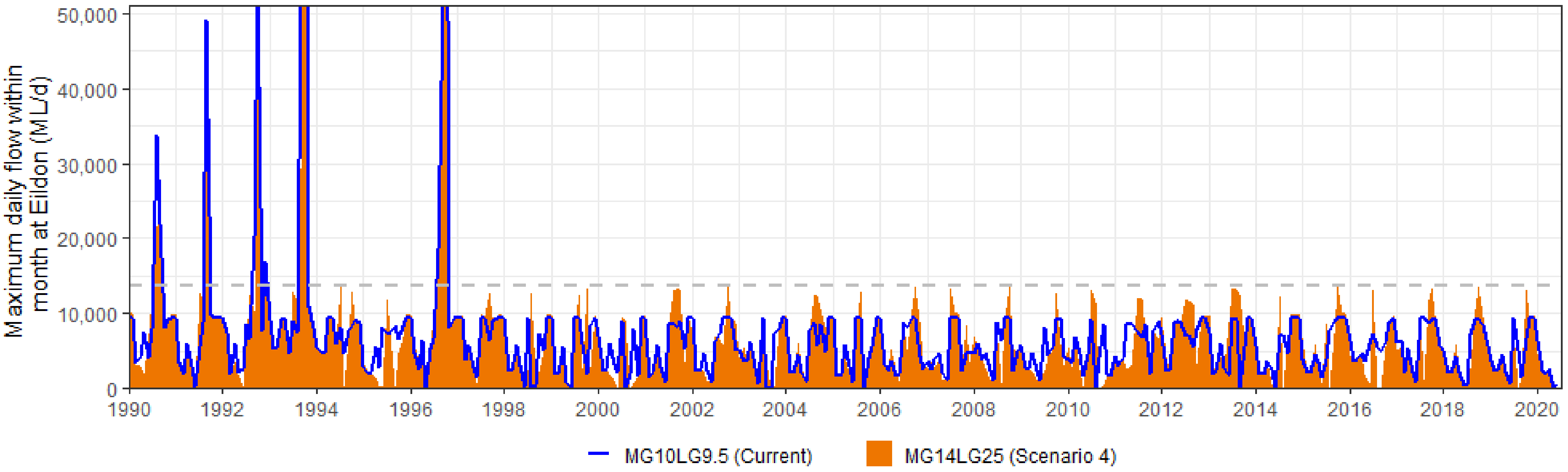
Reproduced from Reconnecting River Country (RRC) program stakeholder engagement materials for Murray flow options (FINAL v2.0 July 2022).

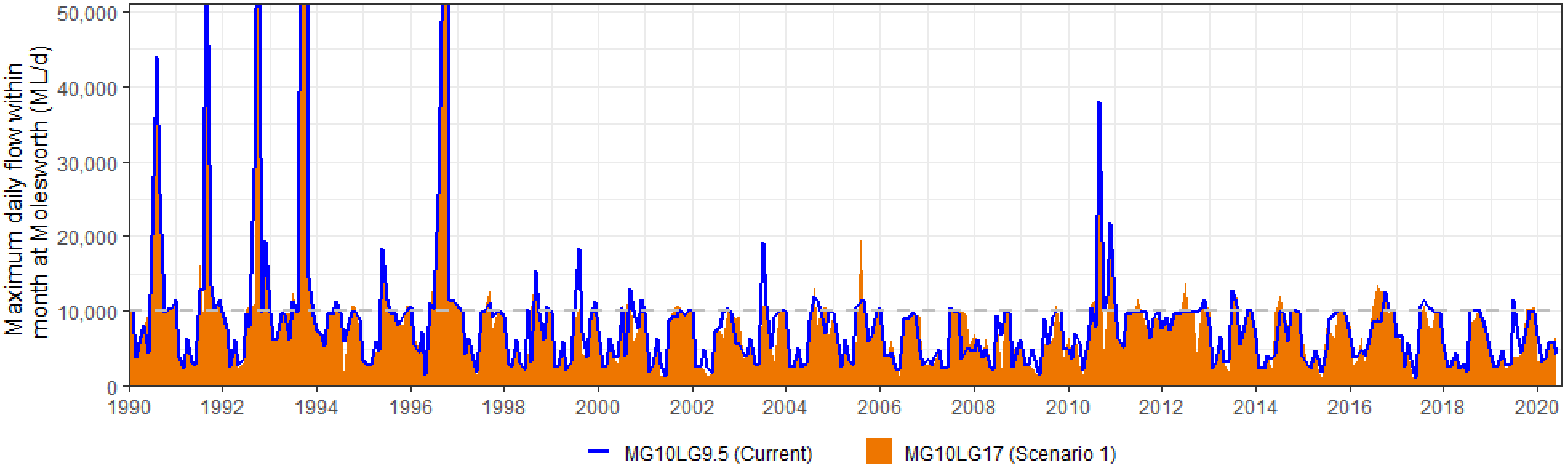
Appendix B Goulburn River – GBCCL Source model results – maximum flow within month; historic climate (1990-2020)

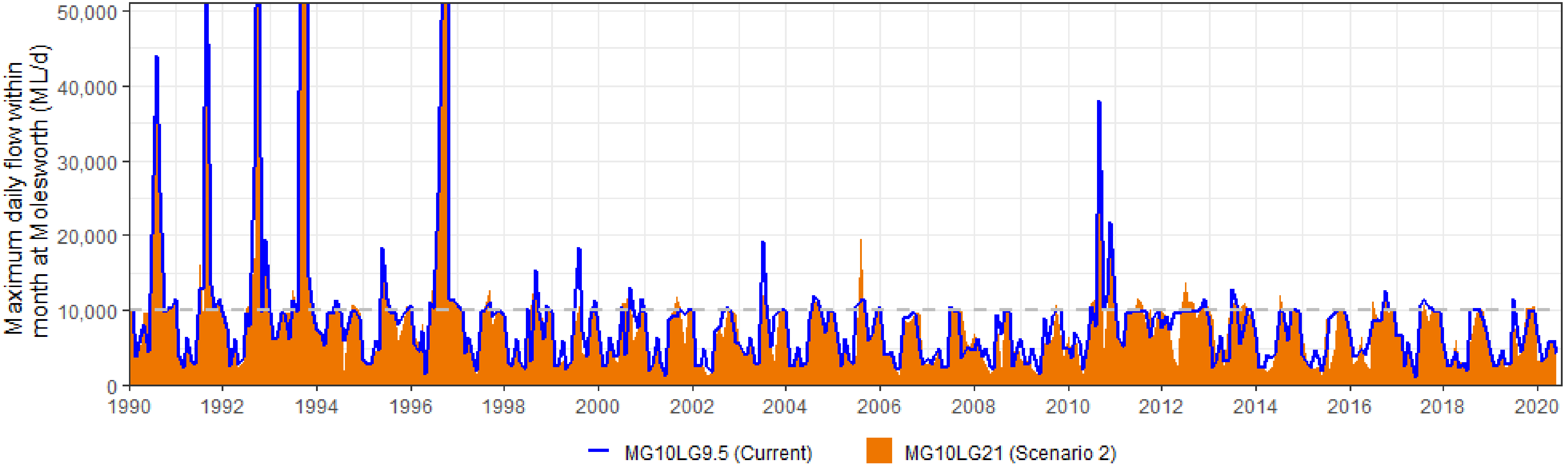

Maximum daily flow within month at Eildon (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)

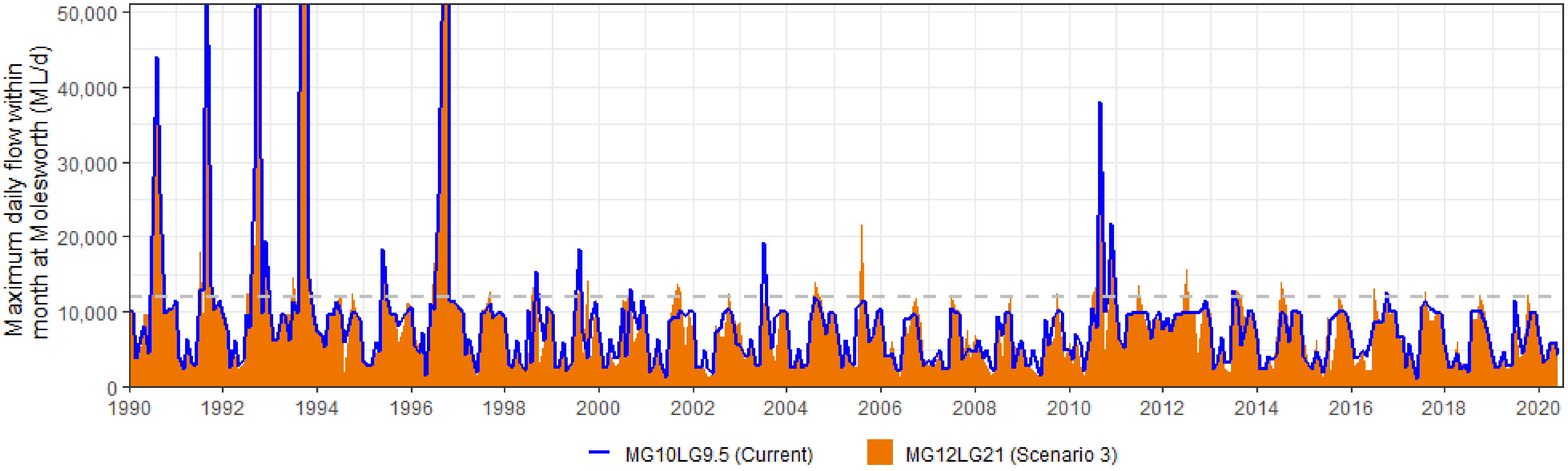

Maximum daily flow within month at Eildon (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG10LG21 (Scenario 2)

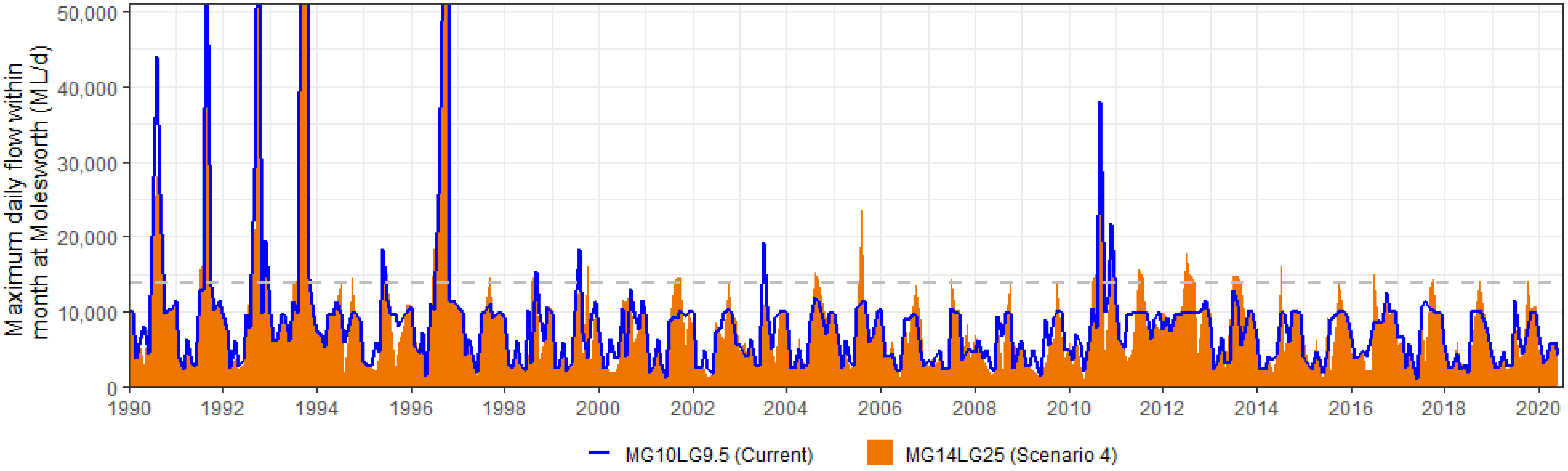

Maximum daily flow within month at Eildon (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG12LG21 (Scenario 3)

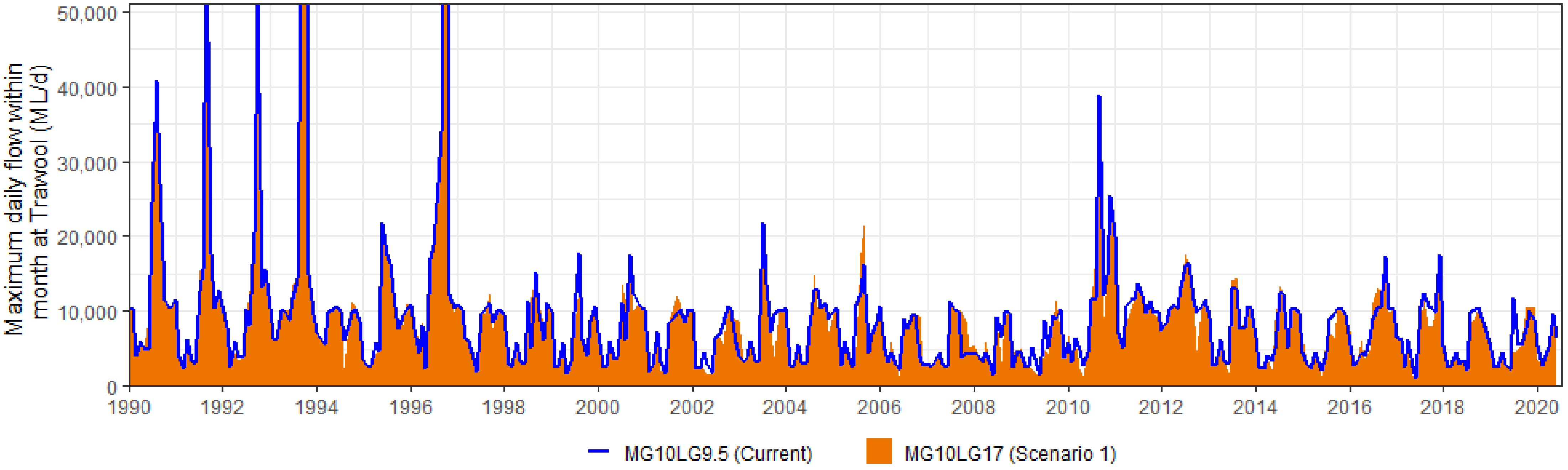

Maximum daily flow within month at Eildon (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG14LG25 (Scenario 4)

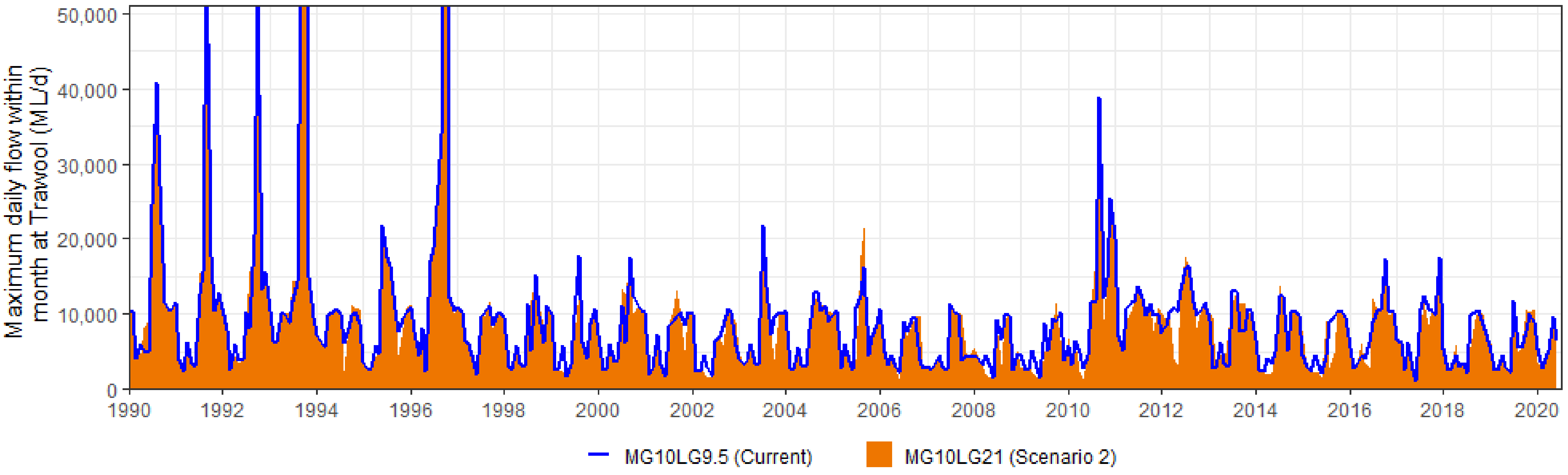

Maximum daily flow within month at Molesworth (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)

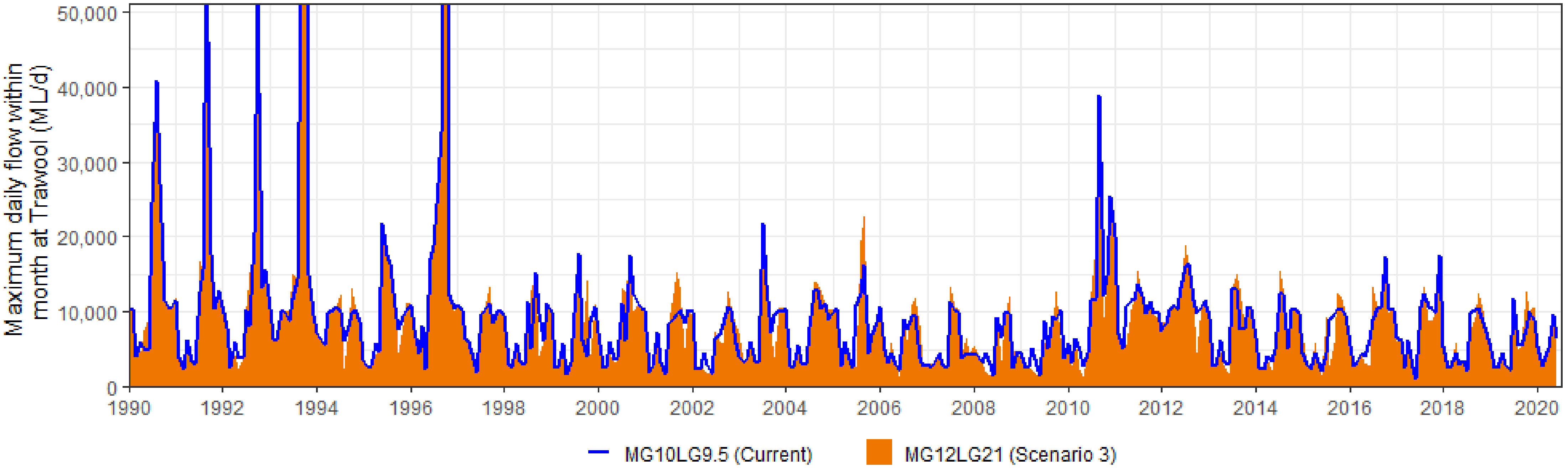

Maximum daily flow within month at Molesworth (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG10LG21 (Scenario 2)


Maximum daily flow within month at Molesworth (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG12LG21 (Scenario 3)

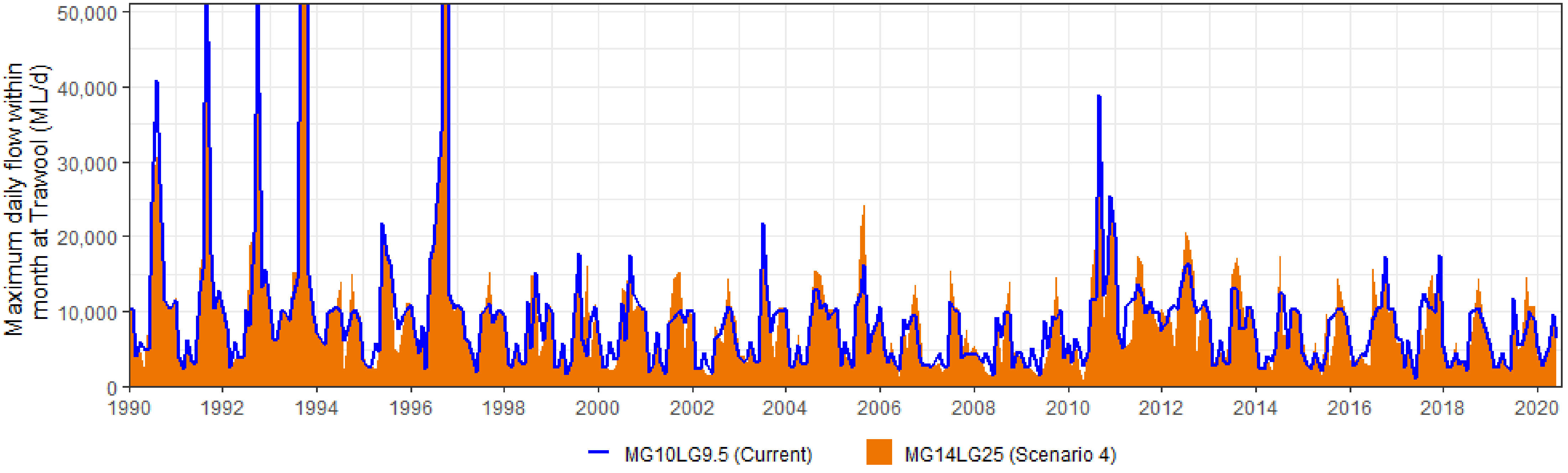

Maximum daily flow within month at Molesworth (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG14LG25 (Scenario 4)


Maximum daily flow within month at Trawool (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)

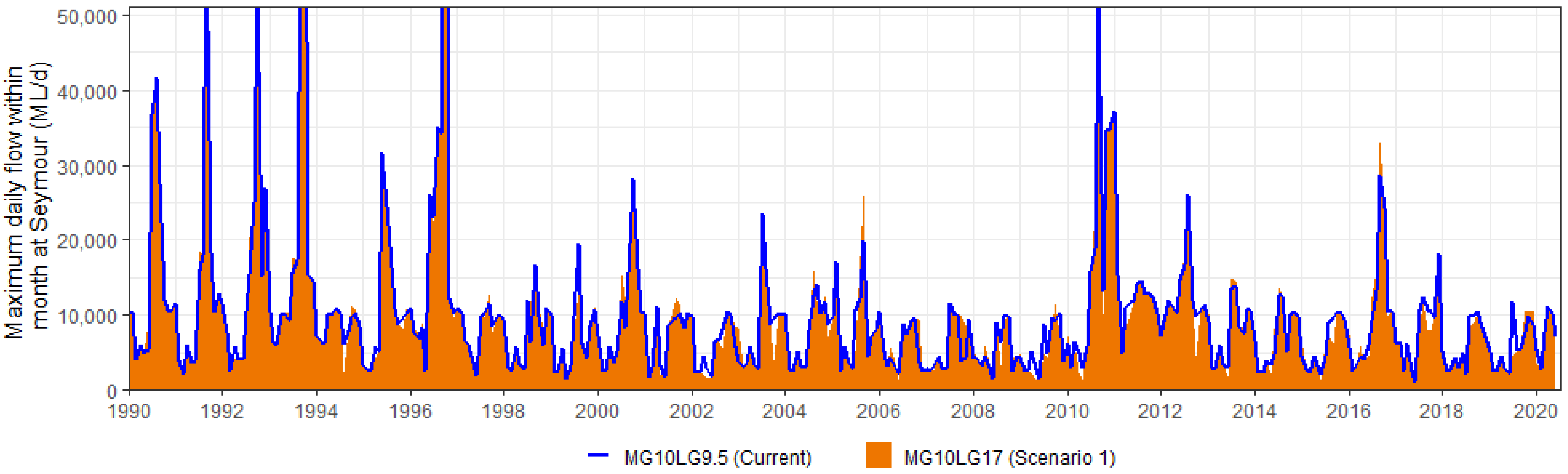

Maximum daily flow within month at Trawool (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG10LG21 (Scenario 2)

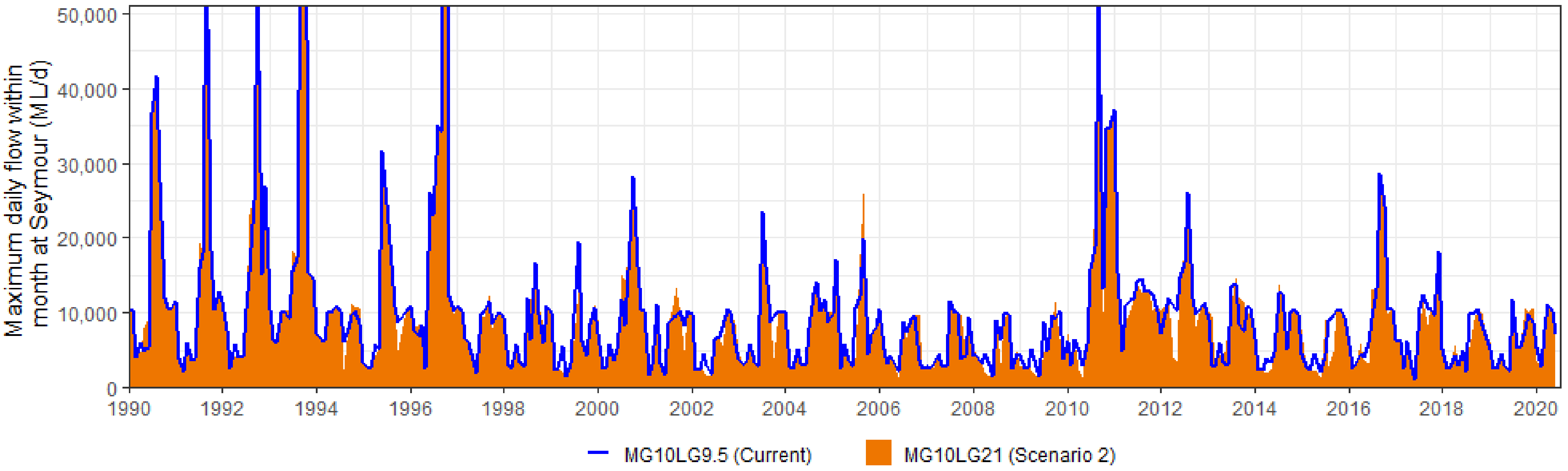


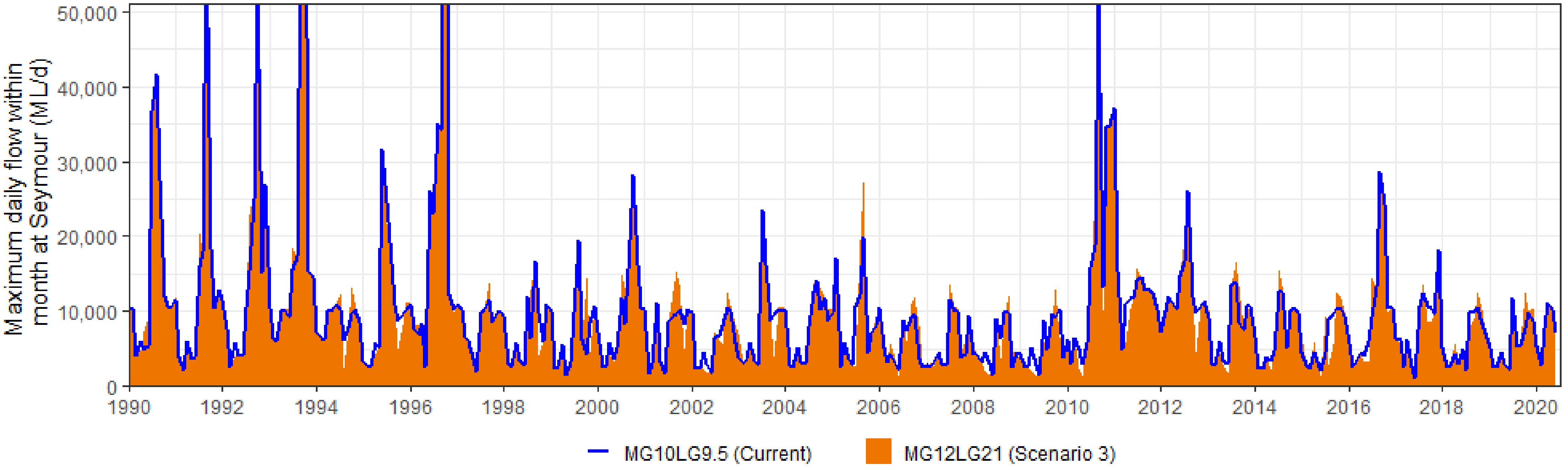
Maximum daily flow within month at Trawool (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG12LG21 (Scenario 3)

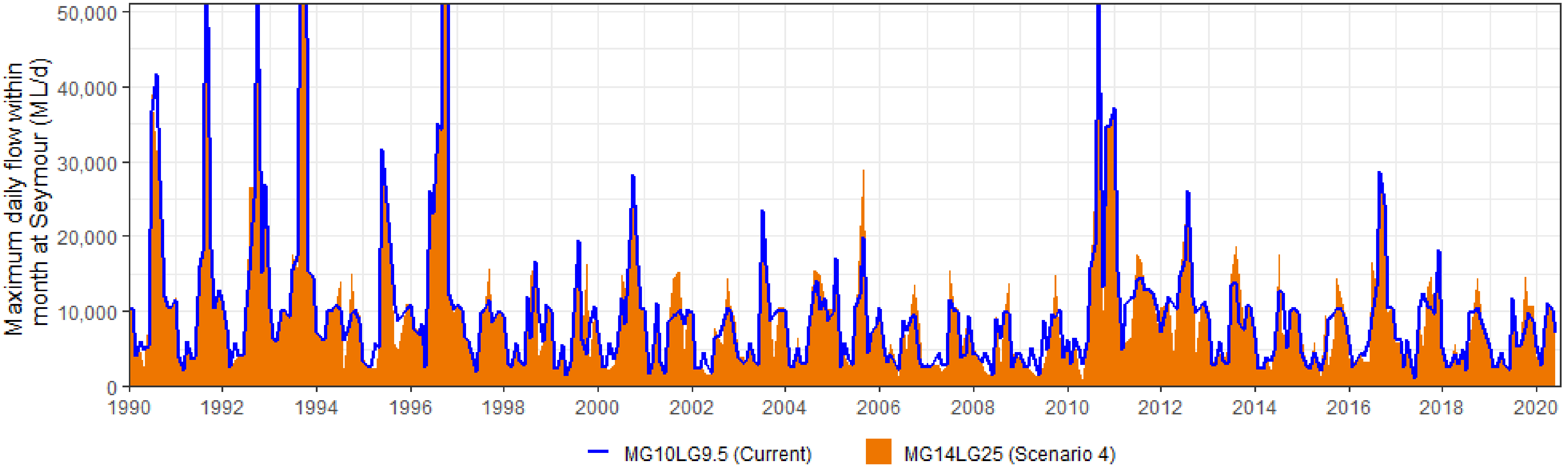


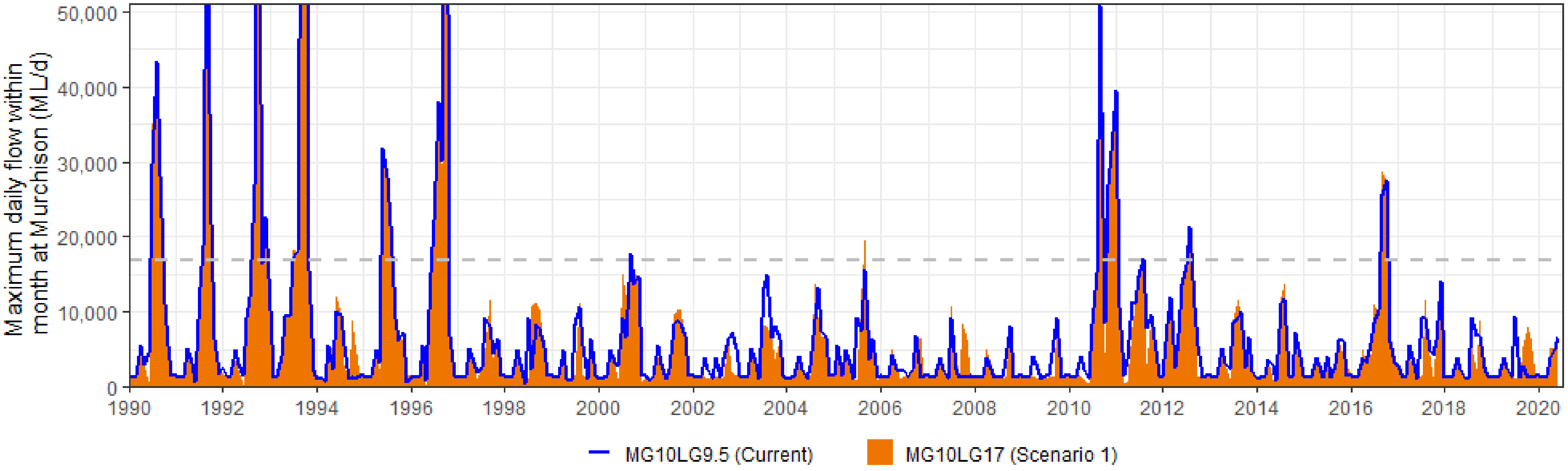
Maximum daily flow within month at Trawool (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG14LG25 (Scenario 4)

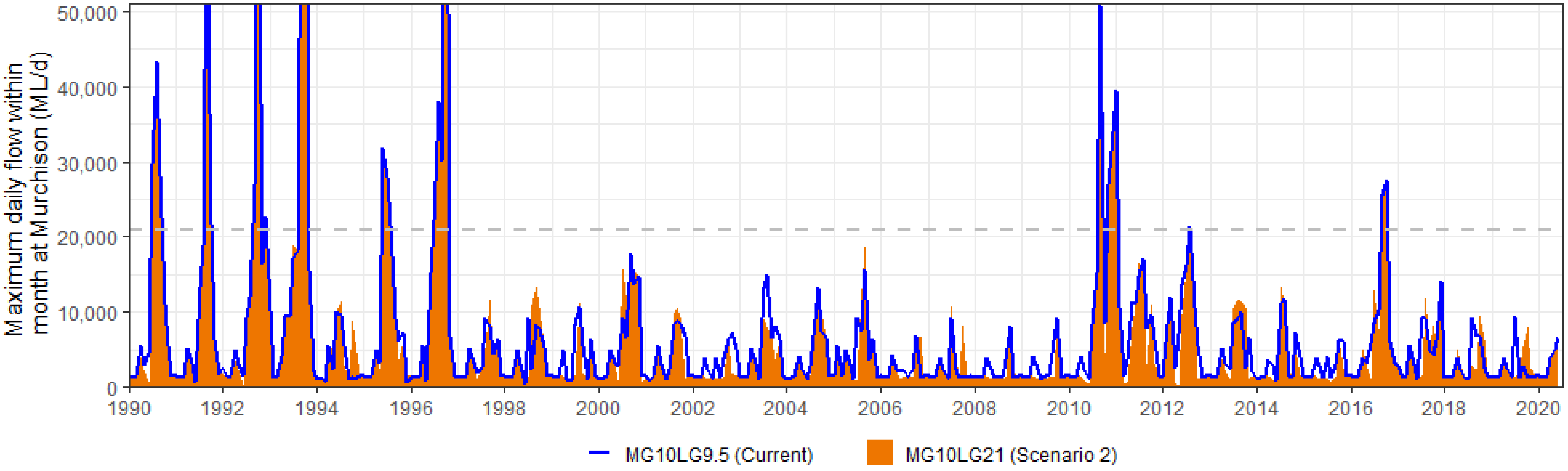

Maximum daily flow within month at Seymour (ML/d)
0
10,000
20,000
30,000
40,000
50,000
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)

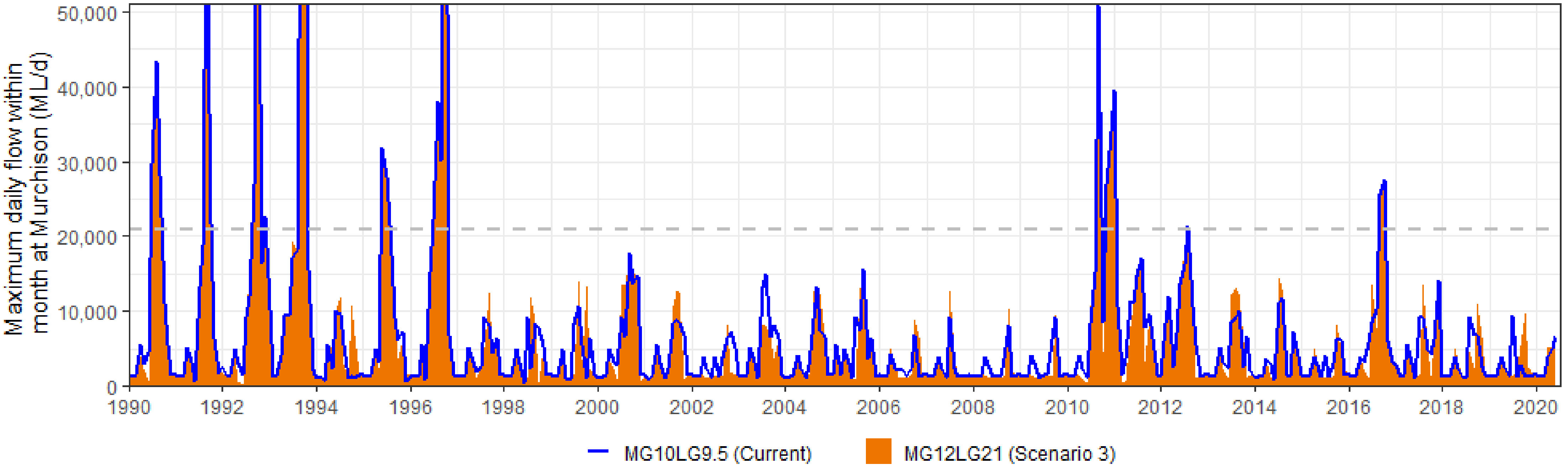

Maximum daily flow within month at Seymour (ML/d)
0
10,000
20,000
30,000
40,000
50,000
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG10LG21 (Scenario 2)

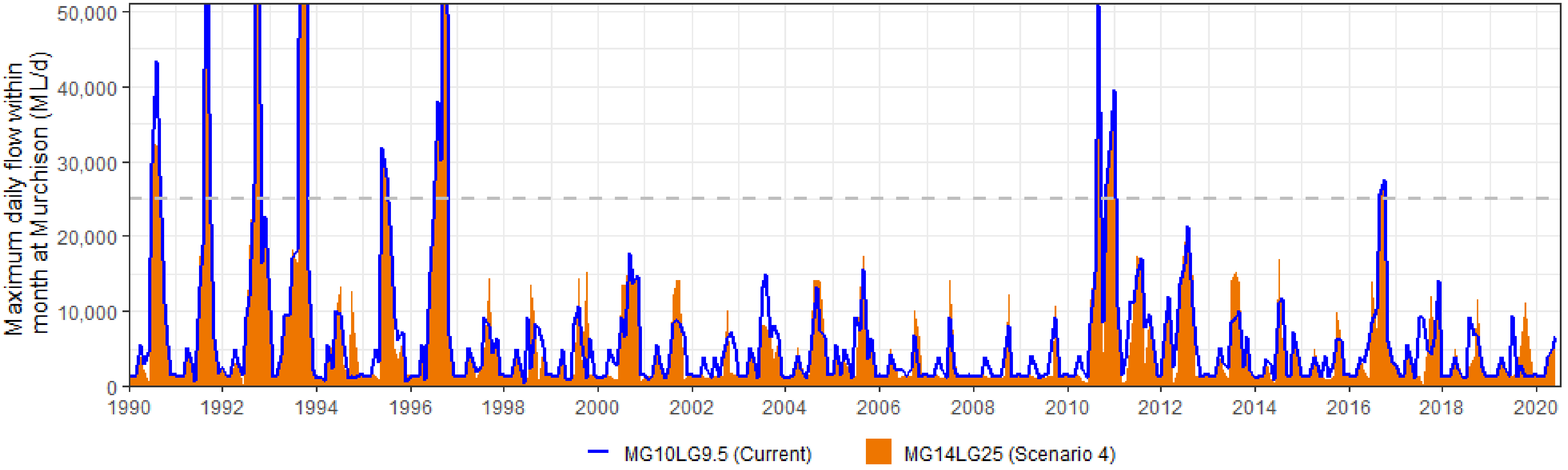

Maximum daily flow within month at Seymour (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG12LG21 (Scenario 3)

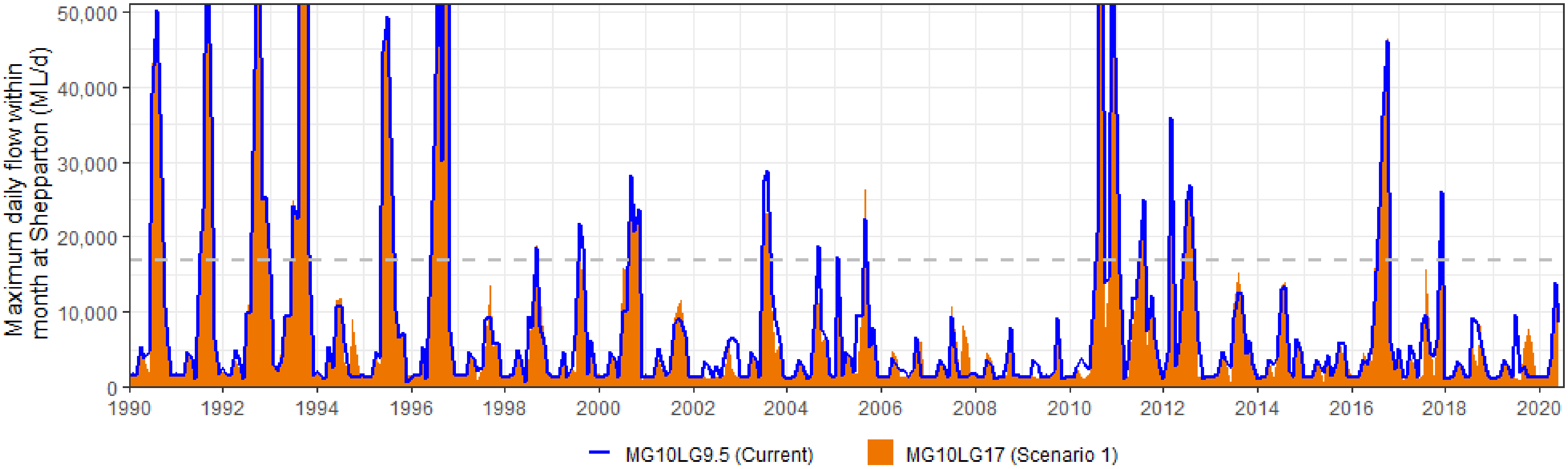

Maximum daily flow within month at Seymour (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG14LG25 (Scenario 4)

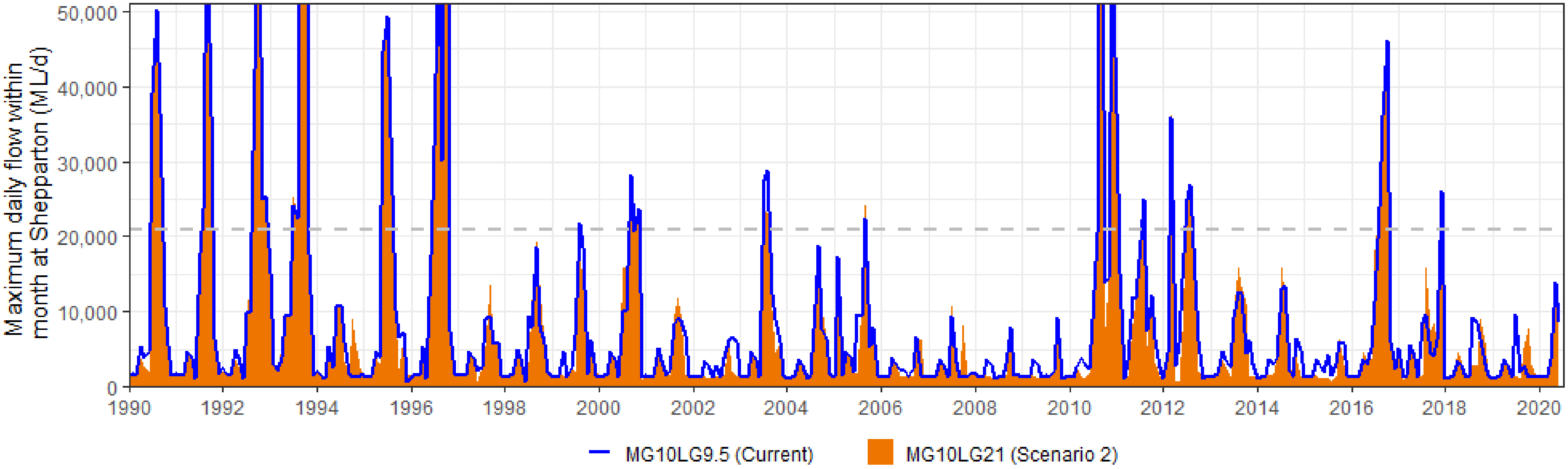

Maximum daily flow within month at Murchison (ML/d)
0
10,000
20,000
30,000
40,000
50,000
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)

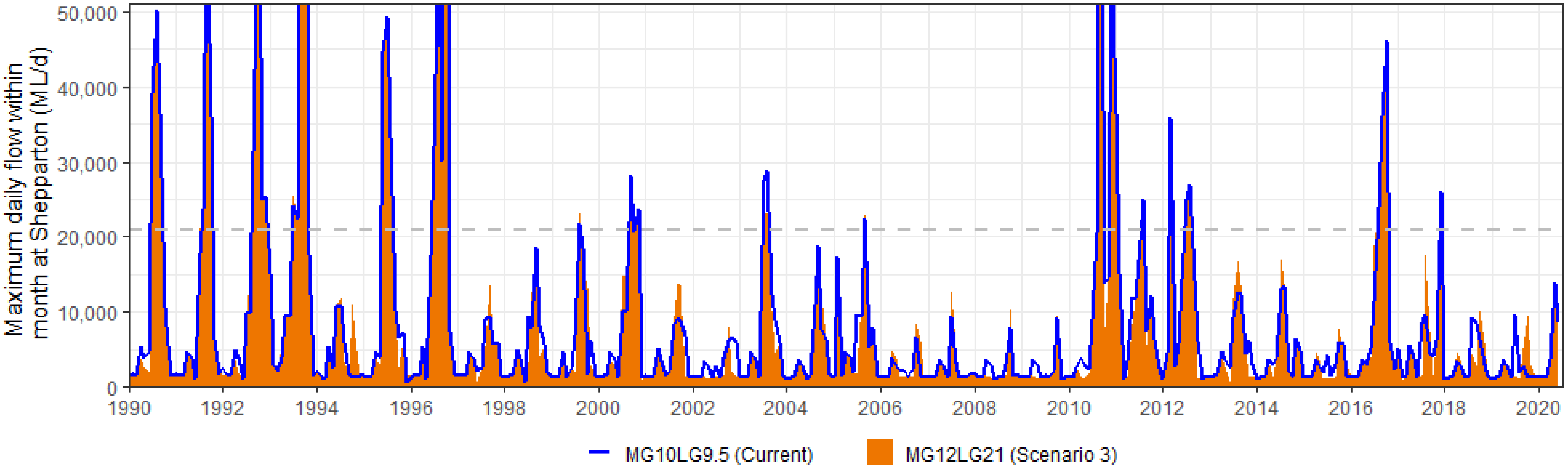

Maximum daily flow within month at Murchison (ML/d)
0
10,000
20,000
30,000
40,000
50,000
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG10LG21 (Scenario 2)

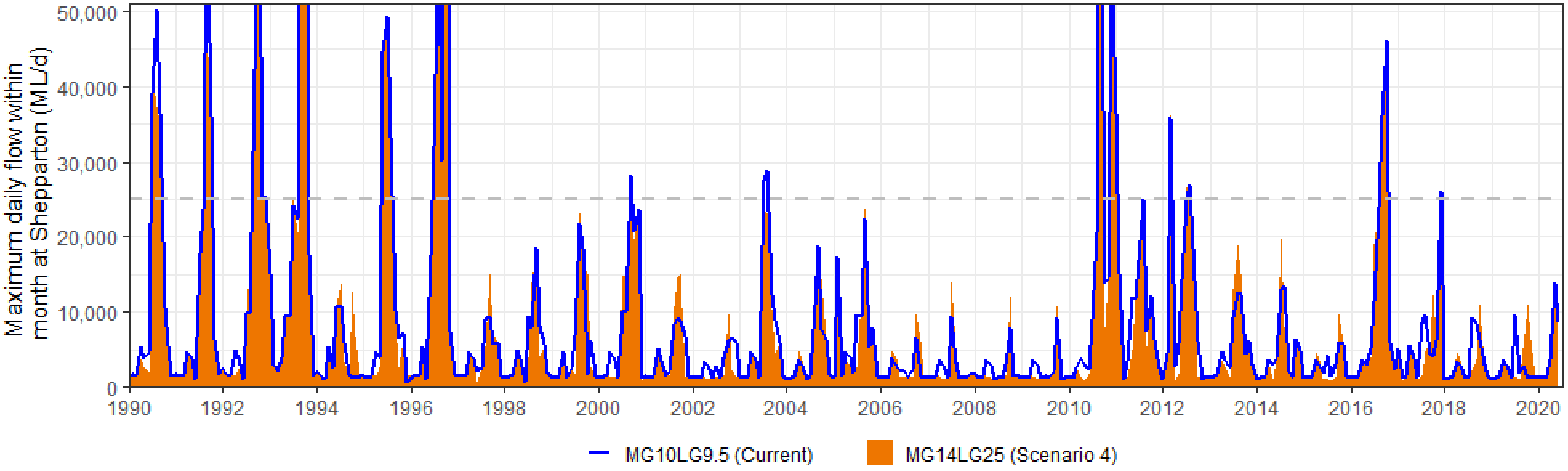

Maximum daily flow within month at Murchison (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG12LG21 (Scenario 3)

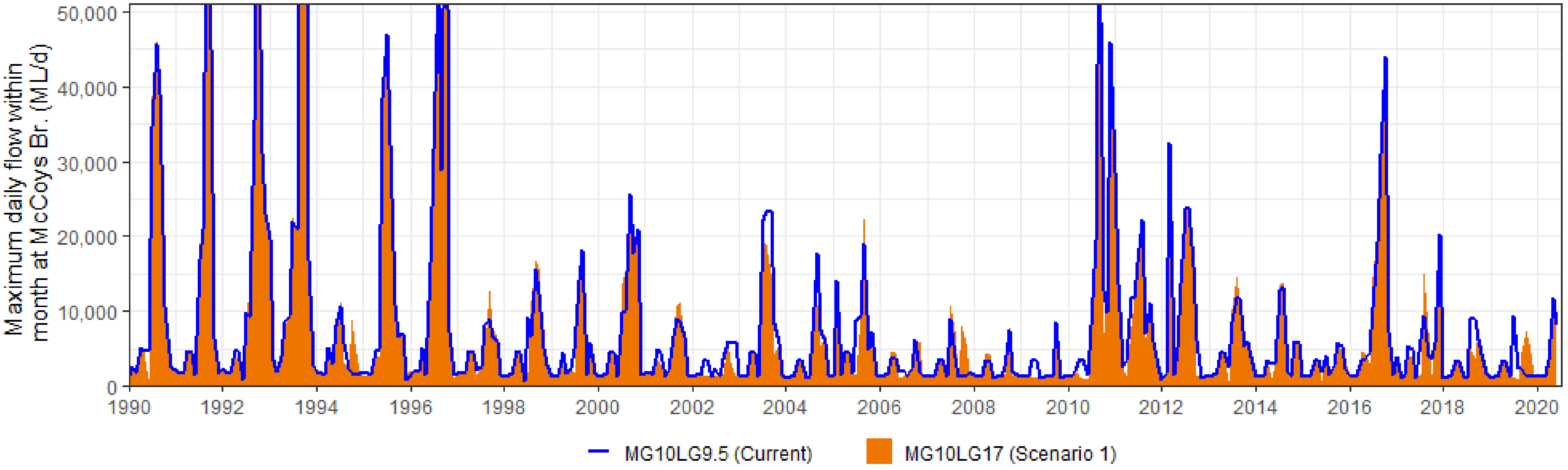

Maximum daily flow within month at Murchison (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG14LG25 (Scenario 4)

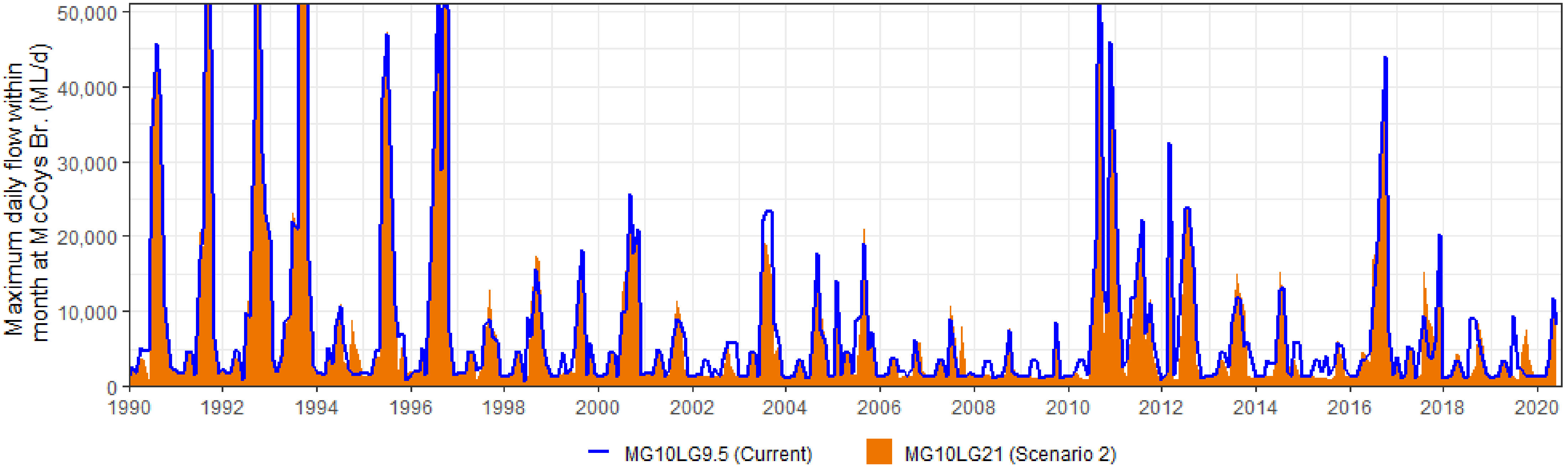

Maximum daily flow within month at Shepparton (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)

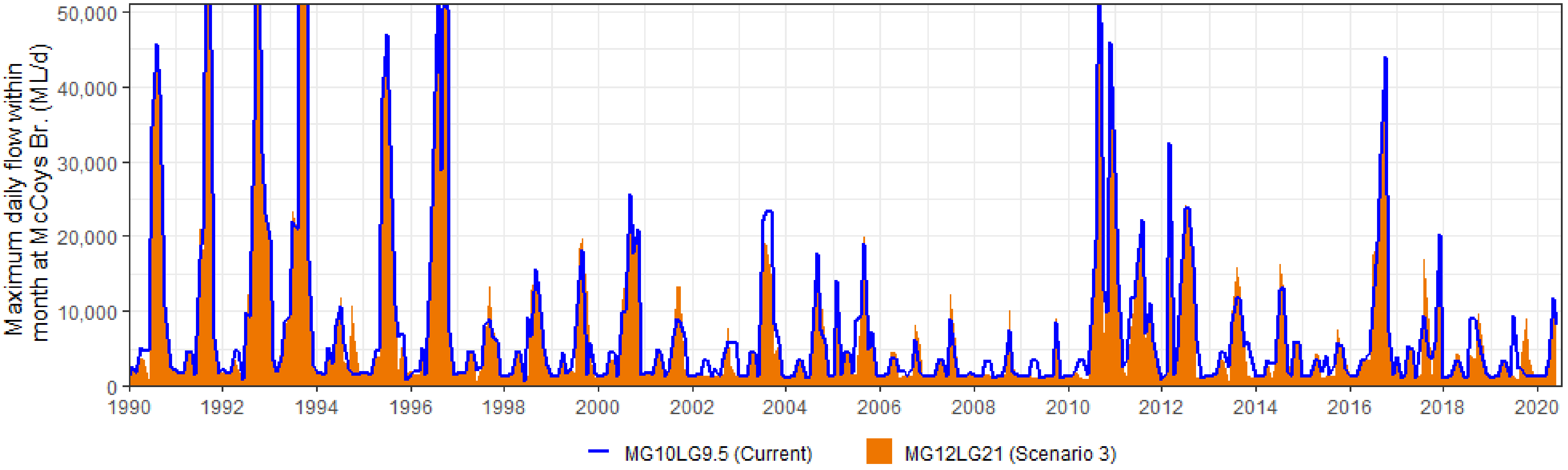

Maximum daily flow within month at Shepparton (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG10LG21 (Scenario 2)

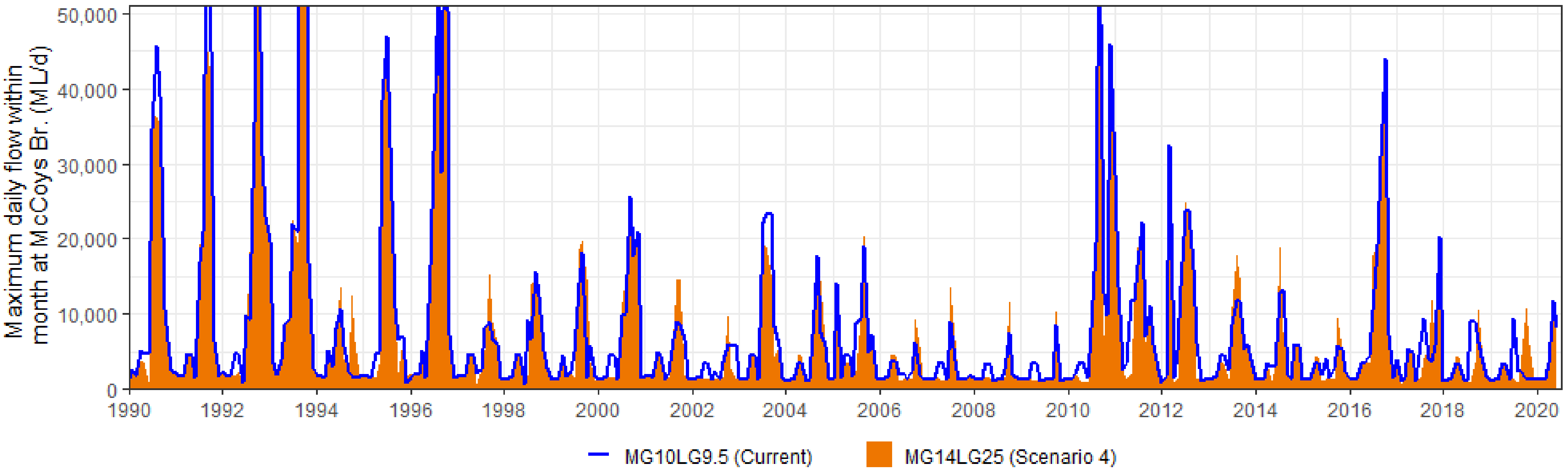

Maximum daily flow within month at Shepparton (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG12LG21 (Scenario 3)


Maximum daily flow within month at Shepparton (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG14LG25 (Scenario 4)

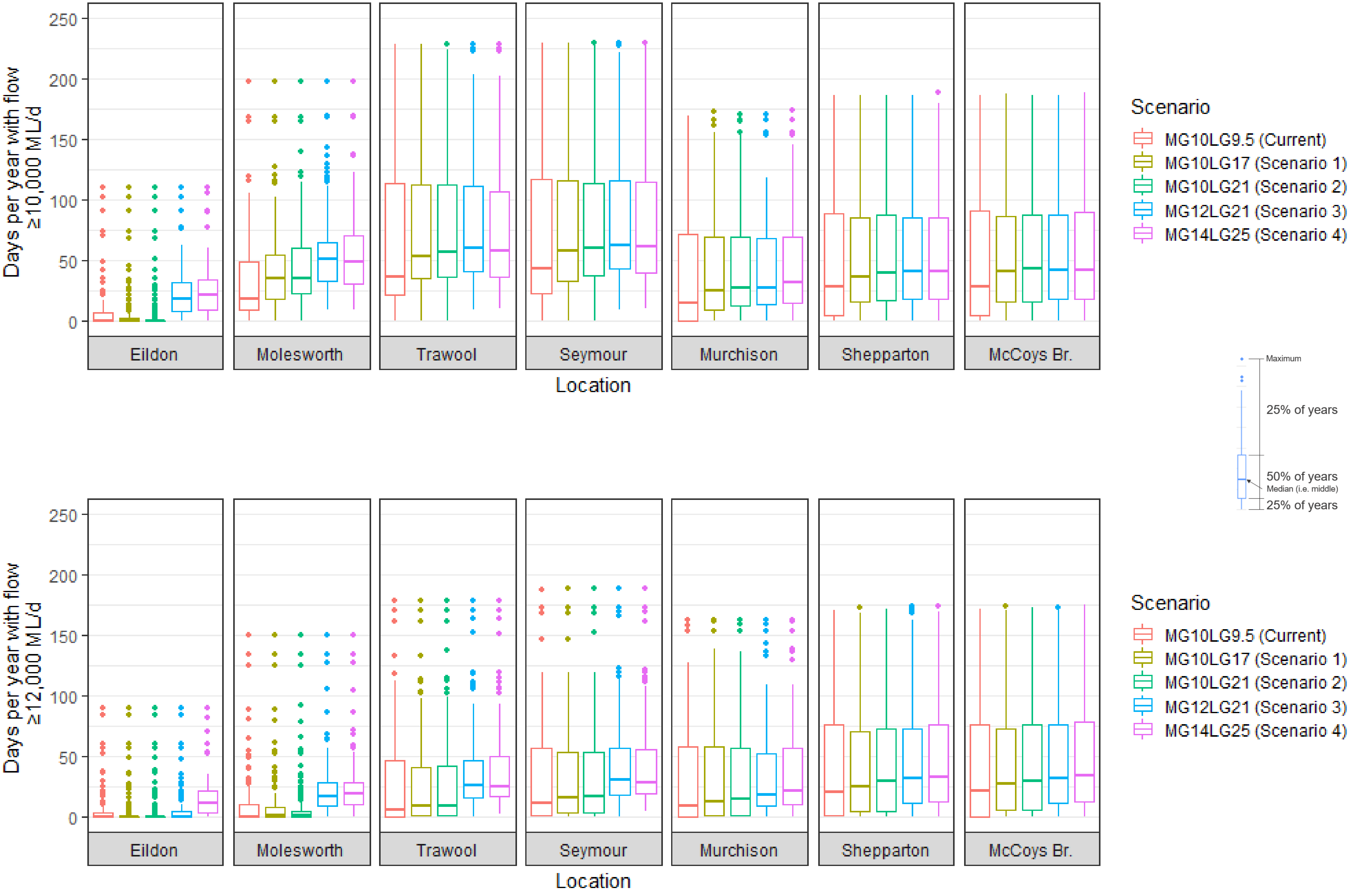

Maximum daily flow within month at McCoys Br. (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)

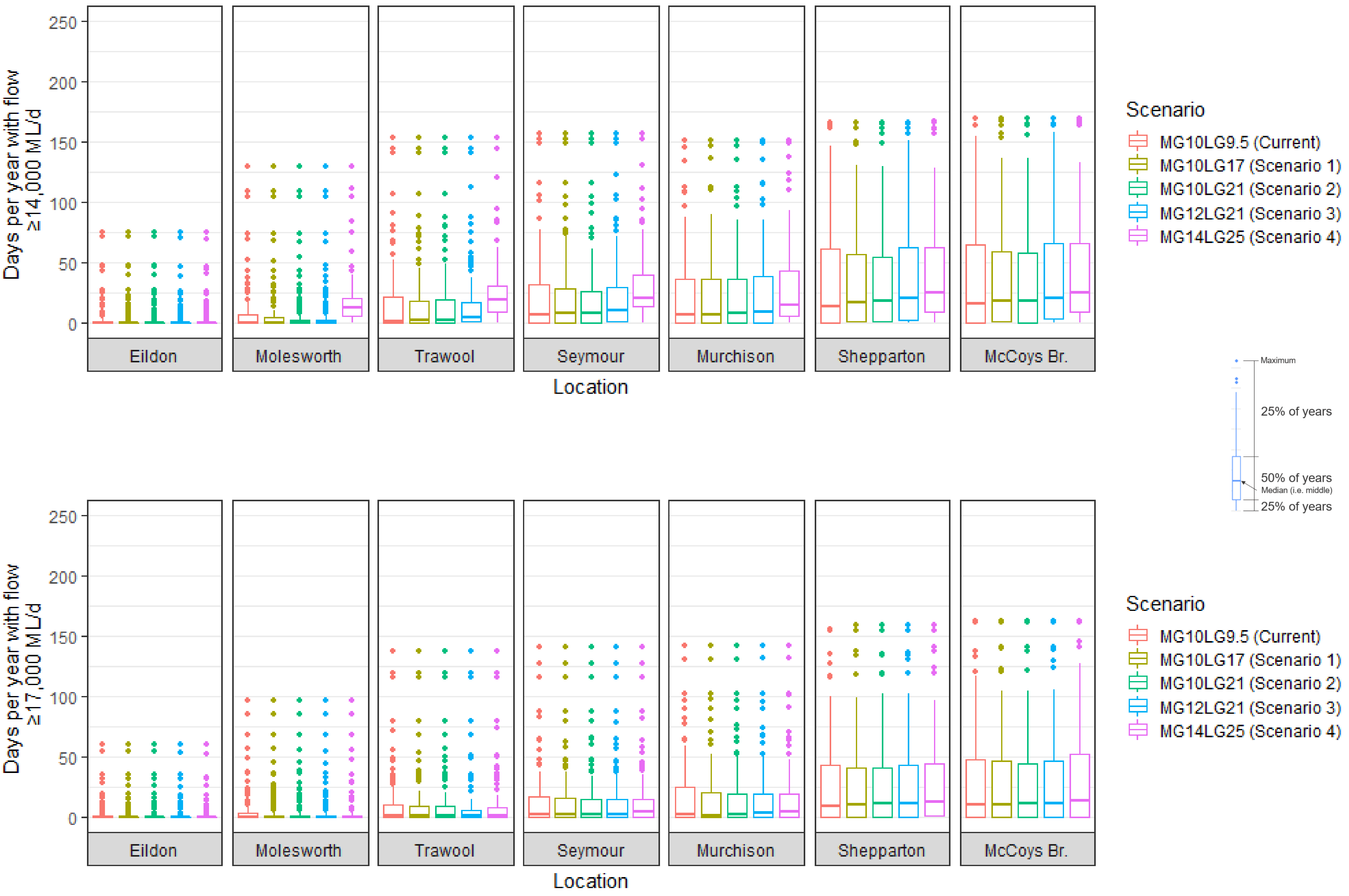

Maximum daily flow within month at McCoys Br. (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG10LG21 (Scenario 2)

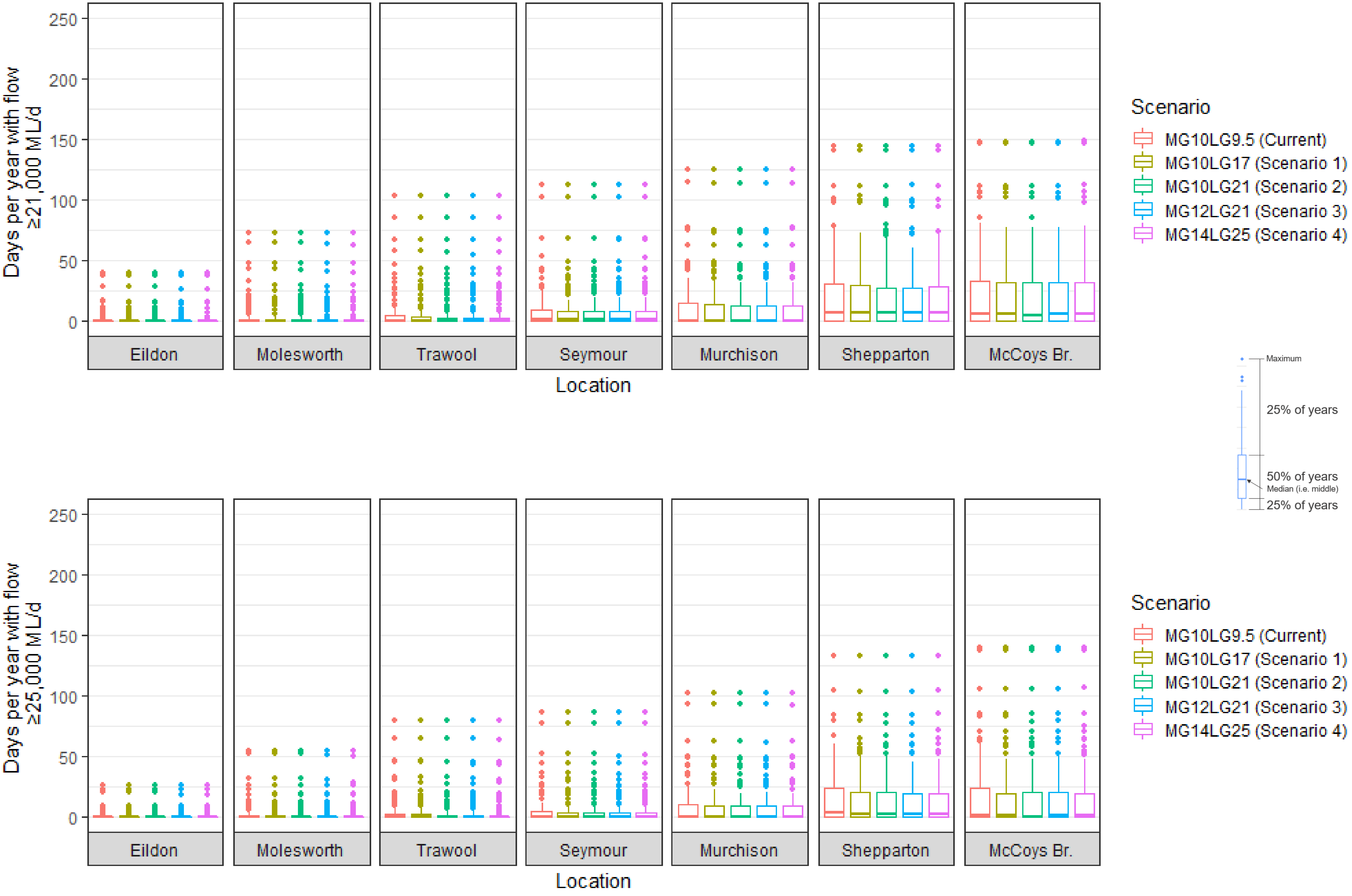

Maximum daily flow within month at McCoys Br. (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG12LG21 (Scenario 3)

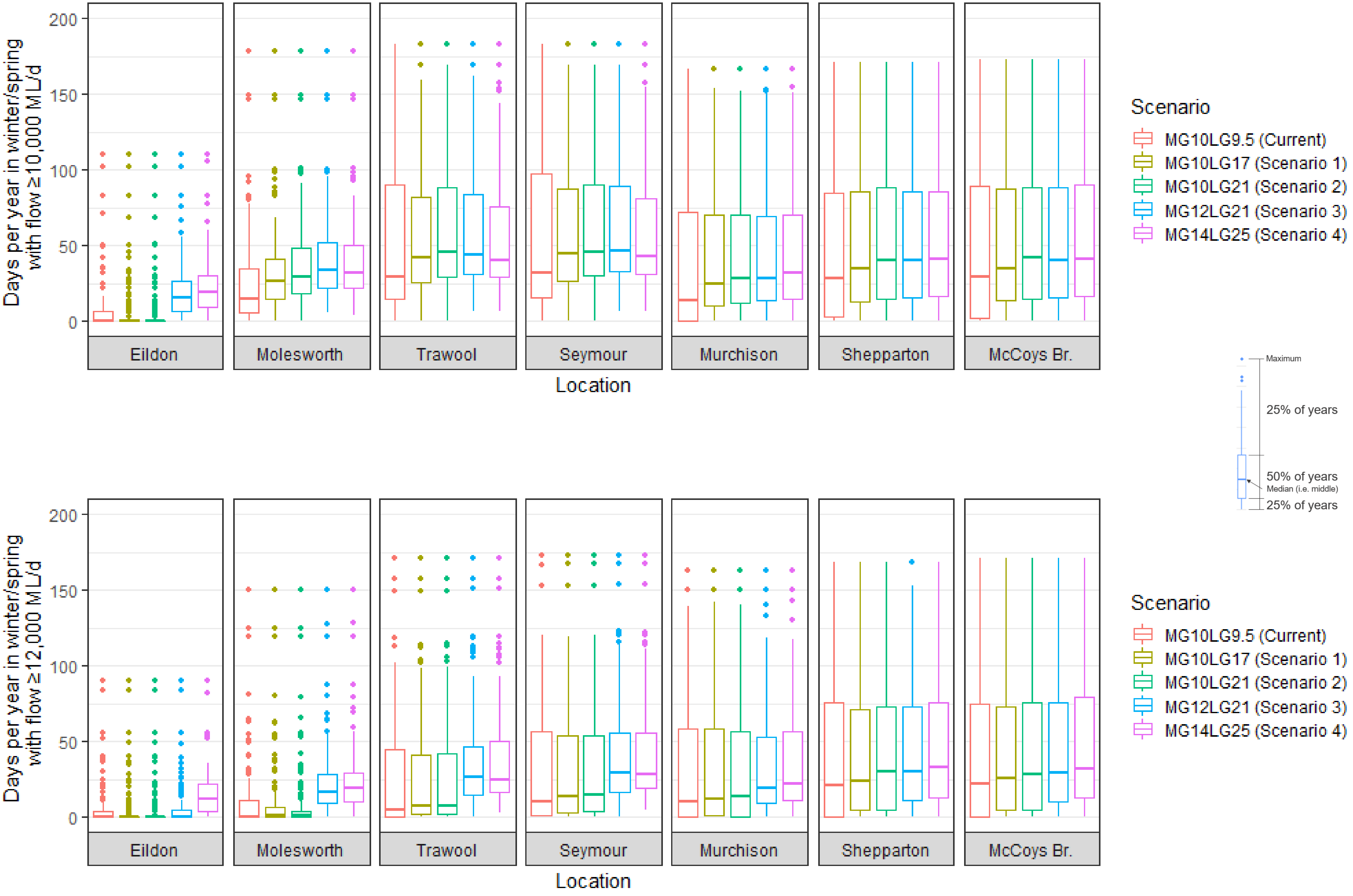

Maximum daily flow within month at McCoys Br. (ML/d)
50,000
40,000
30,000
20,000
10,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
MG10LG9.5 (Current)
MG14LG25 (Scenario 4)

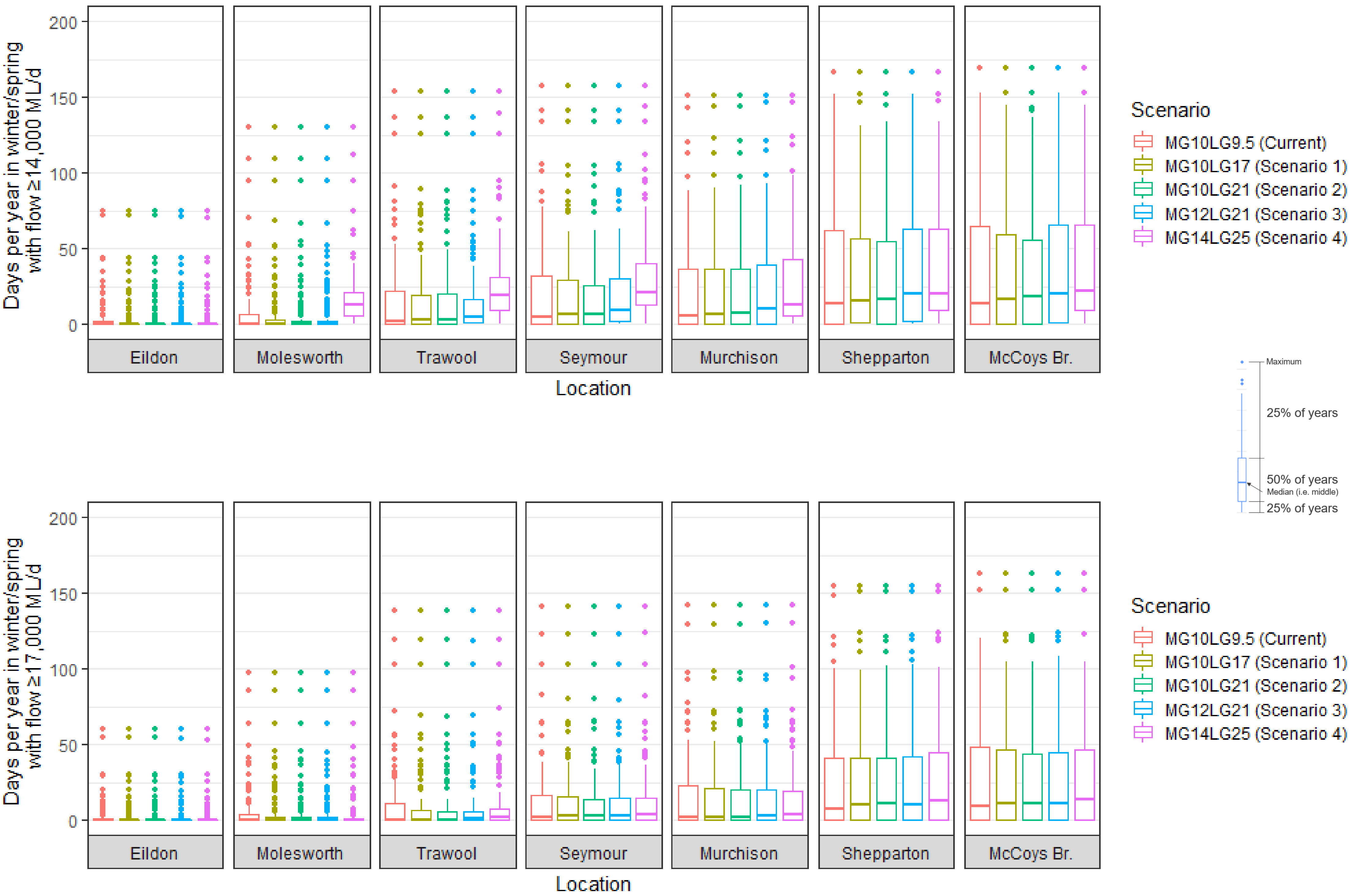
Appendix C Goulburn River – GBCCL Source model results – days per year above thresholds; historic climate (1891-2020)

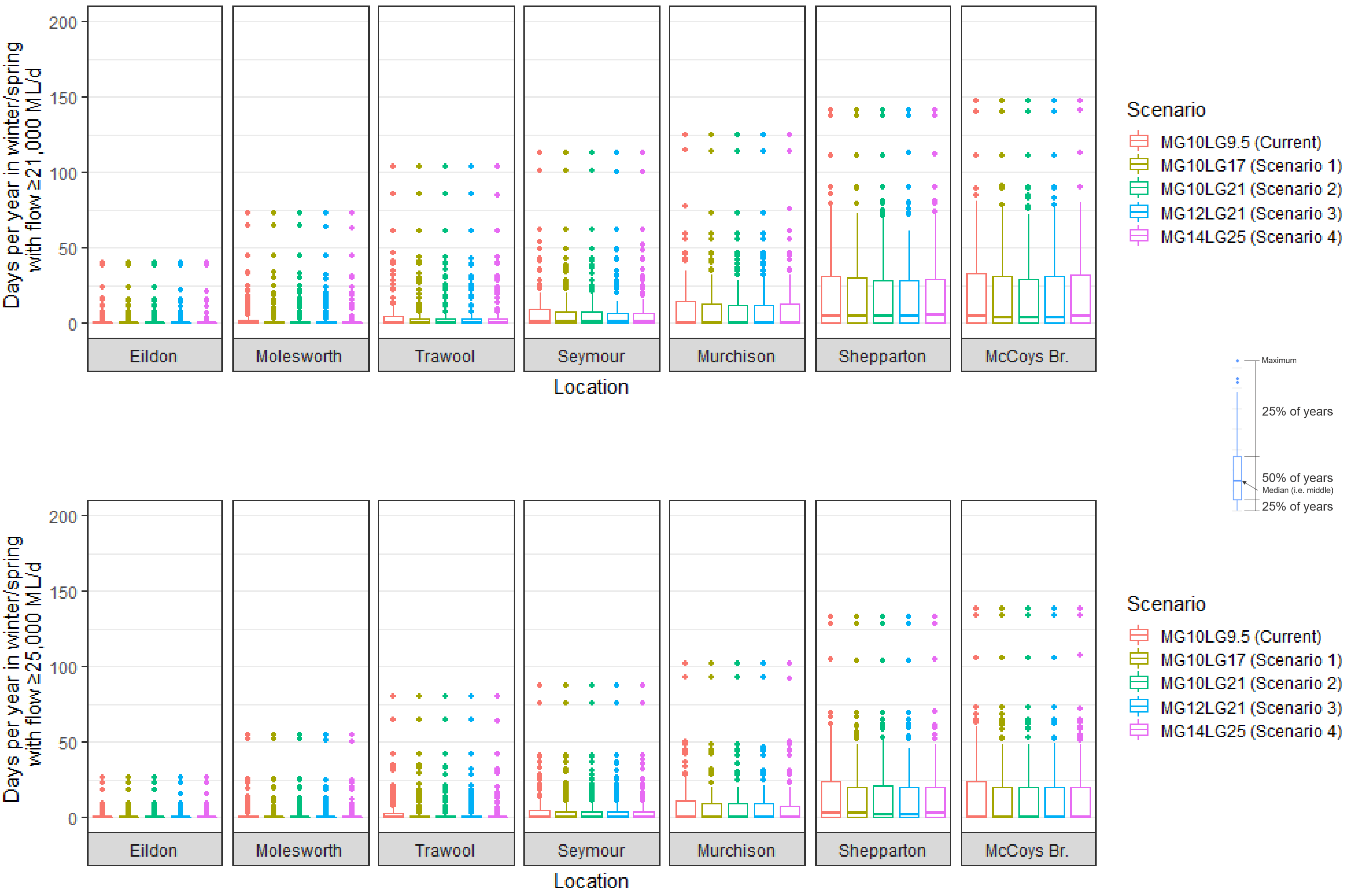

Days per year with flow ≥10,000 ML/d
250
200
150
100
50
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per year with flow ≥12,000 ML/d
250
200
150
100
50
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)

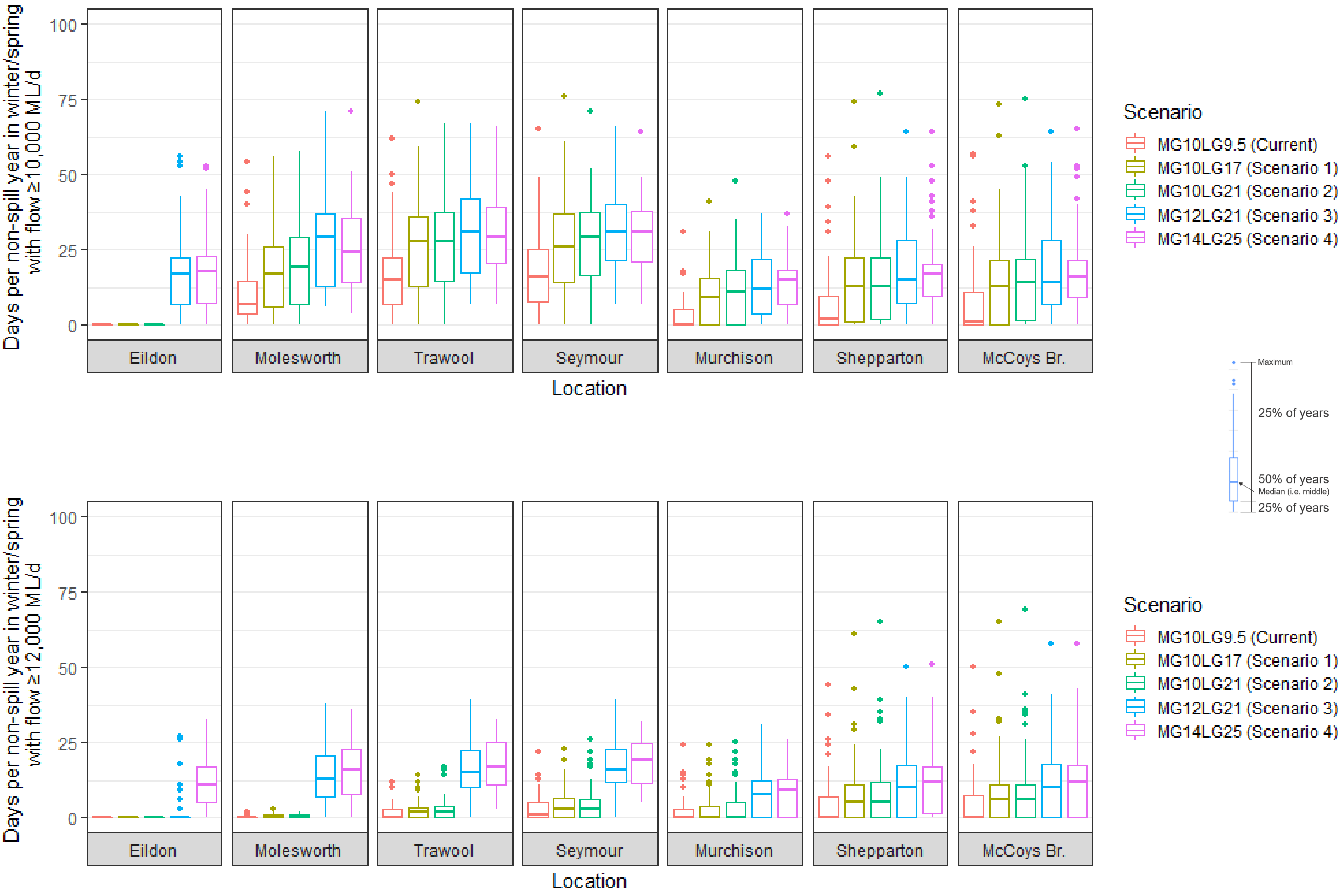

Days per year with flow ≥14,000 ML/d
250
200
150
100
50
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per year with flow ≥17,000 ML/d
250
200
150
100
50
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)

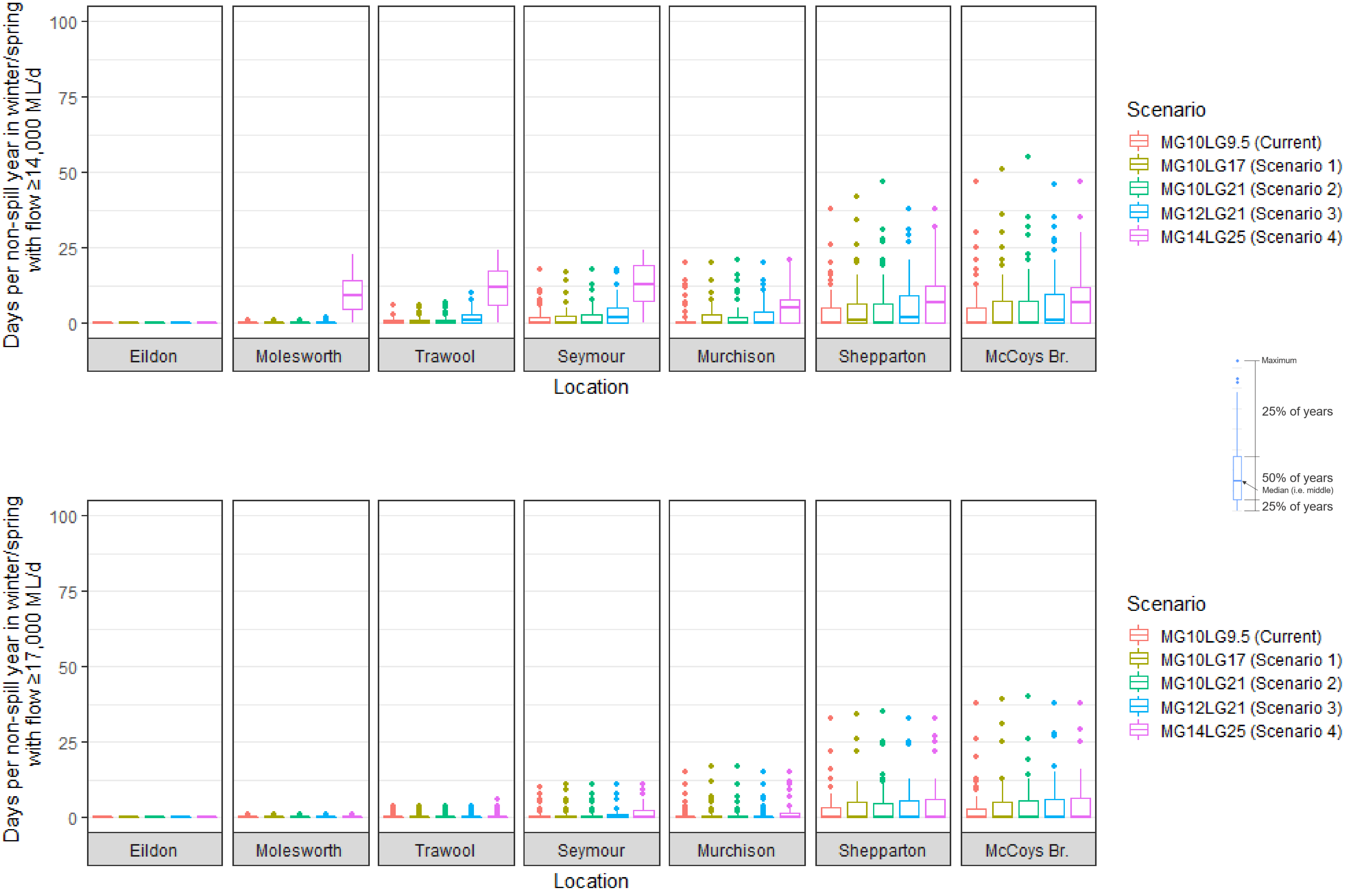

Days per year with flow ≥21,000 ML/d
250
200
150
100
50
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per year with flow ≥25,000 ML/d
250
200
150
100
50
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)

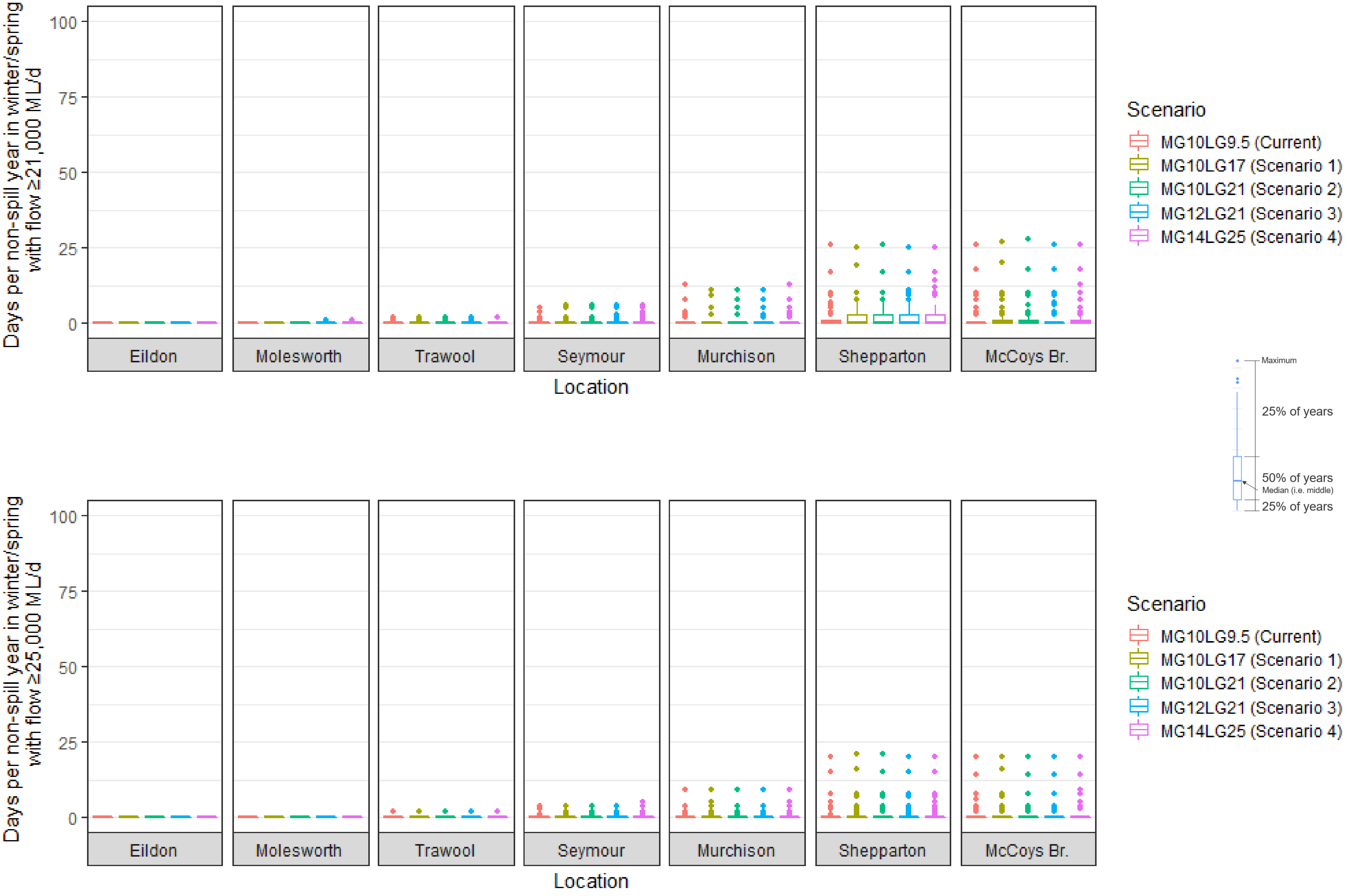

Days per year in winter/spring with flow ≥10,000 ML/d
200
150
100
50
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per year in winter/spring with flow ≥12,000 ML/d
200
150
100
50
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)

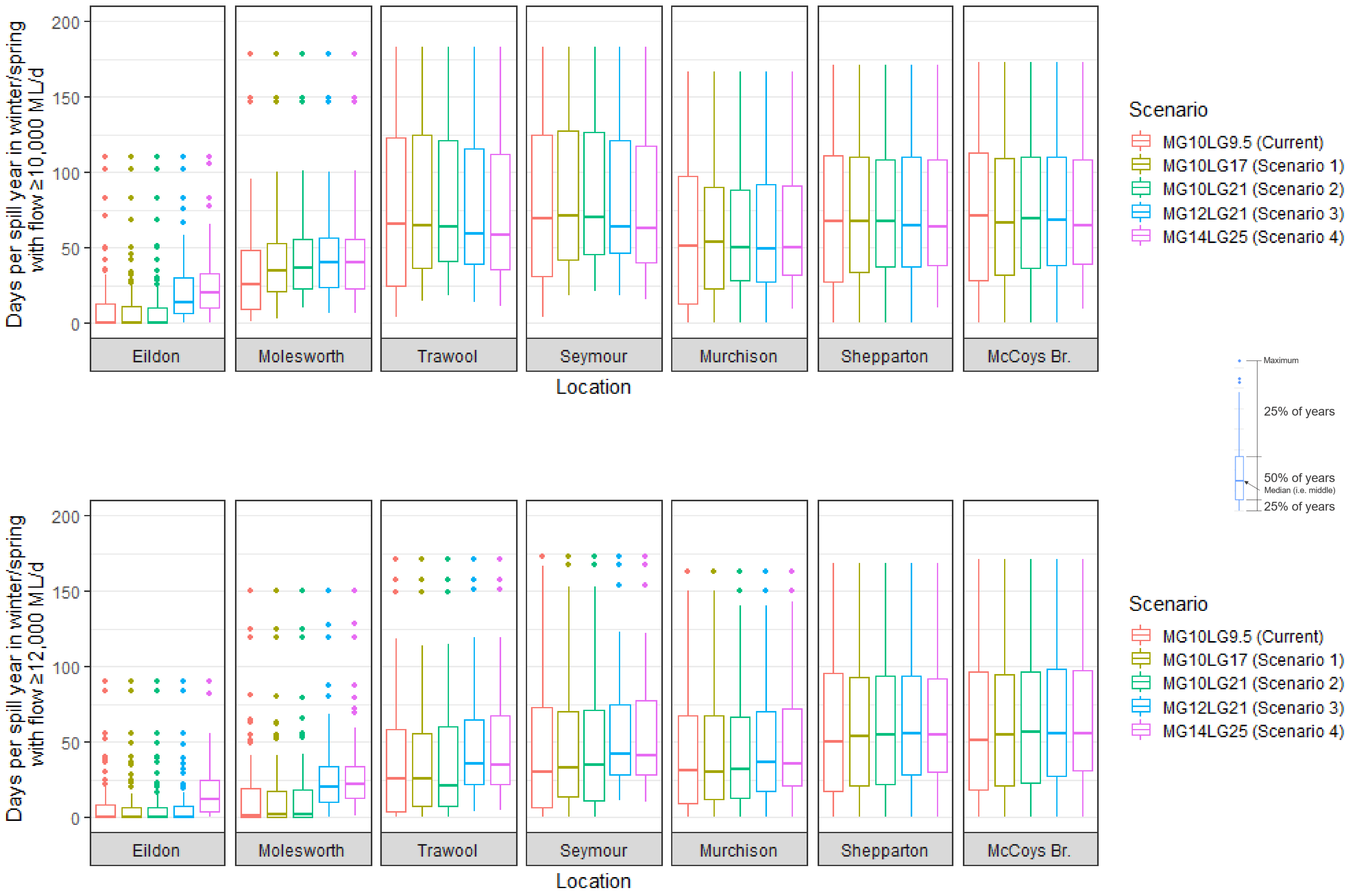

Days per year in winter/spring with flow ≥14,000 ML/d
200
150
100
50
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per year in winter/spring with flow ≥17,000 ML/d
200
150
100
50
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)

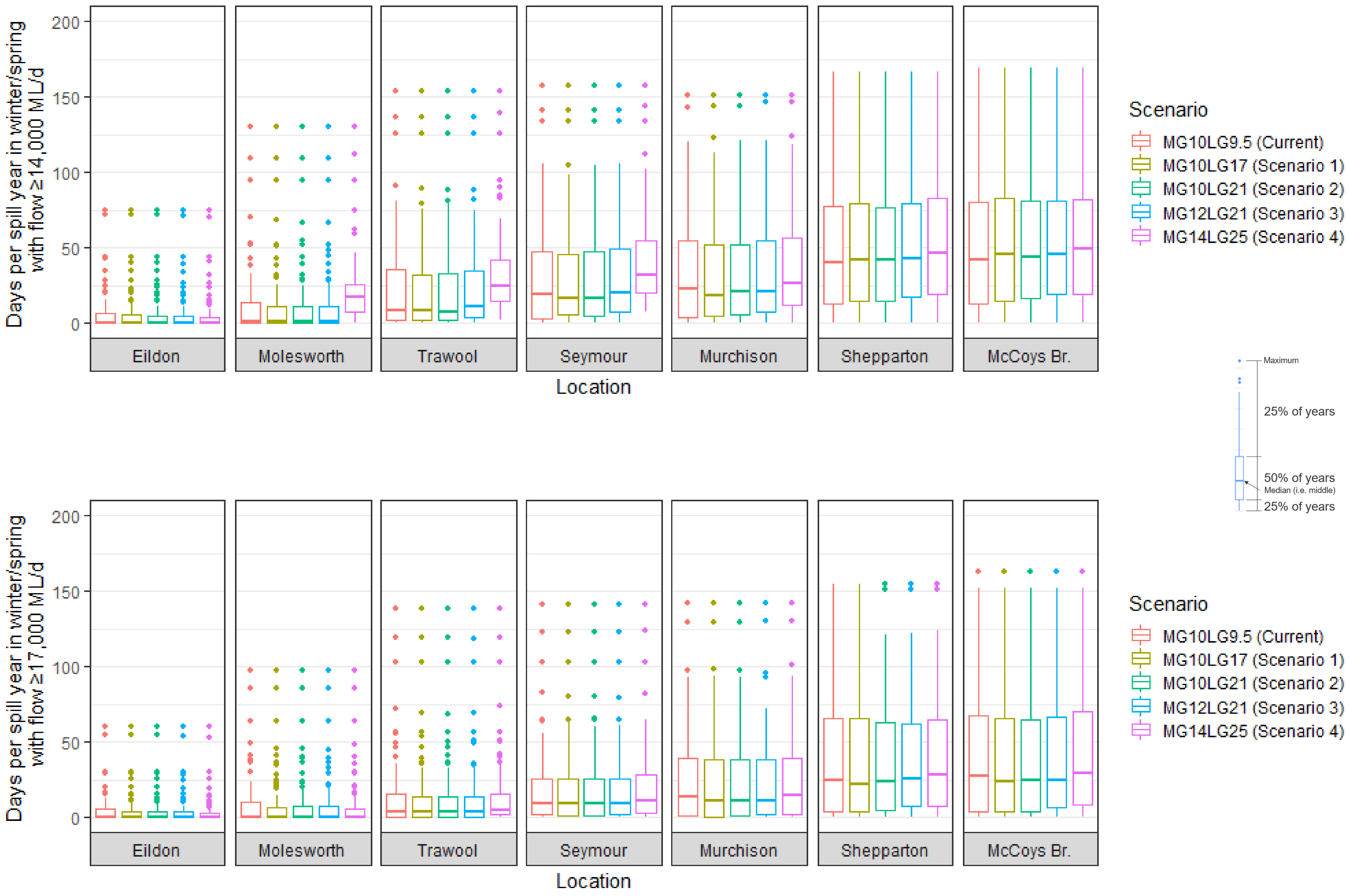

Days per year in winter/spring with flow ≥21,000 ML/d
200
150
100
50
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per year in winter/spring with flow ≥25,000 ML/d
200
150
100
50
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)

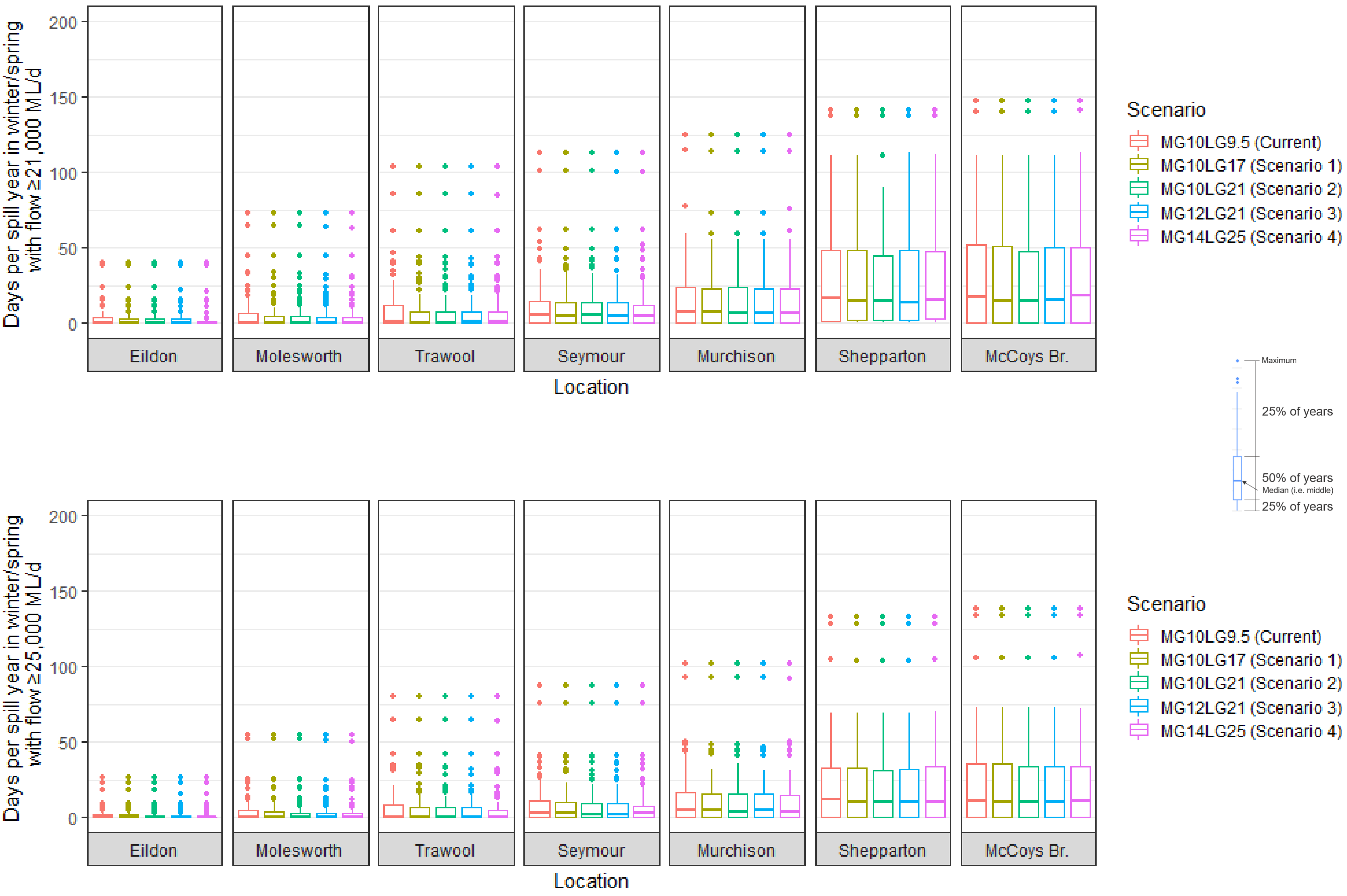

Days per non-spill year in winter/spring with flow ≥10,000 ML/d
100
75
50
25
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per non-spill year in winter/spring with flow ≥12,000 ML/d
100
75
50
25
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)


Days per non-spill year in winter/spring with flow ≥14,000 ML/d
100
75
50
25
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per non-spill year in winter/spring with flow ≥17,000 ML/d
100
75
50
25
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)


Days per non-spill year in winter/spring with flow ≥21,000 ML/d
100
75
50
25
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per non-spill year in winter/spring with flow ≥25,000 ML/d
100
75
50
25
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)

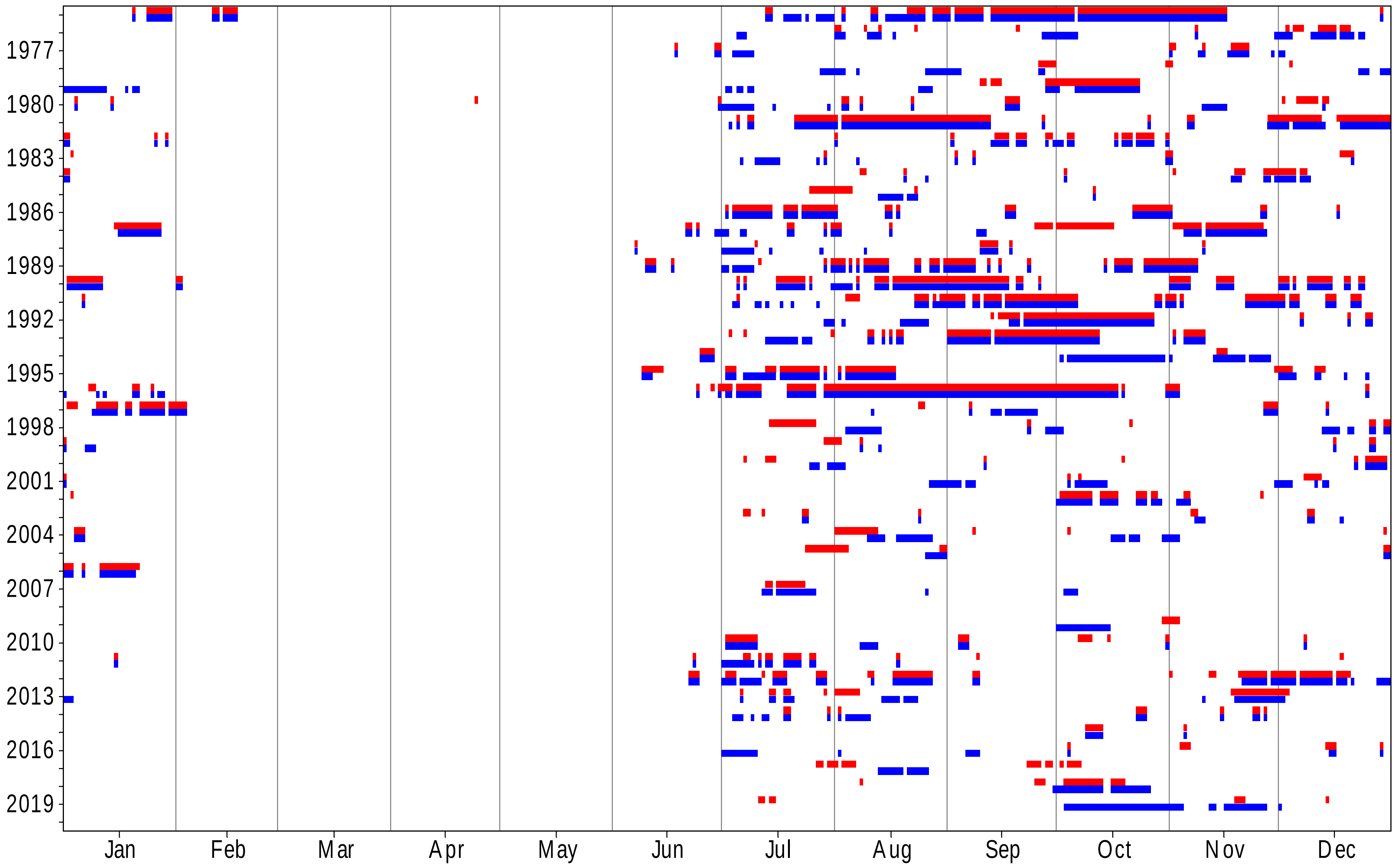

Days per spill year in winter/spring with flow ≥10,000 ML/d
200
150
100
50
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per spill year in winter/spring with flow ≥12,000 ML/d
200
150
100
50
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)


Days per spill year in winter/spring with flow ≥14,000 ML/d
200
150
100
50
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per spill year in winter/spring with flow ≥17,000 ML/d
200
150
100
50
0
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)


Days per spill year in winter/spring with flow ≥21,000 ML/d
0
50
100
150
200
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per spill year in winter/spring with flow ≥25,000 ML/d
0
50
100
150
200
Eildon
Molesworth
Trawool
Seymour
Murchison
Shepparton
McCoys Br.
Location
Scenario
MG10LG9.5 (Current)
MG10LG17 (Scenario 1)
MG10LG21 (Scenario 2)
MG12LG21 (Scenario 3)
MG14LG25 (Scenario 4)

Appendix D Goulburn River – GBCCL Source model results – spells plots; historic climate (1975-2020)

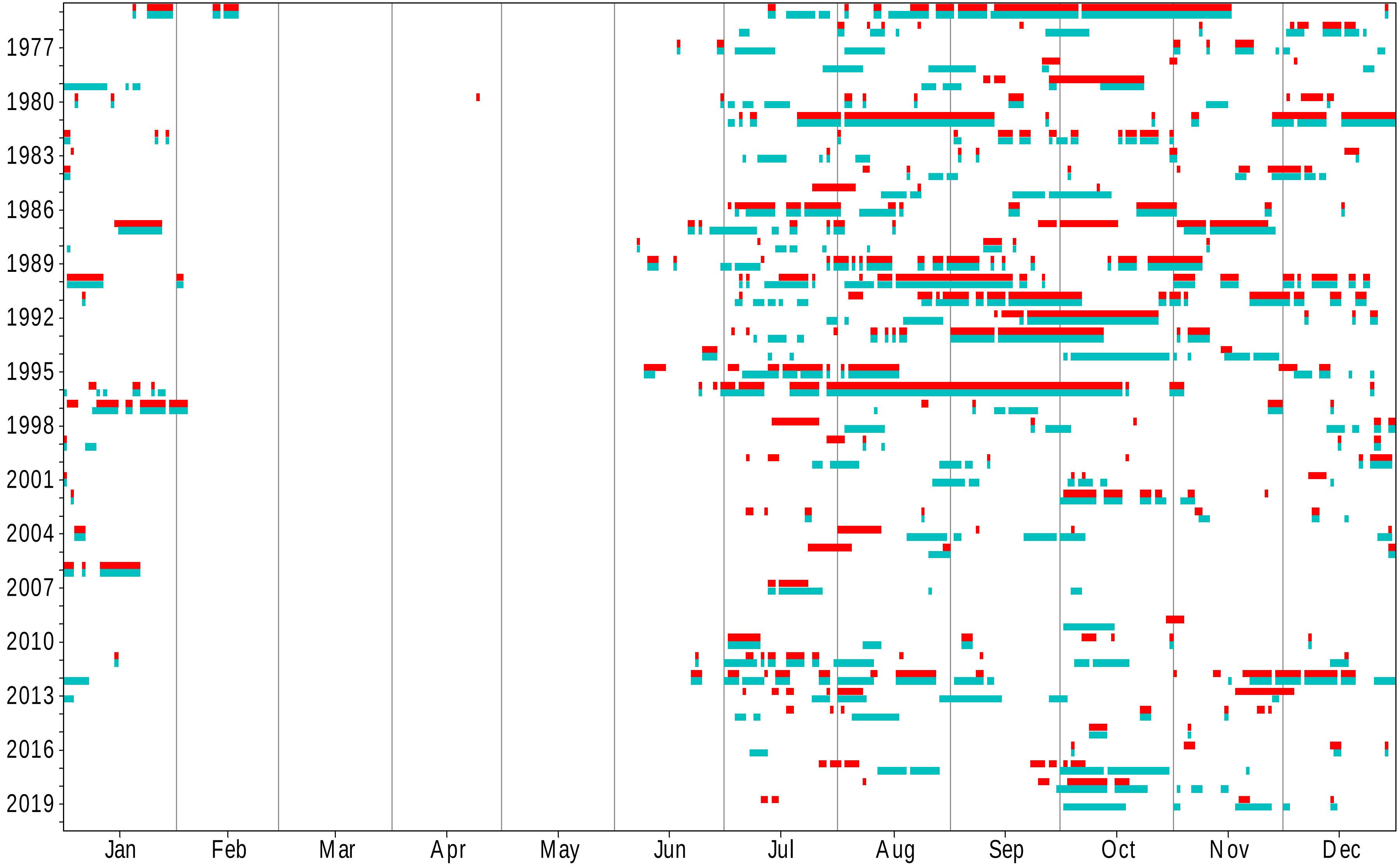
Distribution of Spells



🟥 ≥ 10,000 ML/d @ Molesworth - **Current**

🟦 ≥ 10,000 ML/d @ Molesworth - **M10L17**

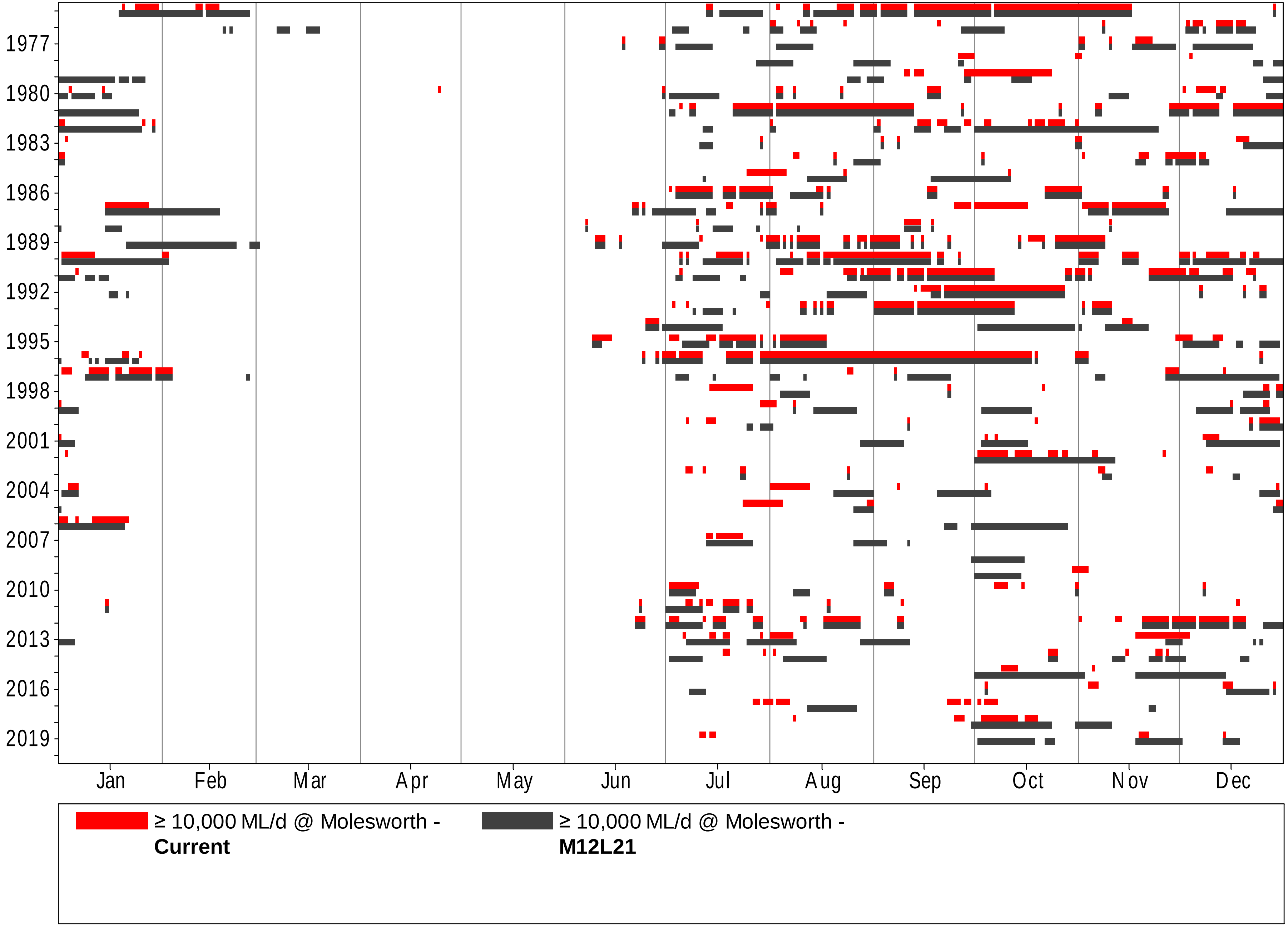
Distribution of Spells



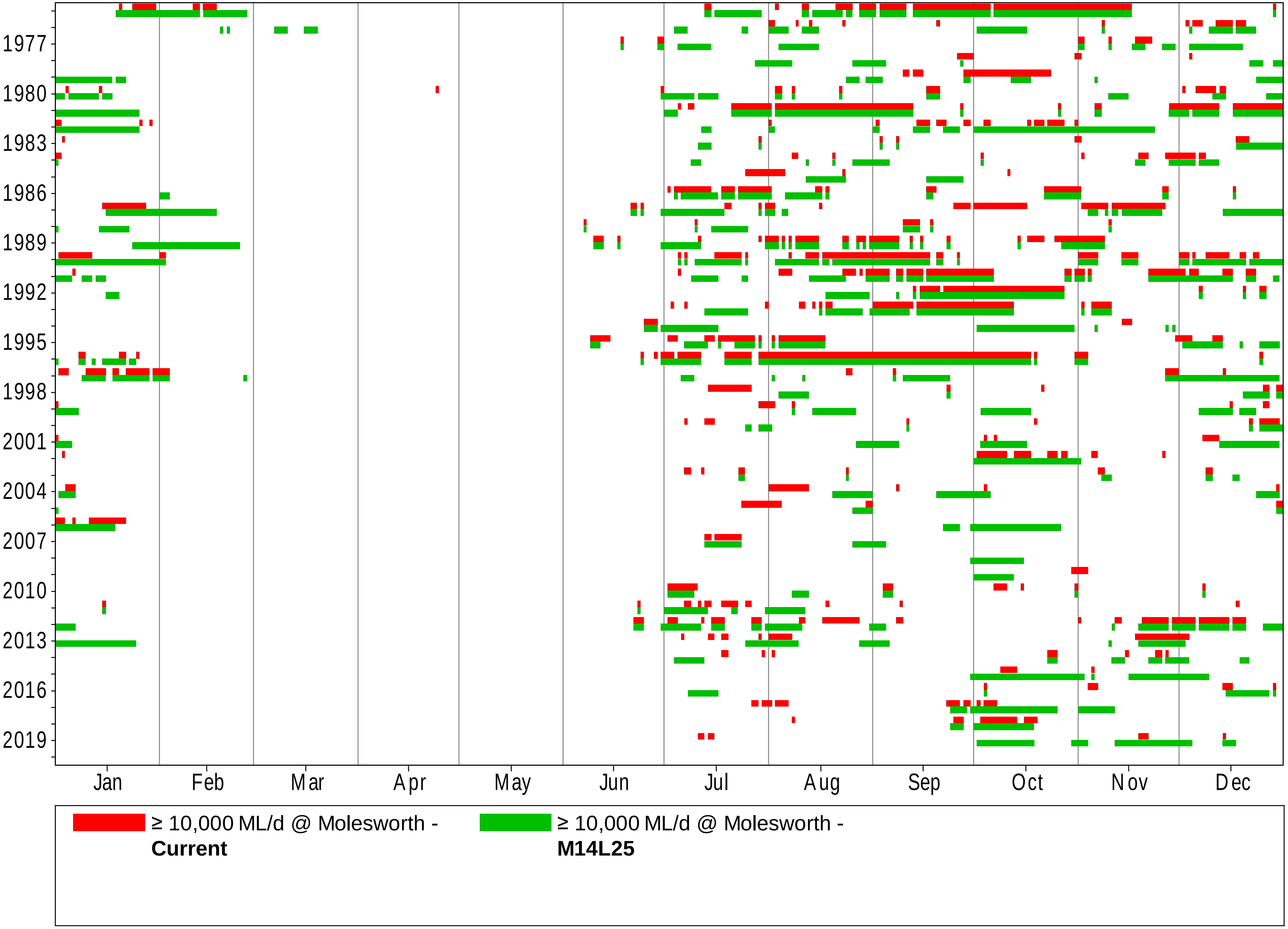
🟥 ≥ 10,000 ML/d @ Molesworth - **Current**

🟦 ≥ 10,000 ML/d @ Molesworth - **M10L21**

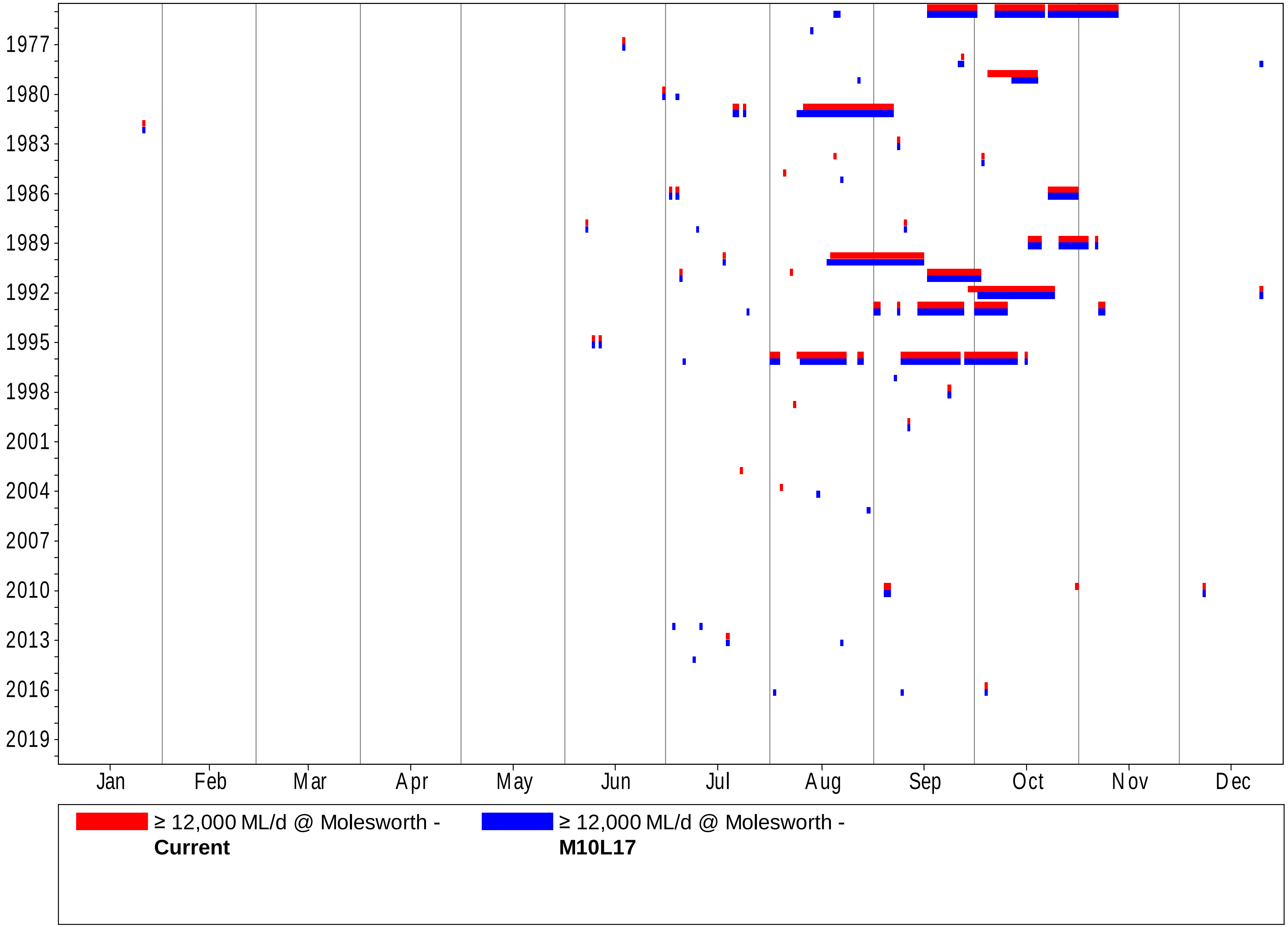
Distribution of Spells



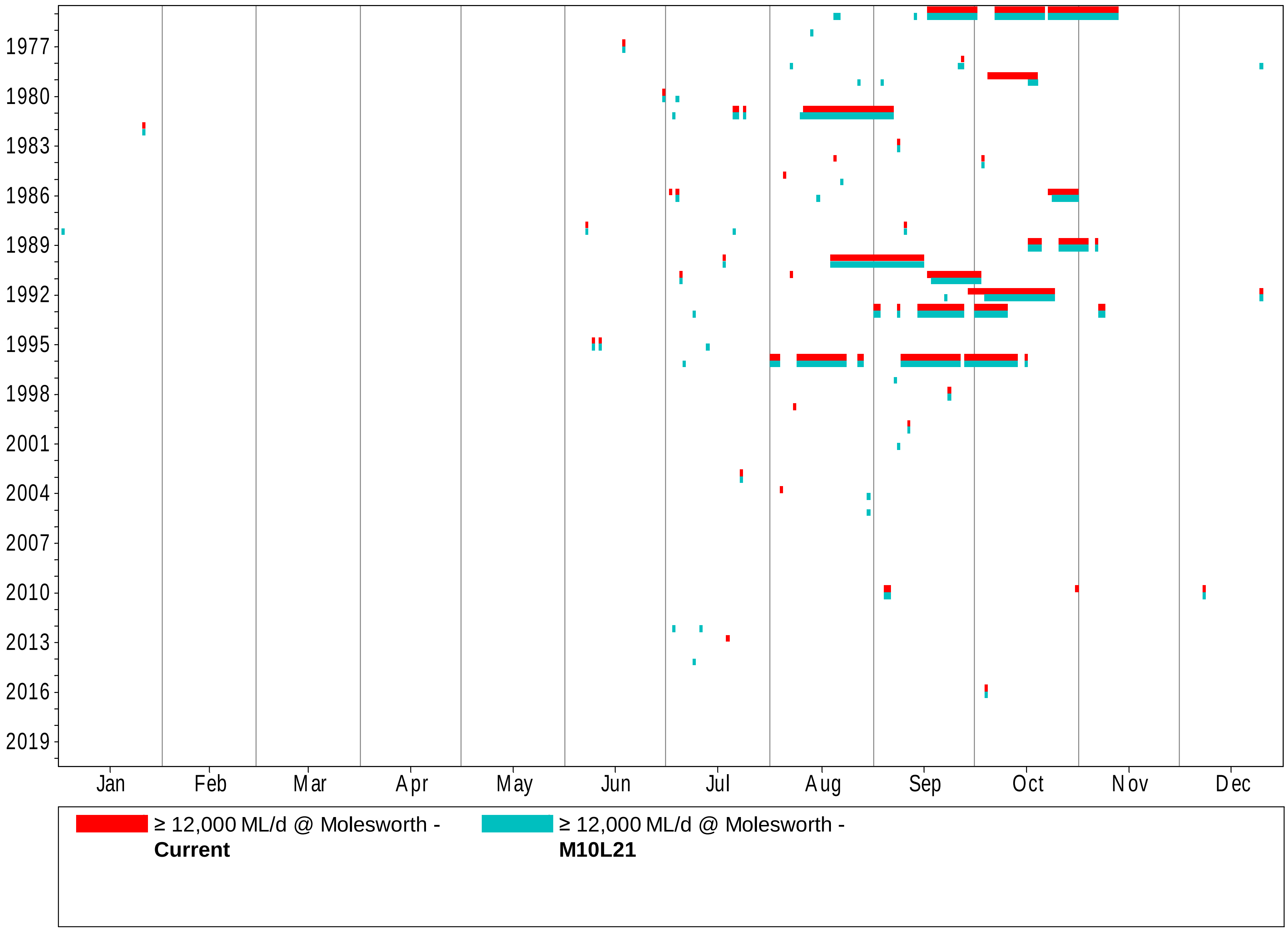
Distribution of Spells

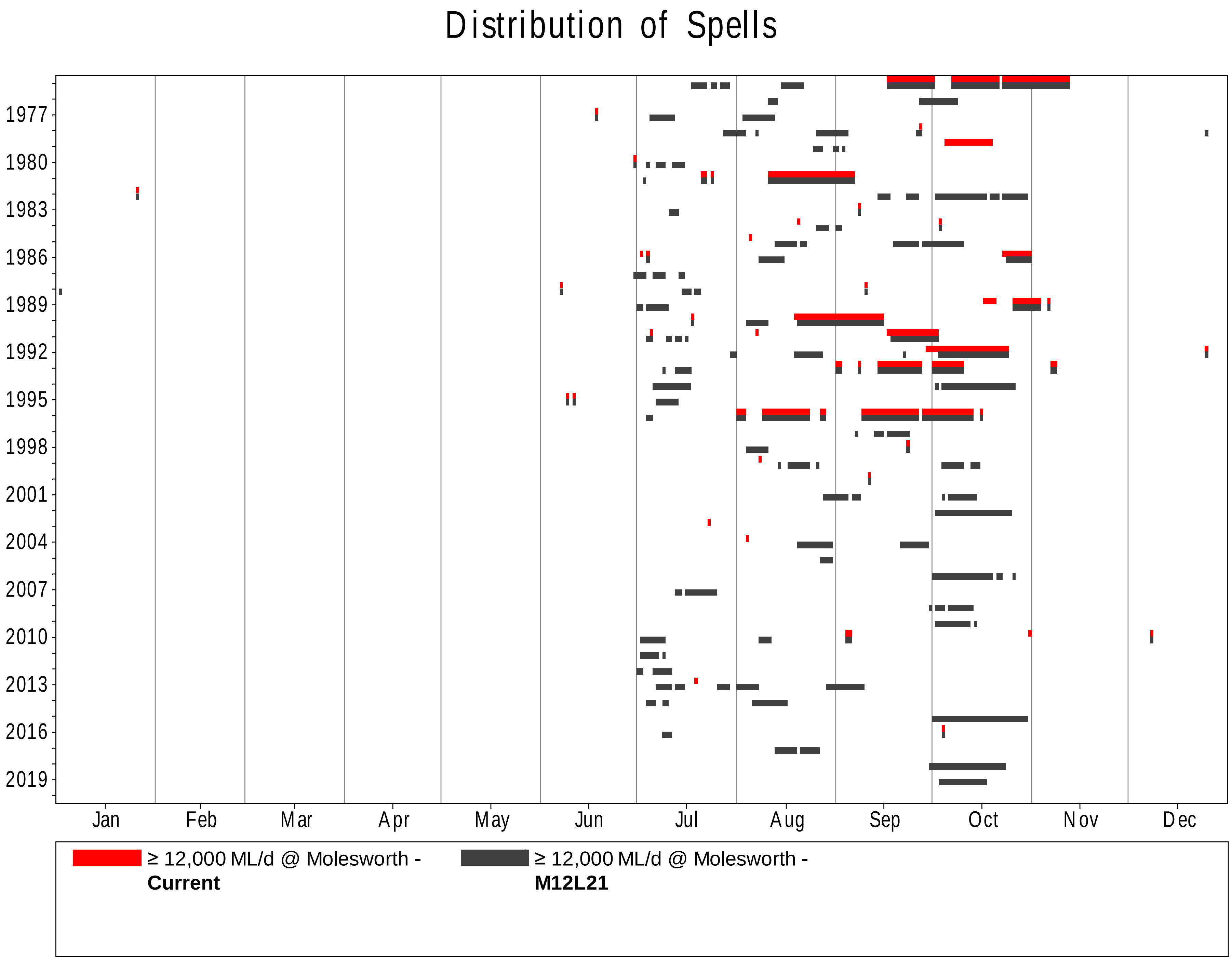


Distribution of Spells

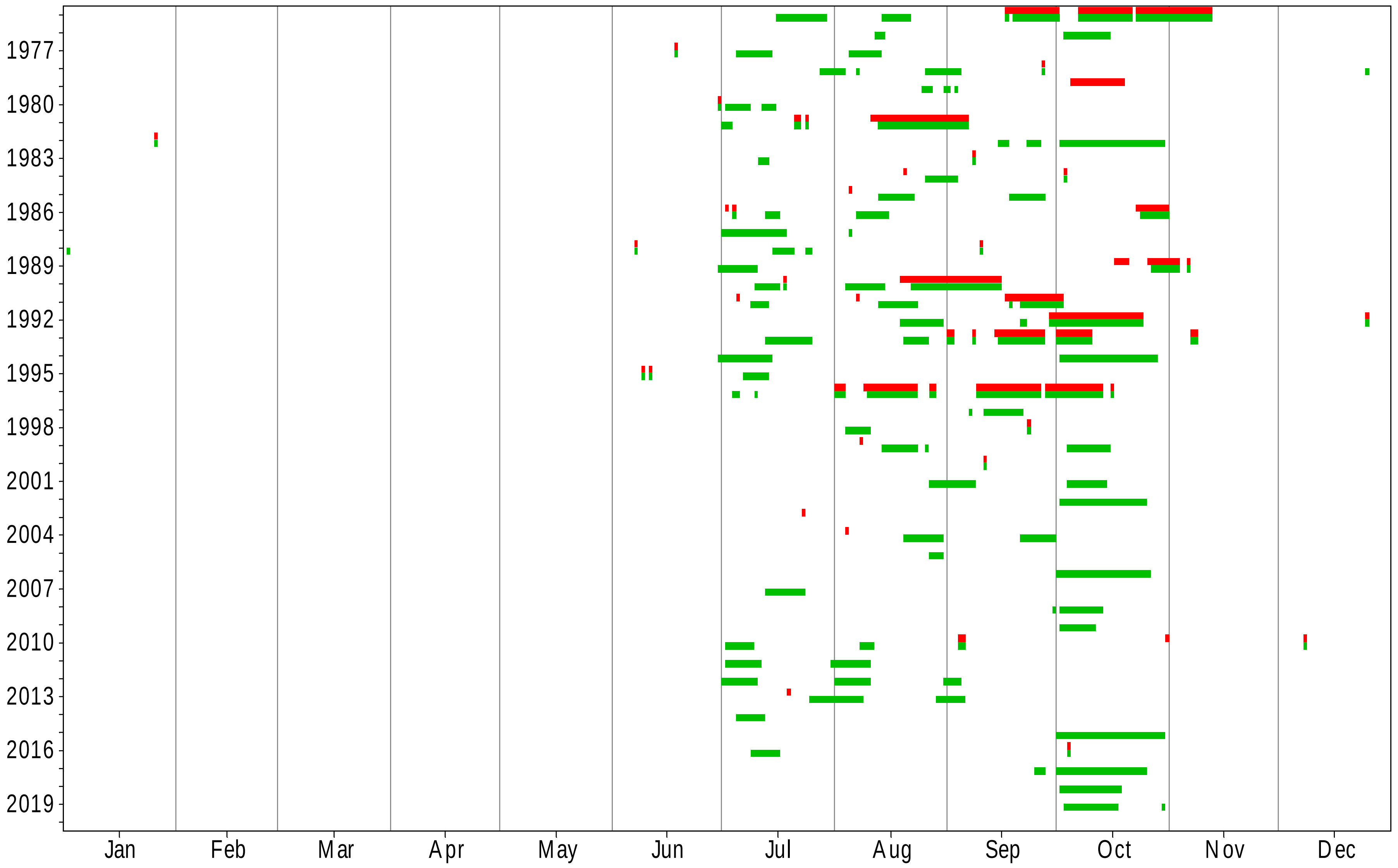


Distribution of Spells




Distribution of Spells
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016
2019
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
≥ 12,000 ML/d @ Molesworth - Current
≥ 12,000 ML/d @ Molesworth - M12L21

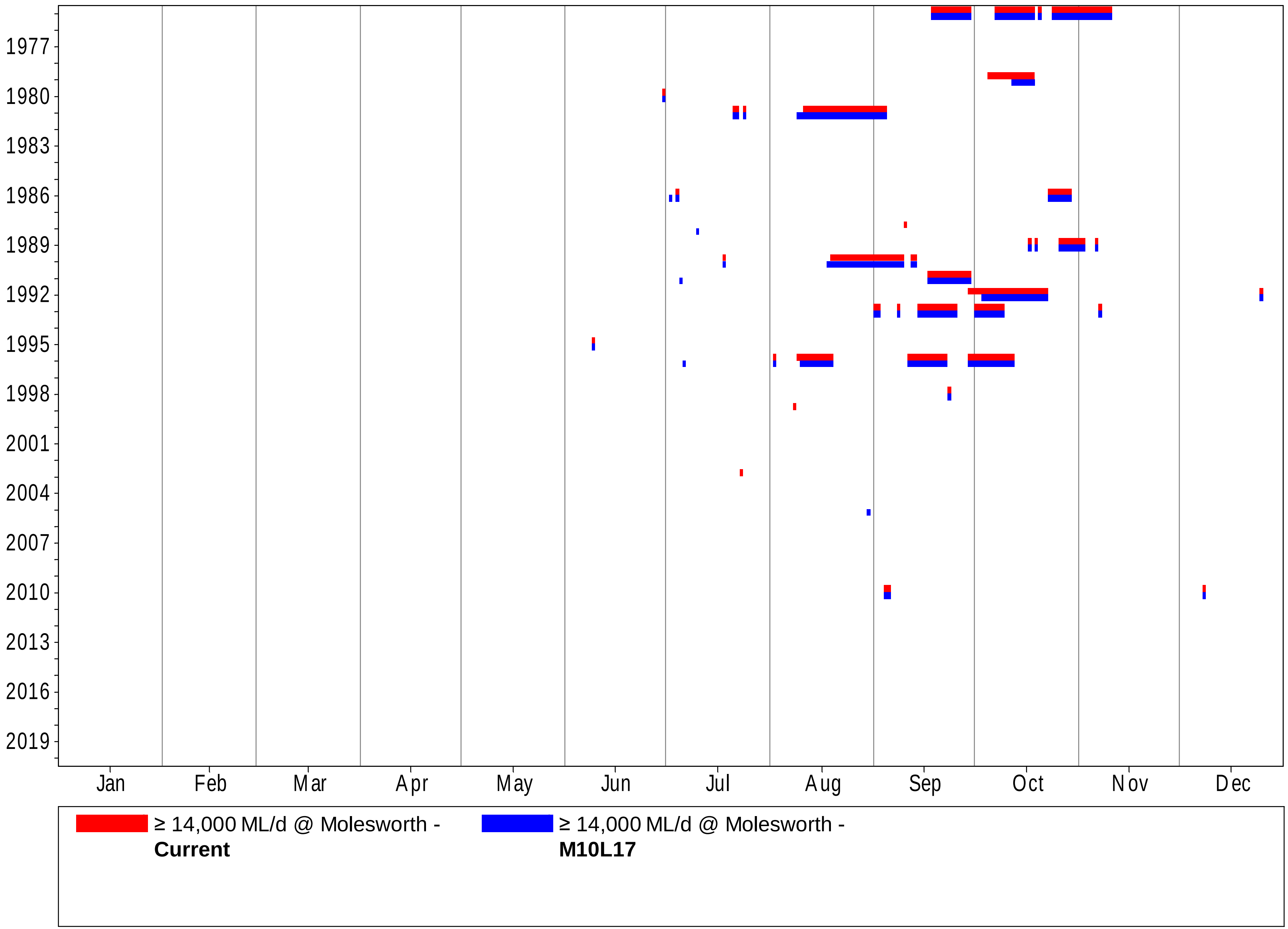
Distribution of Spells



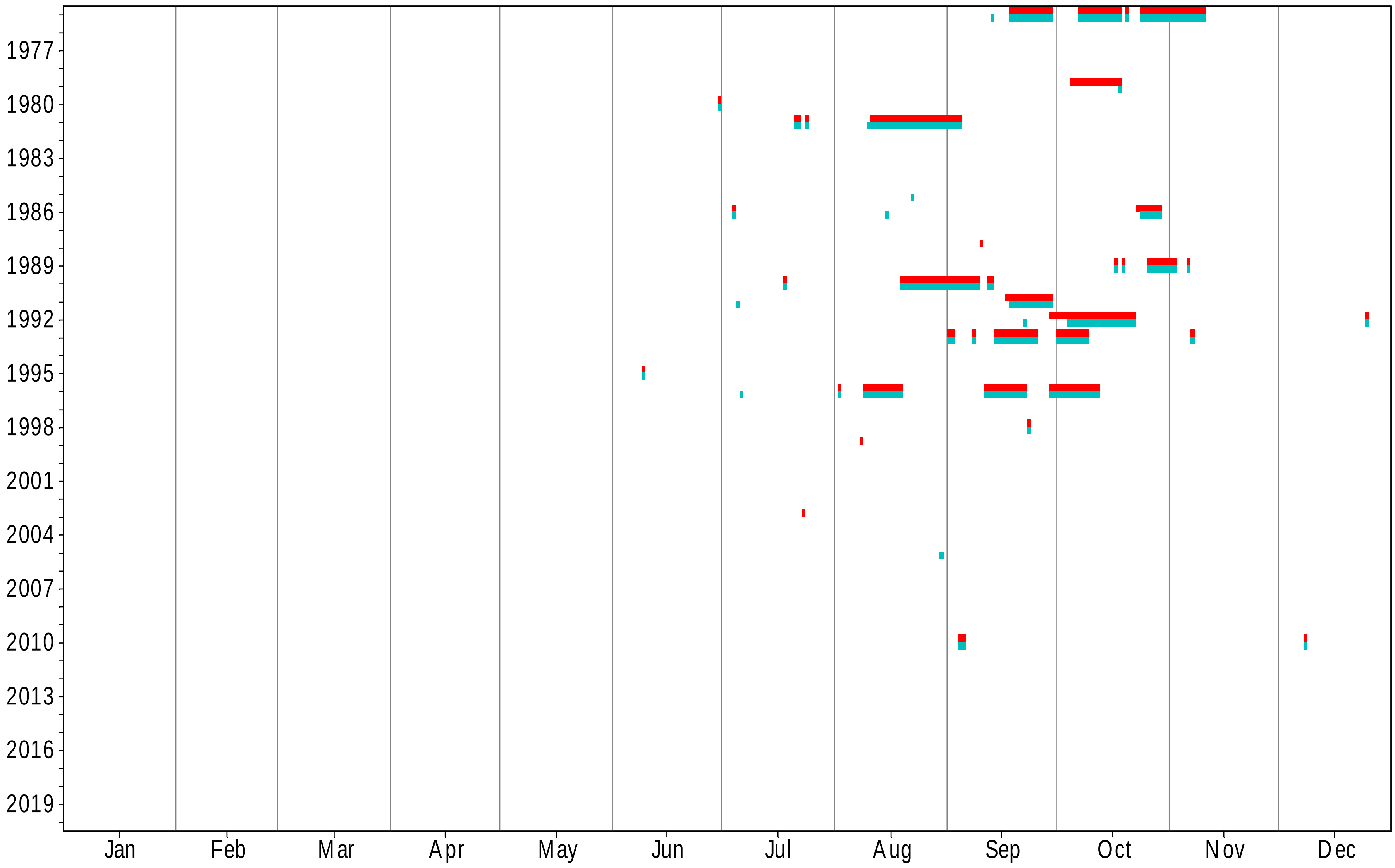
🟥 ≥ 12,000 ML/d @ Molesworth - **Current**

🟩 ≥ 12,000 ML/d @ Molesworth - **M14L25**

Distribution of Spells



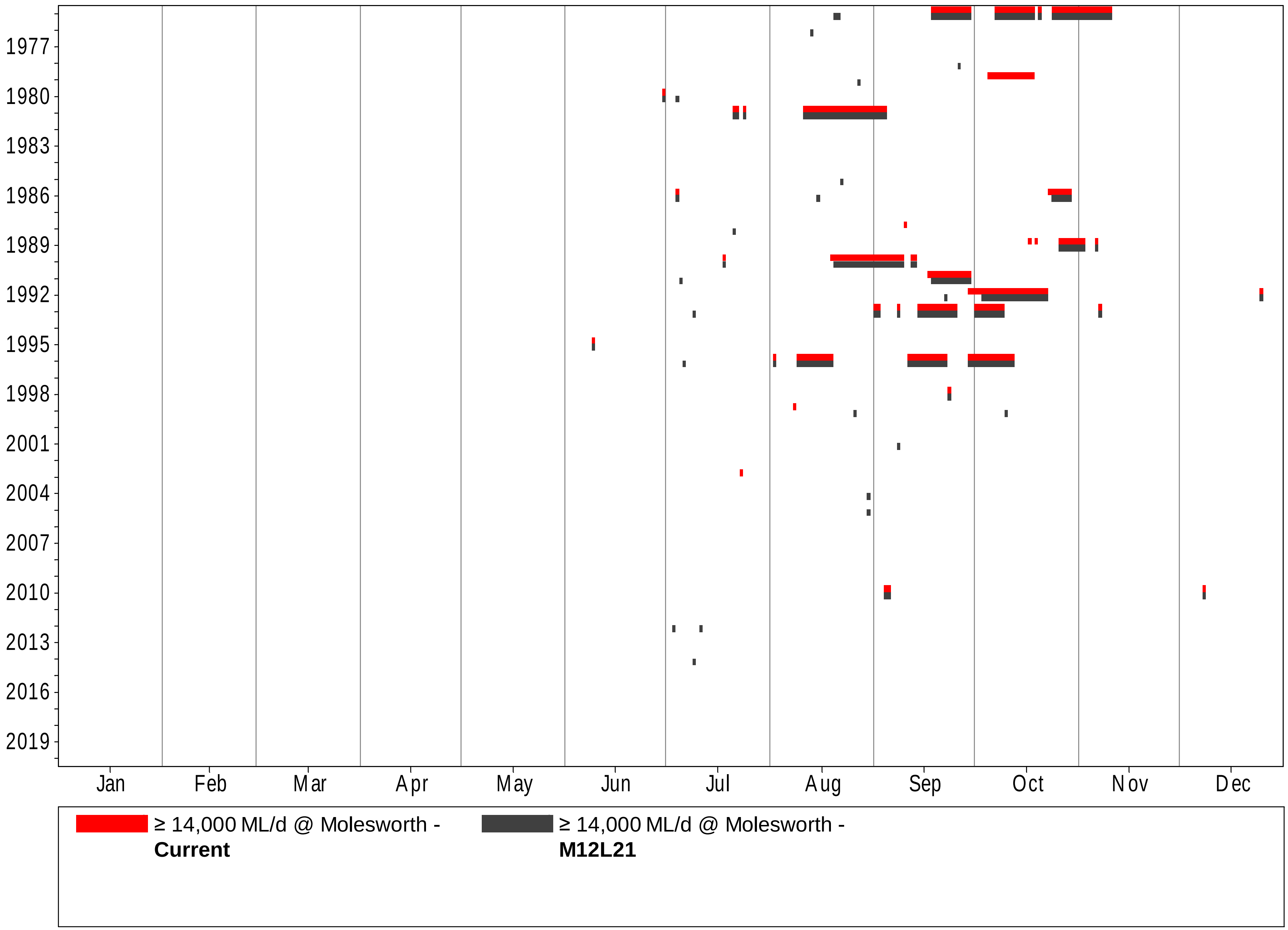
Distribution of Spells



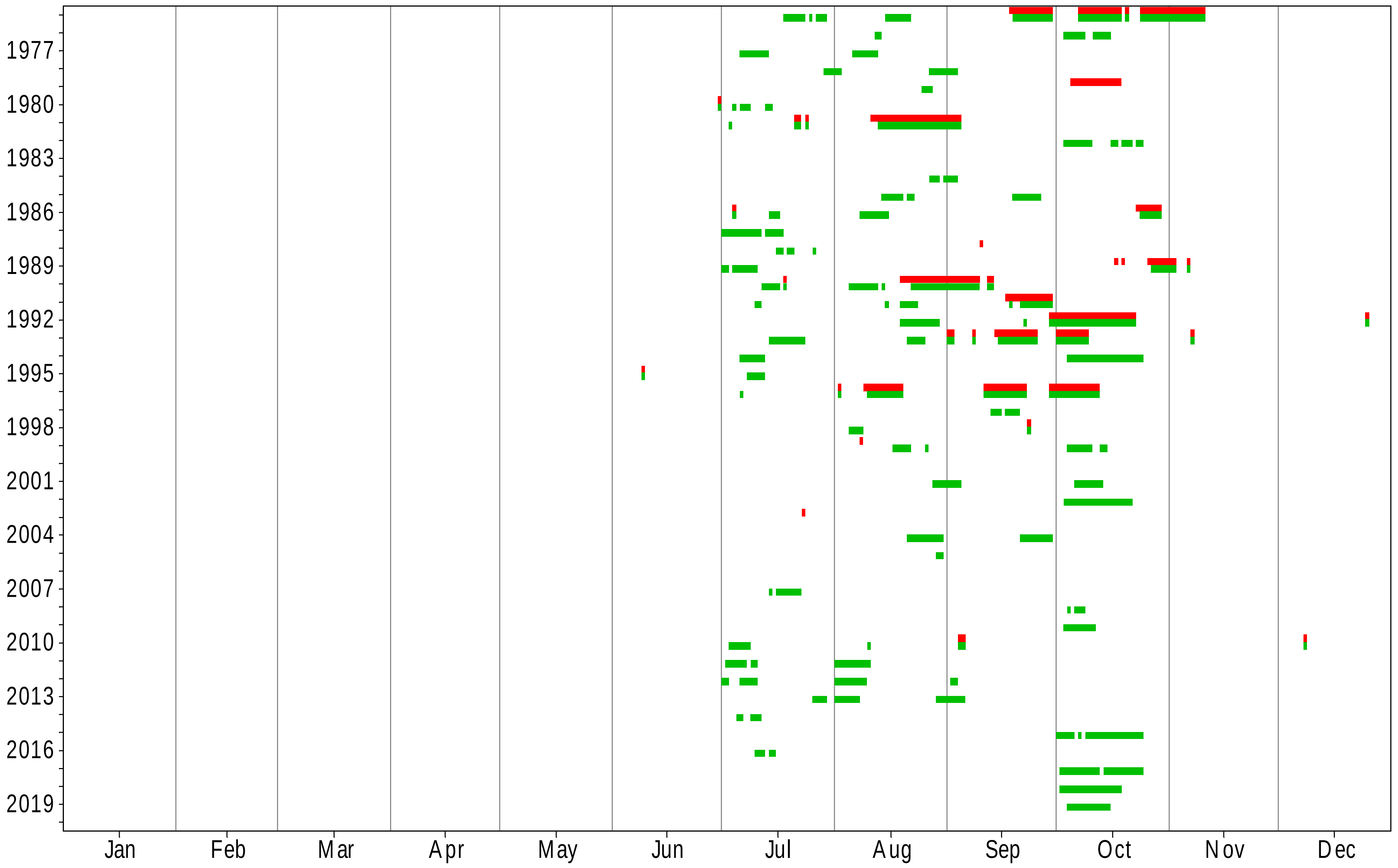
🟥 ≥ 14,000 ML/d @ Molesworth - **Current**

🟩 ≥ 14,000 ML/d @ Molesworth - **M10L21**

Distribution of Spells



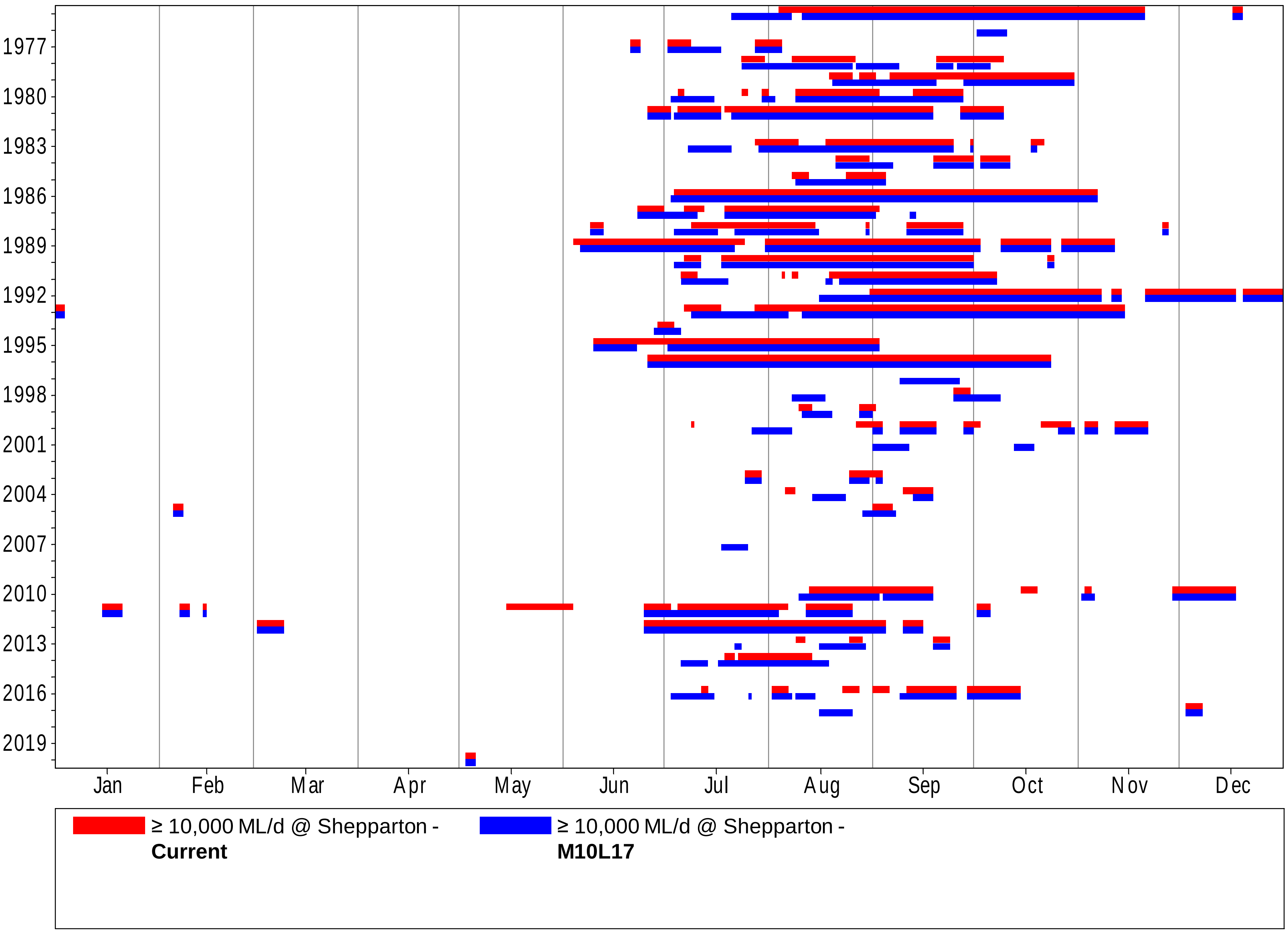
Distribution of Spells



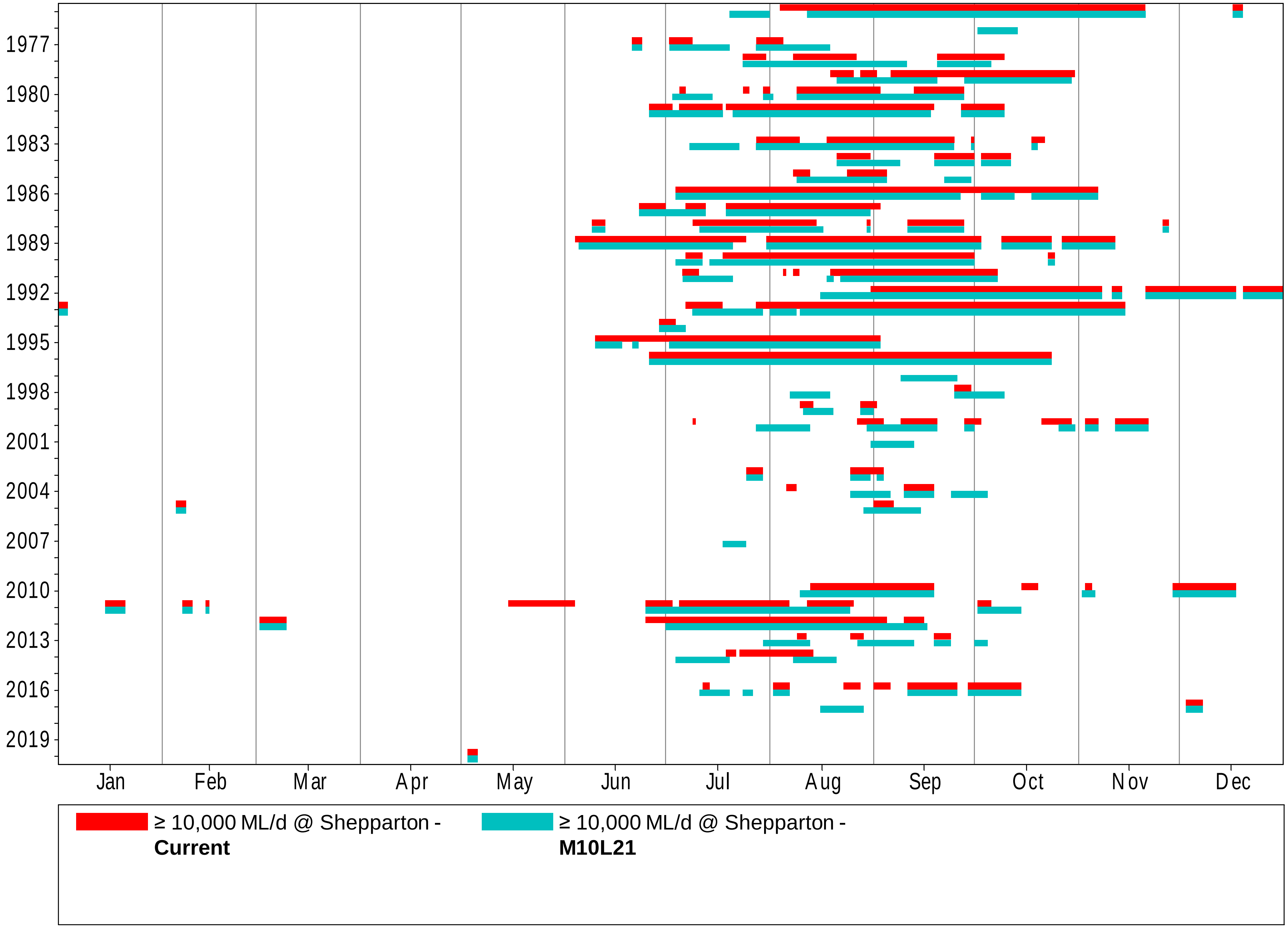
🟥 ≥ 14,000 ML/d @ Molesworth - **Current**

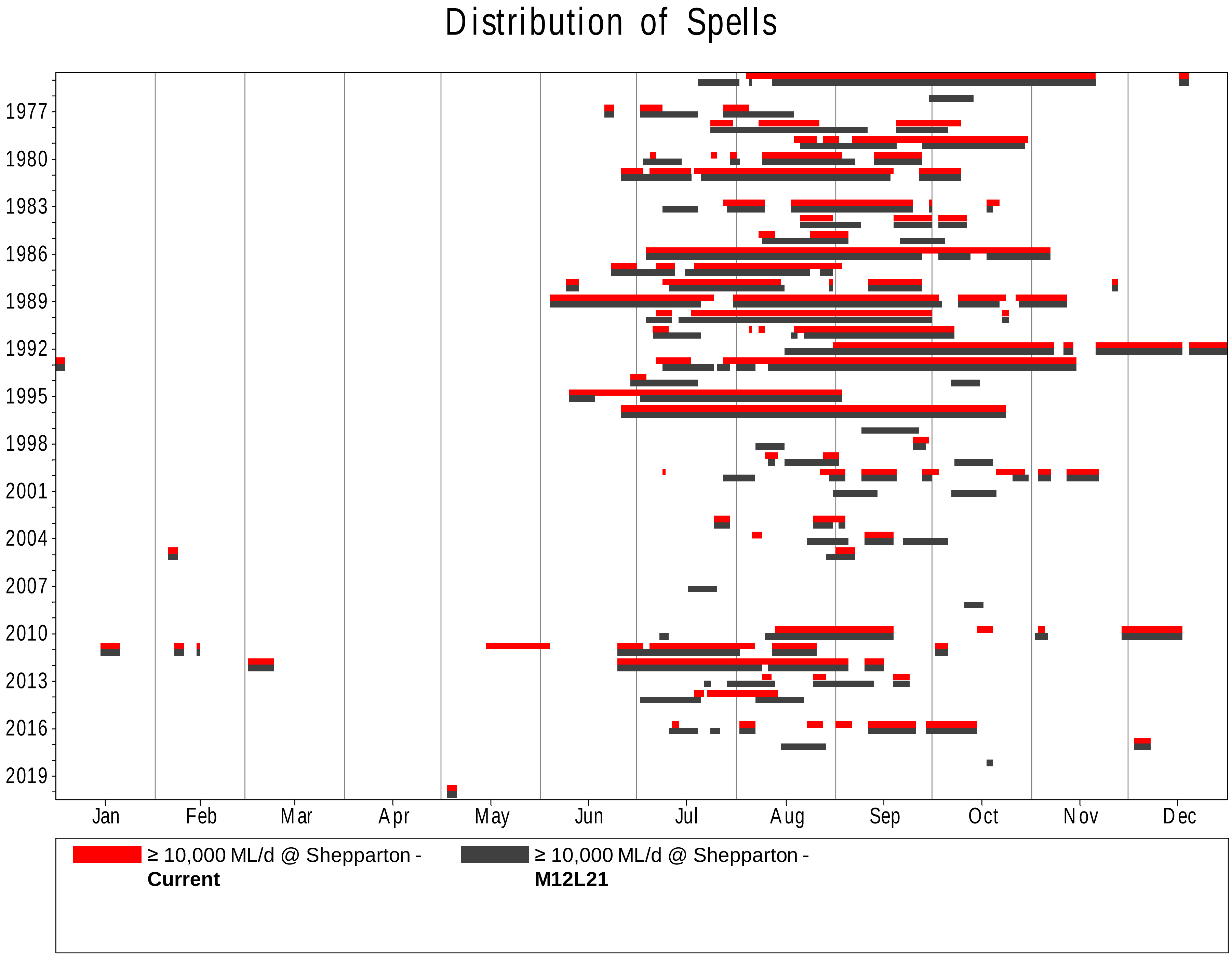
🟩 ≥ 14,000 ML/d @ Molesworth - **M14L25**

Distribution of Spells

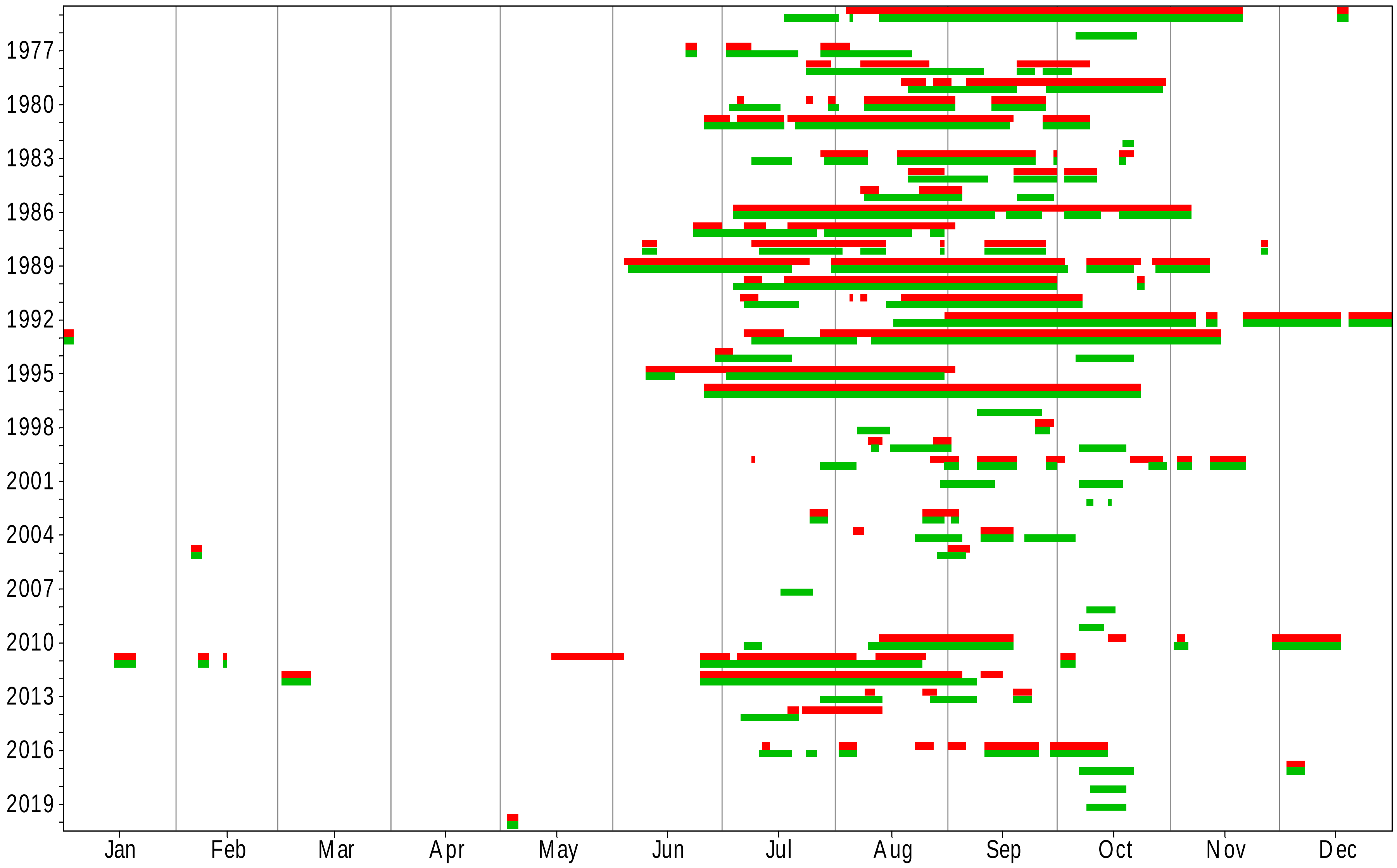


Distribution of Spells




Distribution of Spells
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016
2019
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
≥ 10,000 ML/d @ Shepparton - Current
≥ 10,000 ML/d @ Shepparton - M12L21

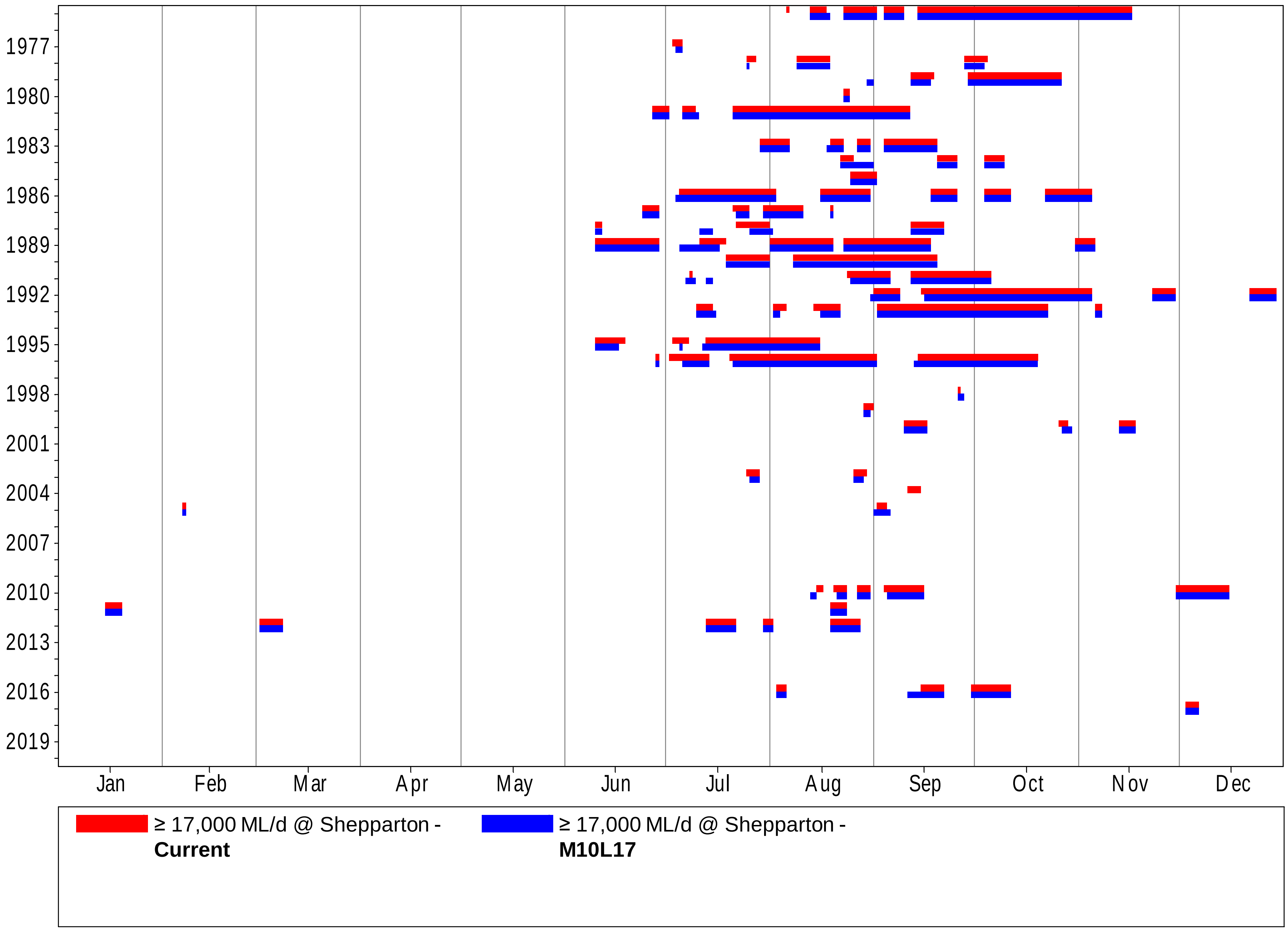
Distribution of Spells



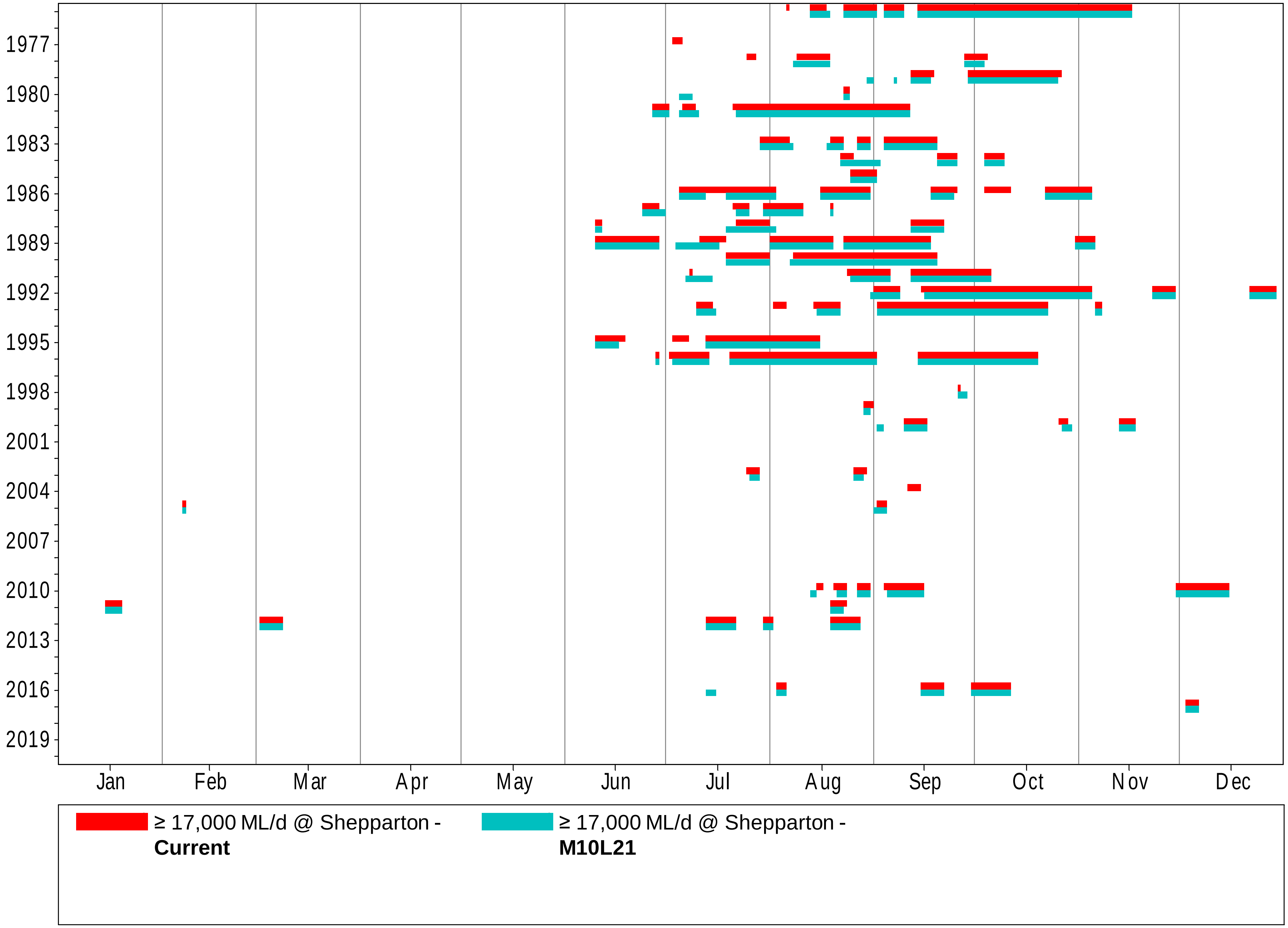
🟥 ≥ 10,000 ML/d @ Shepparton - **Current**

🟩 ≥ 10,000 ML/d @ Shepparton - **M14L25**

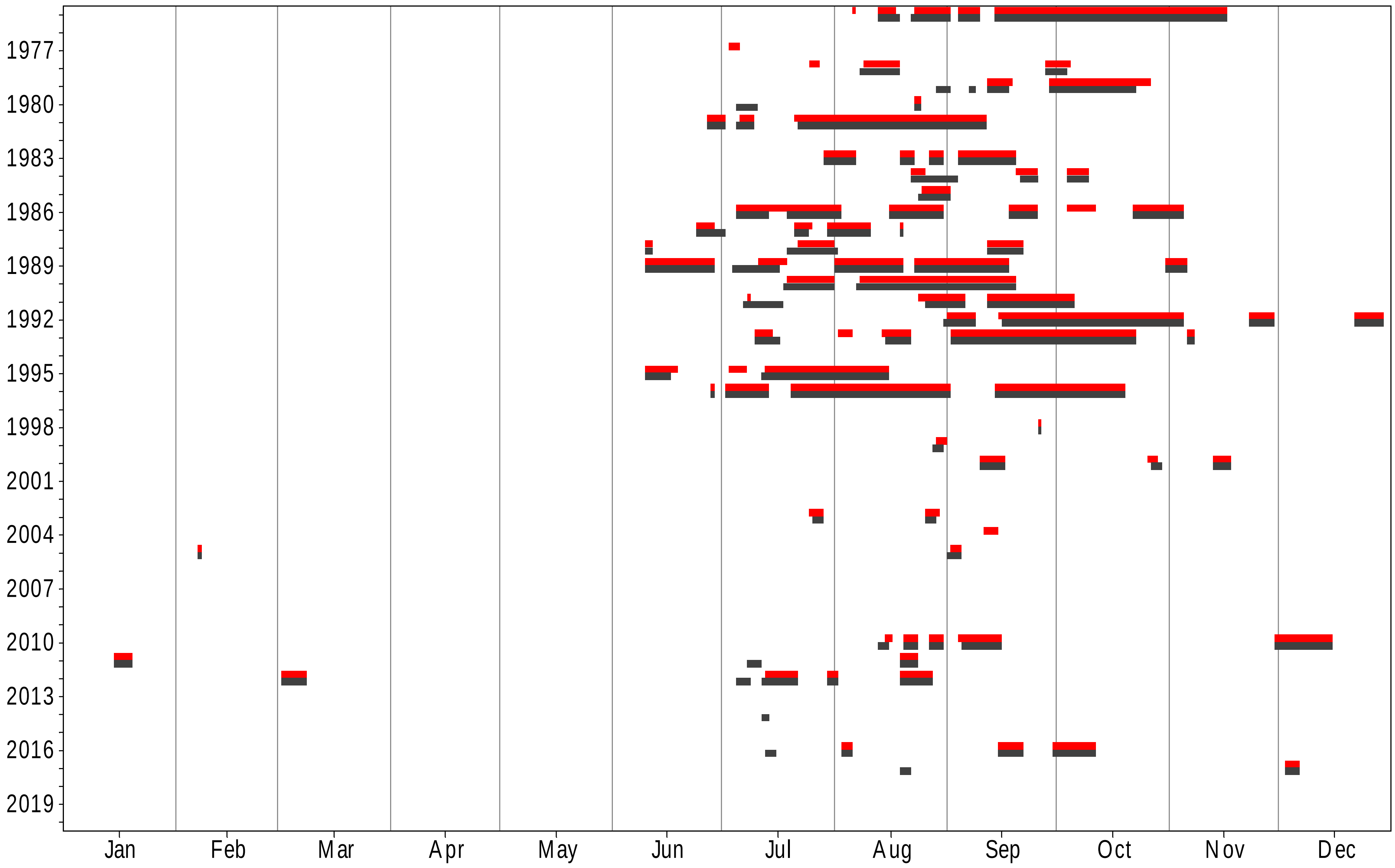
Distribution of Spells



Distribution of Spells



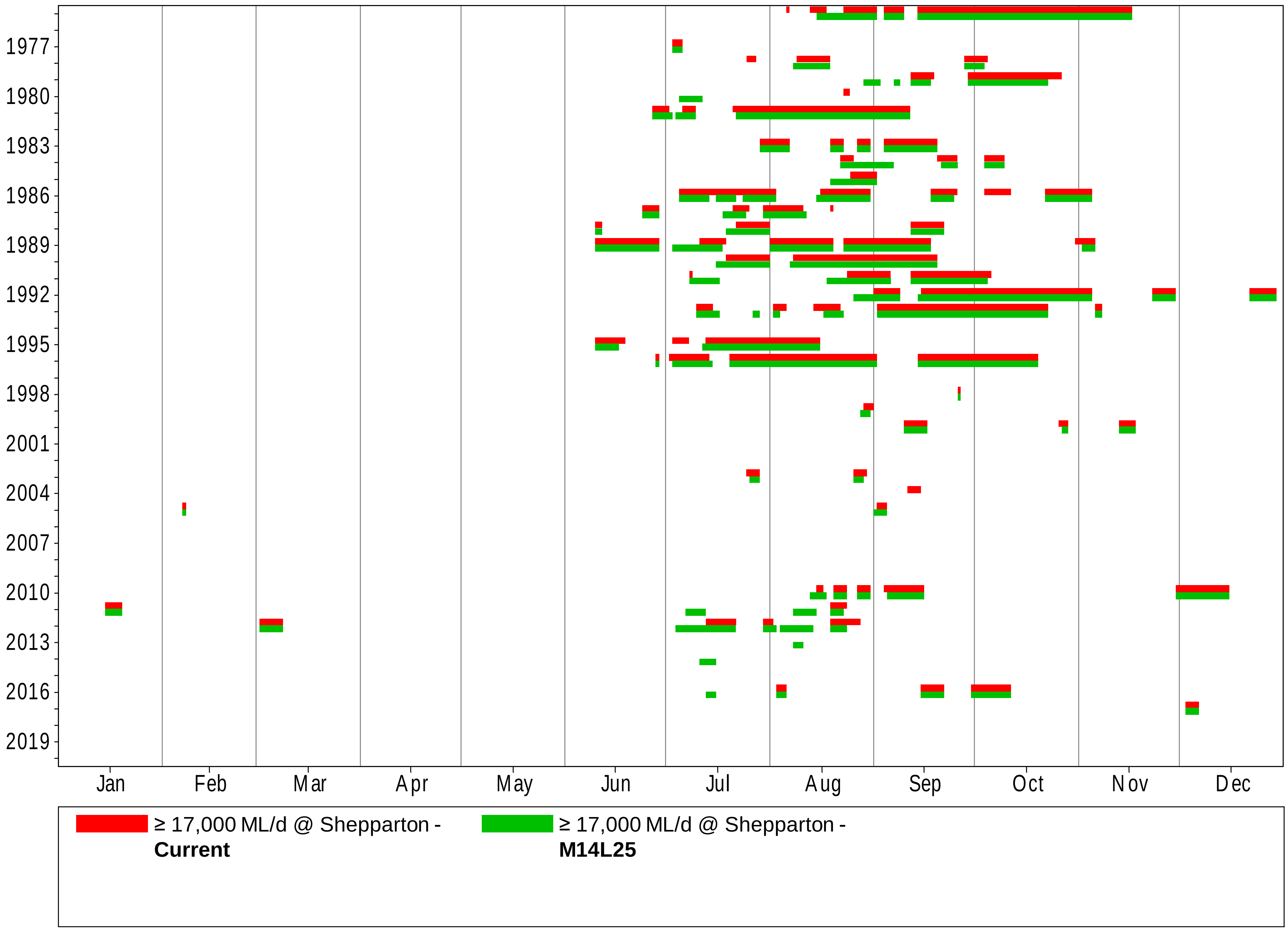
Distribution of Spells



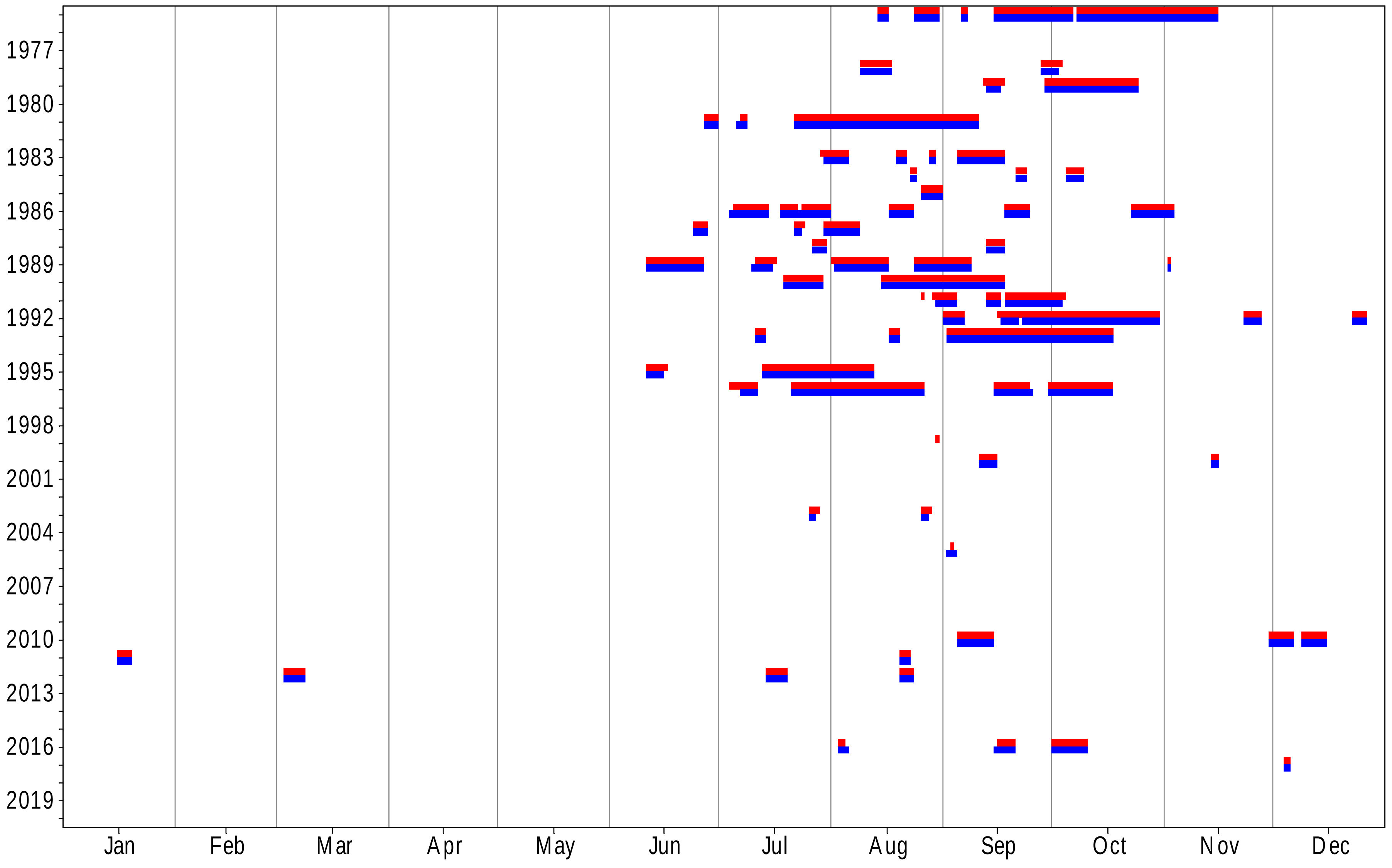
🟥 ≥ 17,000 ML/d @ Shepparton - **Current**

■ ≥ 17,000 ML/d @ Shepparton - **M12L21**

Distribution of Spells



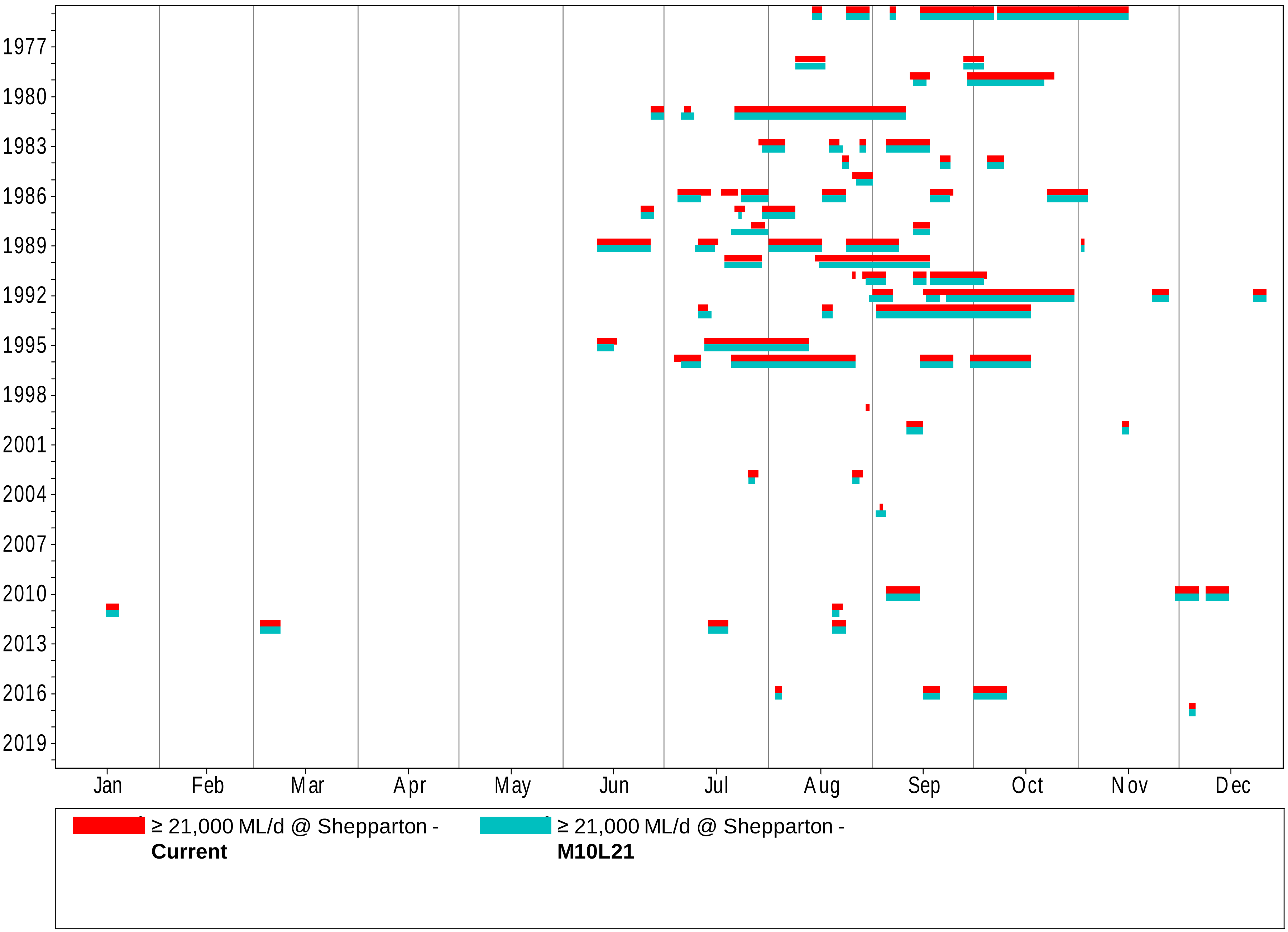
Distribution of Spells



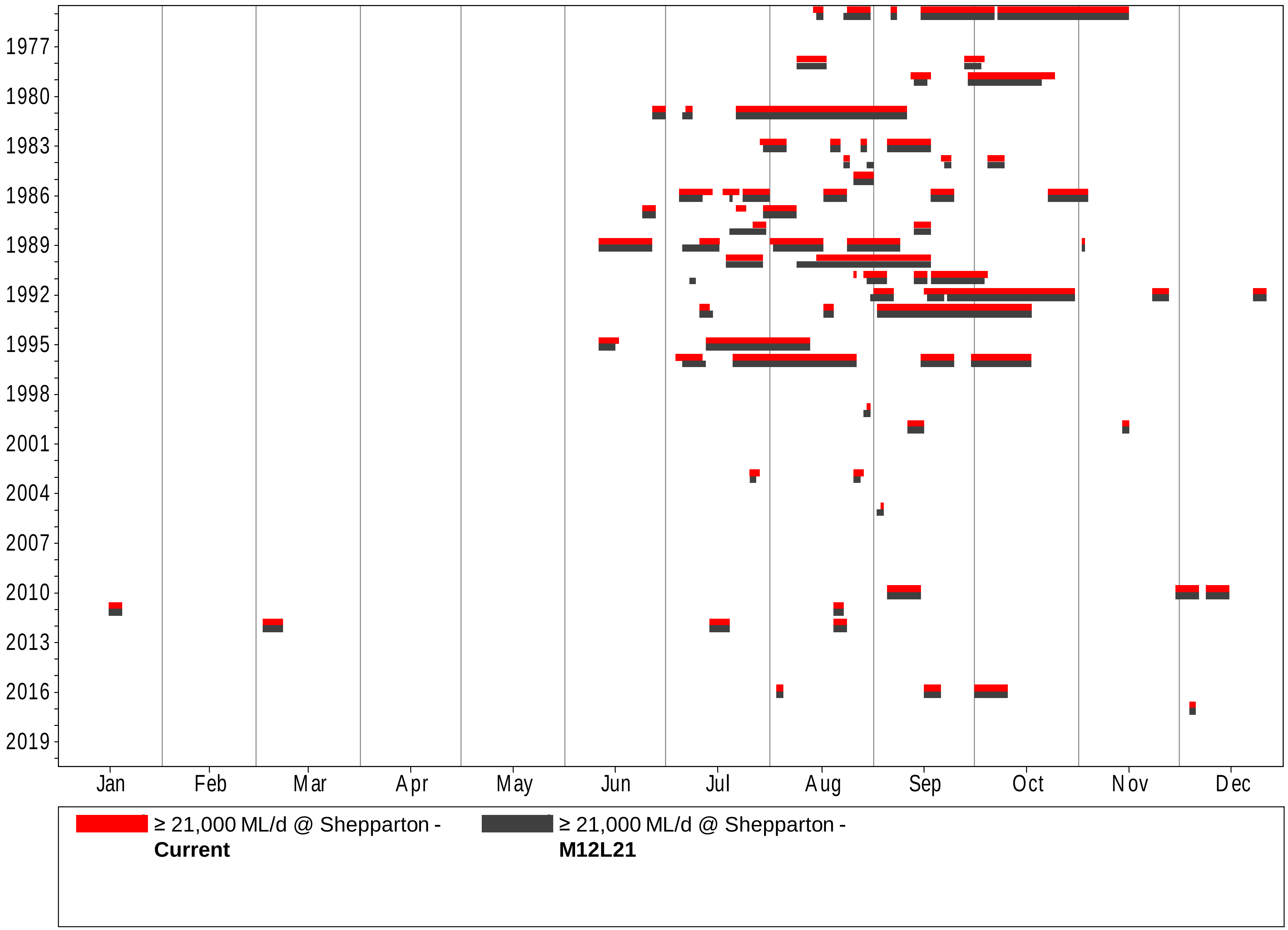
🟥 ≥ 21,000 ML/d @ Shepparton - **Current**

🟦 ≥ 21,000 ML/d @ Shepparton - **M10L17**

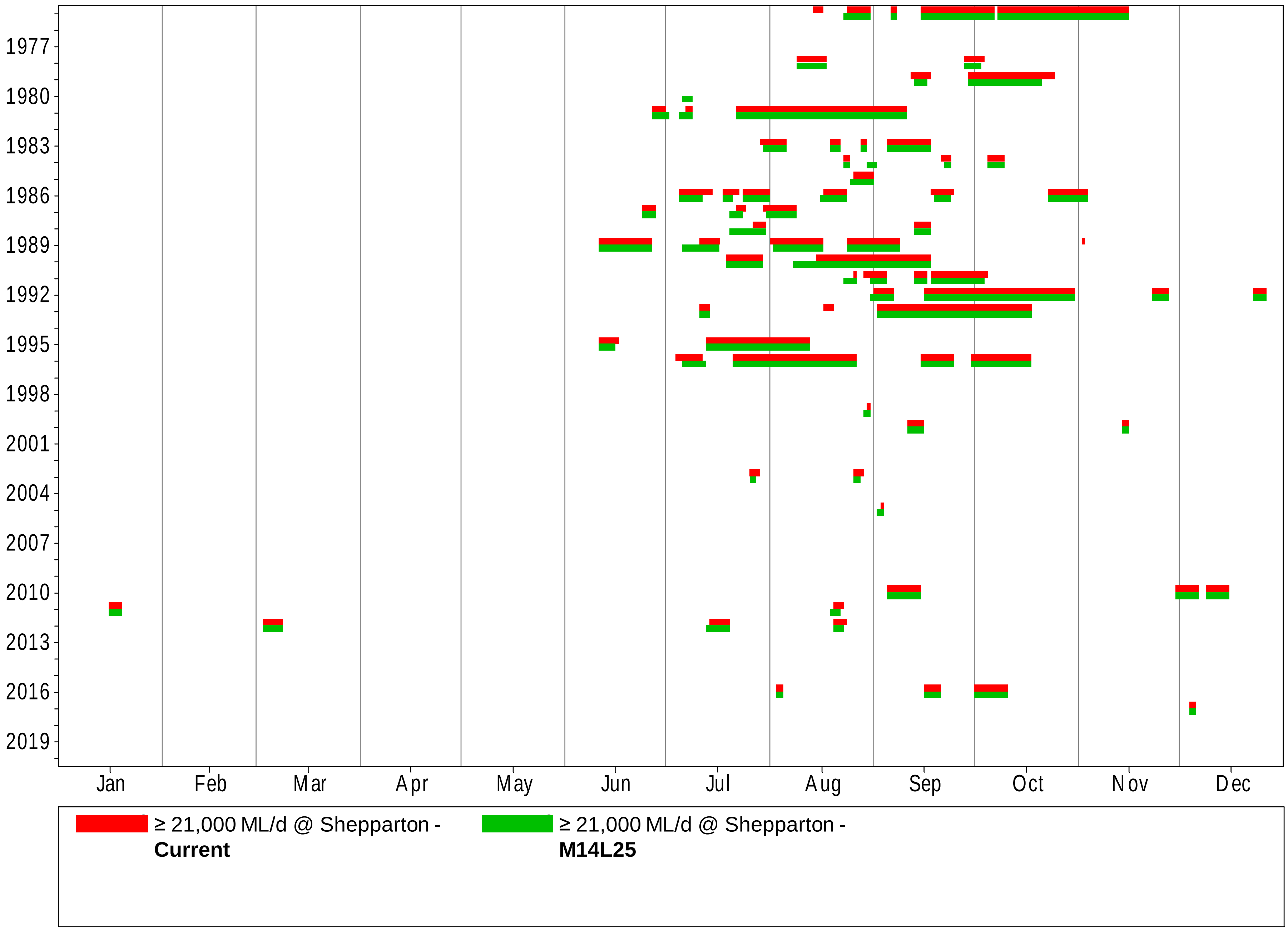
Distribution of Spells



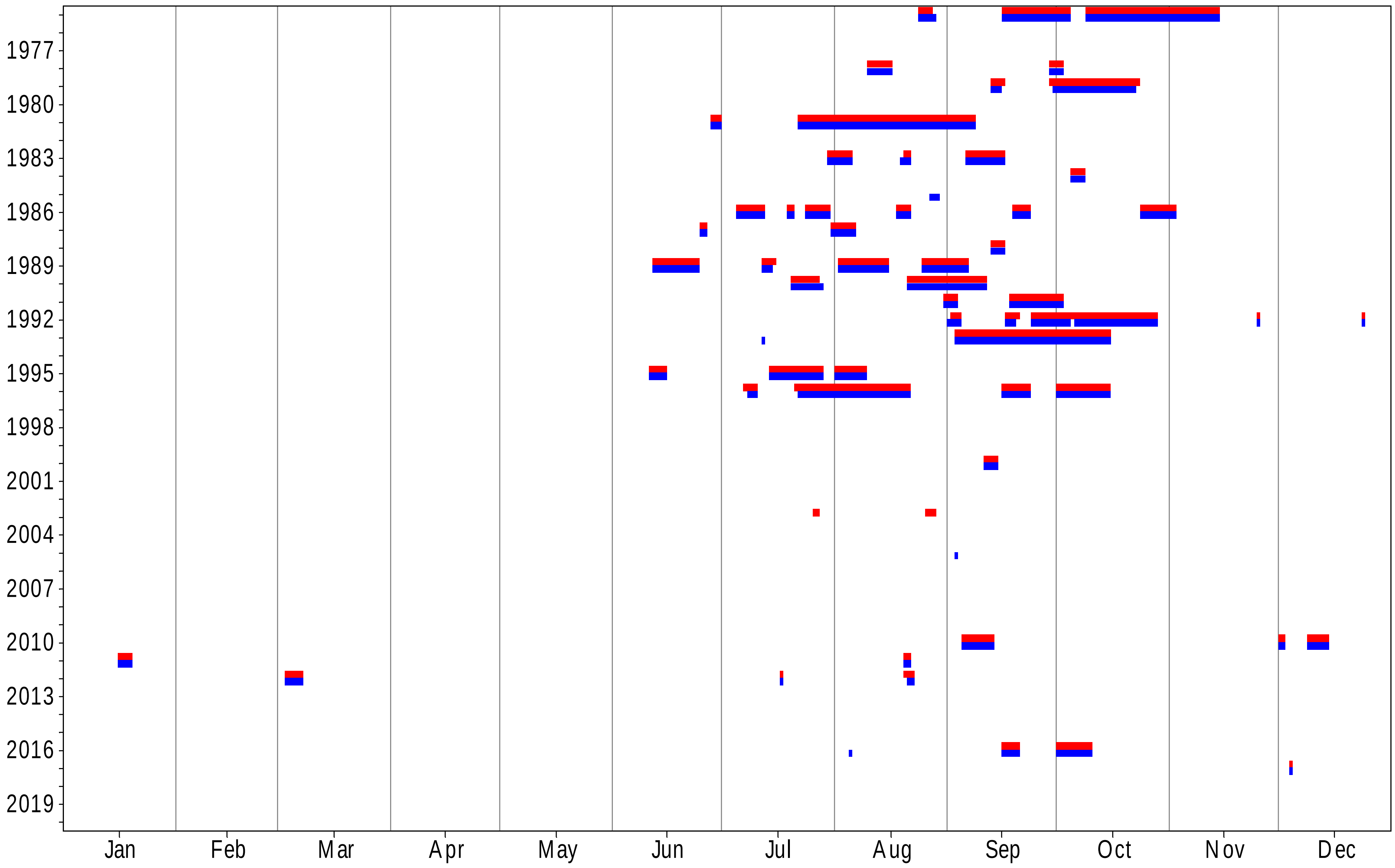
Distribution of Spells



Distribution of Spells



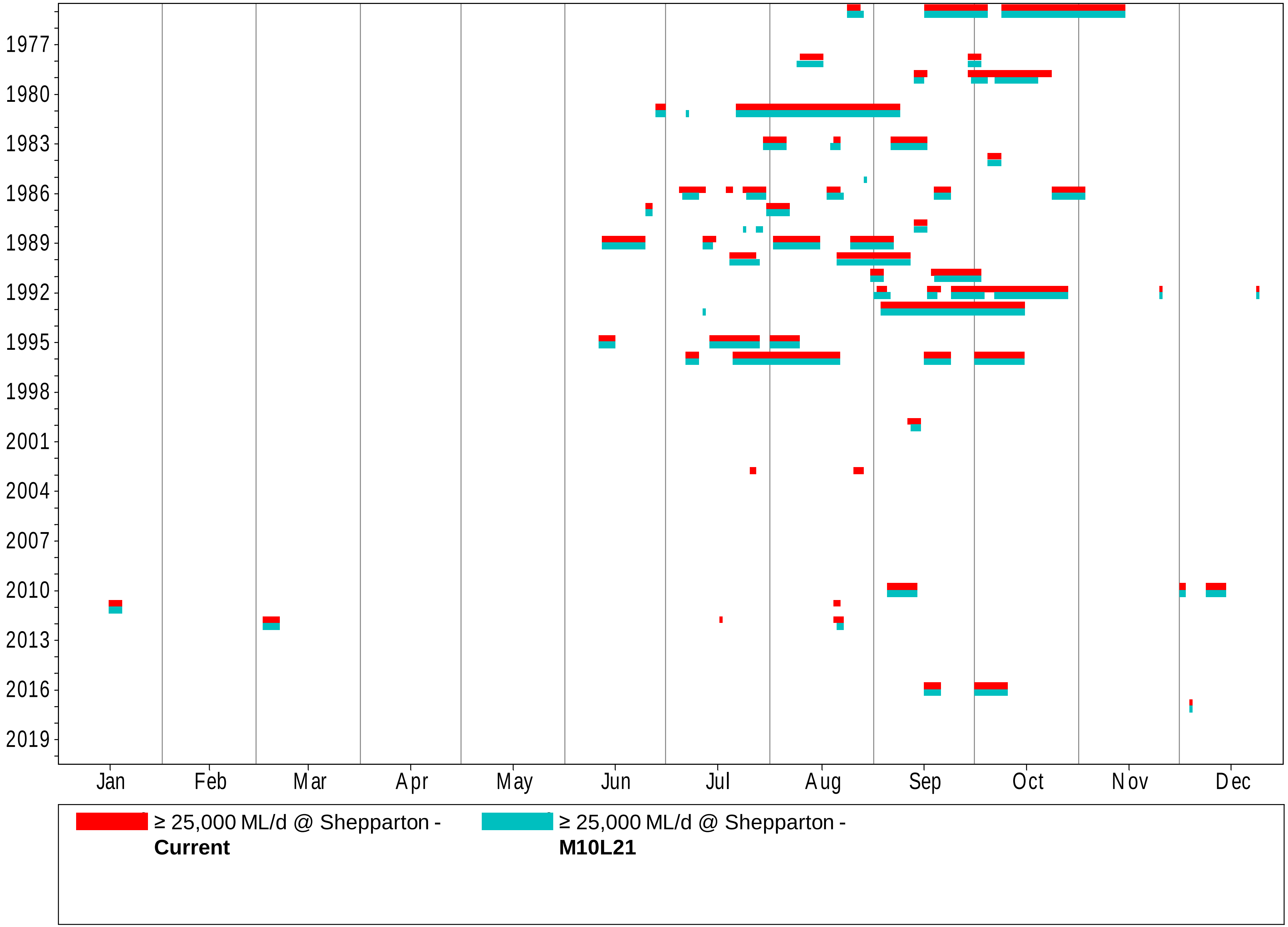
Distribution of Spells



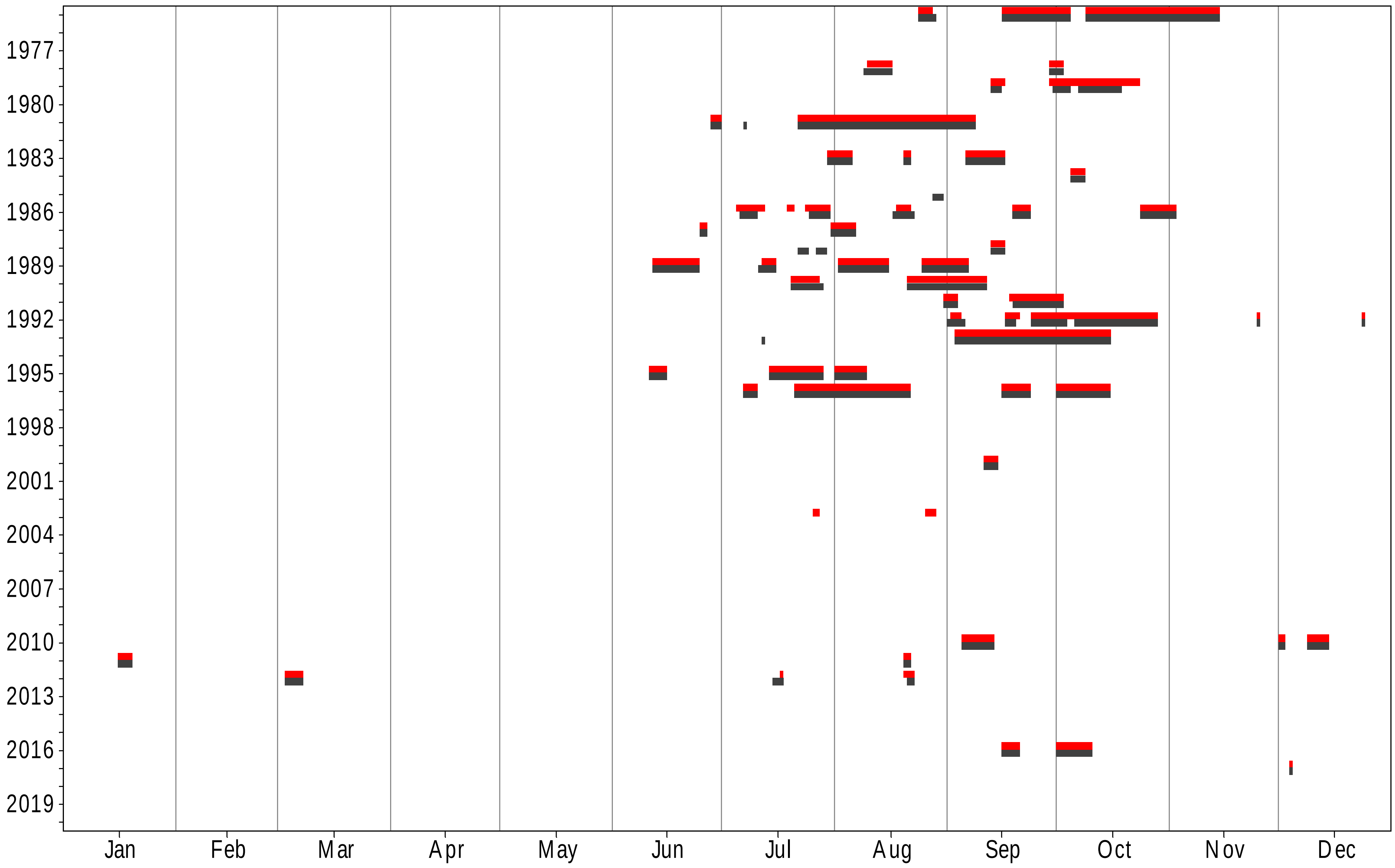
🟥 ≥ 25,000 ML/d @ Shepparton - **Current**

🟦 ≥ 25,000 ML/d @ Shepparton - **M10L17**

Distribution of Spells



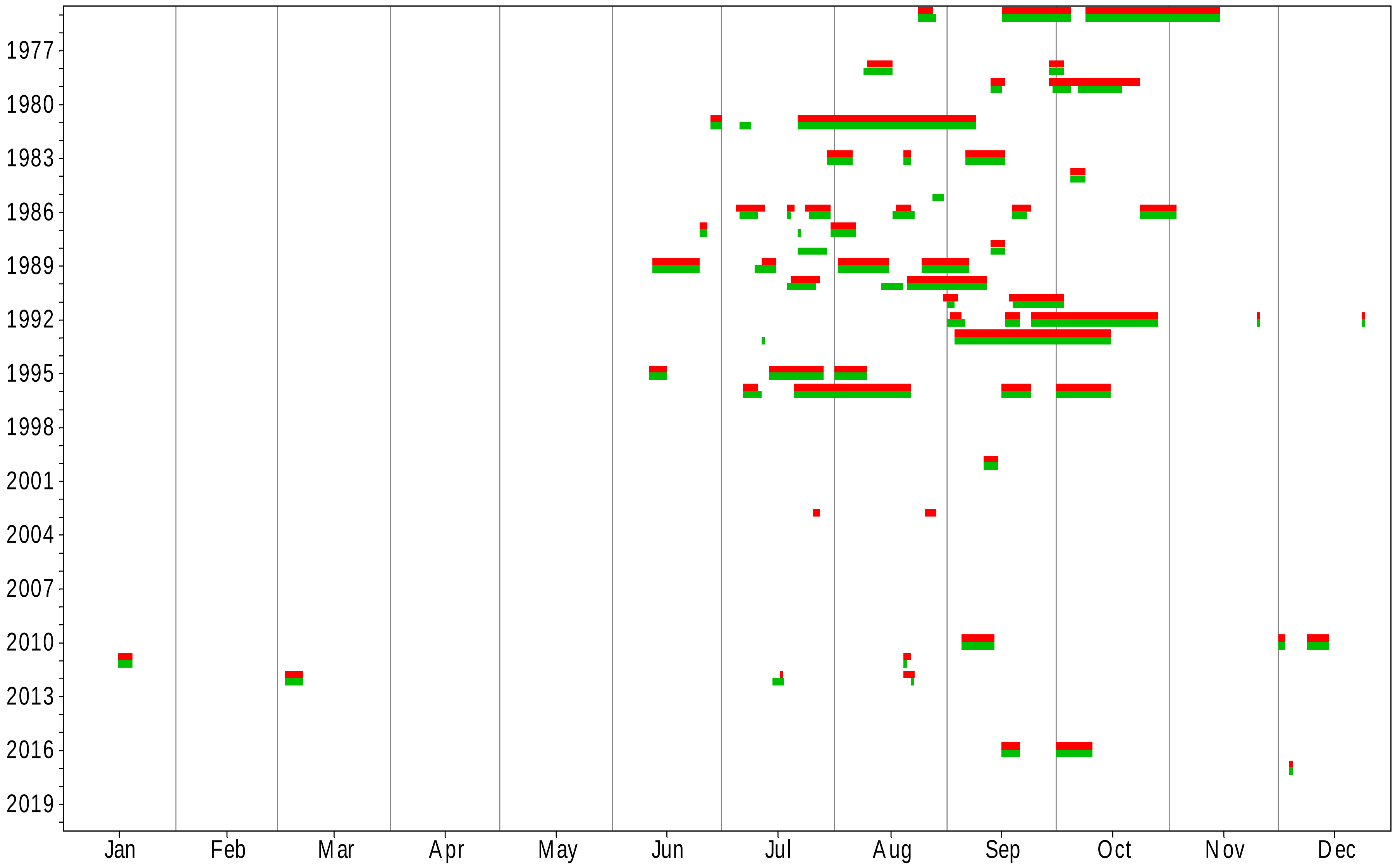
Distribution of Spells



🟥 ≥ 25,000 ML/d @ Shepparton - **Current**

⬛ ≥ 25,000 ML/d @ Shepparton - **M12L21**

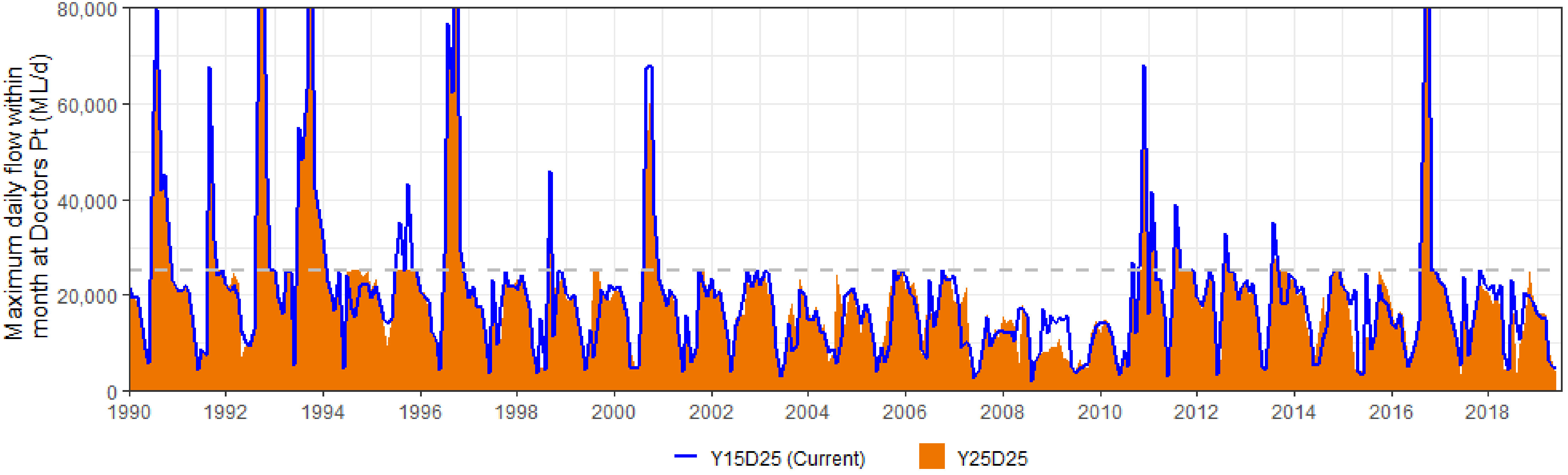
Distribution of Spells

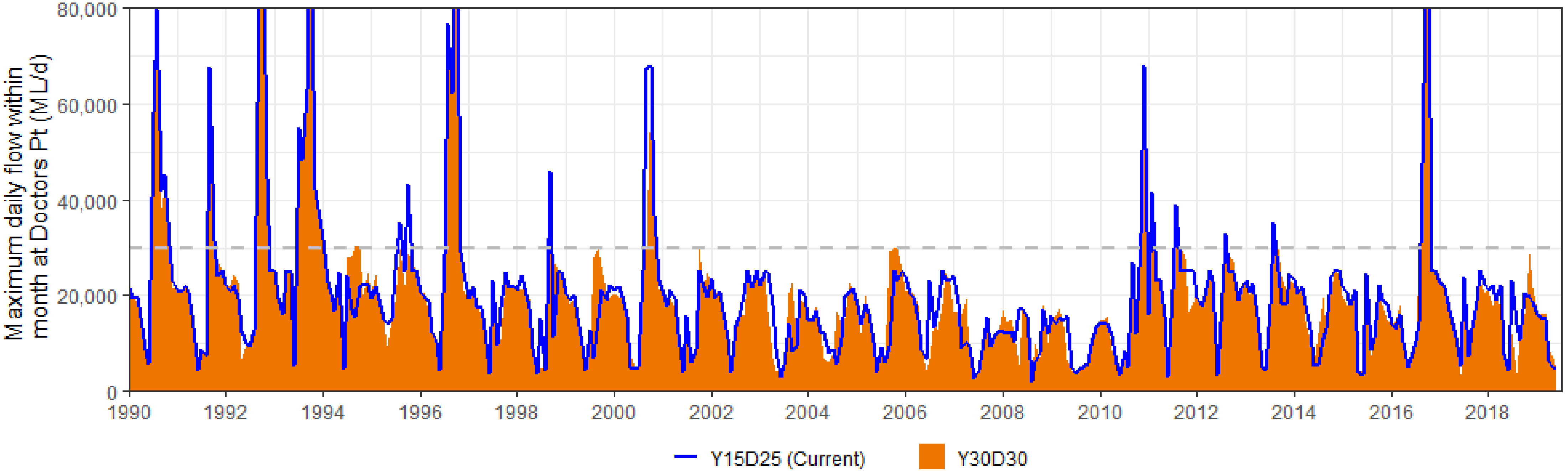


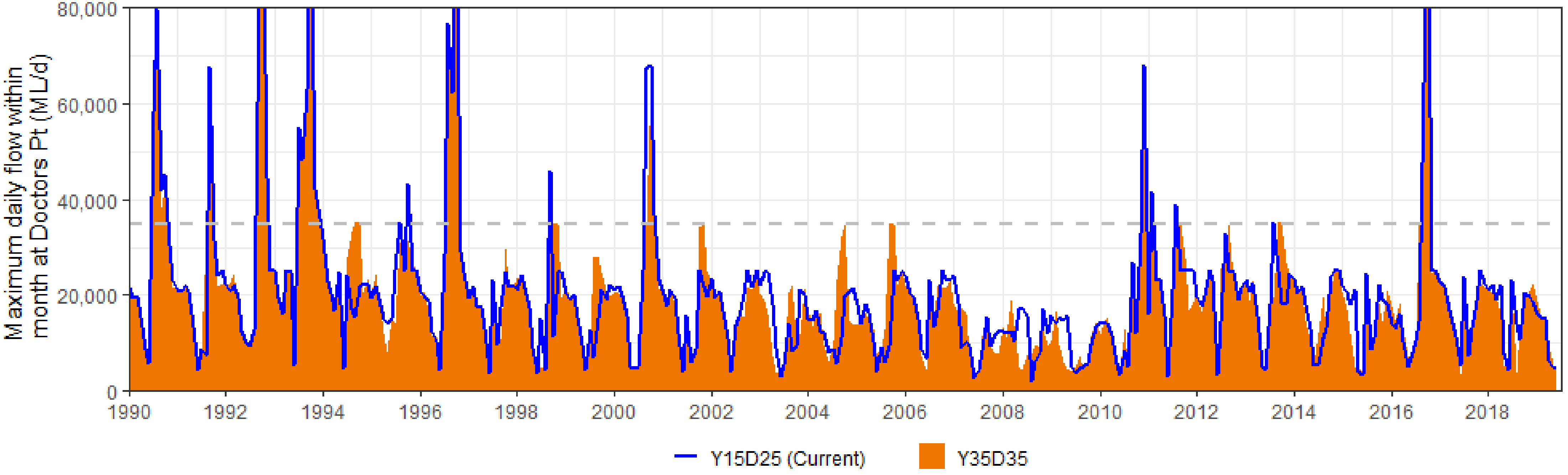
🟥 ≥ 25,000 ML/d @ Shepparton - **Current**

🟩 ≥ 25,000 ML/d @ Shepparton - **M14L25**

Appendix E River Murray – SMM results – maximum flow within month; historic climate (1990-2019)


Maximum daily flow within month at Doctors Pt (ML/d)
80,000
60,000
40,000
20,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Y15D25 (Current)
Y25D25


Maximum daily flow within month at Doctors Pt (ML/d)
80,000
60,000
40,000
20,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Y15D25 (Current)
Y30D30


Maximum daily flow within month at Doctors Pt (ML/d)
80,000
60,000
40,000
20,000
0
1990
1992
1994
1996
1998
2000
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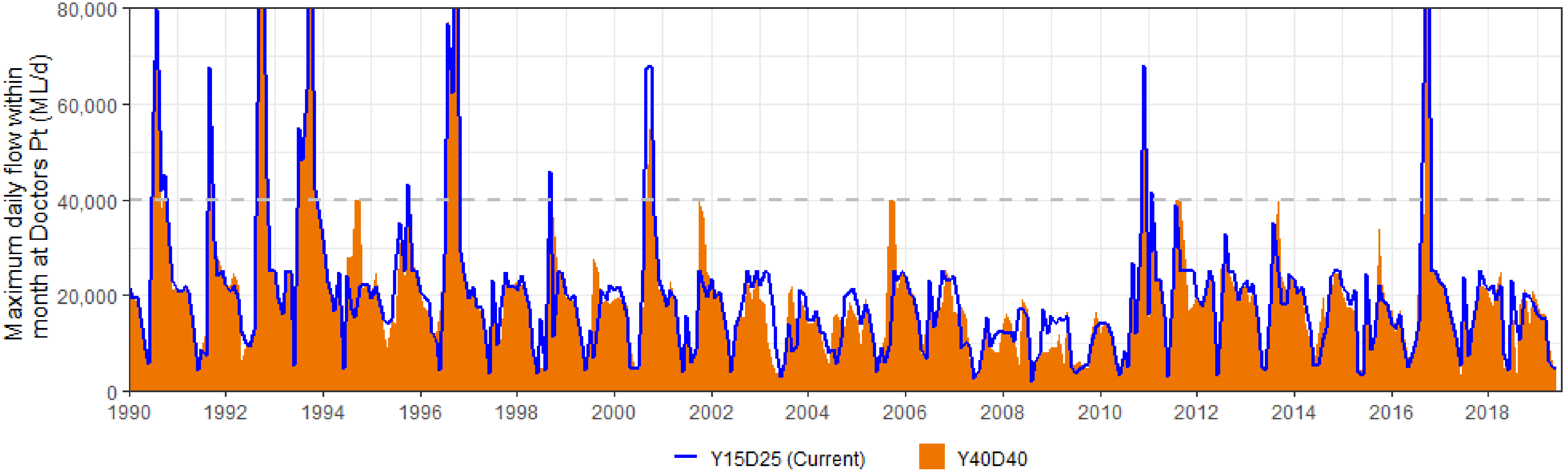
Y35D35


Maximum daily flow within month at Doctors Pt (ML/d)
80,000
60,000
40,000
20,000
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2016
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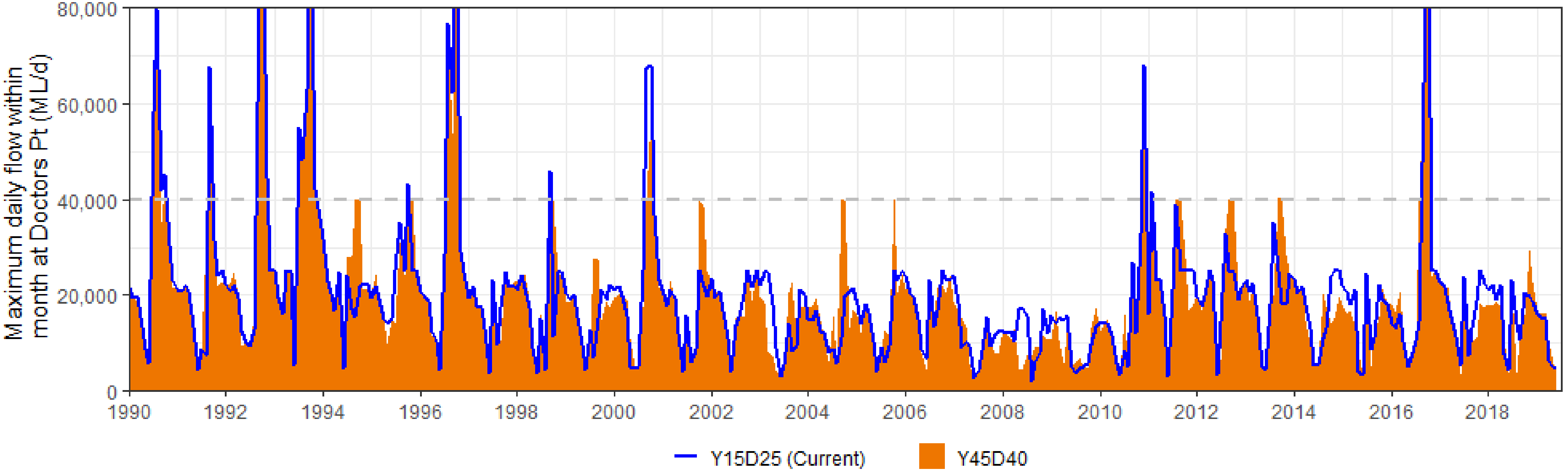
Y40D40


Maximum daily flow within month at Doctors Pt (ML/d)
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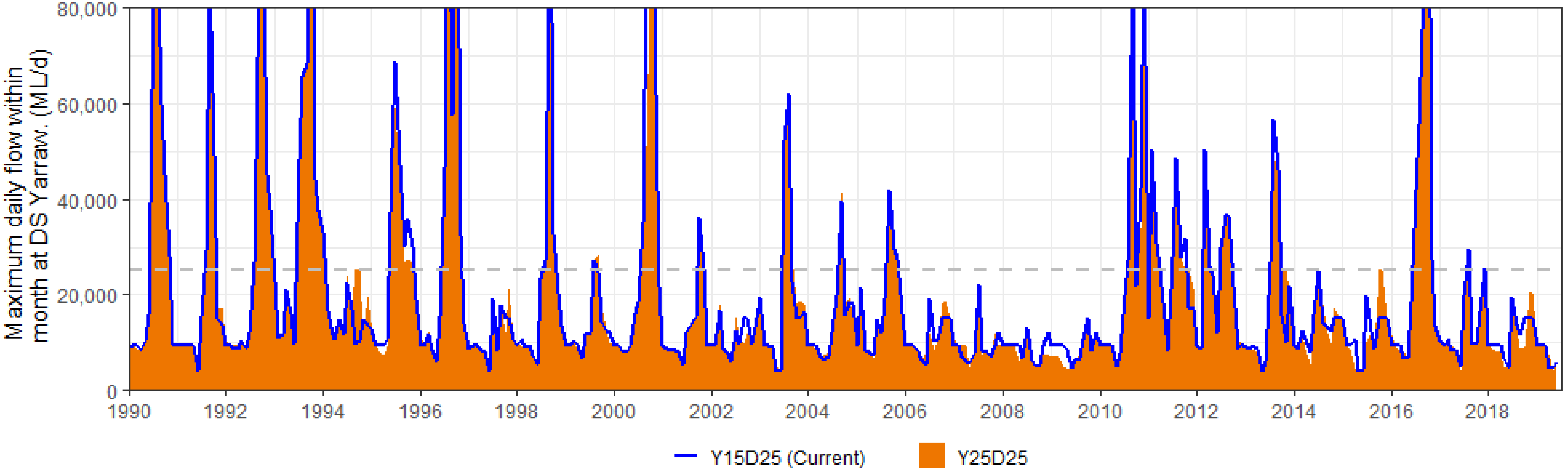
Y45D40


Maximum daily flow within month at DS Yarraw. (ML/d)
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20,000
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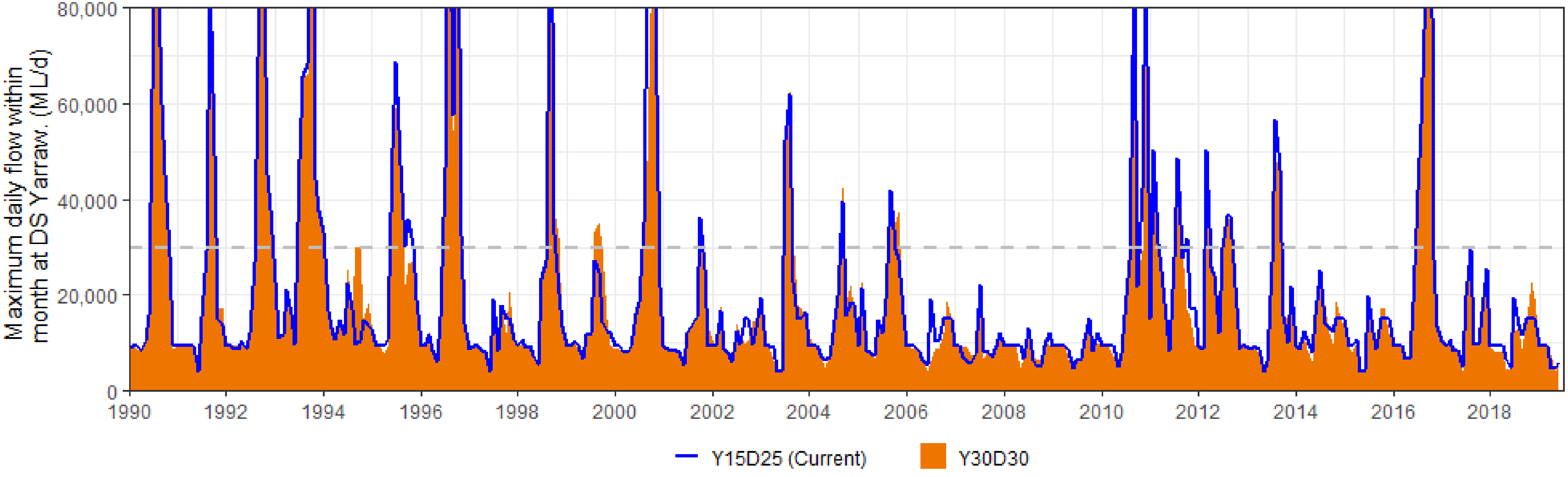
Y25D25


Maximum daily flow within month at DS Yarraw. (ML/d)
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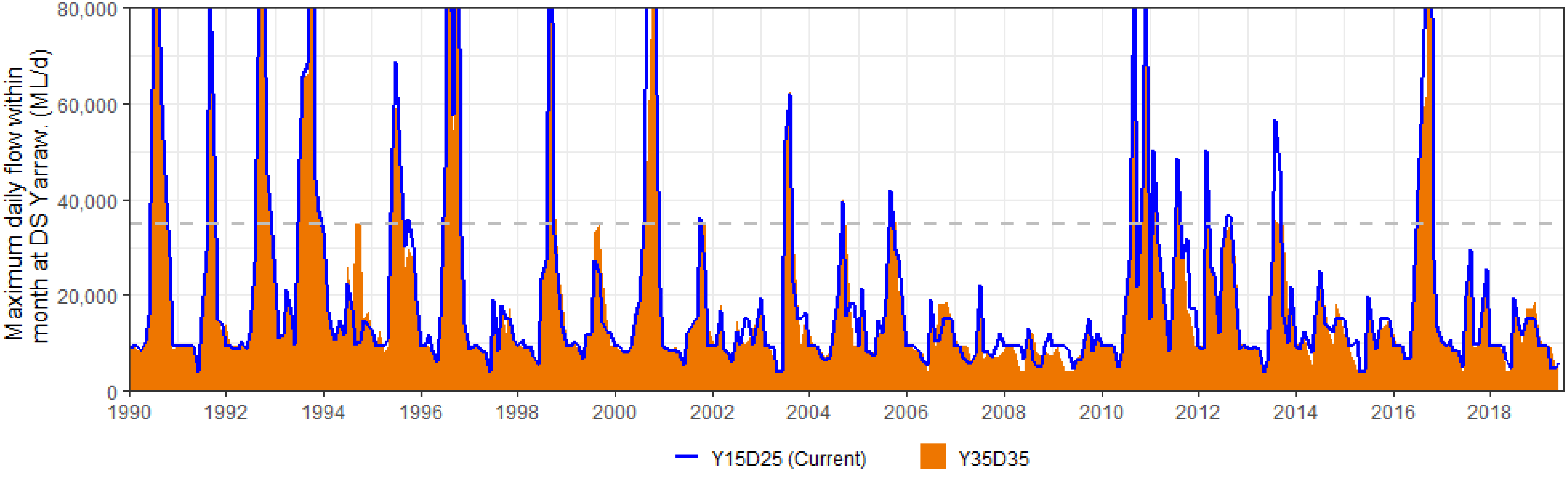
Maximum daily flow within month at DS Yarraw. (ML/d)
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40,000
20,000
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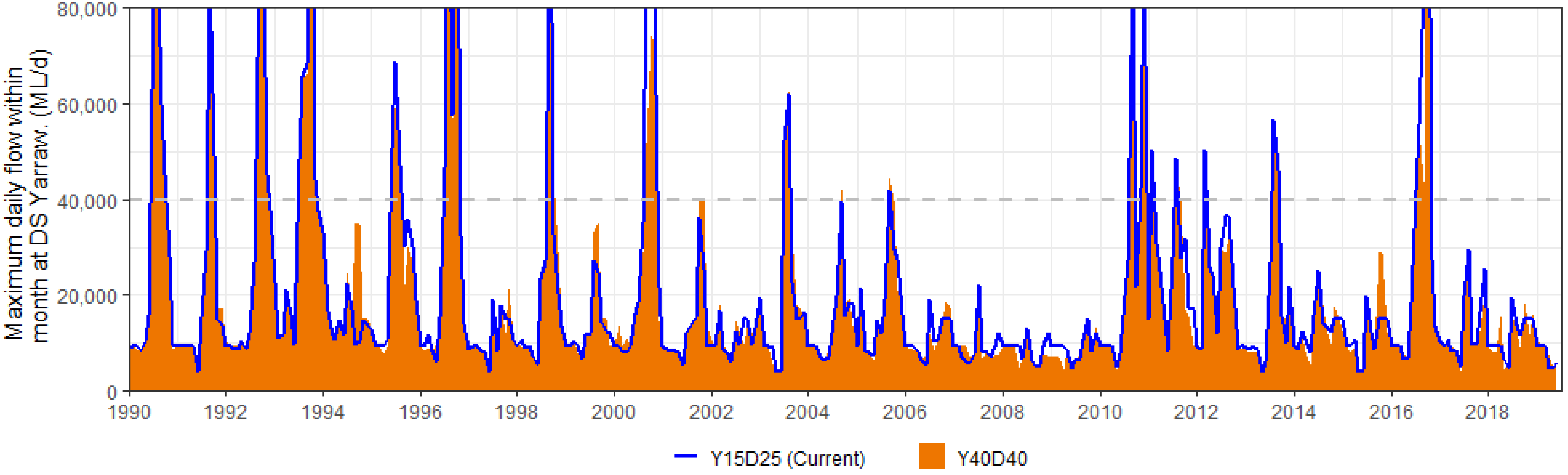
Maximum daily flow within month at DS Yarraw. (ML/d)
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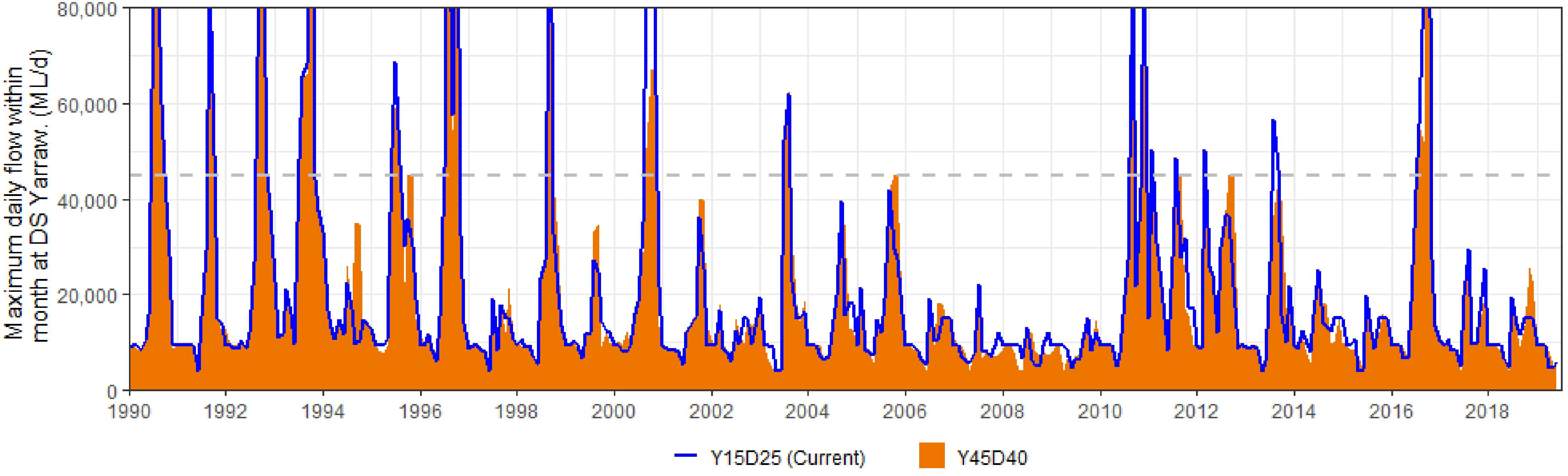
Maximum daily flow within month at DS Yarraw. (ML/d)
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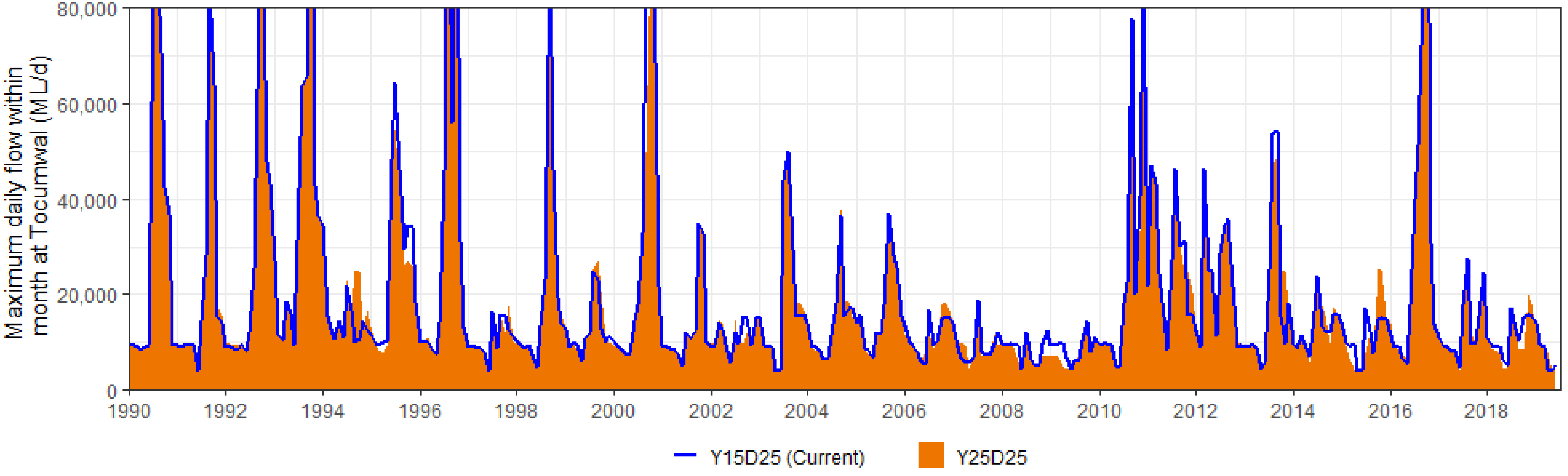
Y45D40


Maximum daily flow within month at Tocumwal (ML/d)
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60,000
40,000
20,000
0
1990
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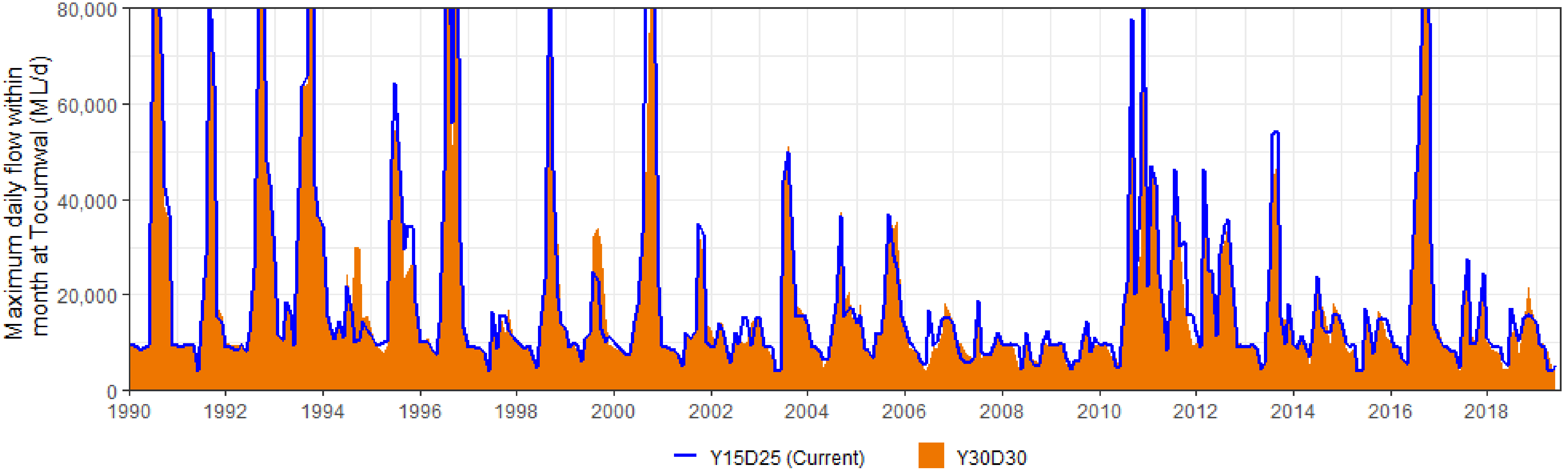
Y25D25


Maximum daily flow within month at Tocumwal (ML/d)
80,000
60,000
40,000
20,000
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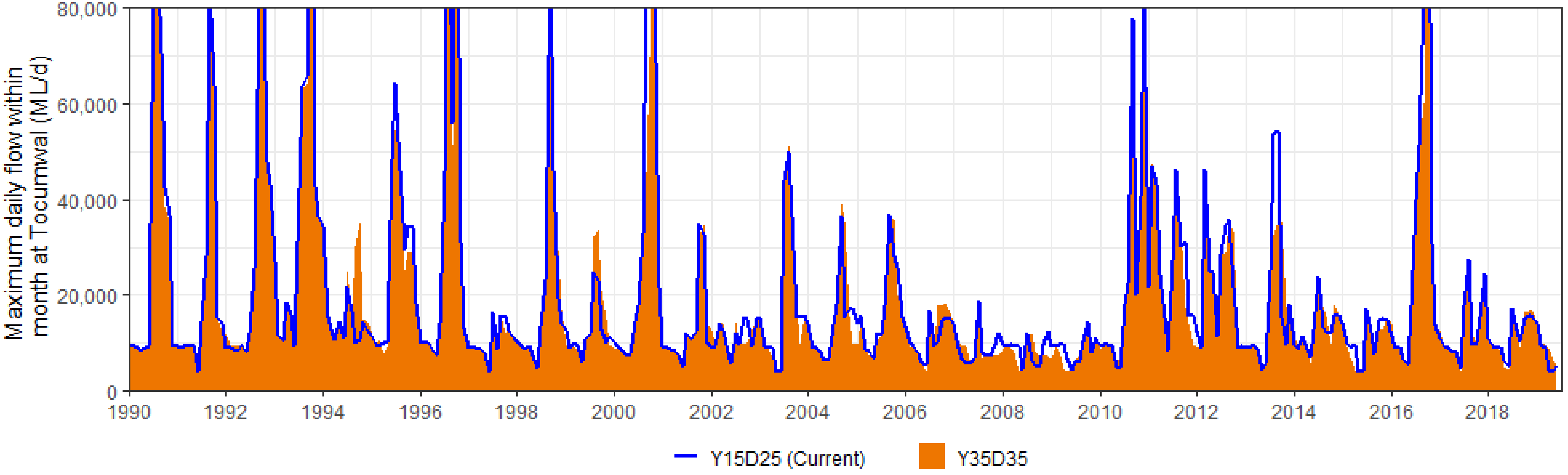
Y30D30


Maximum daily flow within month at Tocumwal (ML/d)
80,000
60,000
40,000
20,000
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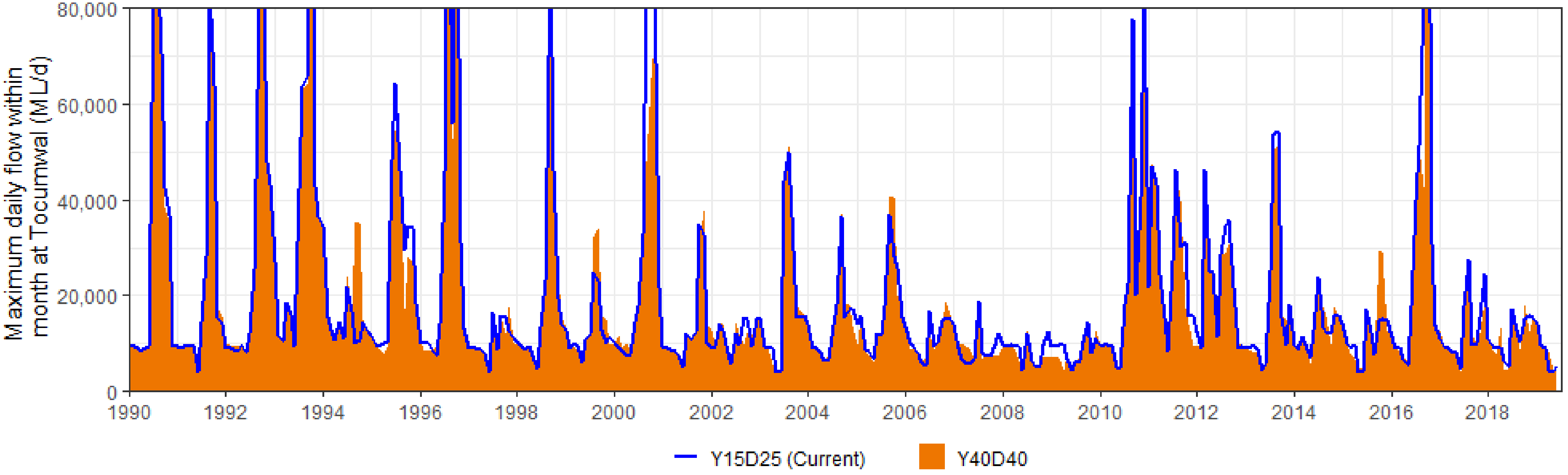
Y35D35


Maximum daily flow within month at Tocumwal (ML/d)
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60,000
40,000
20,000
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2014
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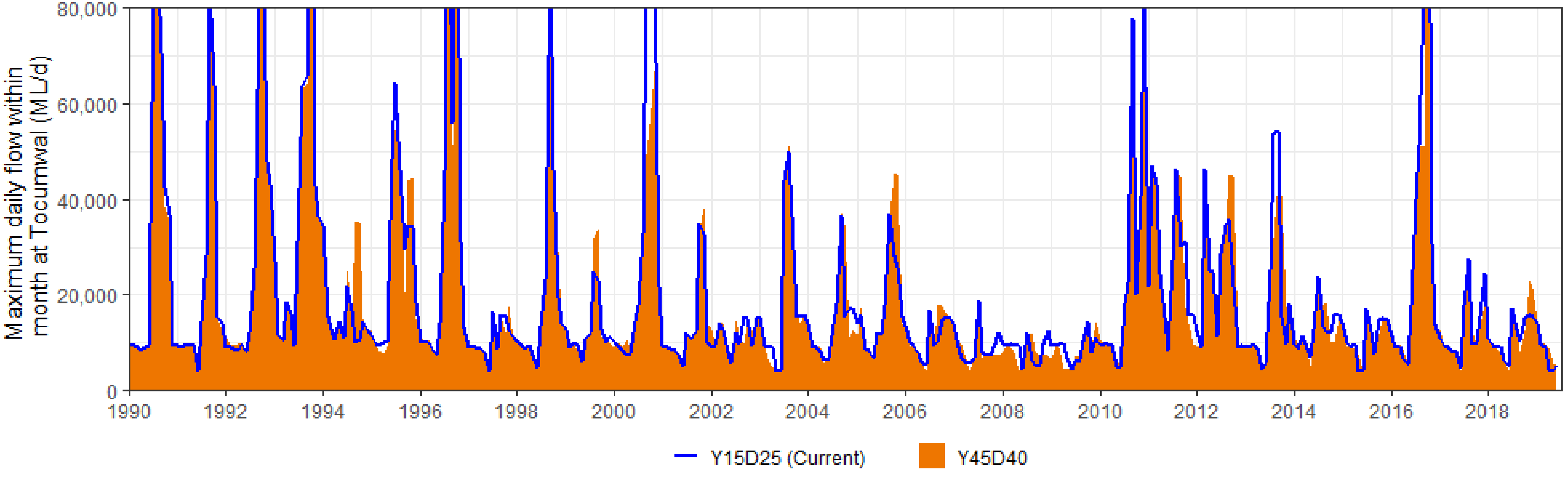
Y40D40


Maximum daily flow within month at Tocumwal (ML/d)
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60,000
40,000
20,000
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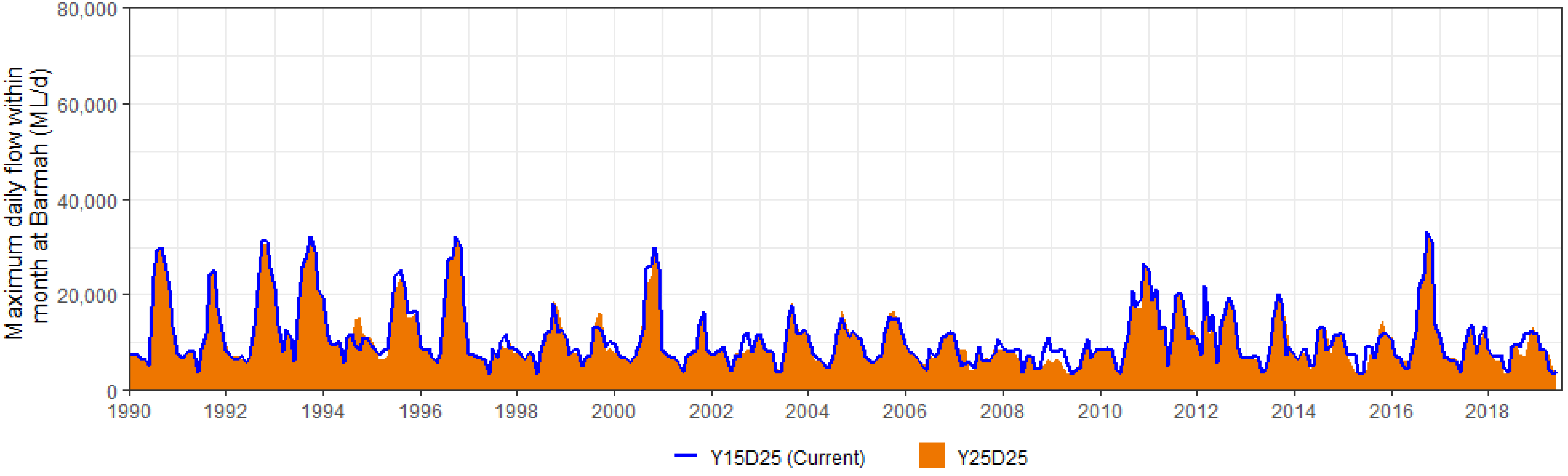
Maximum daily flow within month at Barmah (ML/d)
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60,000
40,000
20,000
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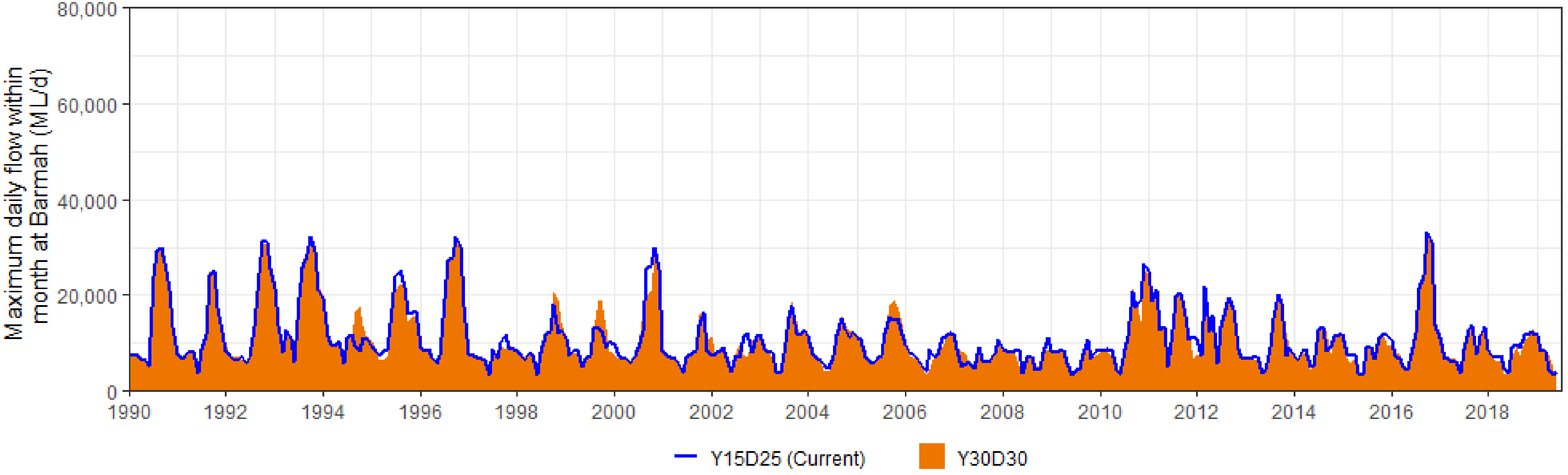
Y25D25


Maximum daily flow within month at Barmah (ML/d)
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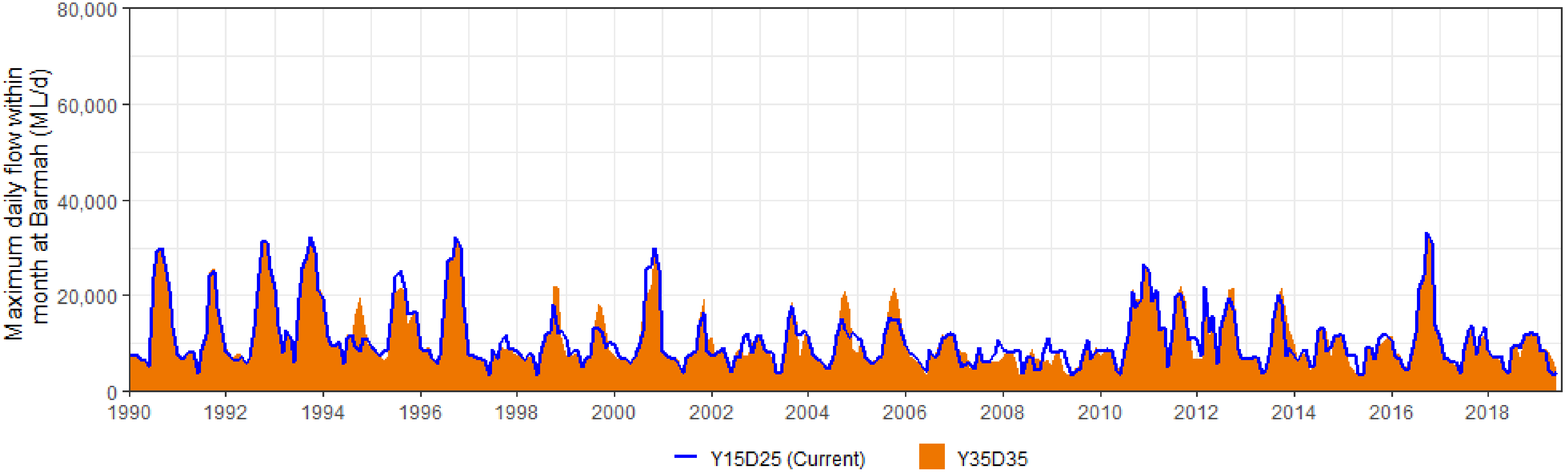
Y30D30


Maximum daily flow within month at Barmah (ML/d)
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40,000
20,000
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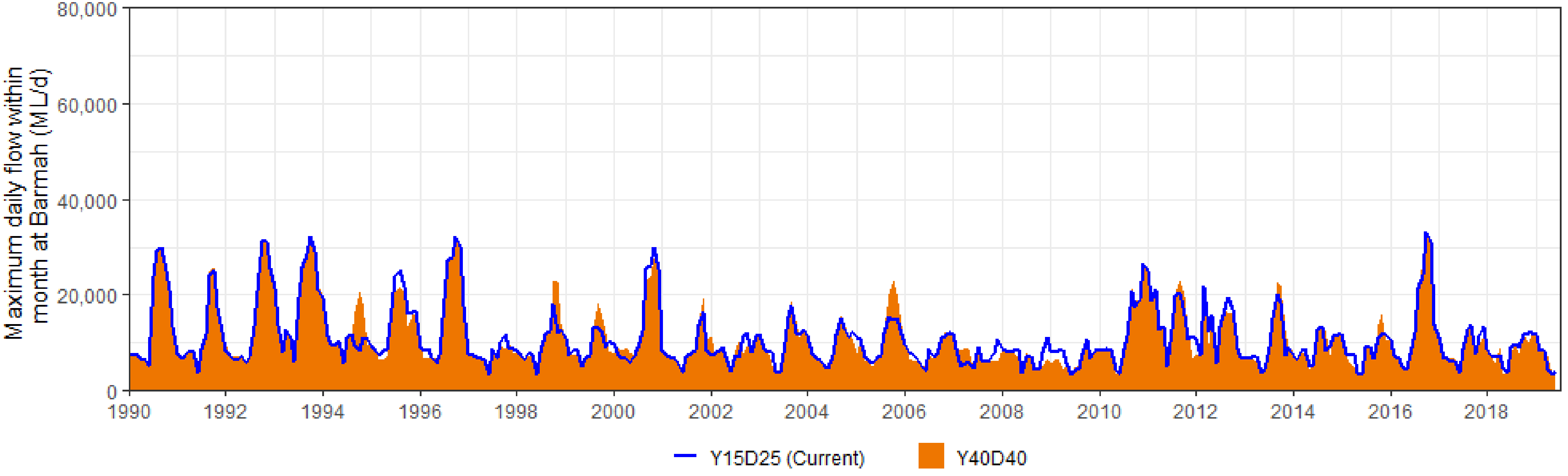
Y35D35


Maximum daily flow within month at Barmah (ML/d)
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60,000
40,000
20,000
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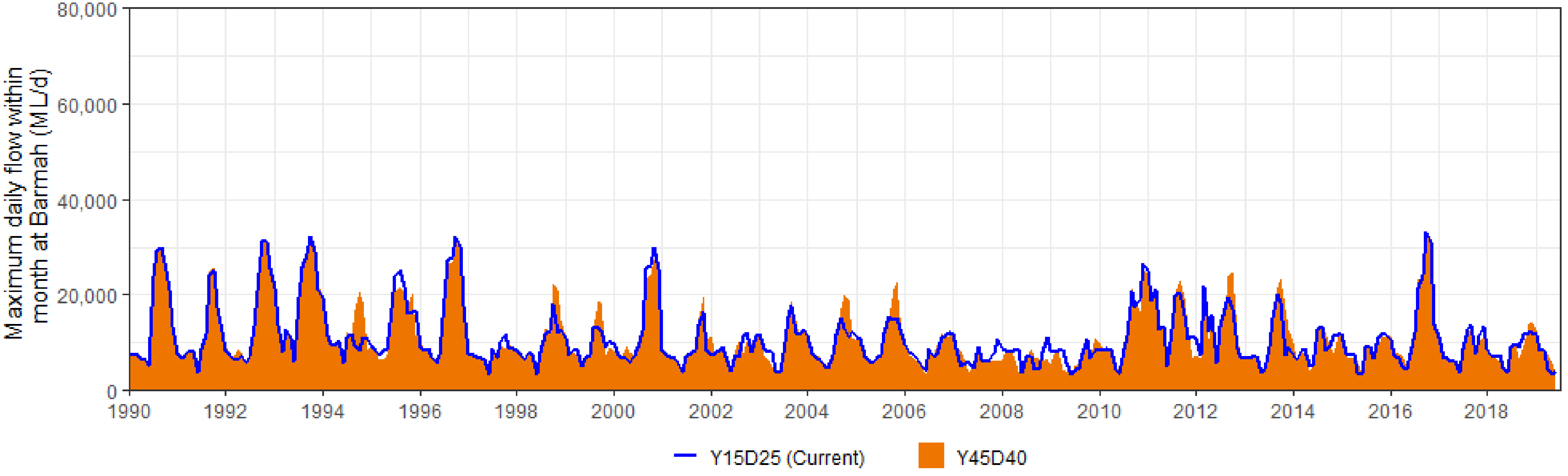
Y40D40


Maximum daily flow within month at Barmah (ML/d)
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20,000
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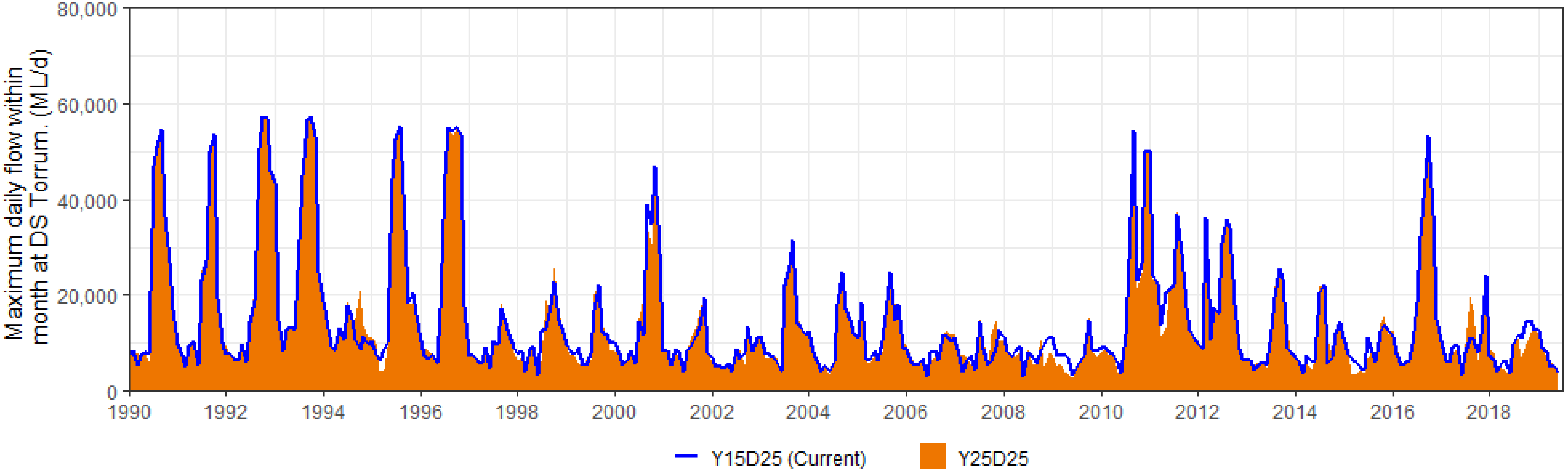
Y45D40


Maximum daily flow within month at DS Torrum. (ML/d)
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40,000
20,000
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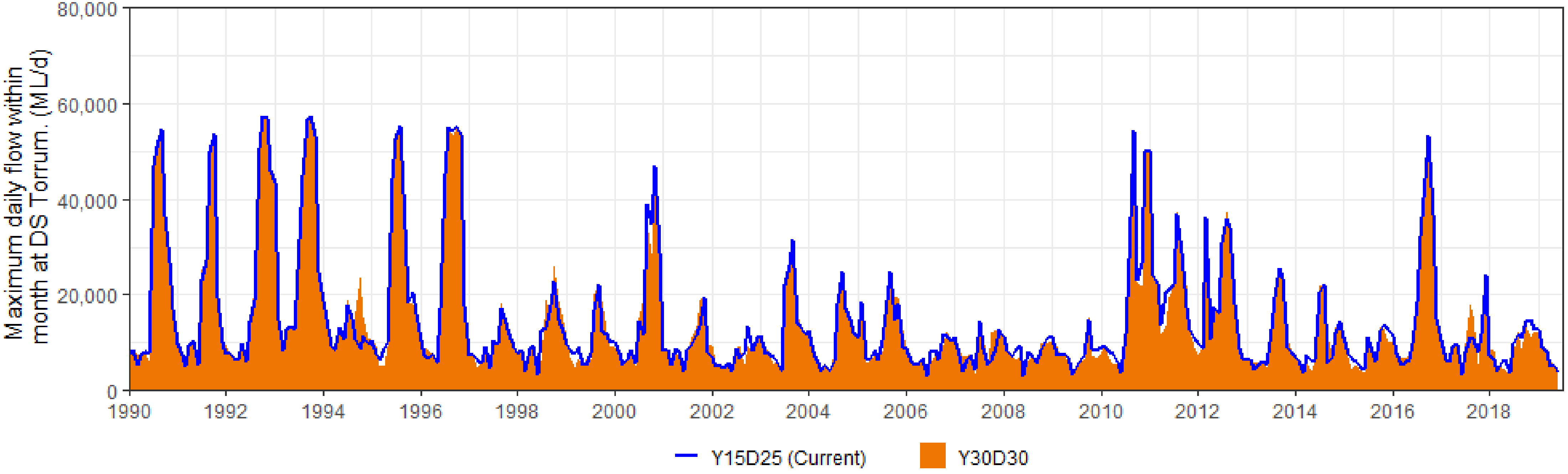
Maximum daily flow within month at DS Torrum. (ML/d)
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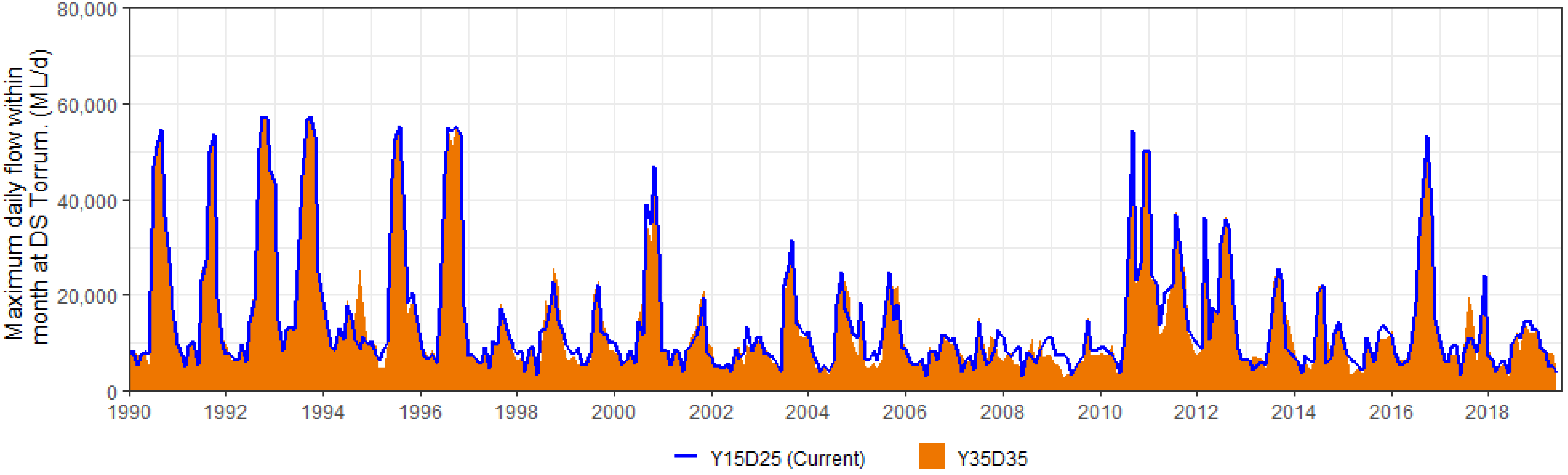
Y30D30



Maximum daily flow within month at DS Torrum. (ML/d)
80,000
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40,000
20,000
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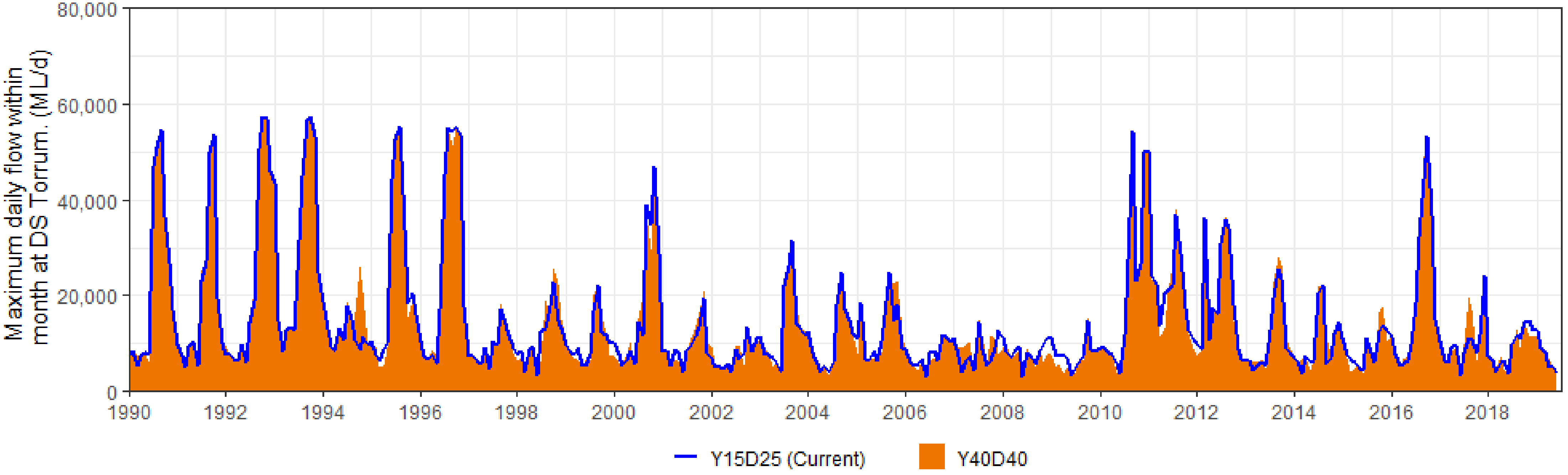
Y35D35



Maximum daily flow within month at DS Torrum. (ML/d)
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40,000
20,000
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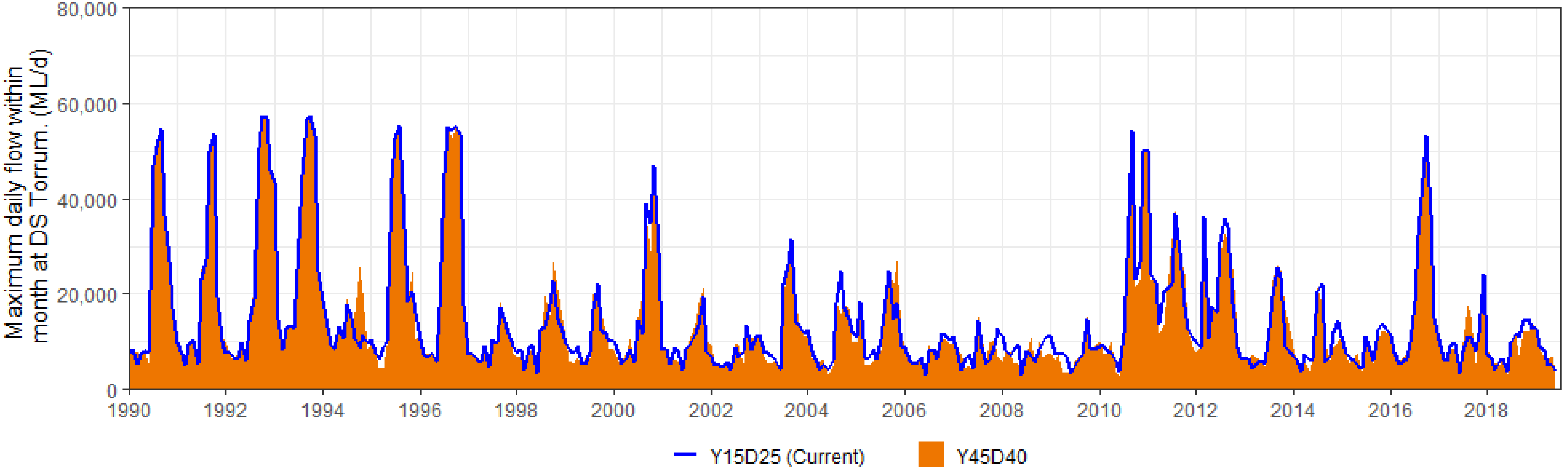
Y40D40


Maximum daily flow within month at DS Torrum. (ML/d)
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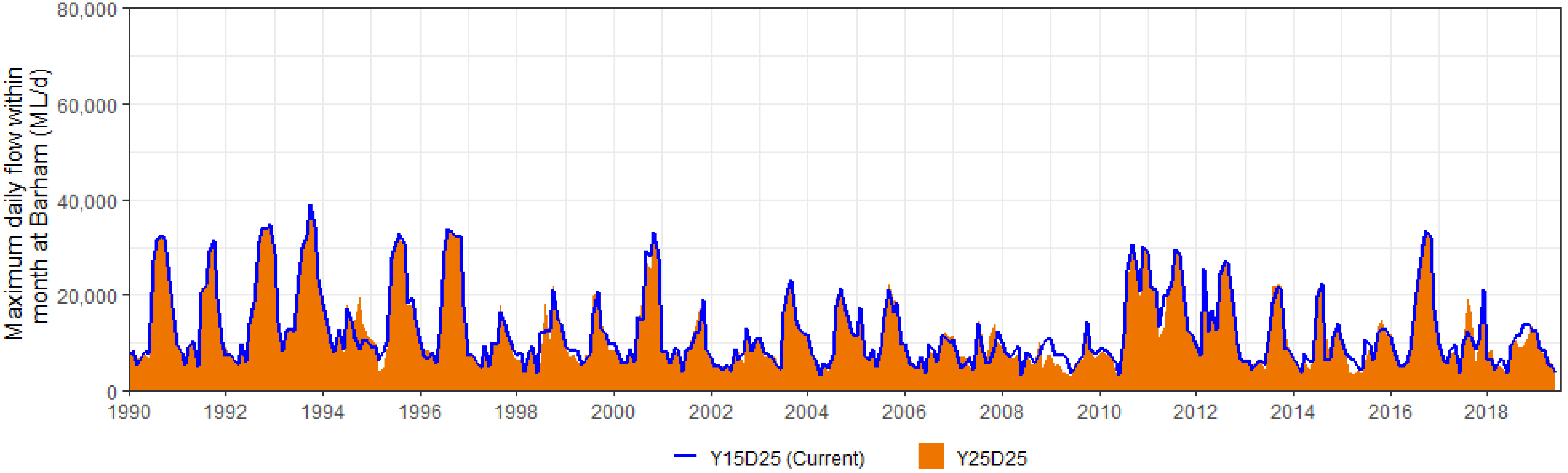
Y45D40


Maximum daily flow within month at Barham (ML/d)
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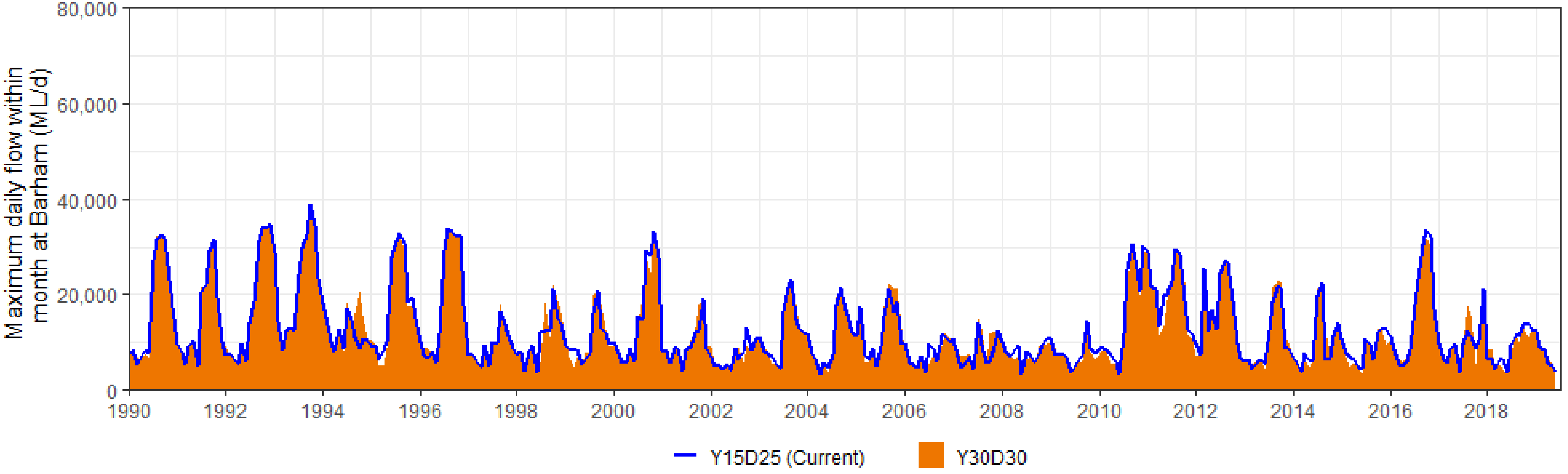
Y25D25


Maximum daily flow within month at Barham (ML/d)
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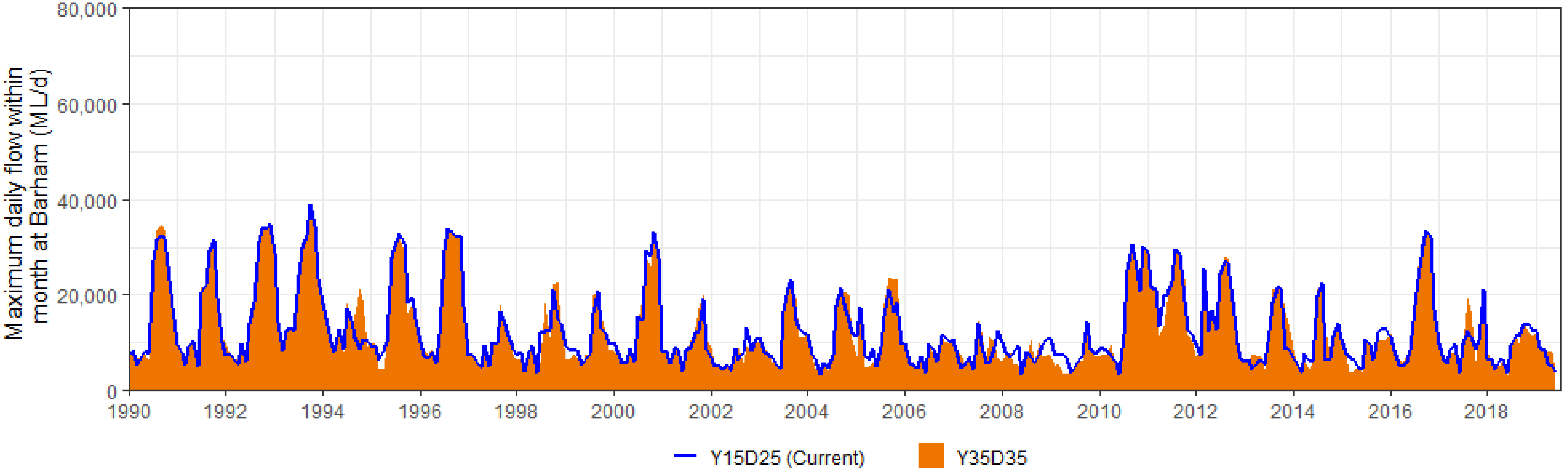
Y30D30


Maximum daily flow within month at Barham (ML/d)
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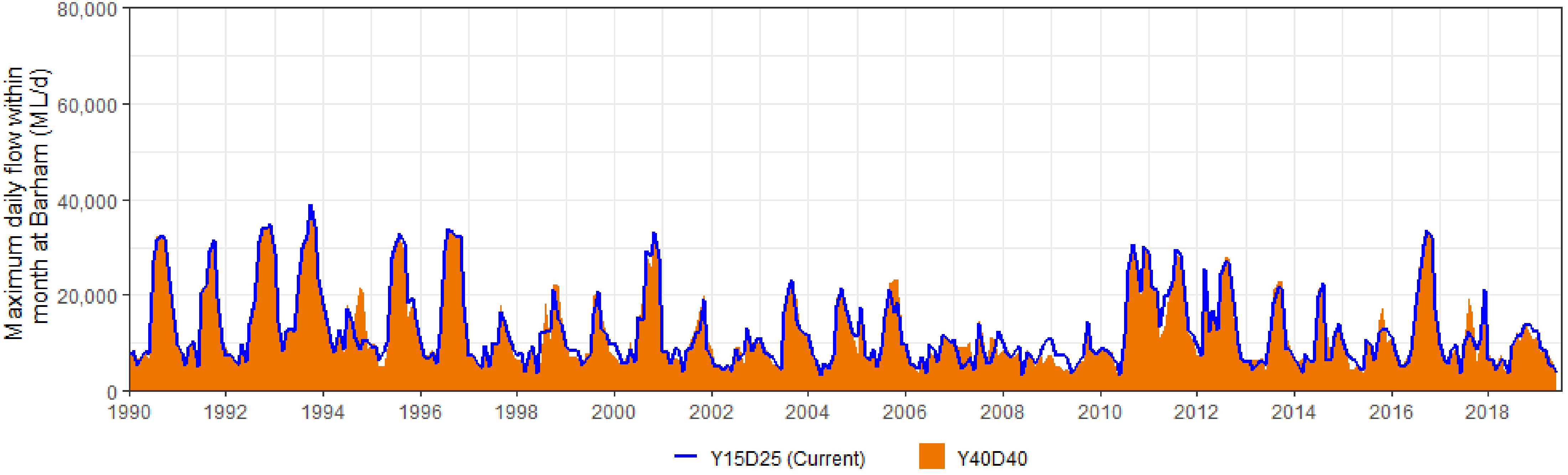
Y35D35


Maximum daily flow within month at Barham (ML/d)
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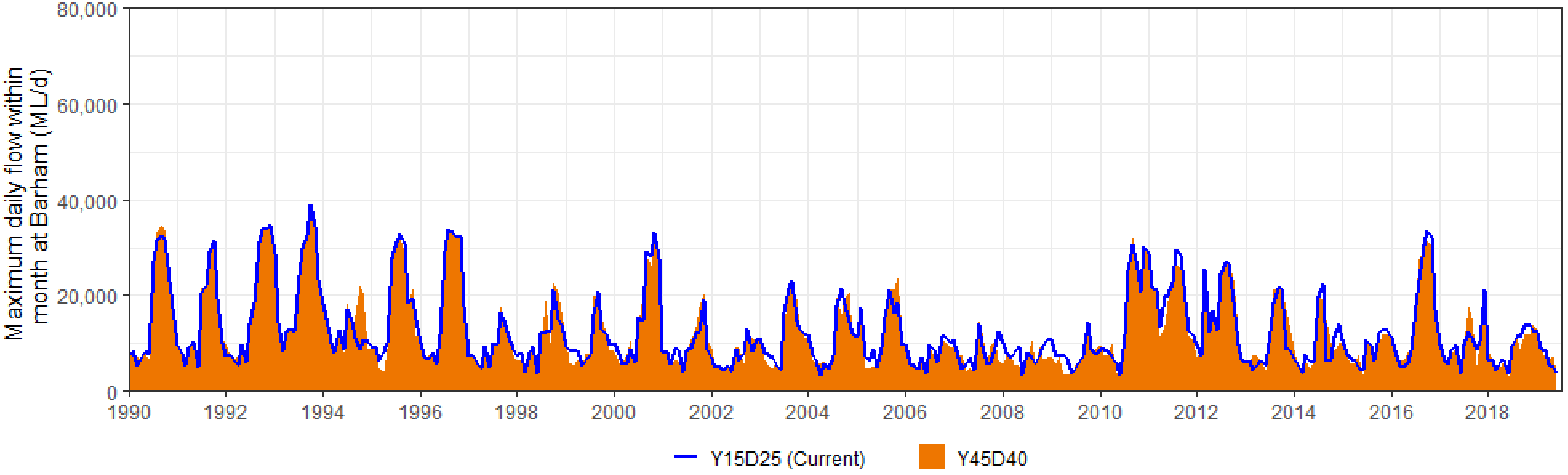
Y15D25 (Current)
Y40D40


Maximum daily flow within month at Barham (ML/d)
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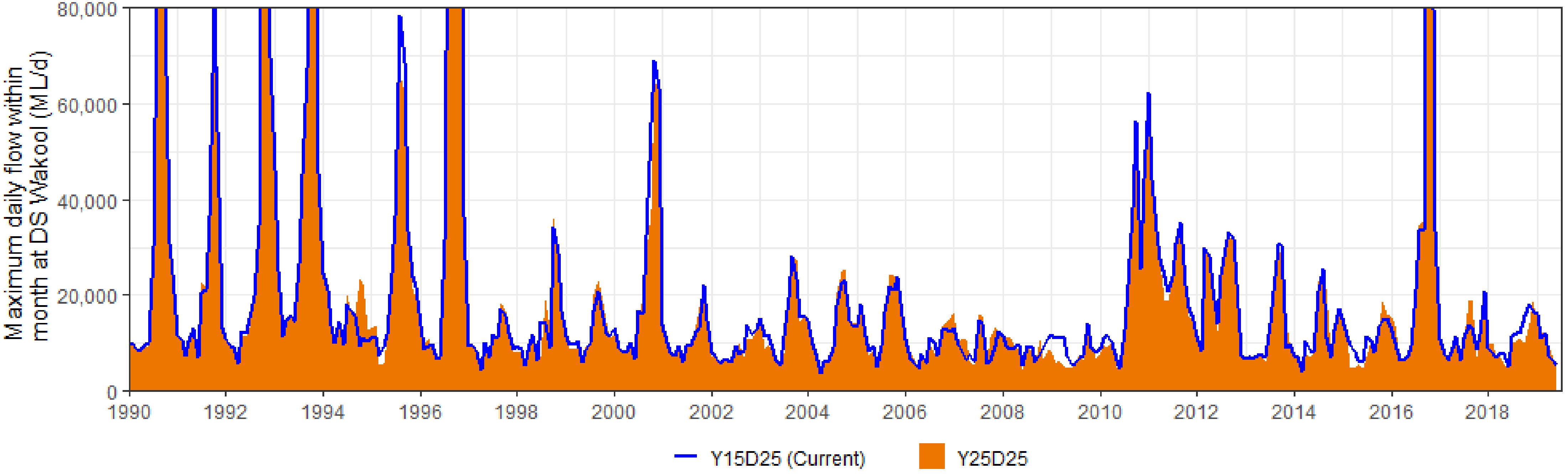
Y45D40


Maximum daily flow within month at DS Wakool (ML/d)
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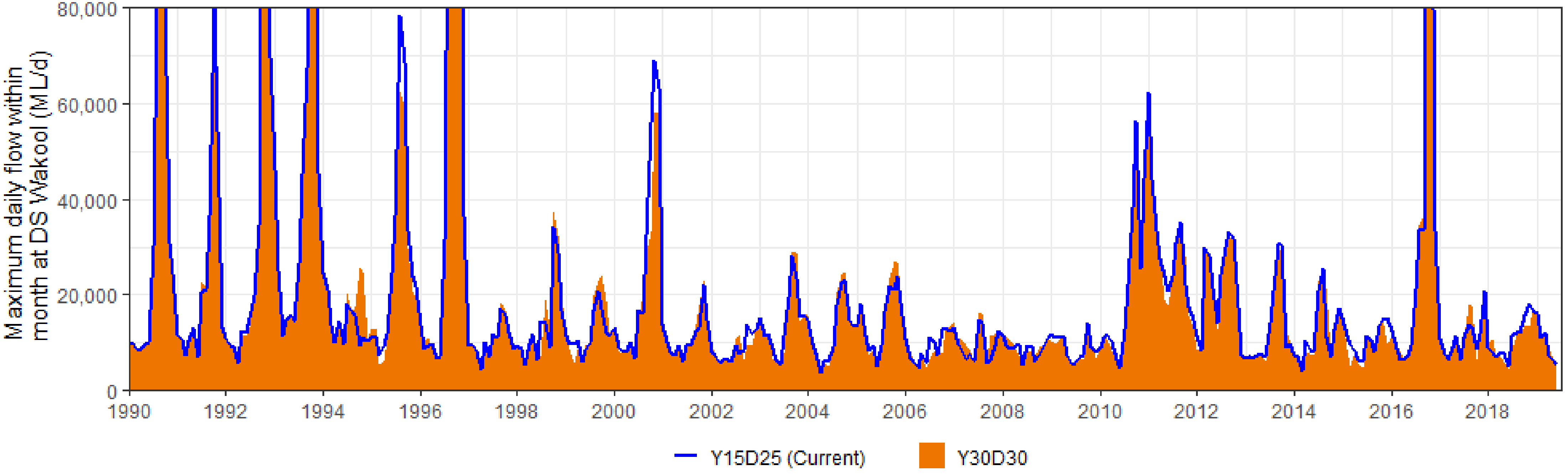
Y25D25


Maximum daily flow within month at DS Wakool (ML/d)
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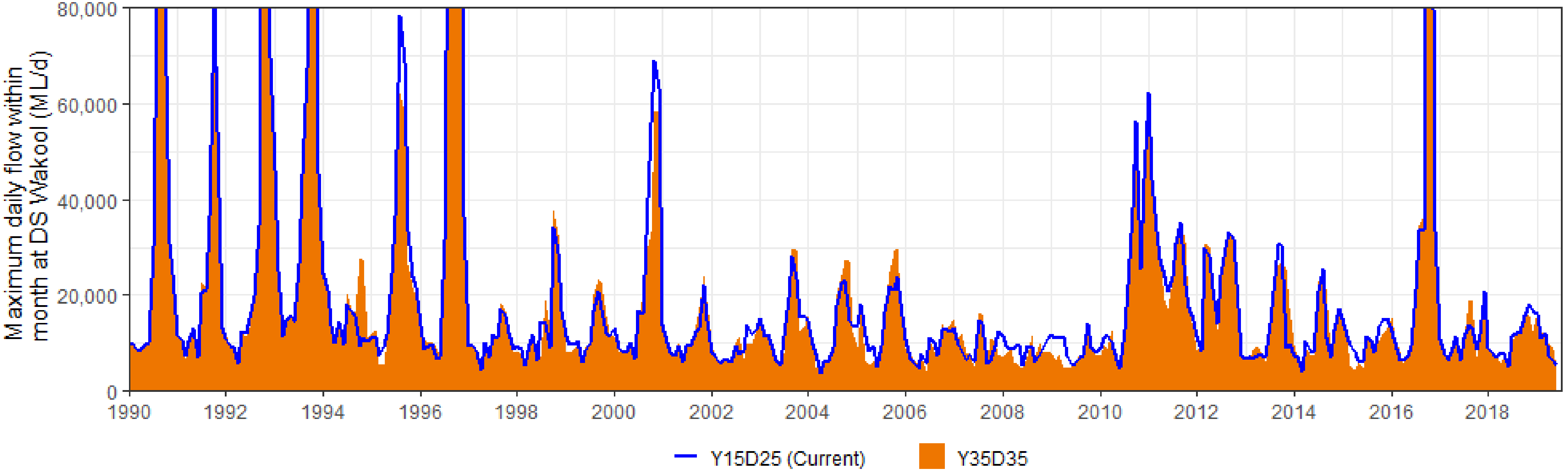
Y30D30


Maximum daily flow within month at DS Wakool (ML/d)
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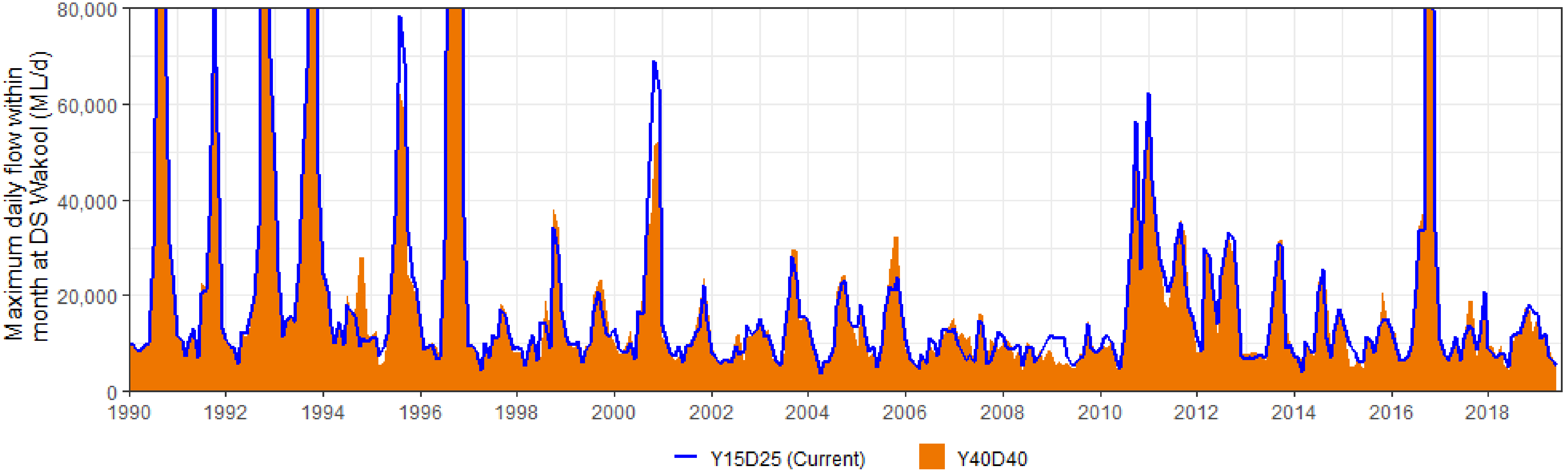
Y35D35


Maximum daily flow within month at DS Wakool (ML/d)
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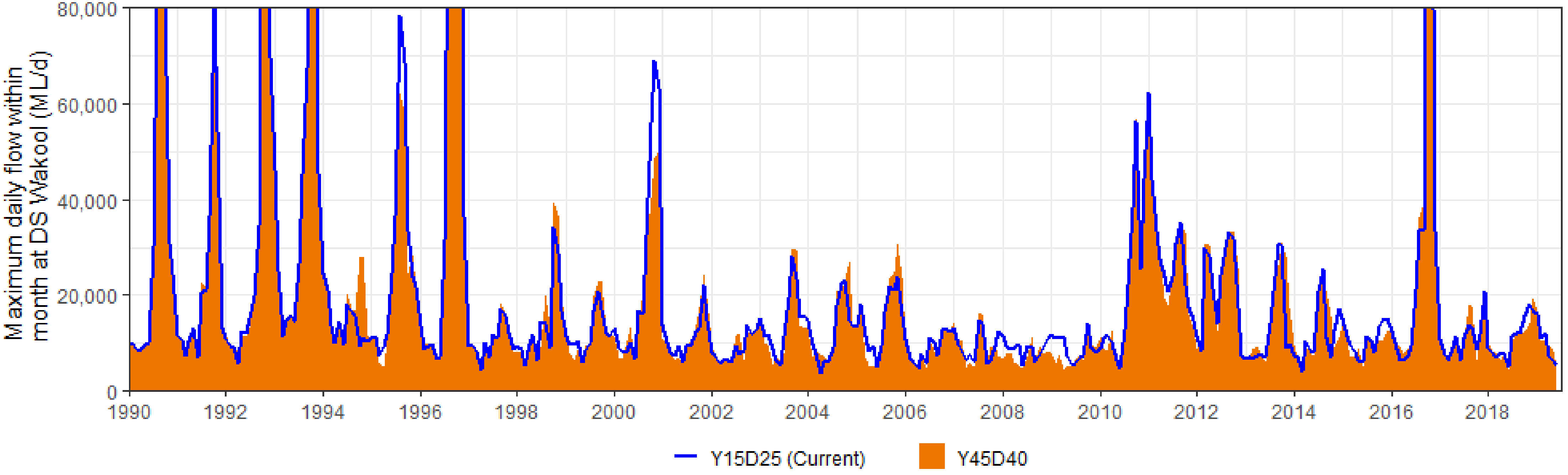
Y40D40


Maximum daily flow within month at DS Wakool (ML/d)
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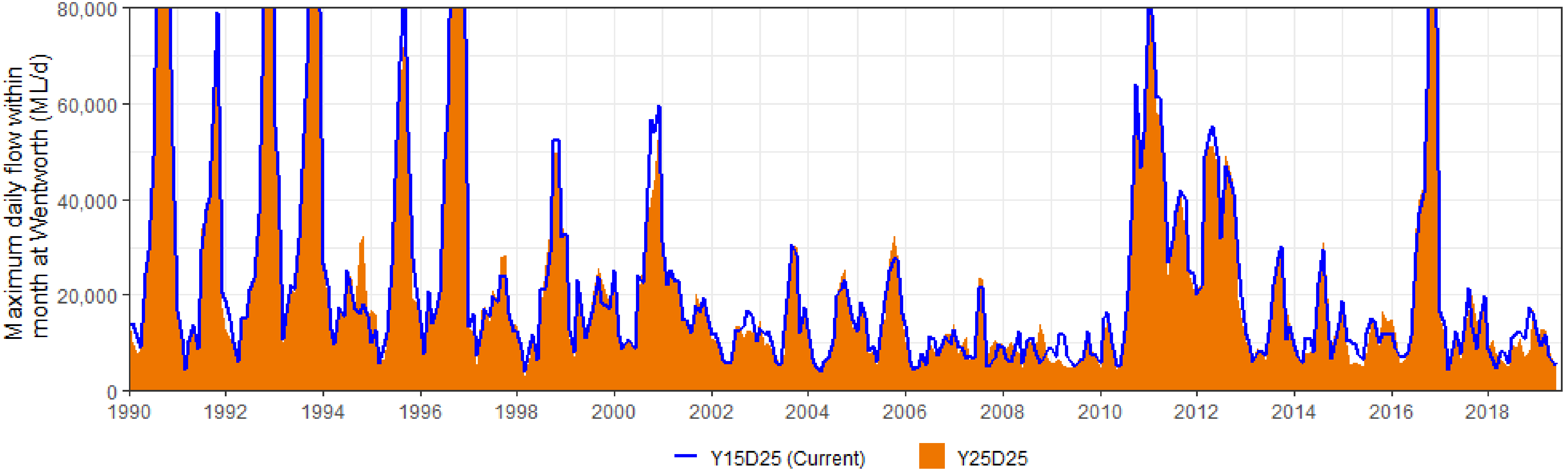
Y45D40


Maximum daily flow within month at Wentworth (ML/d)
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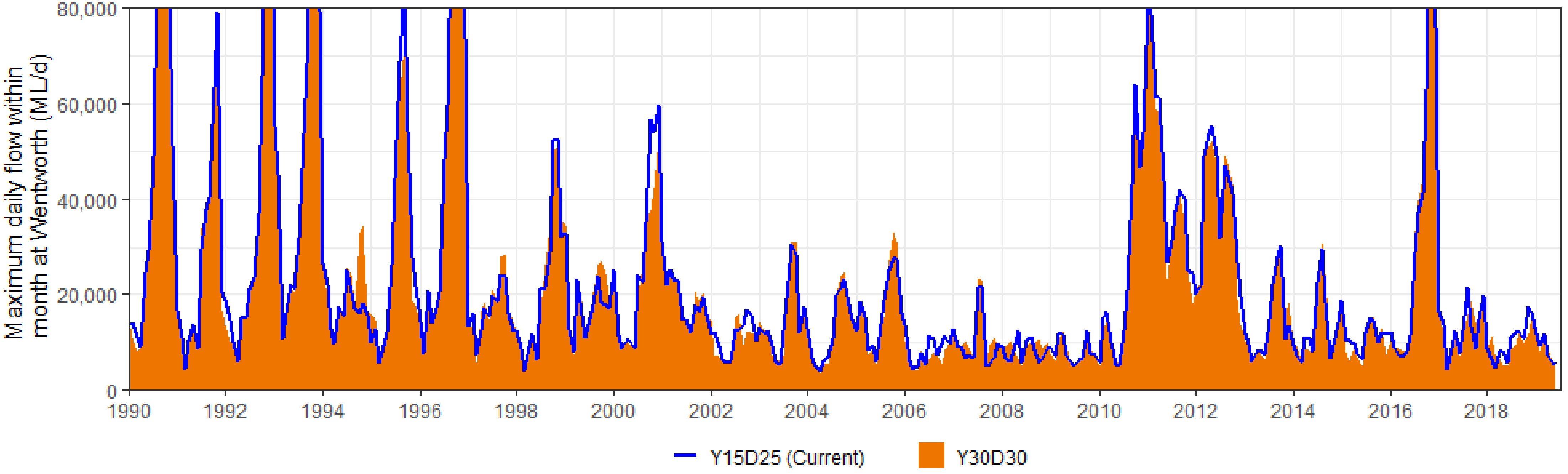
Y25D25


Maximum daily flow within month at Wentworth (ML/d)
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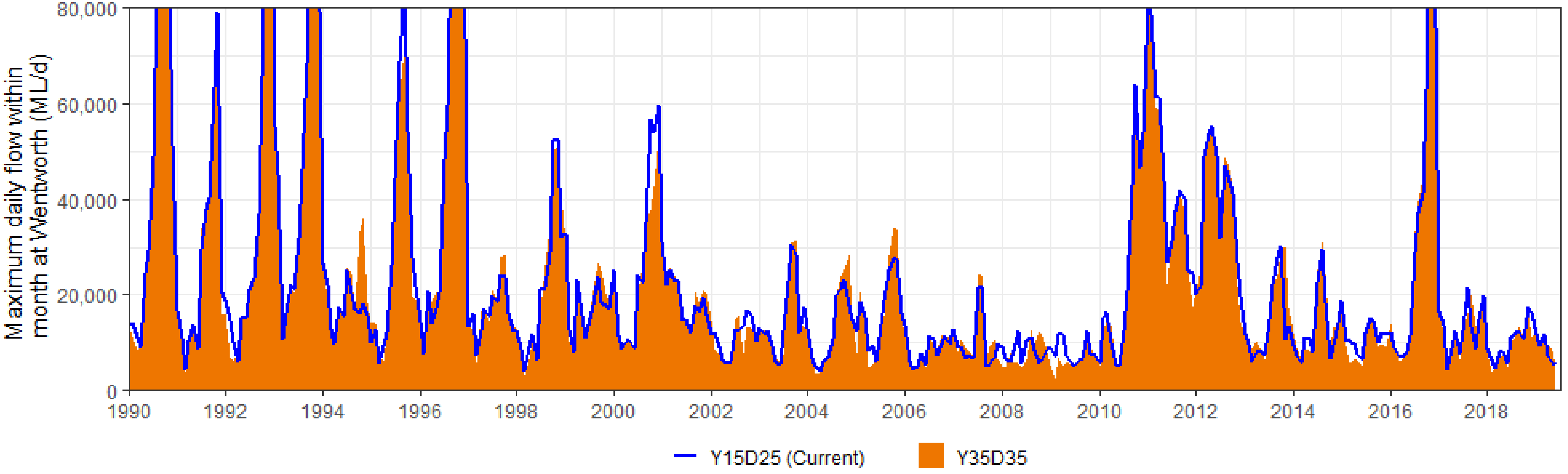
Y15D25 (Current)
Y30D30


Maximum daily flow within month at Wentworth (ML/d)
80,000
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20,000
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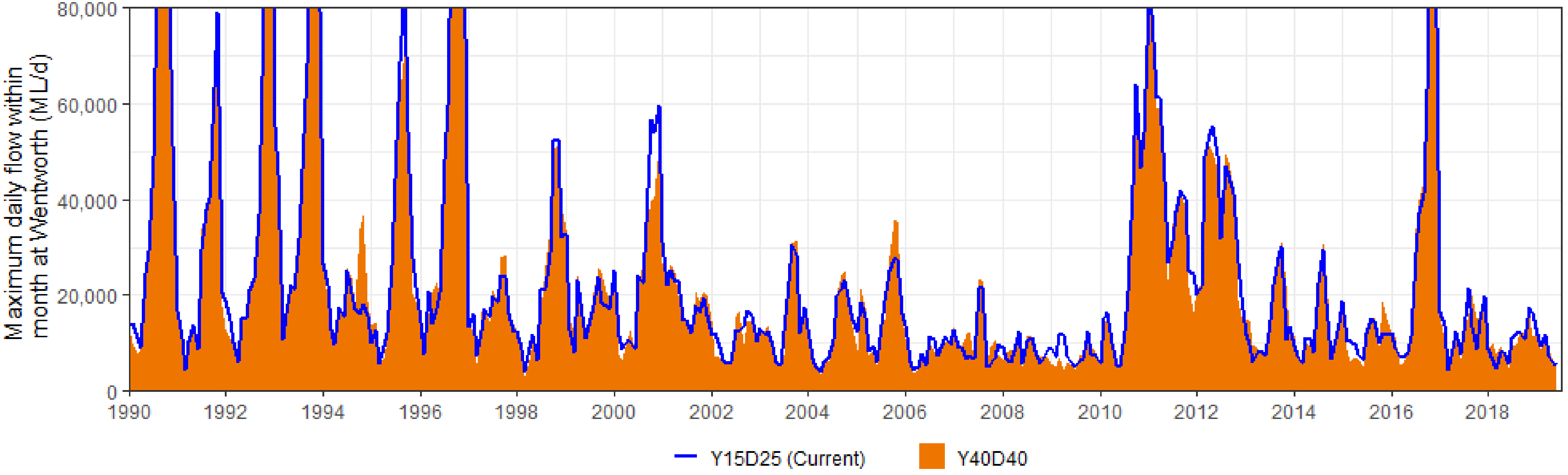
Y15D25 (Current)
Y35D35


Maximum daily flow within month at Wentworth (ML/d)
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20,000
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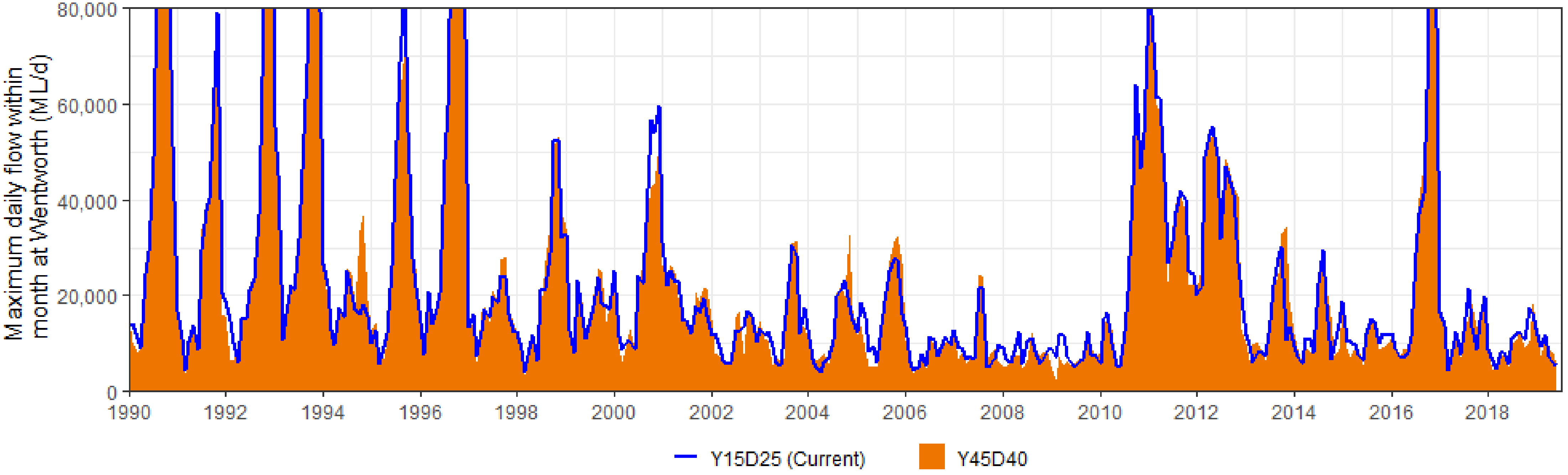
Y40D40


Maximum daily flow within month at Wentworth (ML/d)
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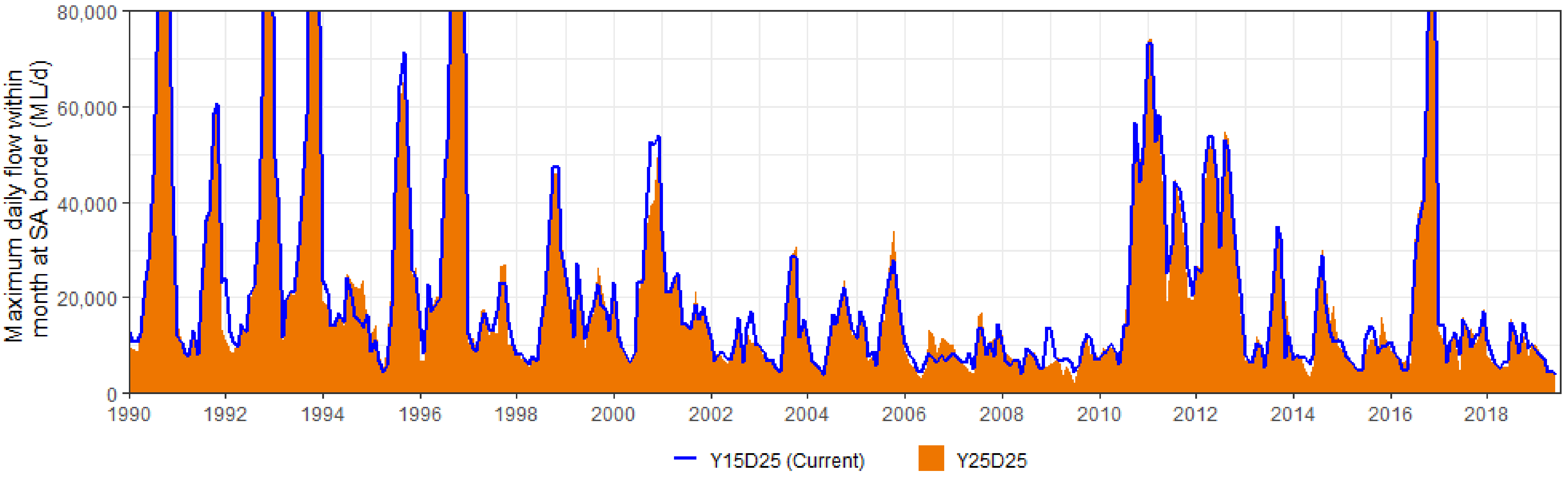
Y15D25 (Current)
Y45D40


Maximum daily flow within month at SA border (ML/d)
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40,000
20,000
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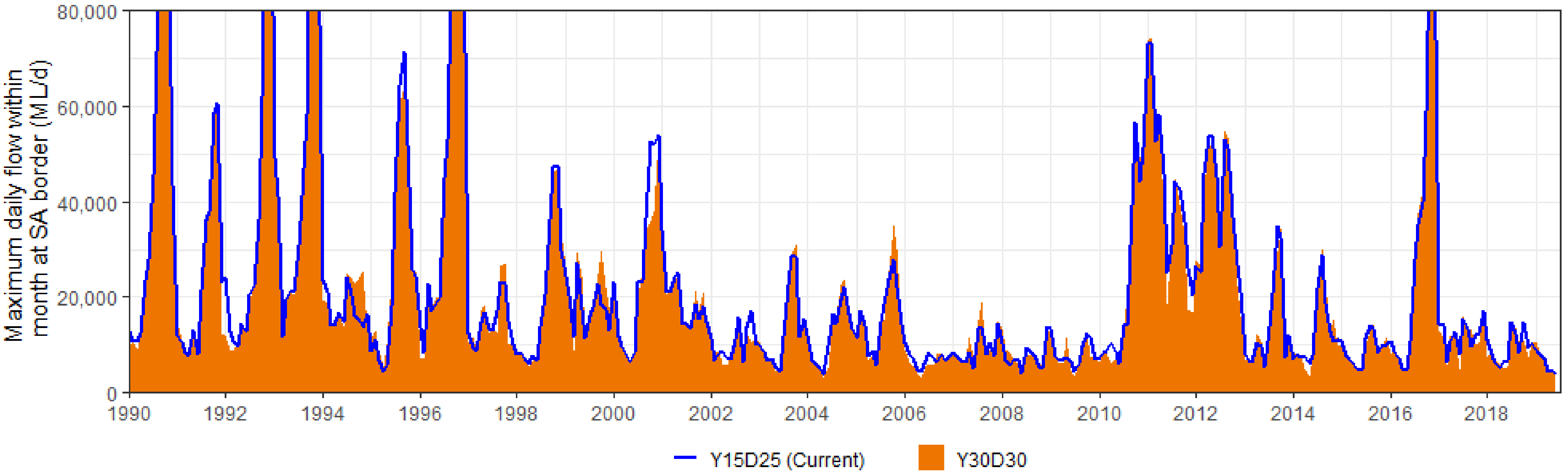
Y15D25 (Current)
Y25D25


Maximum daily flow within month at SA border (ML/d)
80,000
60,000
40,000
20,000
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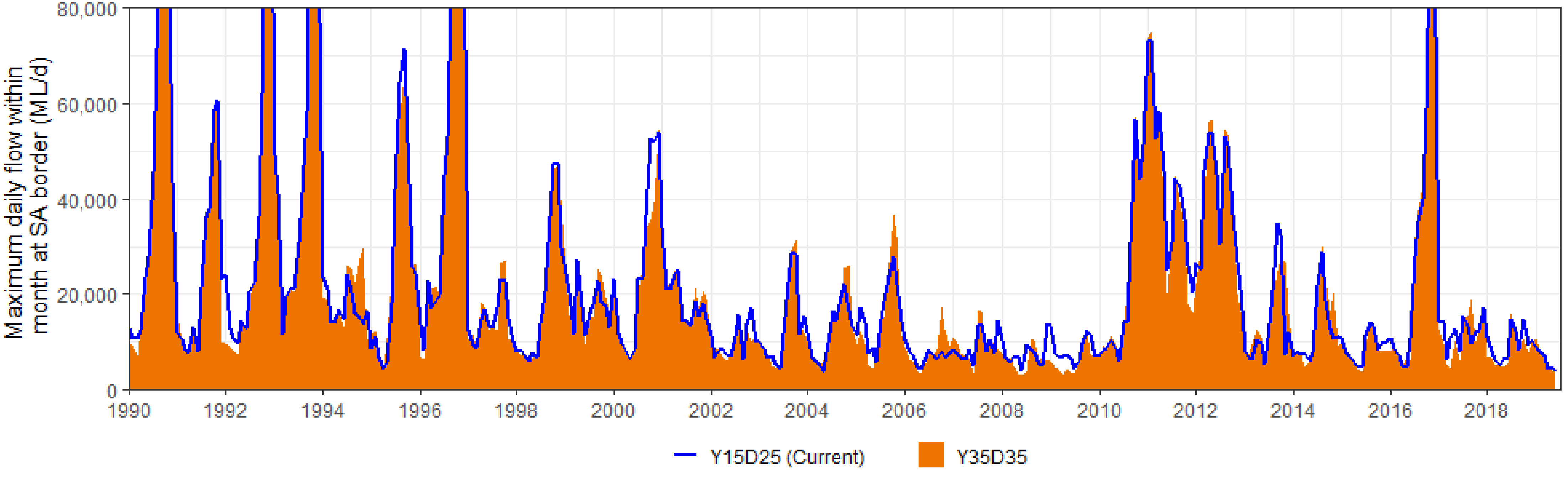
Y15D25 (Current)
Y30D30


Maximum daily flow within month at SA border (ML/d)
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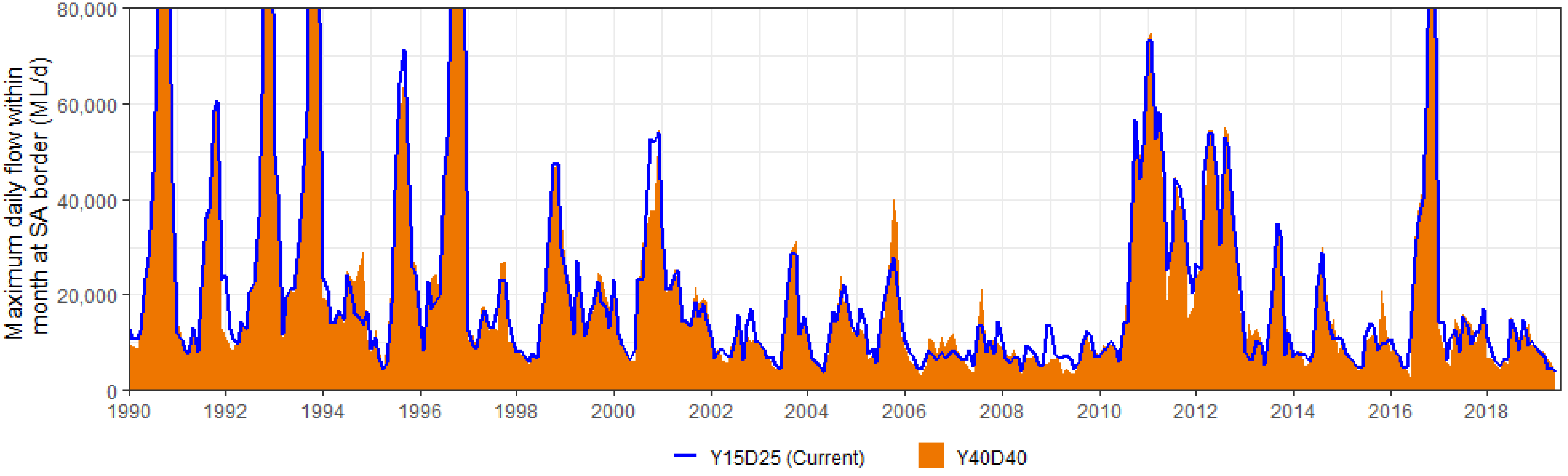
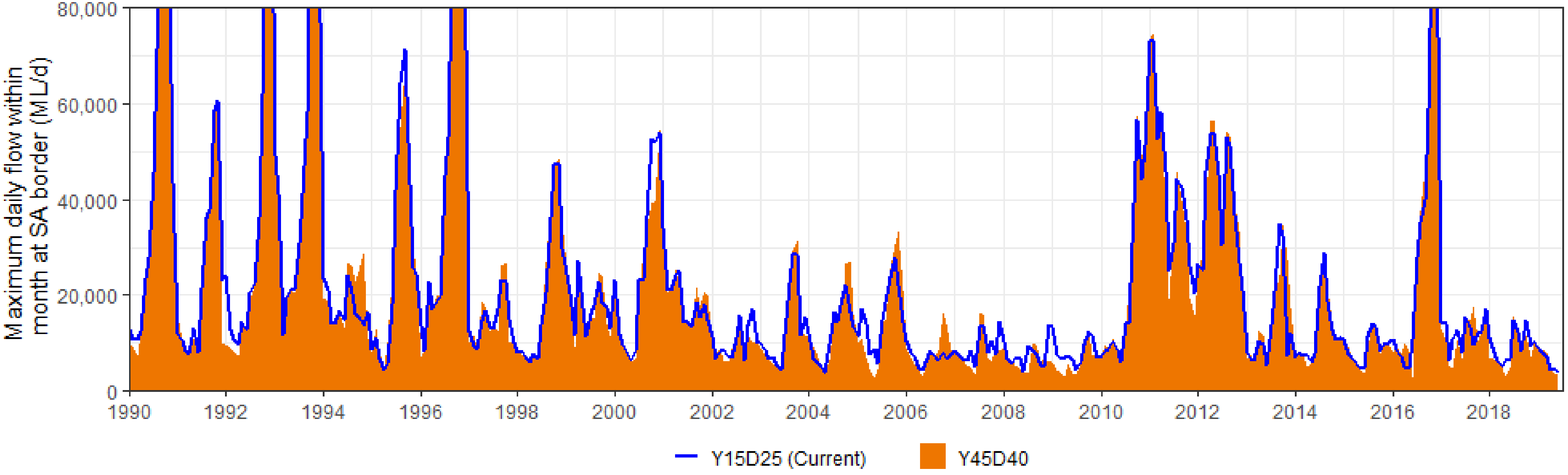
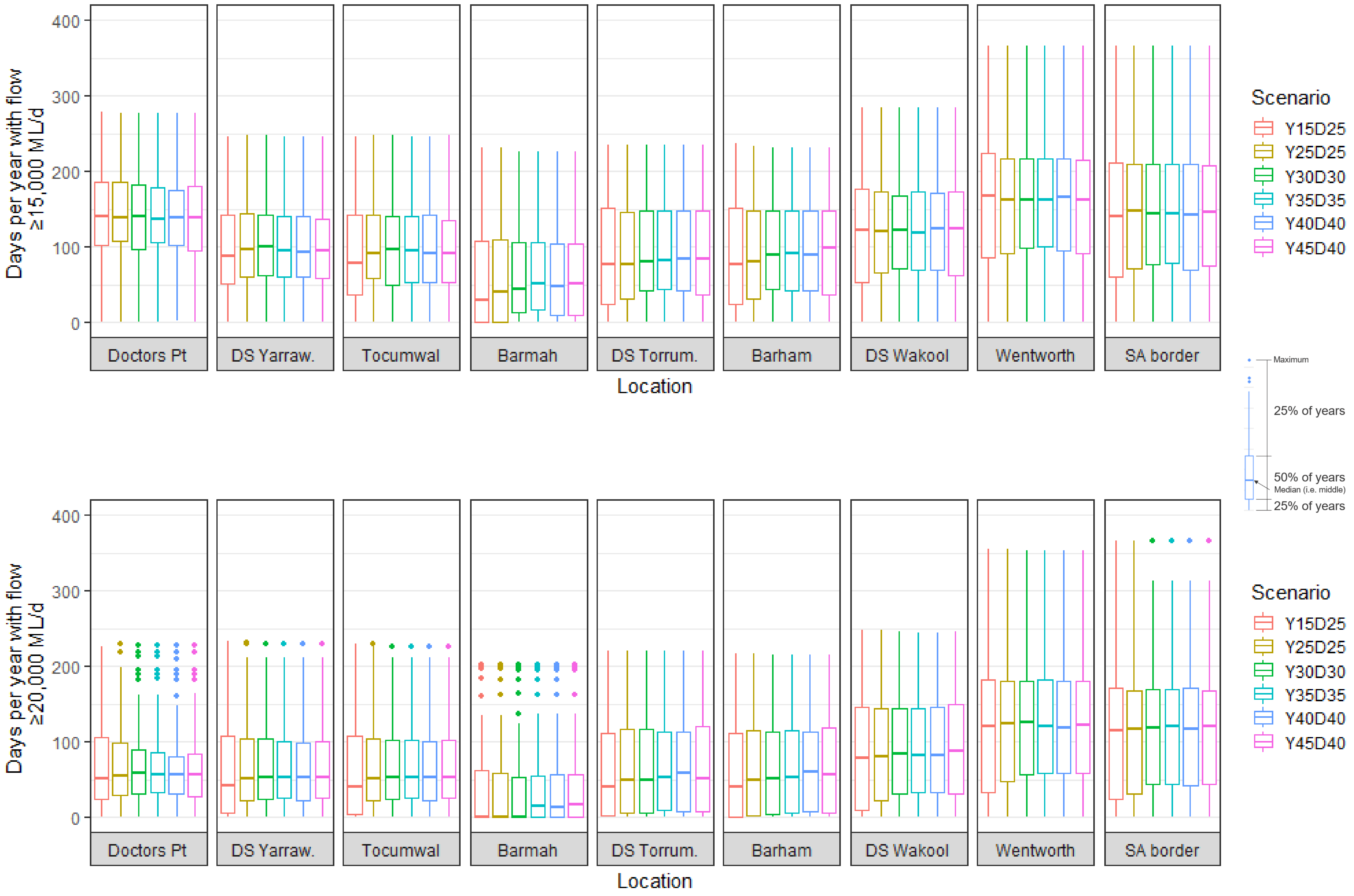
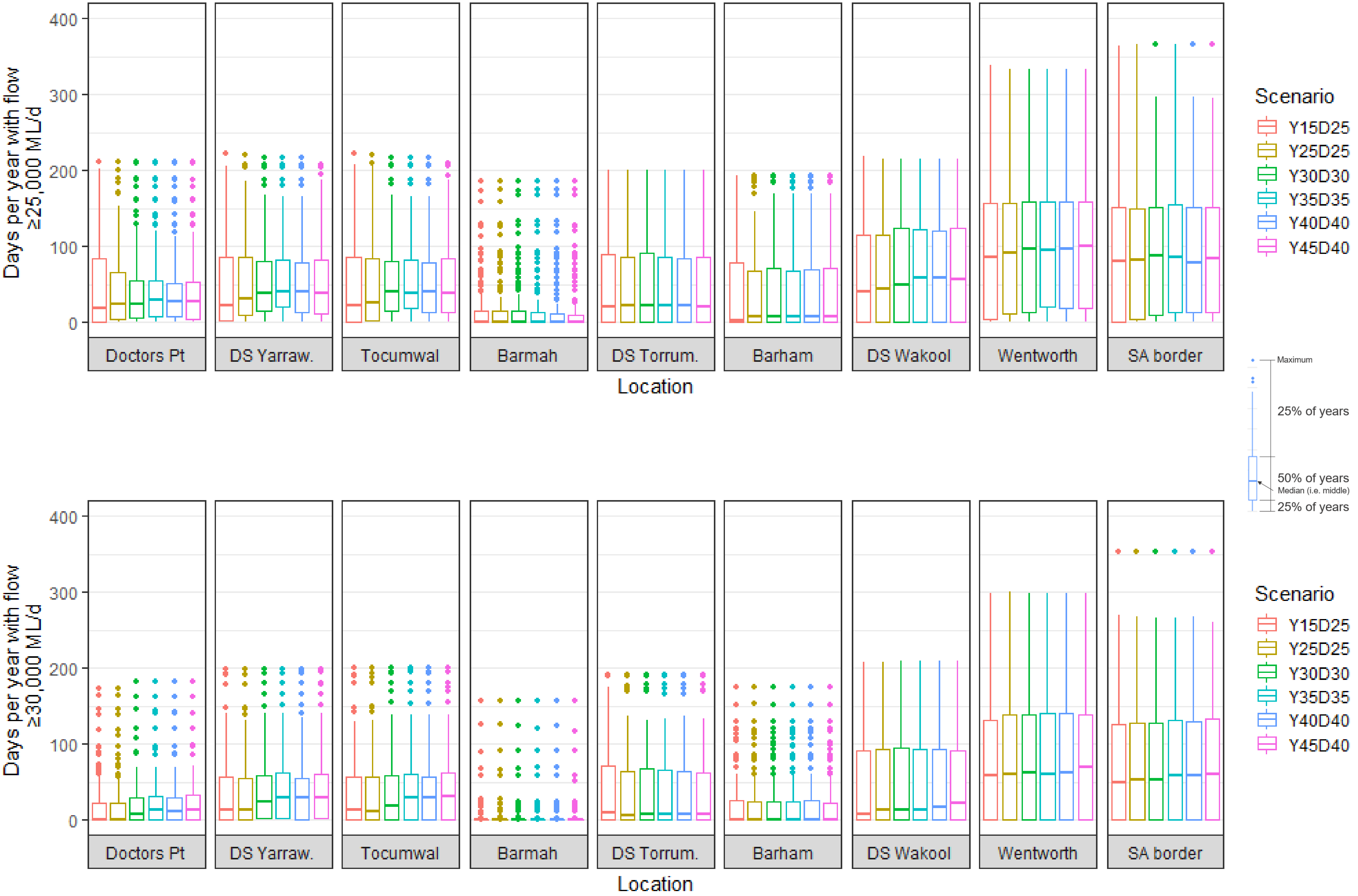
60,000
40,000
20,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Y15D25 (Current)
Y35D35

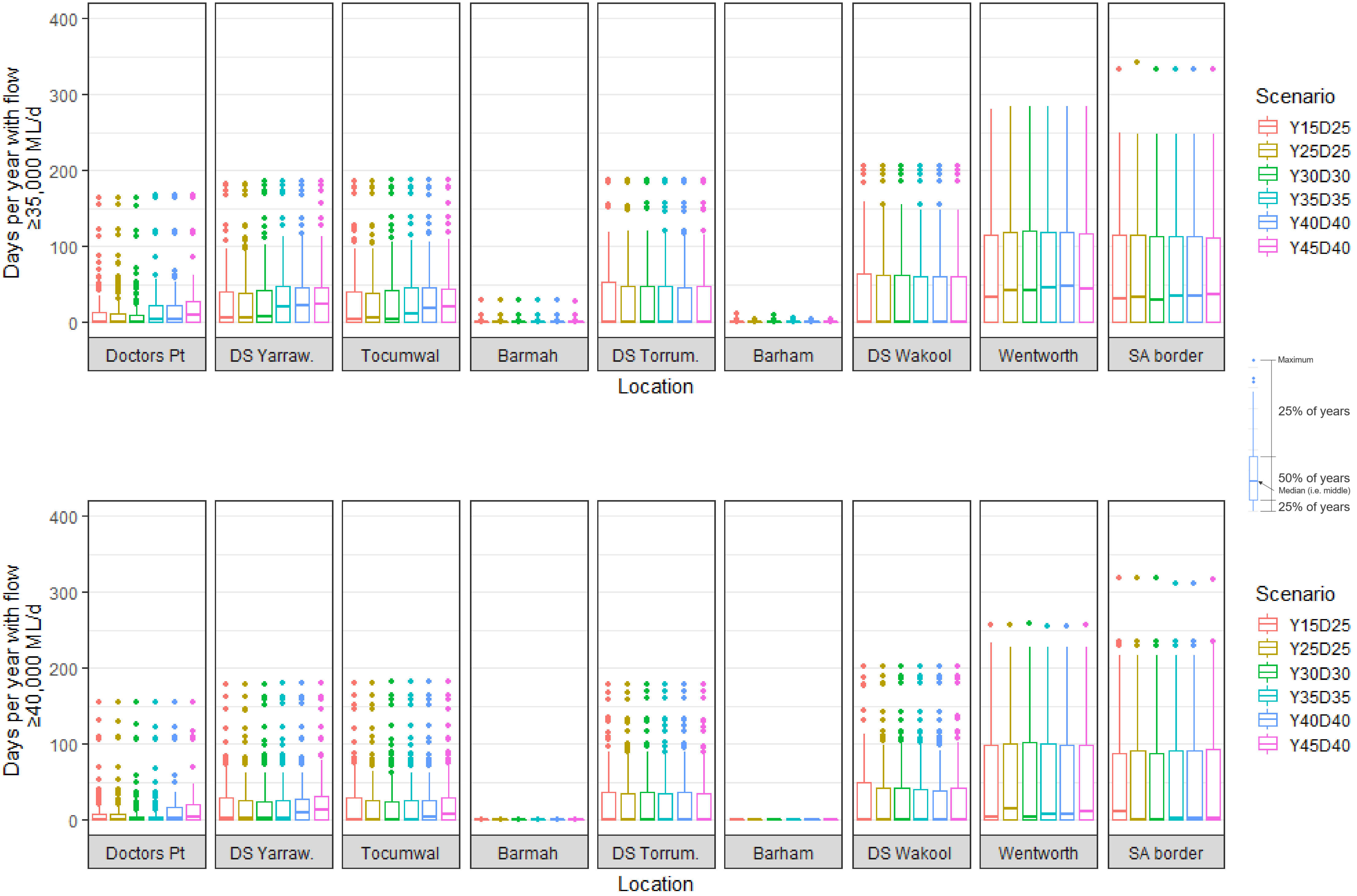

Maximum daily flow within month at SA border (ML/d)
80,000
60,000
40,000
20,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Y15D25 (Current)
Y40D40

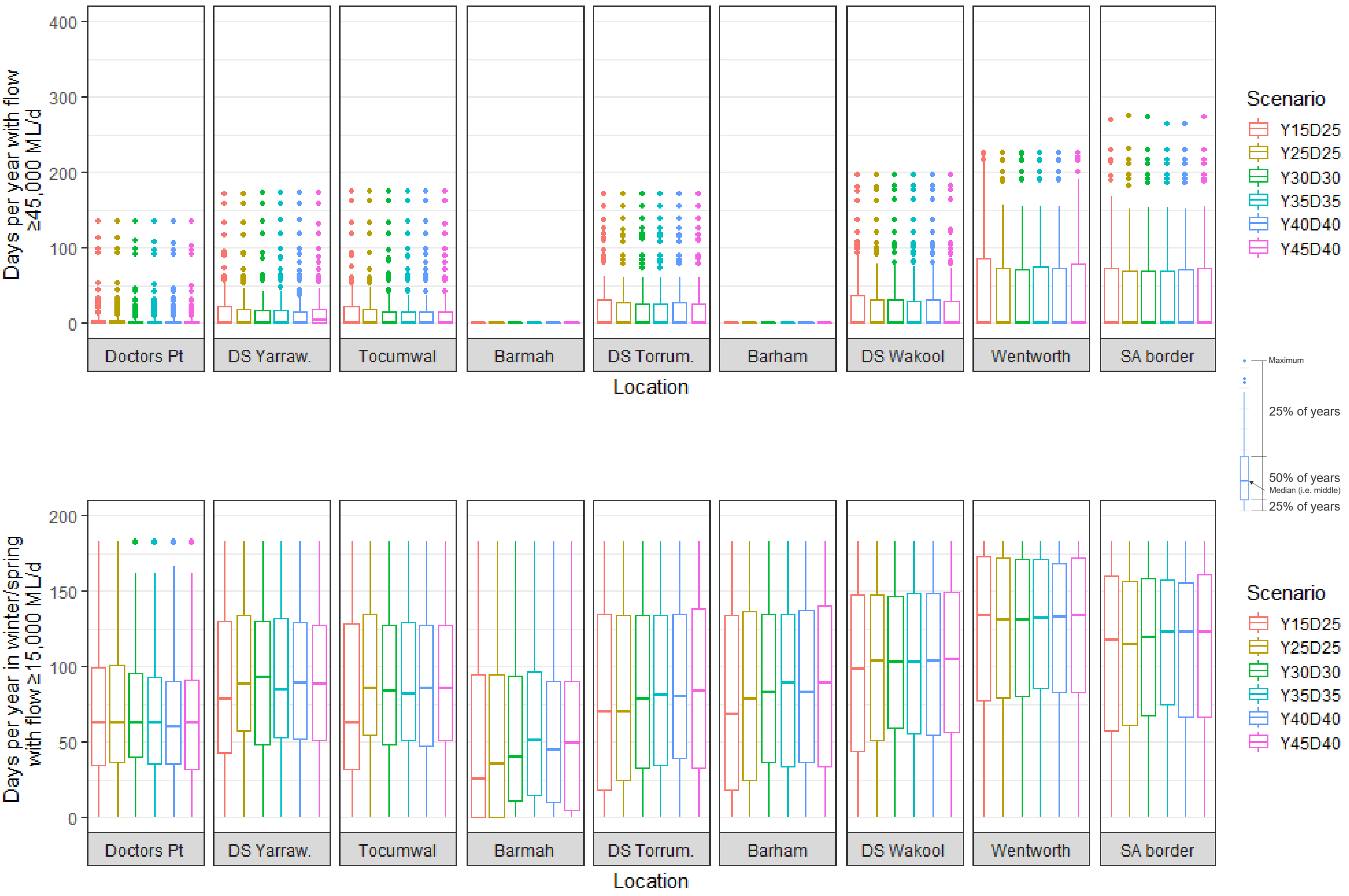

Maximum daily flow within month at SA border (ML/d)
80,000
60,000
40,000
20,000
0
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Y15D25 (Current)
Y45D40

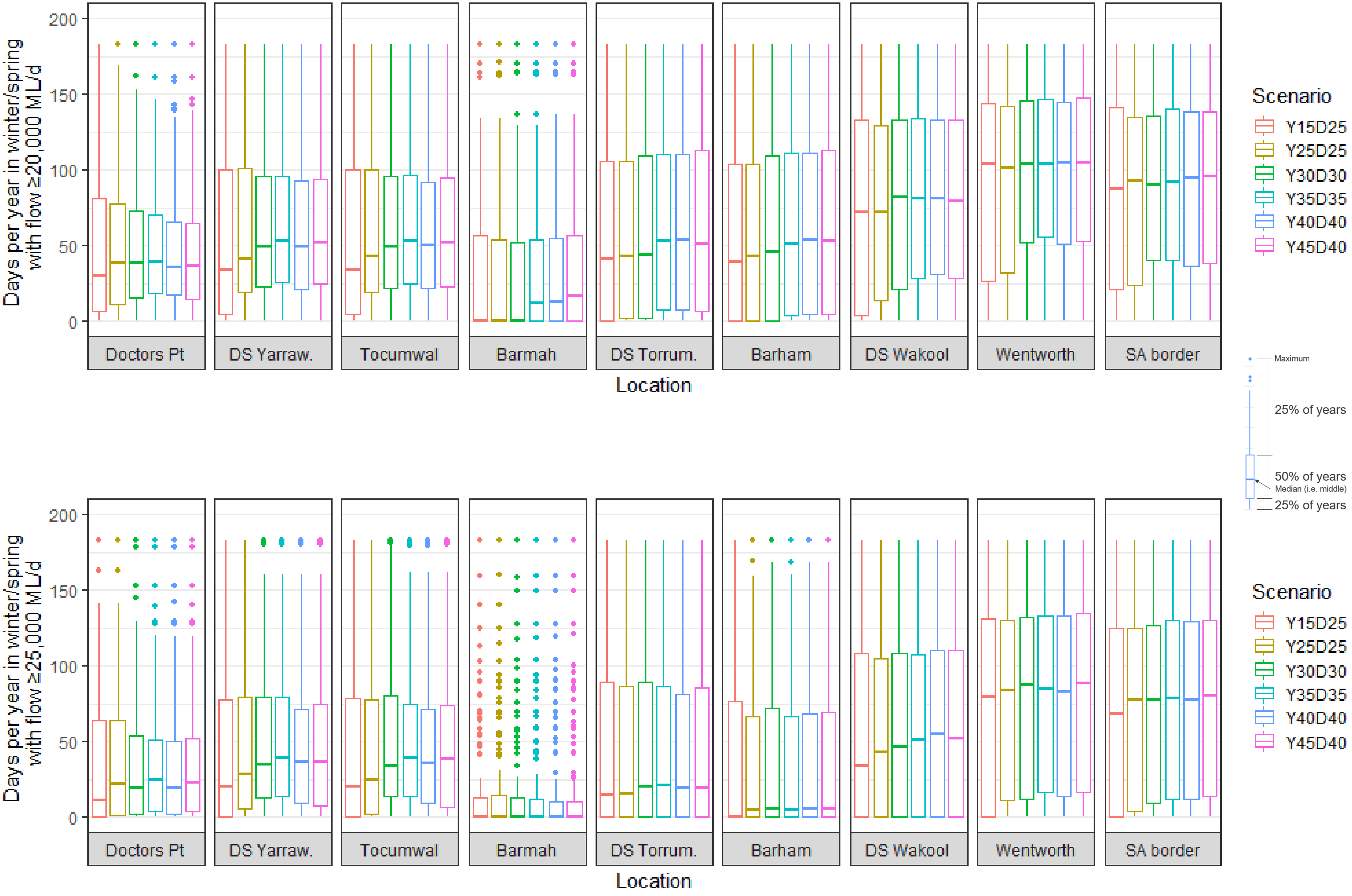
Appendix F River Murray – SMM results – days per year above thresholds; historic climate (1895-2019)

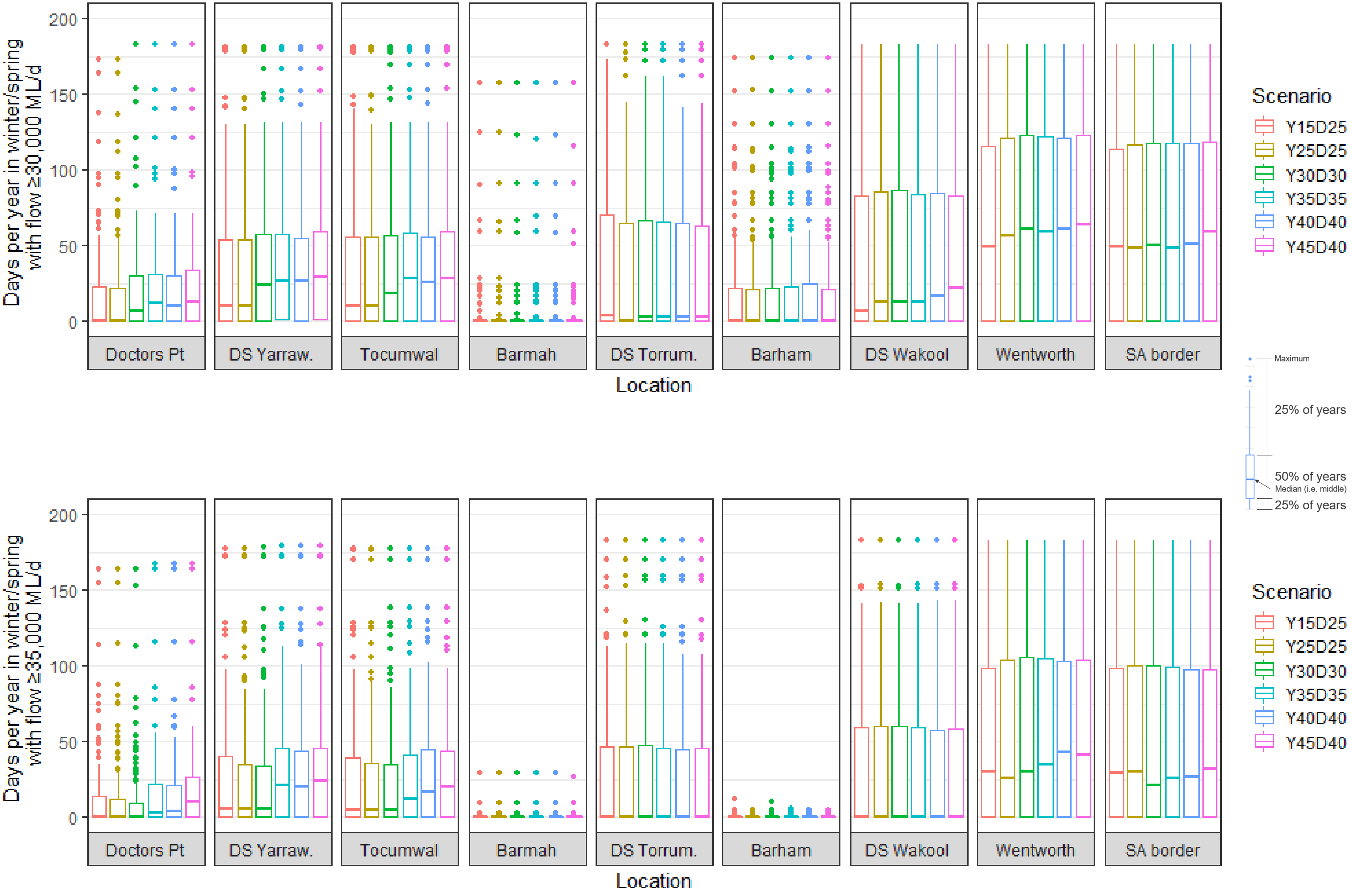

Days per year with flow ≥15,000 ML/d
400
300
200
100
0
Doctors Pt
DS Yarraw.
Tocumwal
Barmah
DS Torrum.
Barham
DS Wakool
Wentworth
SA border
Location
Scenario
Y15D25
Y25D25
Y30D30
Y35D35
Y40D40
Y45D40
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per year with flow ≥20,000 ML/d
400
300
200
100
0
Doctors Pt
DS Yarraw.
Tocumwal
Barmah
DS Torrum.
Barham
DS Wakool
Wentworth
SA border
Location
Scenario
Y15D25
Y25D25
Y30D30
Y35D35
Y40D40
Y45D40

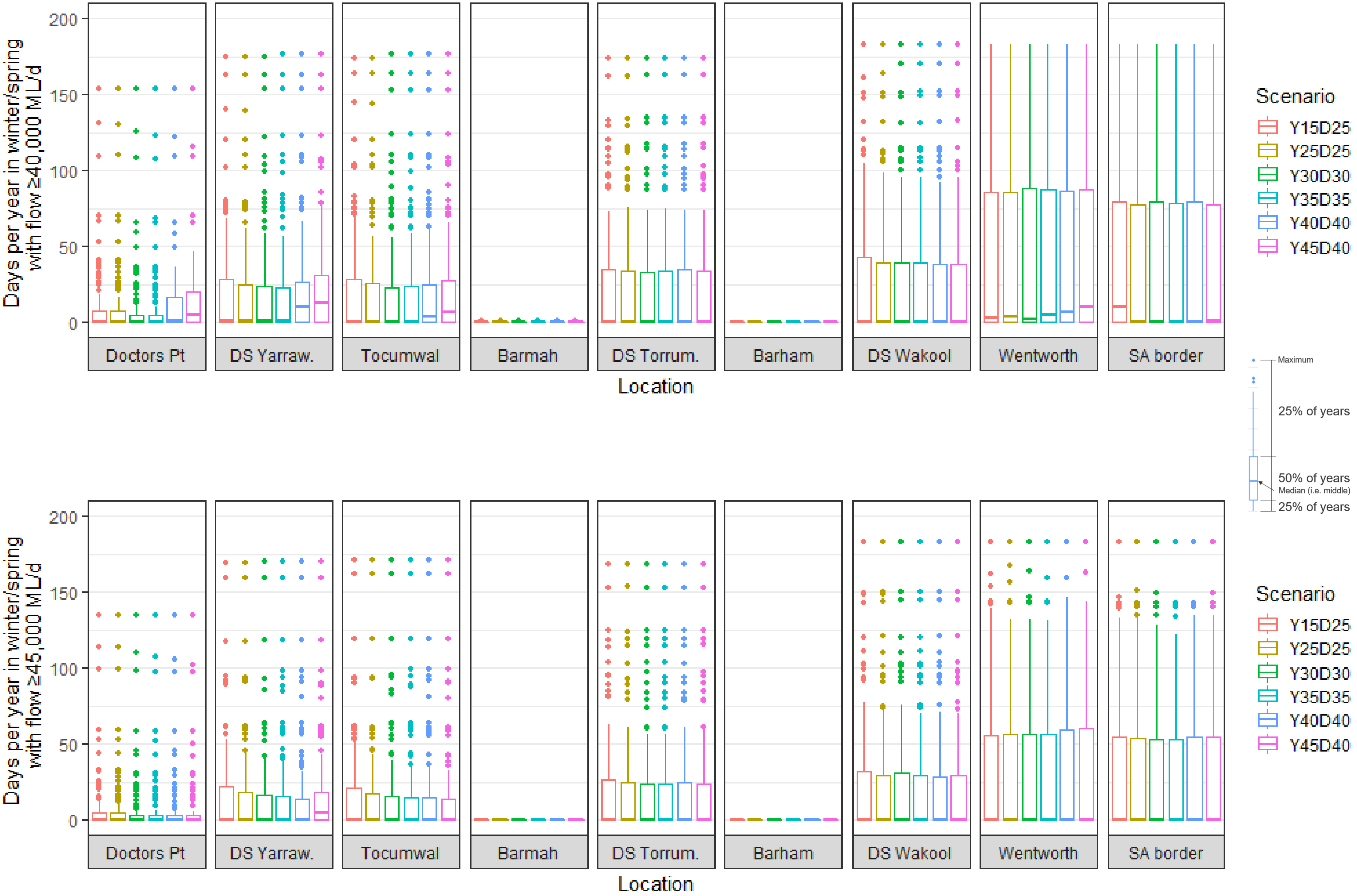

Days per year with flow ≥25,000 ML/d
0
100
200
300
400
Doctors Pt
DS Yarraw.
Tocumwal
Barmah
DS Torrum.
Barham
DS Wakool
Wentworth
SA border
Location
Scenario
Y15D25
Y25D25
Y30D30
Y35D35
Y40D40
Y45D40
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per year with flow ≥30,000 ML/d
0
100
200
300
400
Doctors Pt
DS Yarraw.
Tocumwal
Barmah
DS Torrum.
Barham
DS Wakool
Wentworth
SA border
Location
Scenario
Y15D25
Y25D25
Y30D30
Y35D35
Y40D40
Y45D40


Days per year with flow ≥35,000 ML/d
400
300
200
100
0
Doctors Pt
DS Yarraw.
Tocumwal
Barmah
DS Torrum.
Barham
DS Wakool
Wentworth
SA border
Location
Scenario
Y15D25
Y25D25
Y30D30
Y35D35
Y40D40
Y45D40
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per year with flow ≥40,000 ML/d
400
300
200
100
0
Doctors Pt
DS Yarraw.
Tocumwal
Barmah
DS Torrum.
Barham
DS Wakool
Wentworth
SA border
Location
Scenario
Y15D25
Y25D25
Y30D30
Y35D35
Y40D40
Y45D40


Days per year with flow ≥45,000 ML/d
400
300
200
100
0
Doctors Pt
DS Yarraw.
Tocumwal
Barmah
DS Torrum.
Barham
DS Wakool
Wentworth
SA border
Location
Scenario
Y15D25
Y25D25
Y30D30
Y35D35
Y40D40
Y45D40
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per year in winter/spring with flow ≥15,000 ML/d
200
150
100
50
0
Doctors Pt
DS Yarraw.
Tocumwal
Barmah
DS Torrum.
Barham
DS Wakool
Wentworth
SA border
Location
Scenario
Y15D25
Y25D25
Y30D30
Y35D35
Y40D40
Y45D40

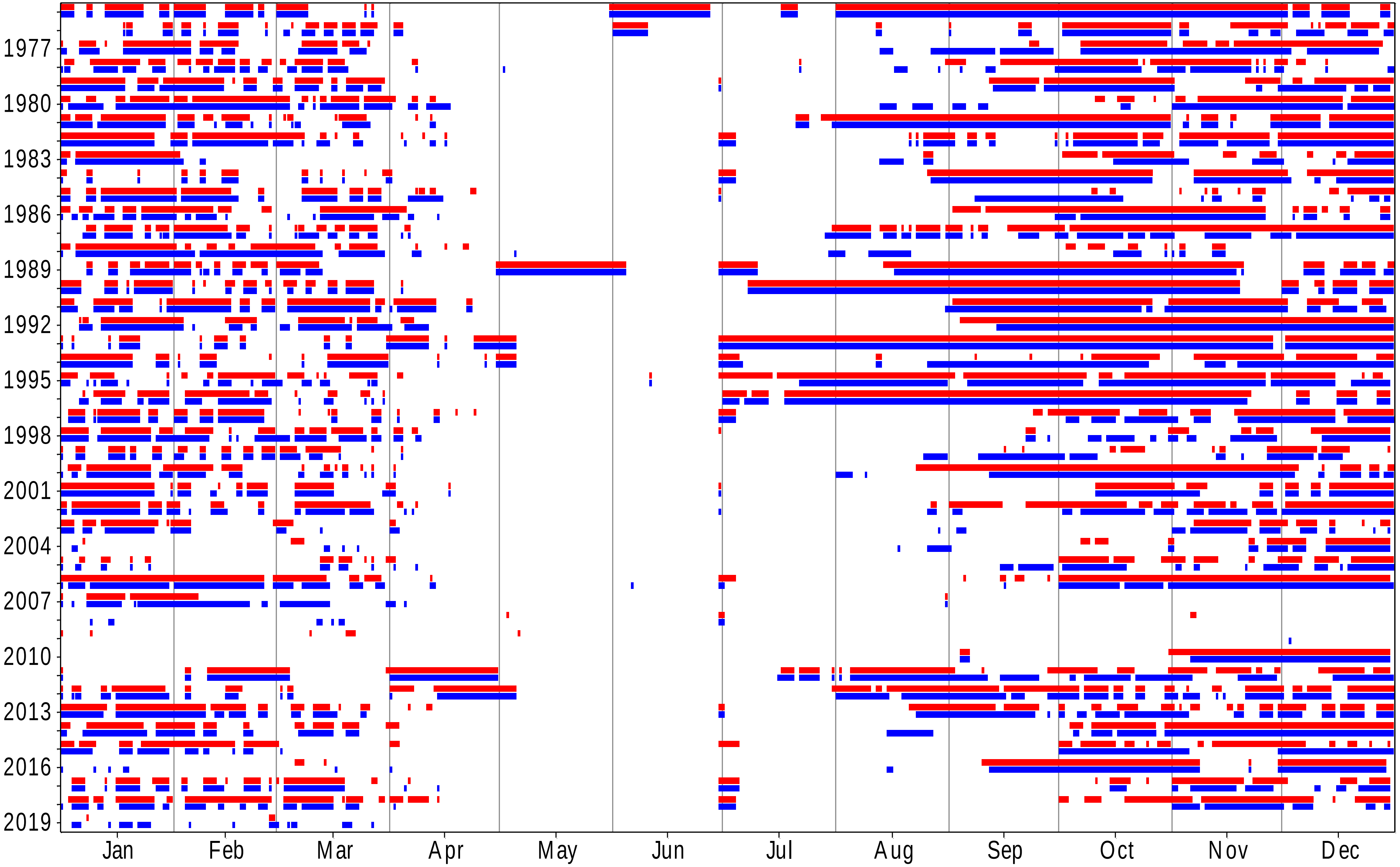

Days per year in winter/spring with flow ≥20,000 ML/d
200
150
100
50
0
Doctors Pt
DS Yarraw.
Tocumwal
Barmah
DS Torrum.
Barham
DS Wakool
Wentworth
SA border
Location
Scenario
Y15D25
Y25D25
Y30D30
Y35D35
Y40D40
Y45D40
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per year in winter/spring with flow ≥25,000 ML/d
200
150
100
50
0
Doctors Pt
DS Yarraw.
Tocumwal
Barmah
DS Torrum.
Barham
DS Wakool
Wentworth
SA border
Location
Scenario
Y15D25
Y25D25
Y30D30
Y35D35
Y40D40
Y45D40


Days per year in winter/spring with flow ≥30,000 ML/d
200
150
100
50
0
Doctors Pt
DS Yarraw.
Tocumwal
Barmah
DS Torrum.
Barham
DS Wakool
Wentworth
SA border
Location
Scenario
Y15D25
Y25D25
Y30D30
Y35D35
Y40D40
Y45D40
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per year in winter/spring with flow ≥35,000 ML/d
200
150
100
50
0
Doctors Pt
DS Yarraw.
Tocumwal
Barmah
DS Torrum.
Barham
DS Wakool
Wentworth
SA border
Location
Scenario
Y15D25
Y25D25
Y30D30
Y35D35
Y40D40
Y45D40


Days per year in winter/spring with flow ≥40,000 ML/d
200
150
100
50
0
Doctors Pt
DS Yarraw.
Tocumwal
Barmah
DS Torrum.
Barham
DS Wakool
Wentworth
SA border
Location
Scenario
Y15D25
Y25D25
Y30D30
Y35D35
Y40D40
Y45D40
Maximum
25% of years
50% of years
Median (i.e. middle)
25% of years
Days per year in winter/spring with flow ≥45,000 ML/d
200
150
100
50
0
Doctors Pt
DS Yarraw.
Tocumwal
Barmah
DS Torrum.
Barham
DS Wakool
Wentworth
SA border
Location
Scenario
Y15D25
Y25D25
Y30D30
Y35D35
Y40D40
Y45D40

Appendix G River Murray – SMM results – spells plots; historic climate (1975-2019)

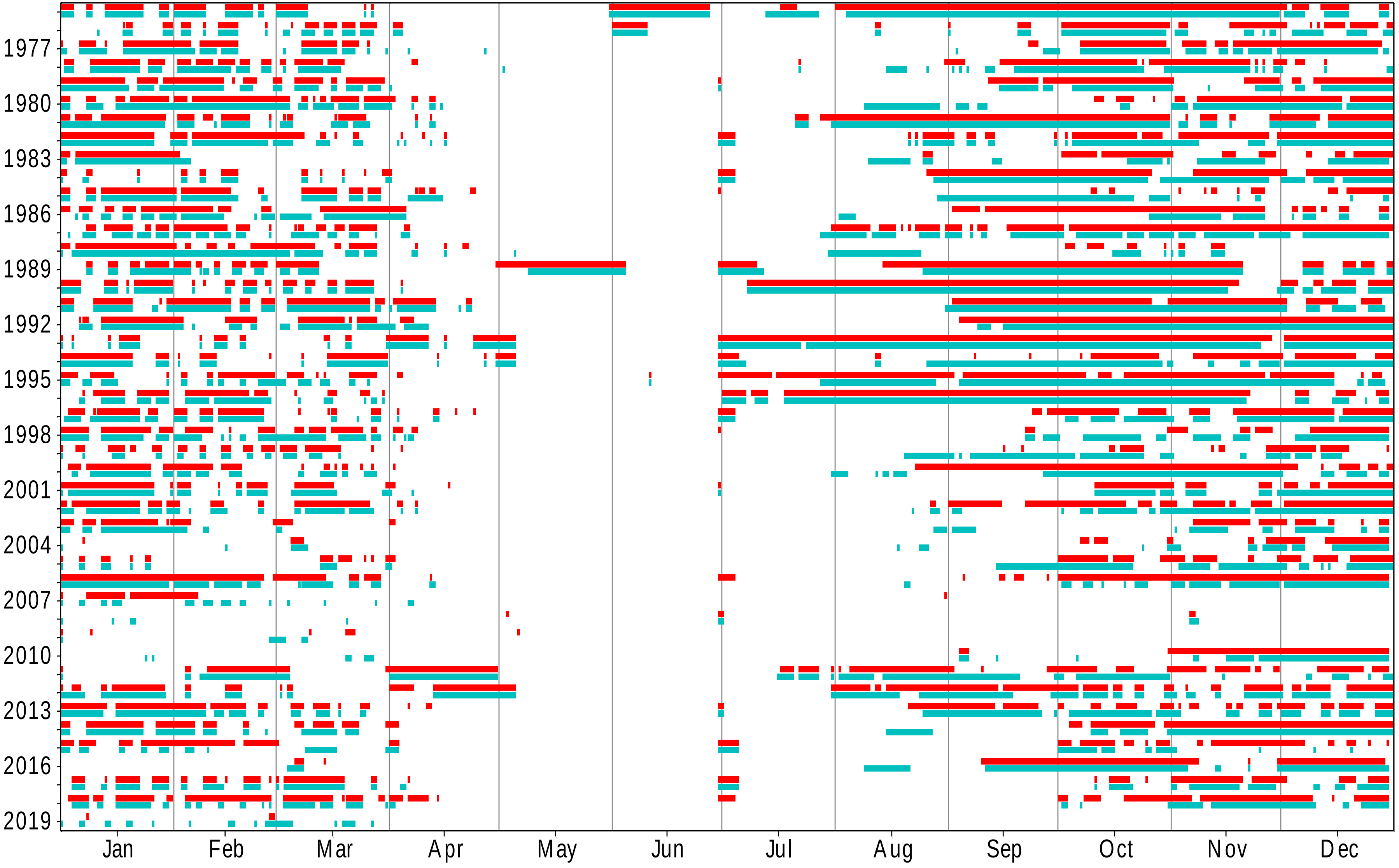
Distribution of Spells



🟥 ≥ 15,000 ML/d @ Doctors Point - **Current**

🟦 ≥ 15,000 ML/d @ Doctors Point - **Y25D25**

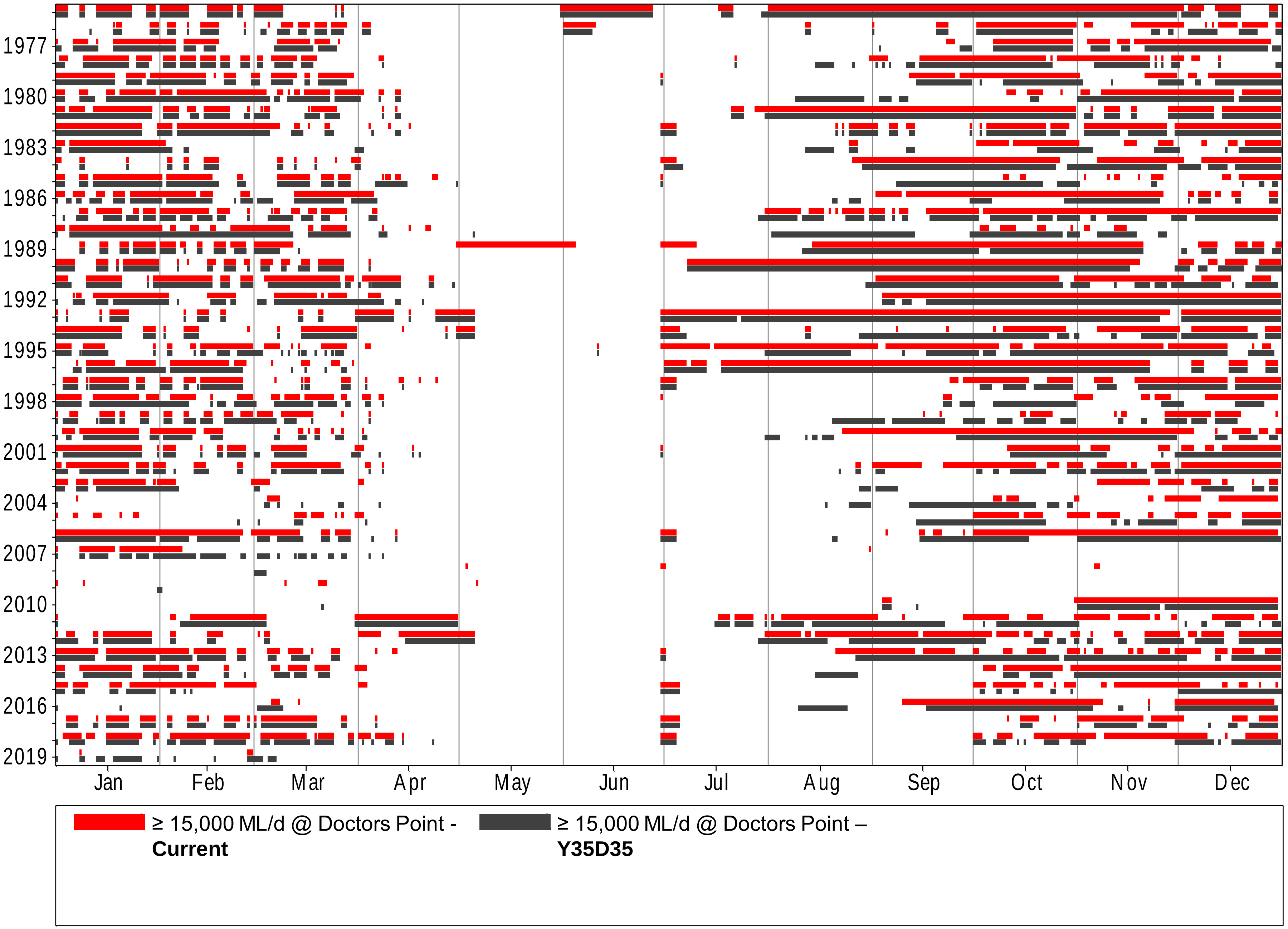
Distribution of Spells



🟥 ≥ 15,000 ML/d @ Doctors Point - **Current**

🟦 ≥ 15,000 ML/d @ Doctors Point – **Y30D30**

Distribution of Spells

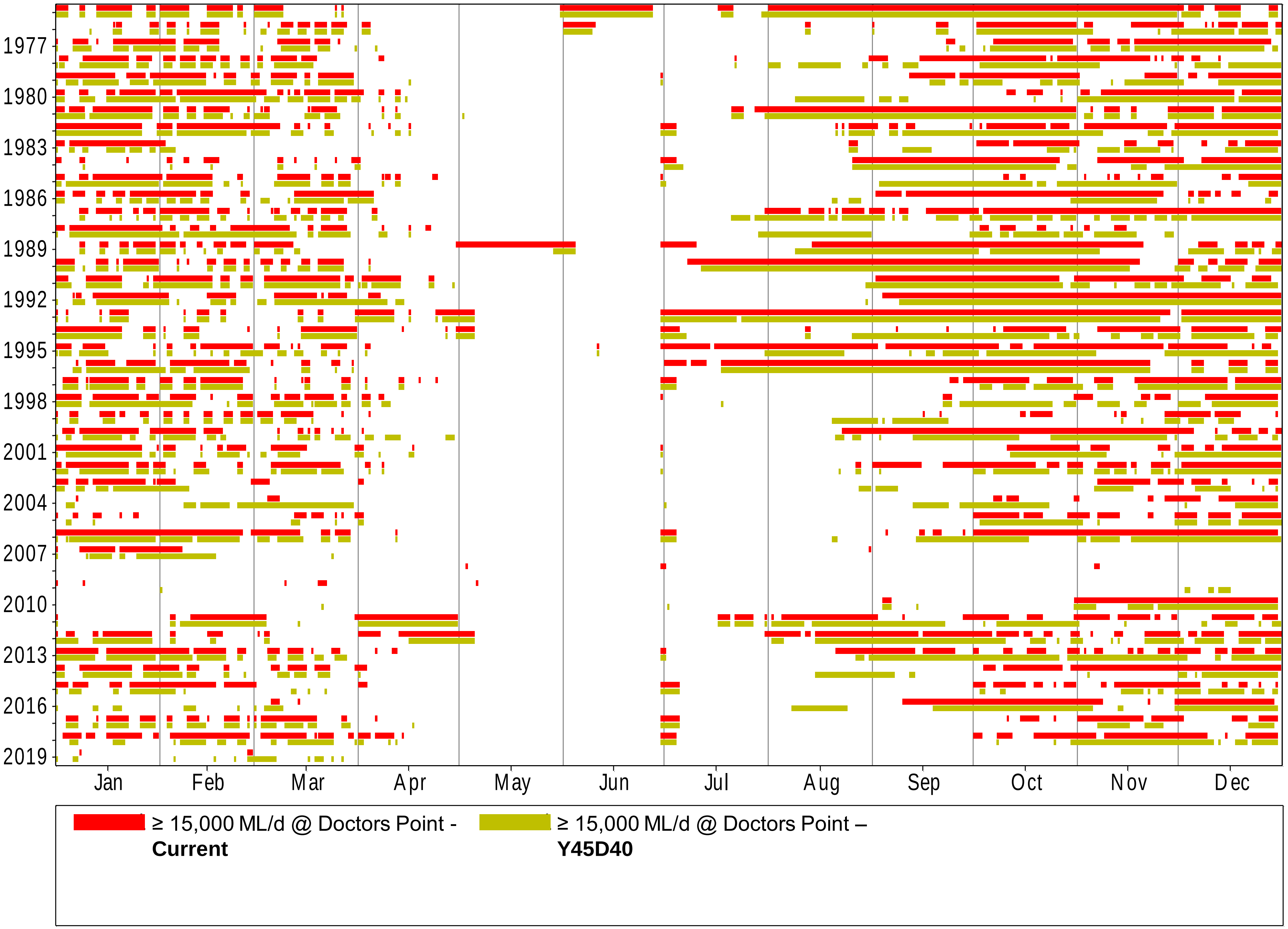


Distribution of Spells

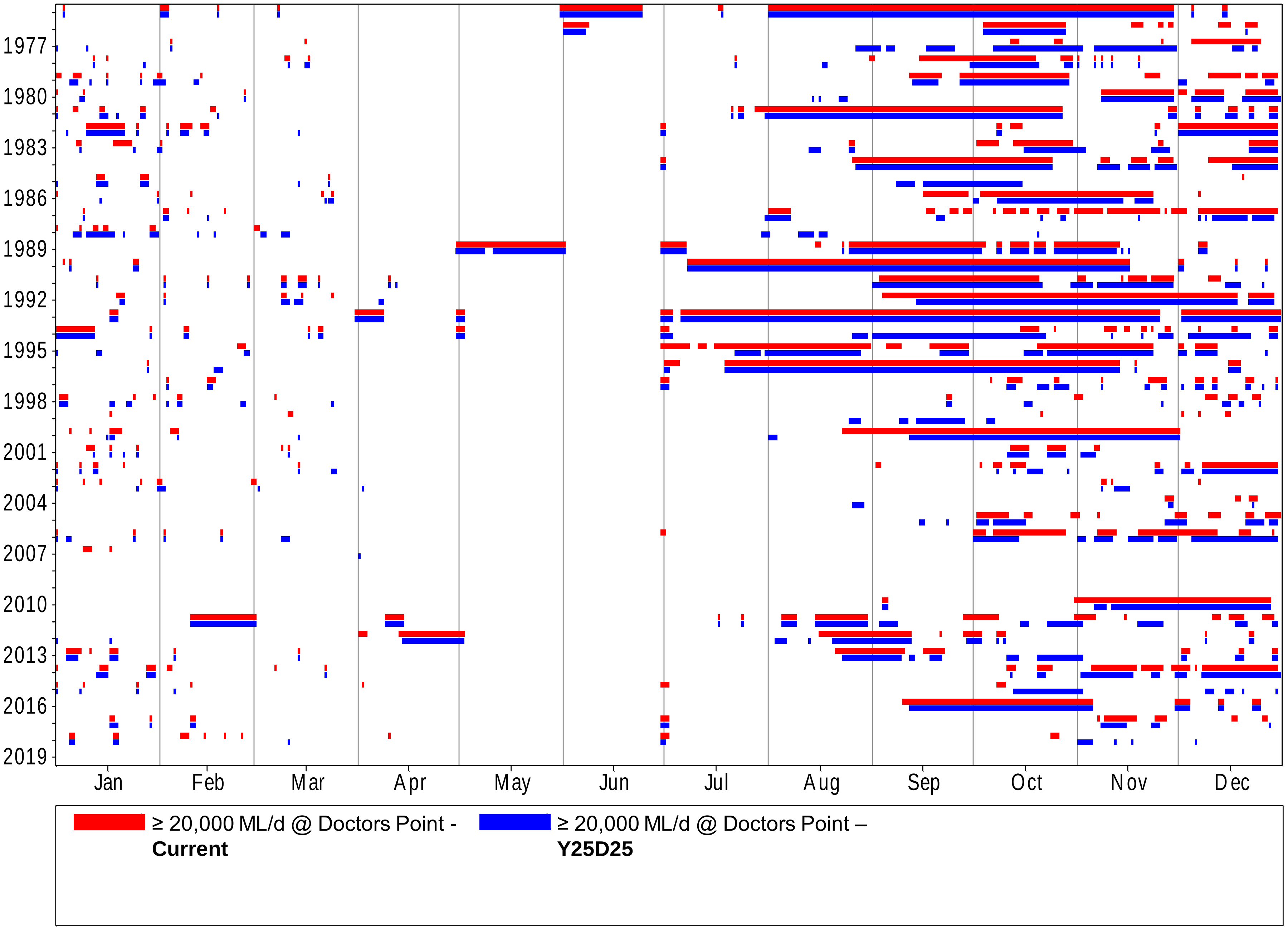
🟥 ≥ 15,000 ML/d @ Doctors Point - **Current**

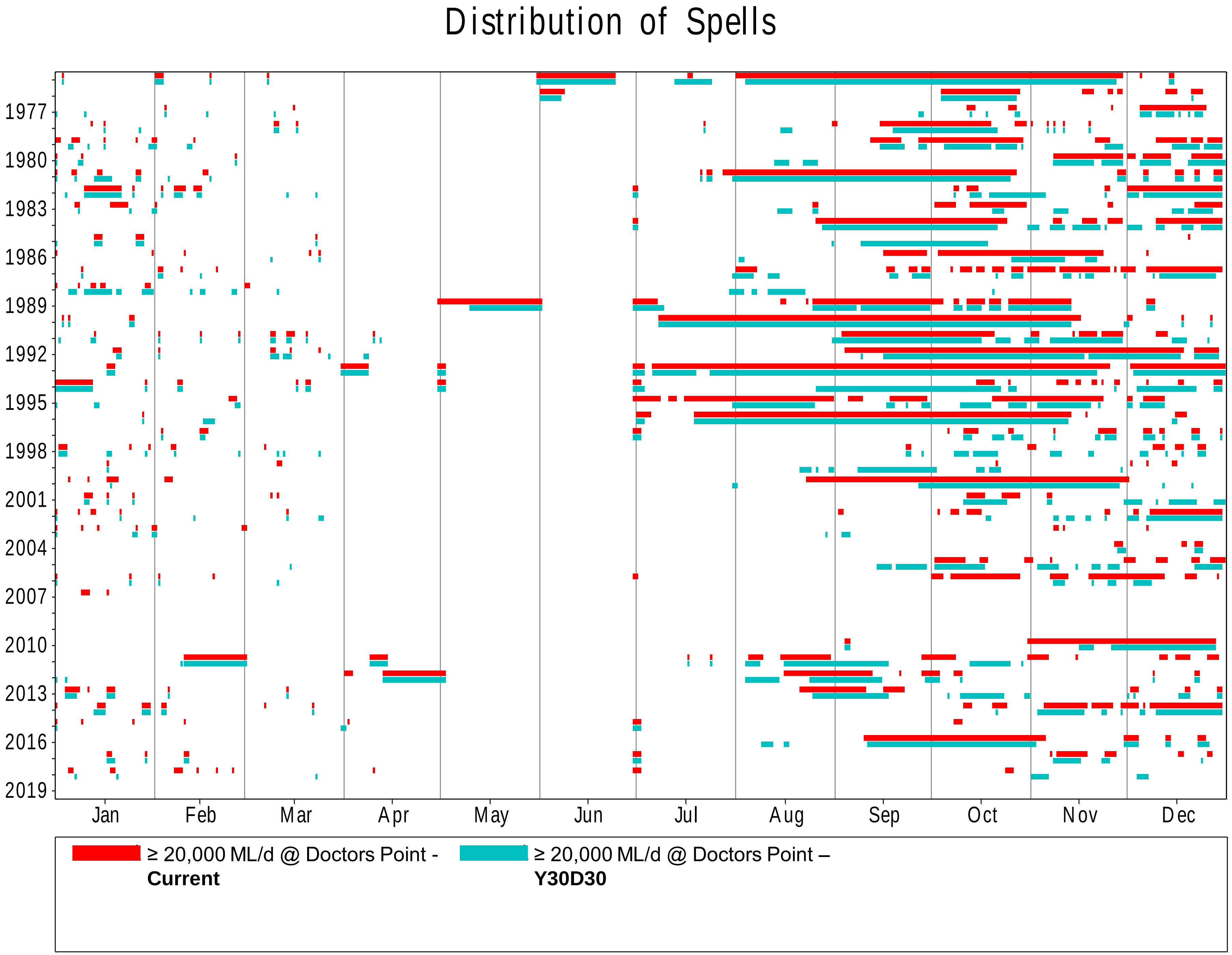
🟩 ≥ 15,000 ML/d @ Doctors Point – **Y40D40**

Distribution of Spells

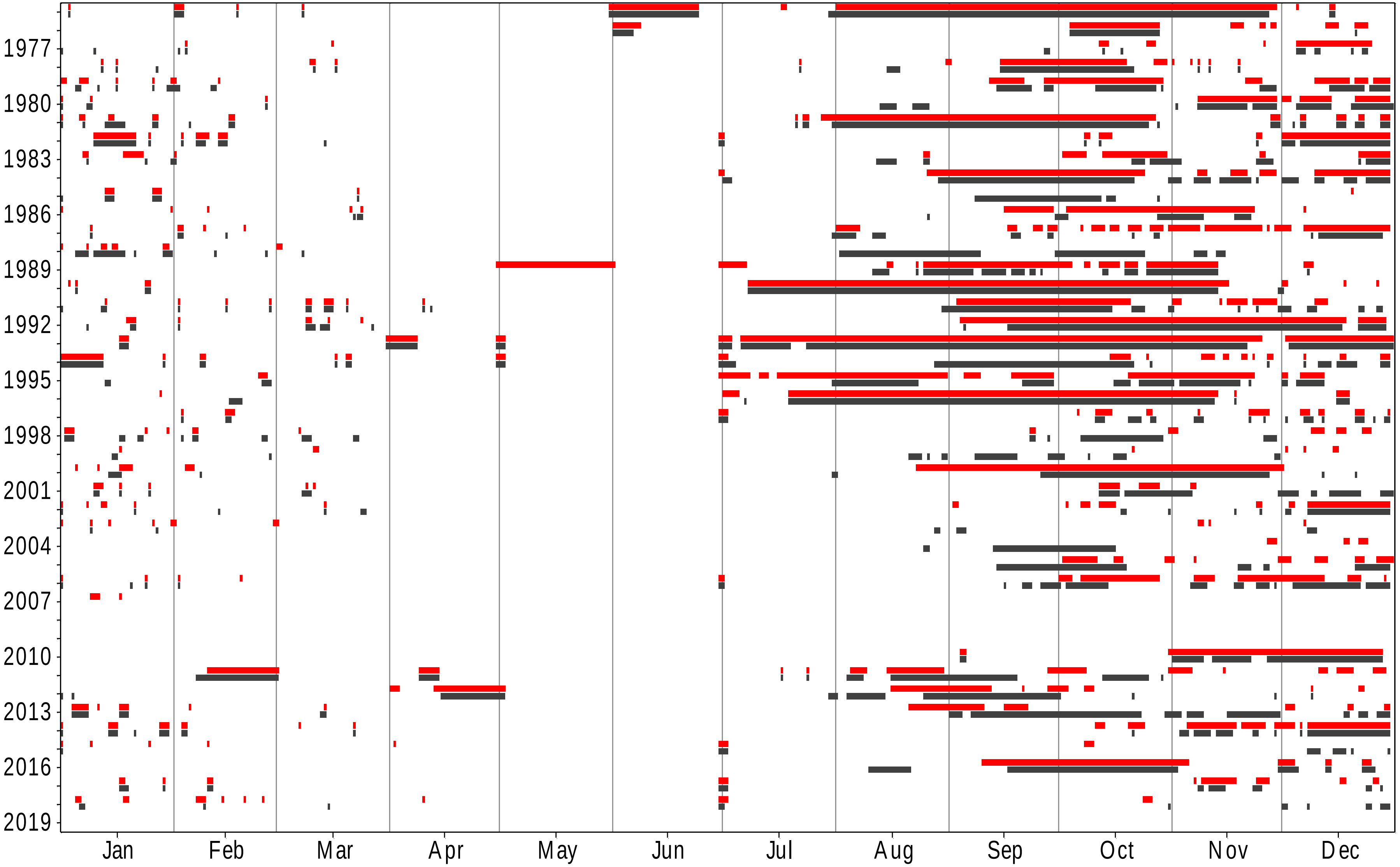


Distribution of Spells




Distribution of Spells

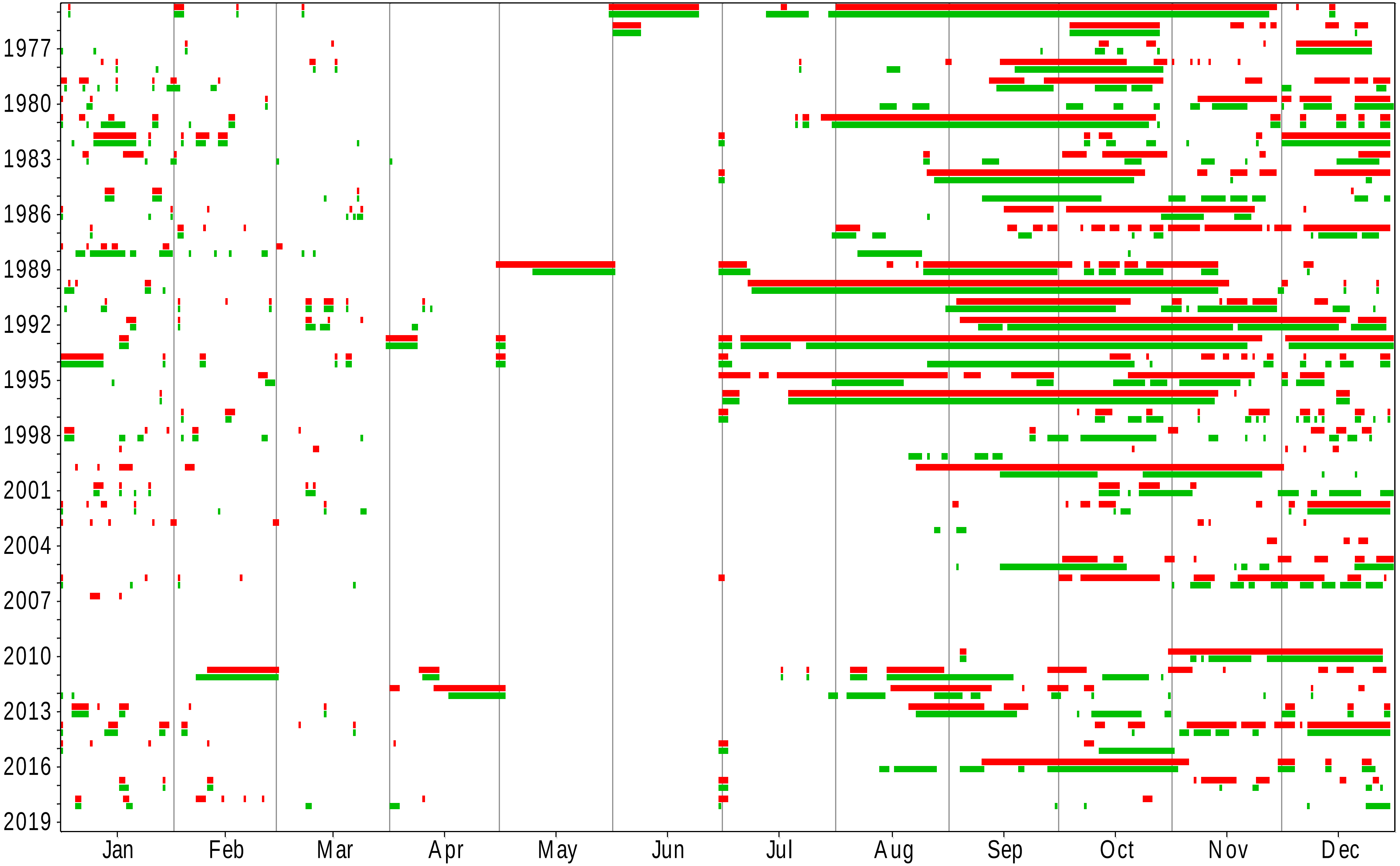
Distribution of Spells



🟥 ≥ 20,000 ML/d @ Doctors Point - **Current**

⬛ ≥ 20,000 ML/d @ Doctors Point – **Y35D35**

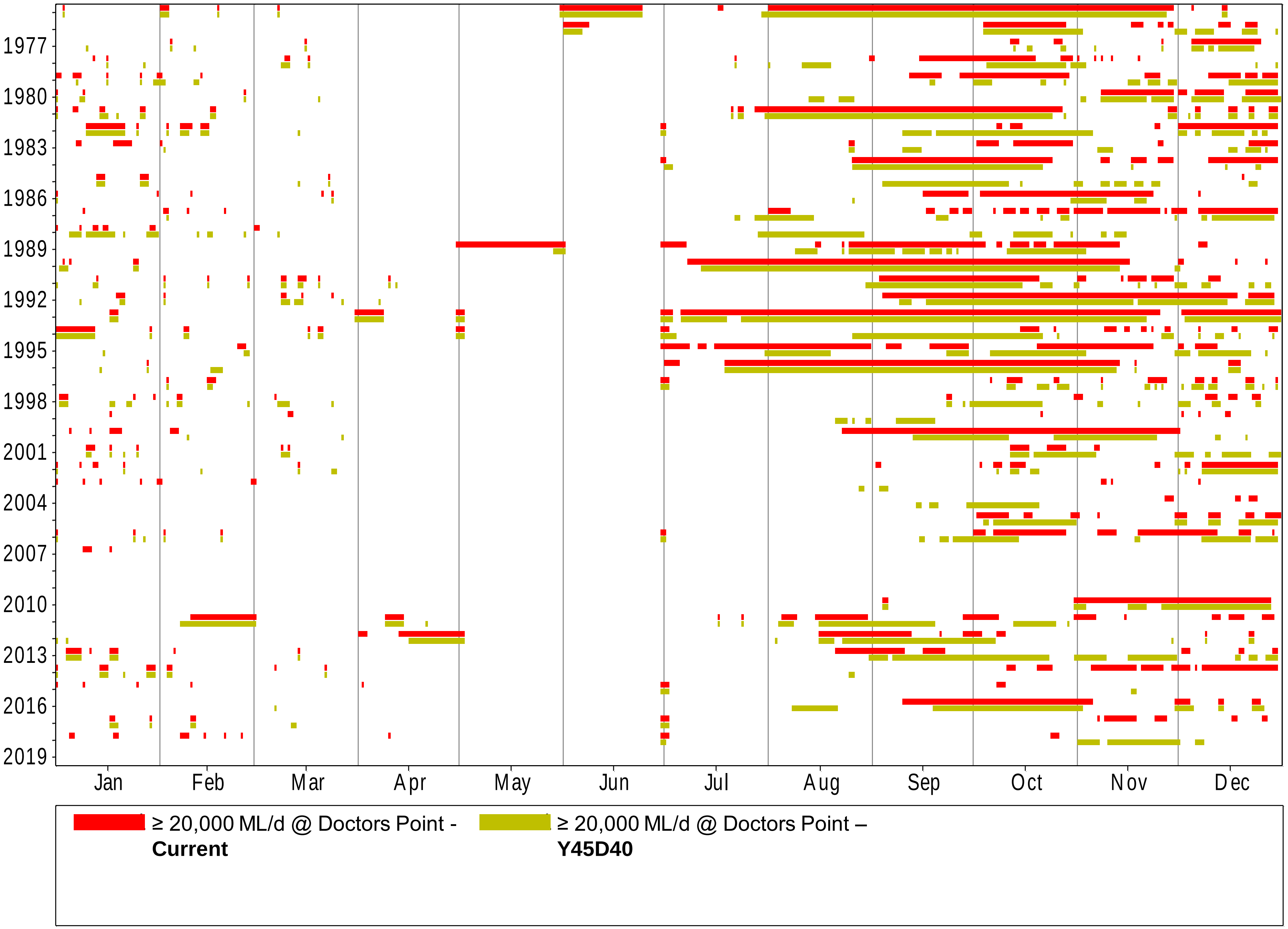
Distribution of Spells



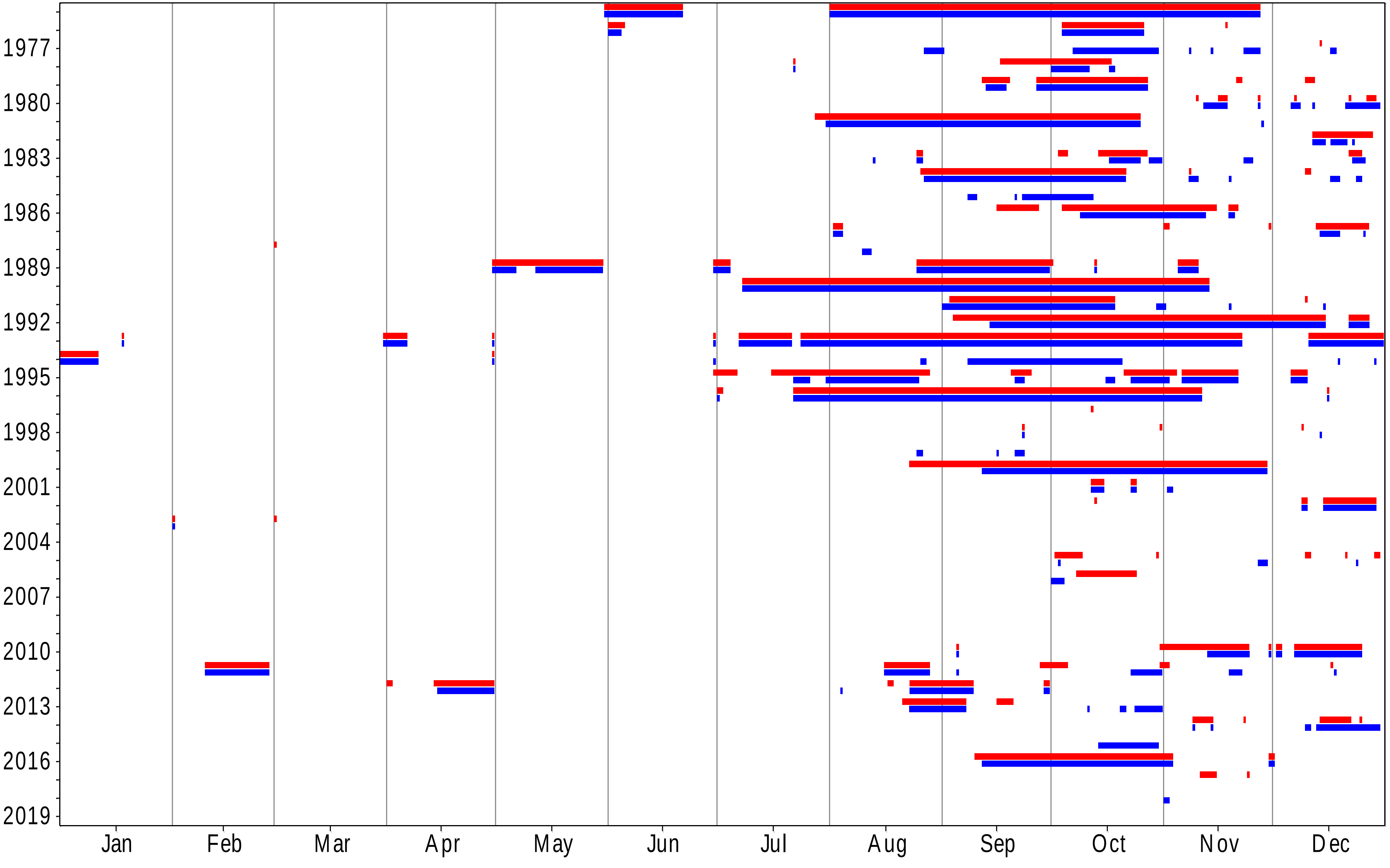
🟥 ≥ 20,000 ML/d @ Doctors Point - **Current**

🟩 ≥ 20,000 ML/d @ Doctors Point – **Y40D40**

Distribution of Spells



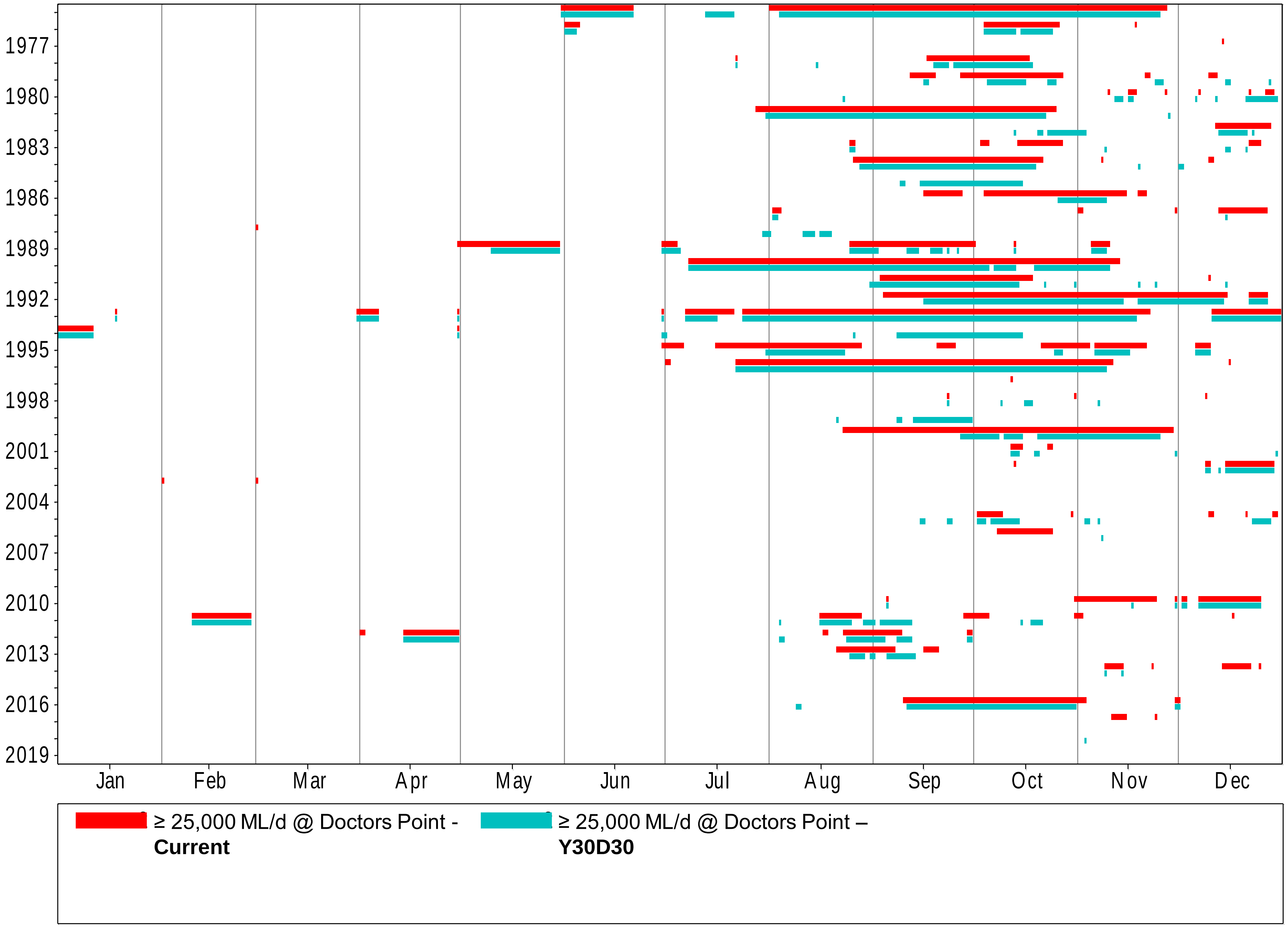
Distribution of Spells



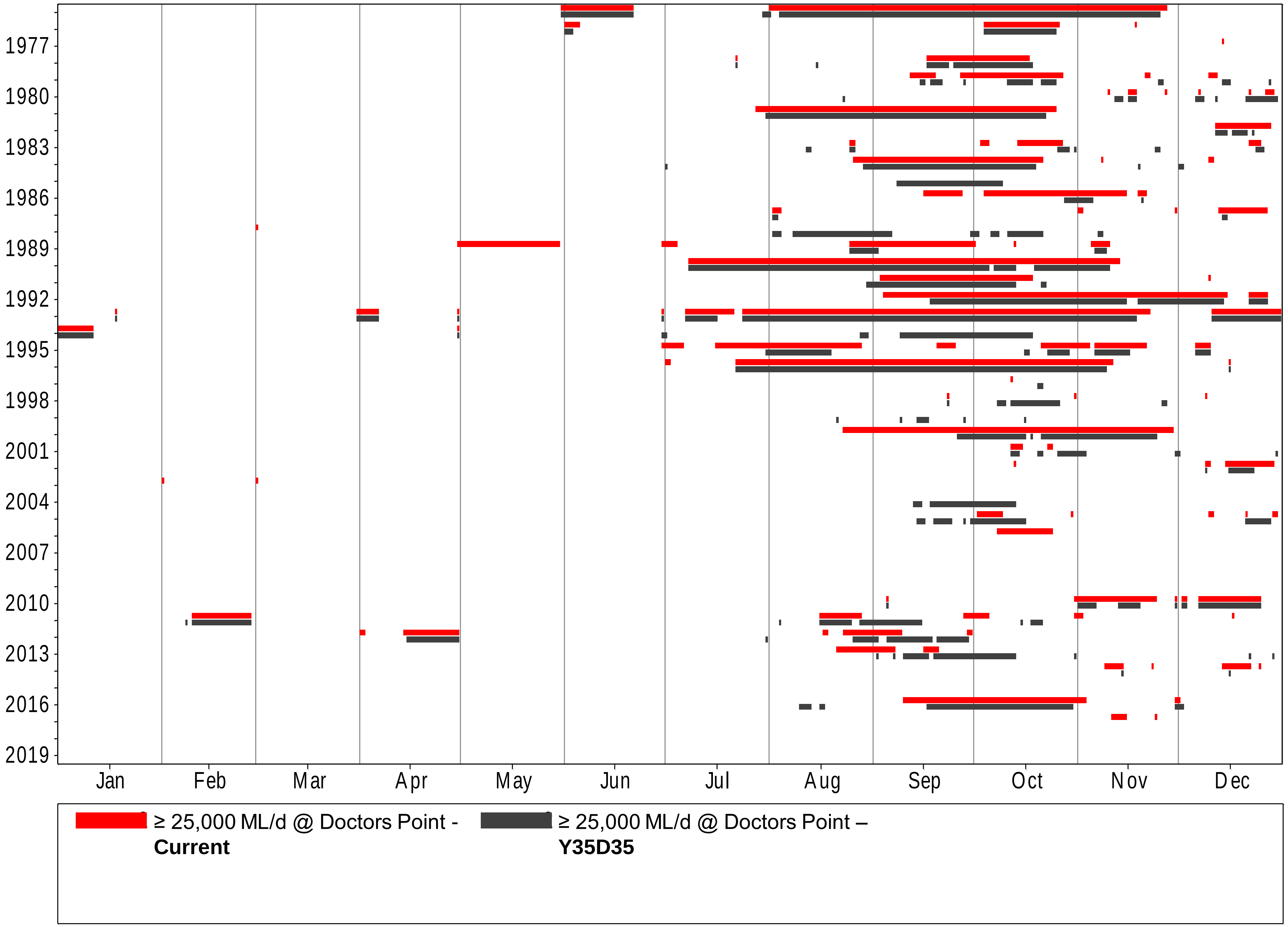
🟥 ≥ 25,000 ML/d @ Doctors Point - **Current**

🟦 ≥ 25,000 ML/d @ Doctors Point – **Y25D25**

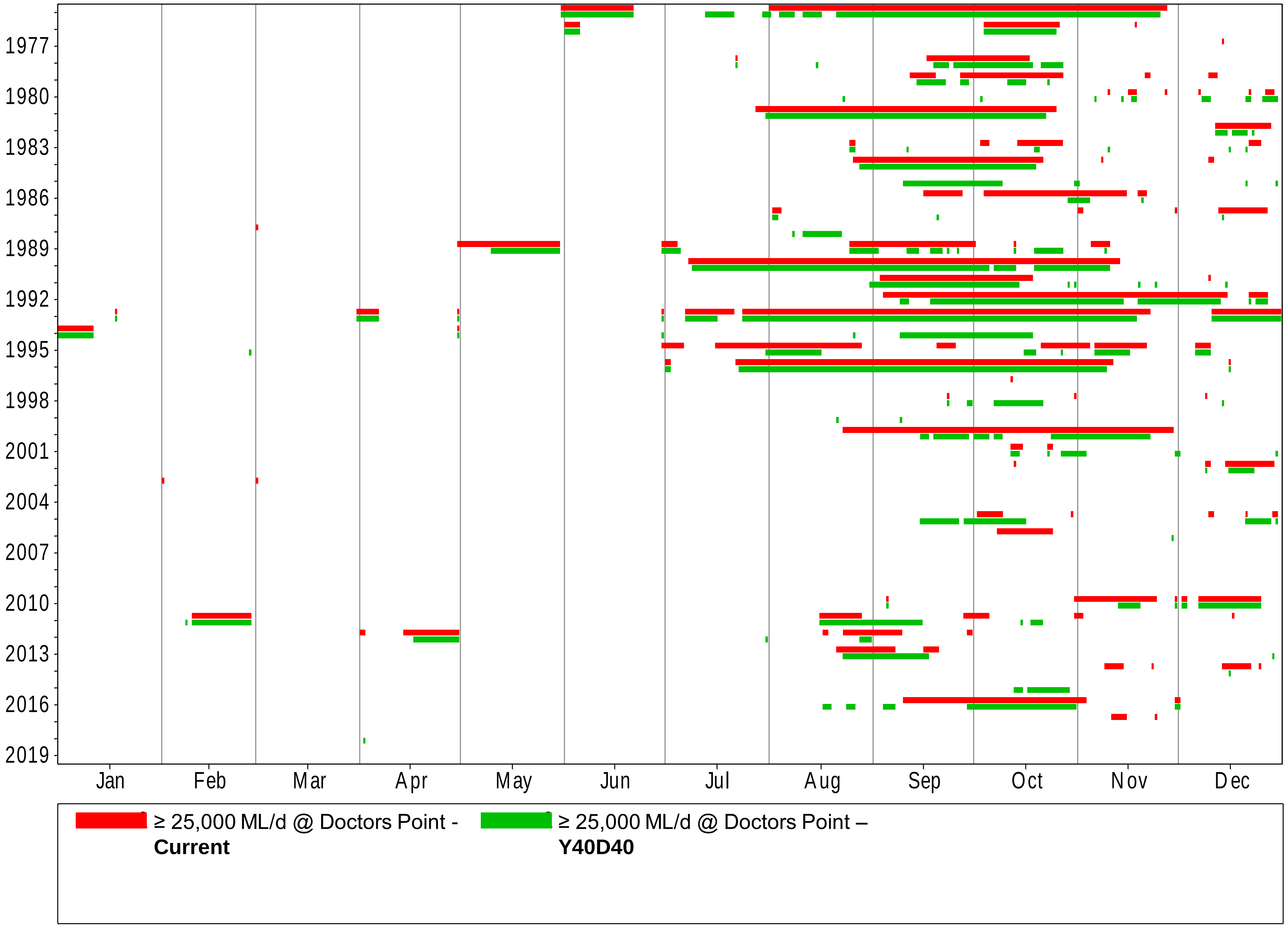
Distribution of Spells



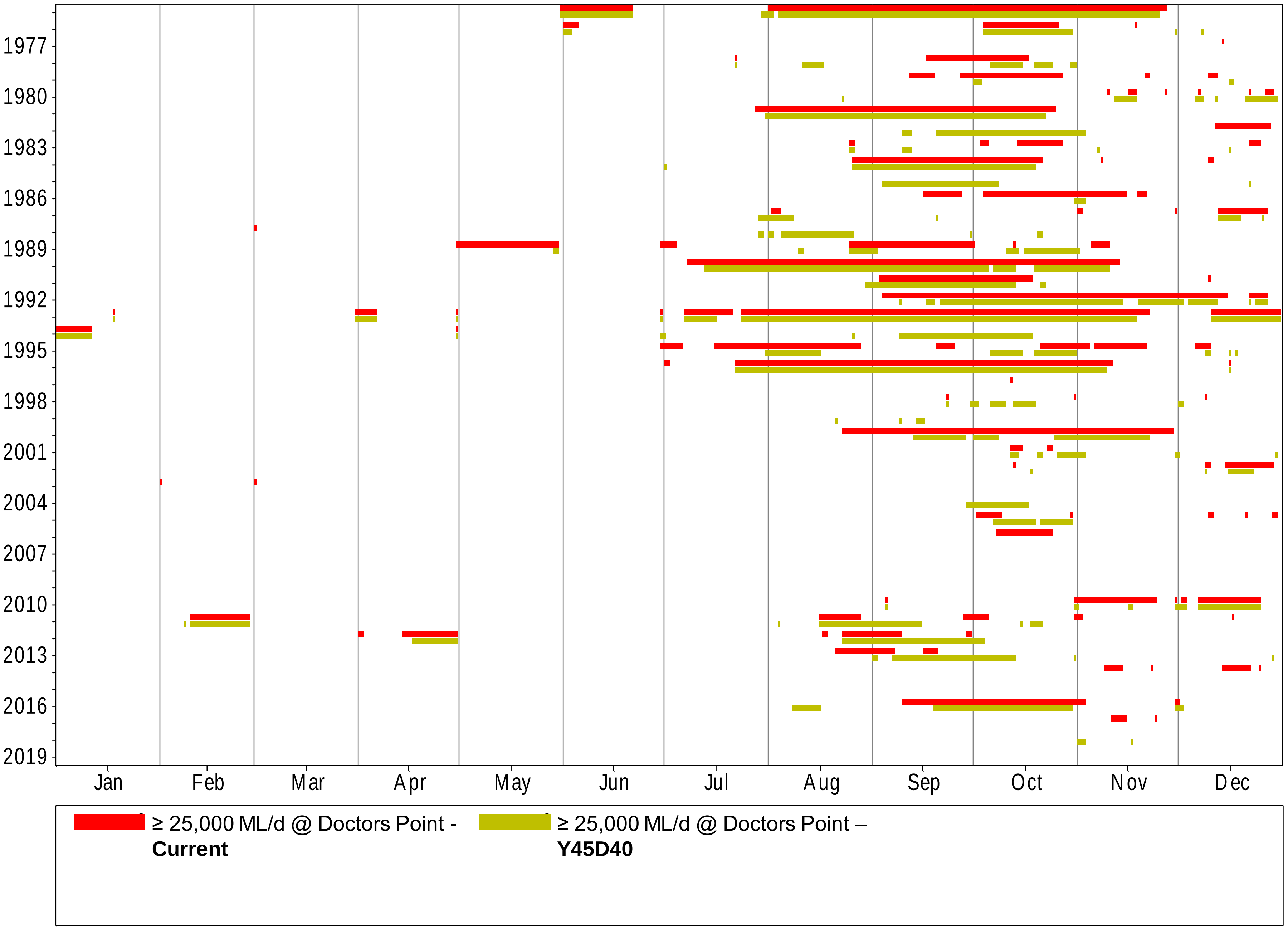
Distribution of Spells



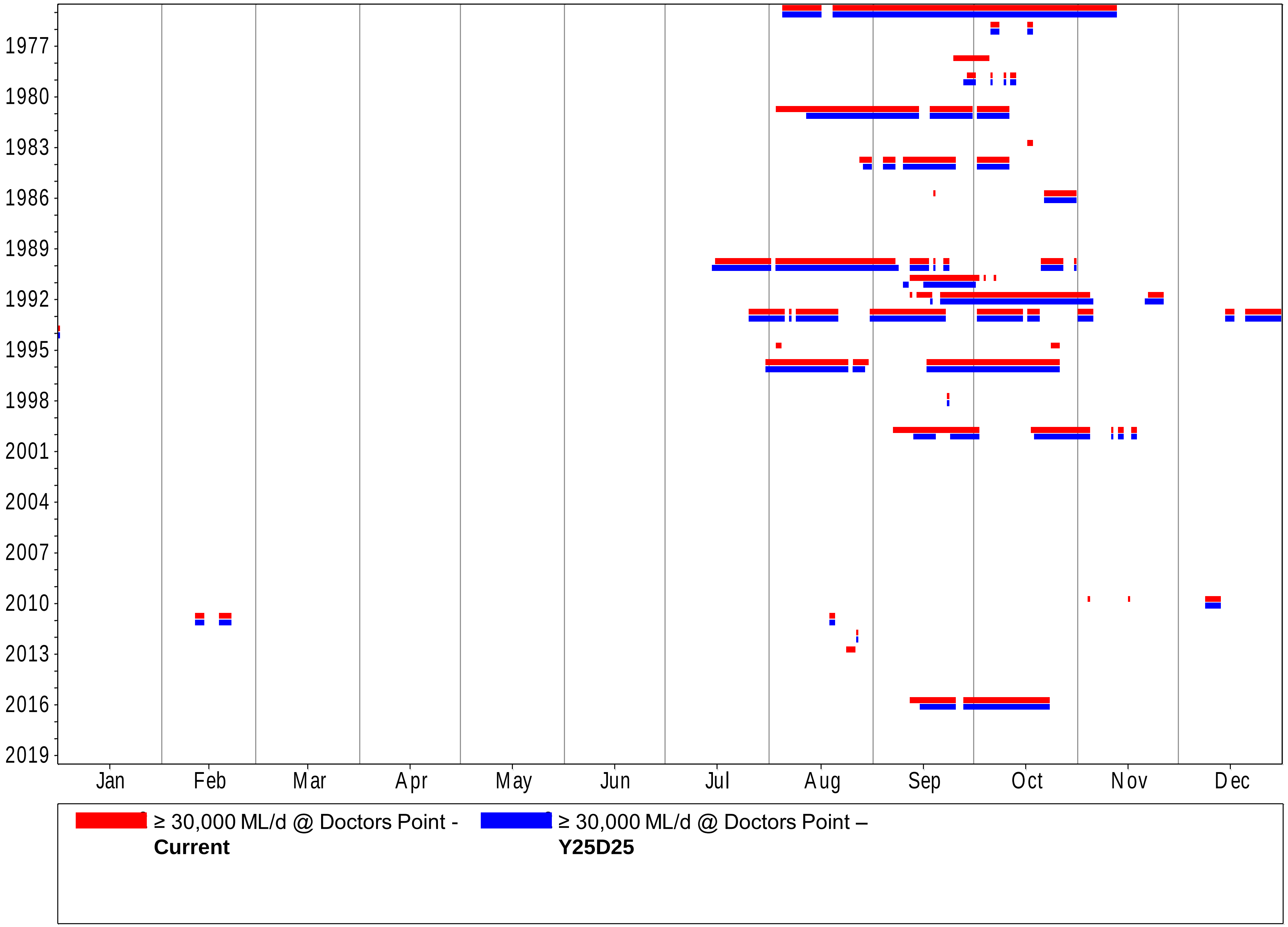
Distribution of Spells



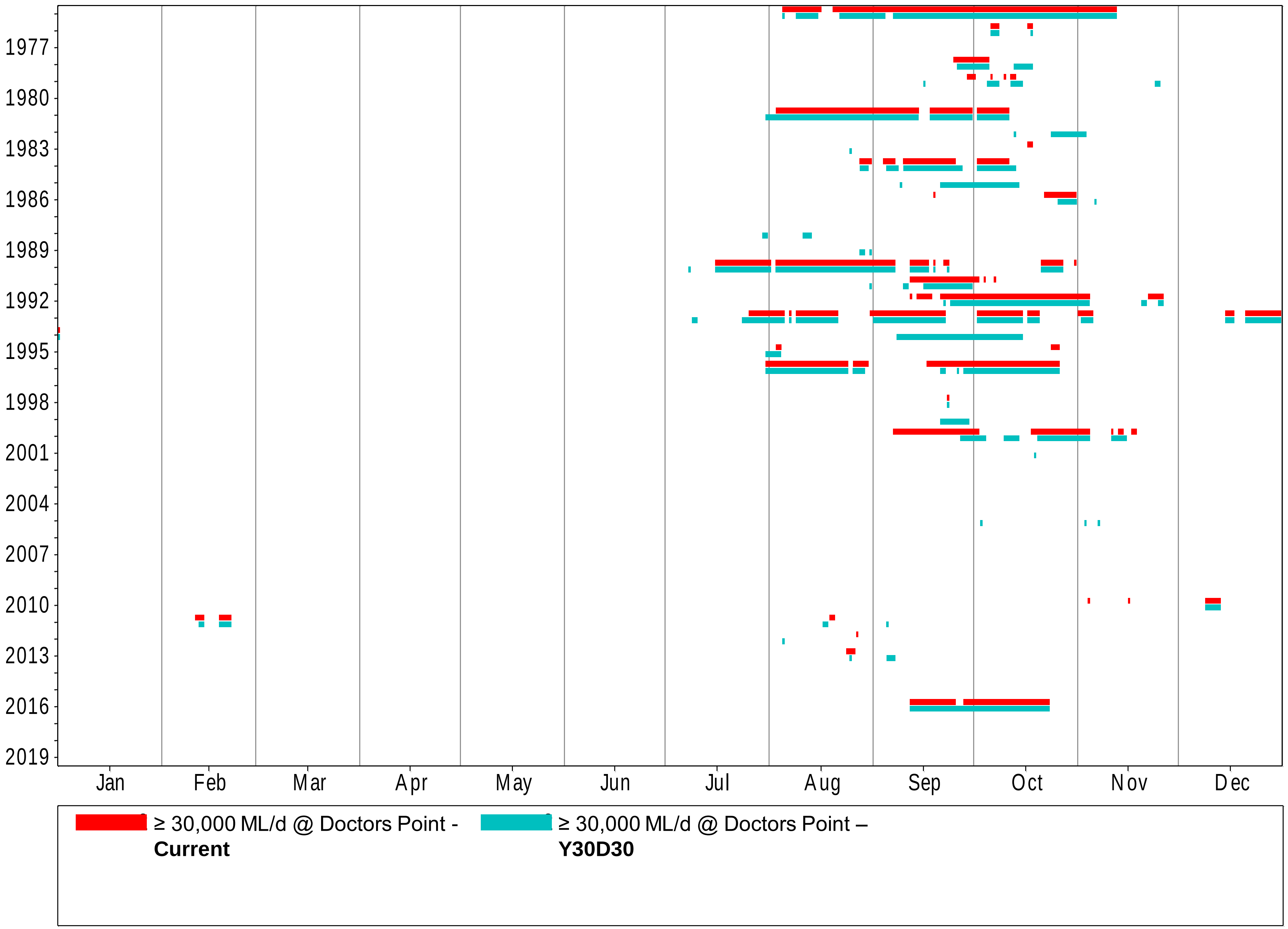
Distribution of Spells



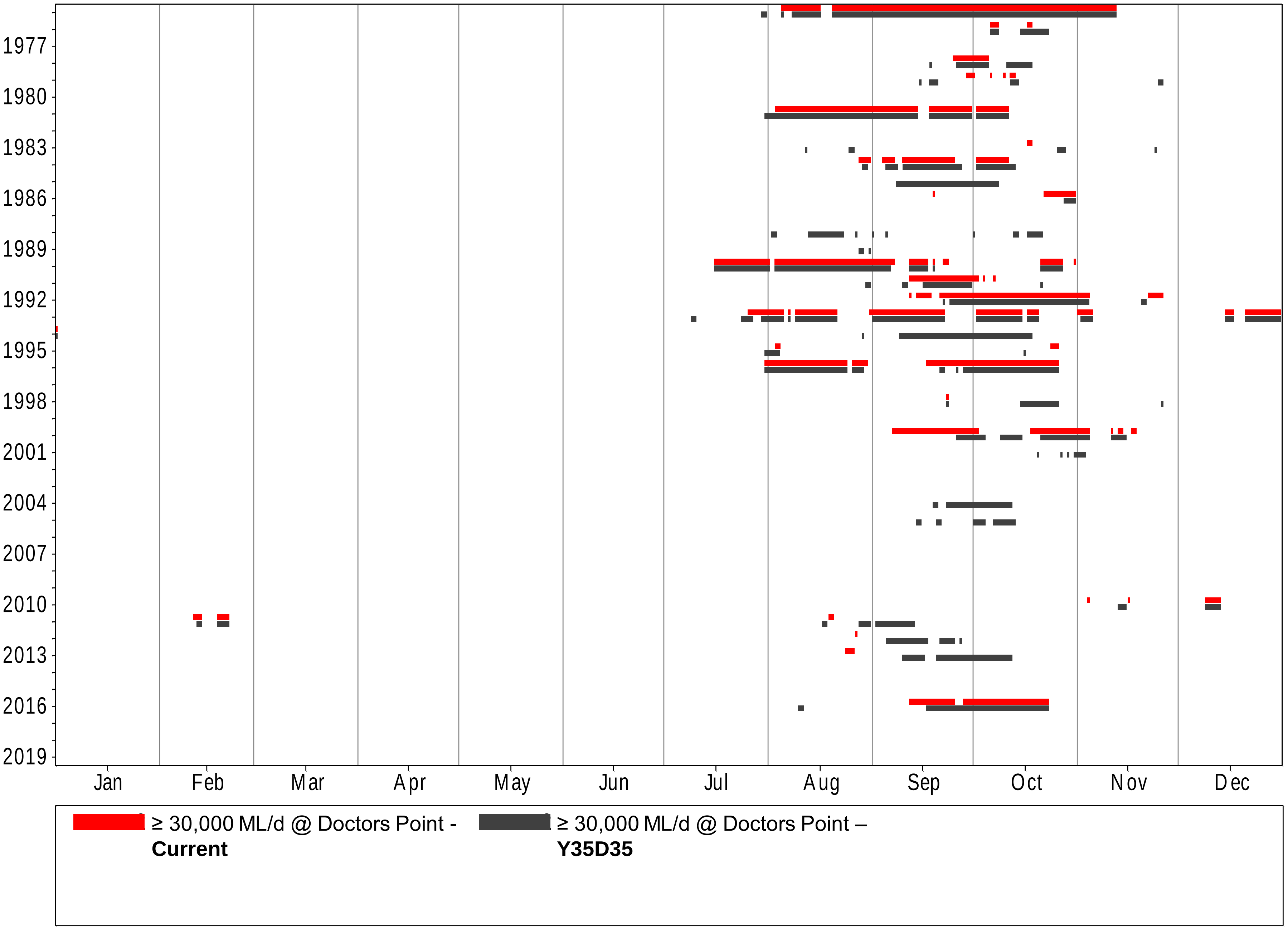
Distribution of Spells



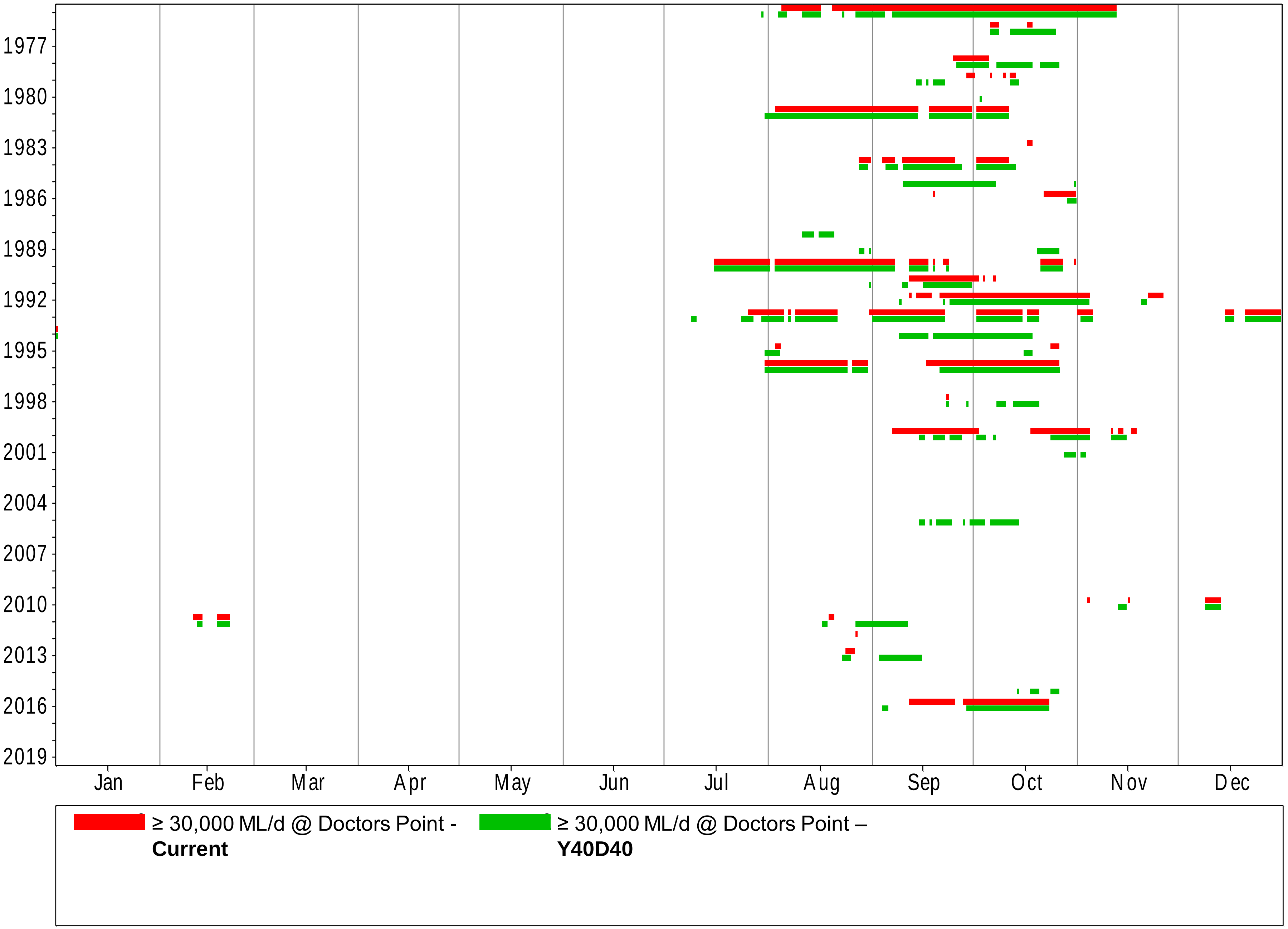
Distribution of Spells



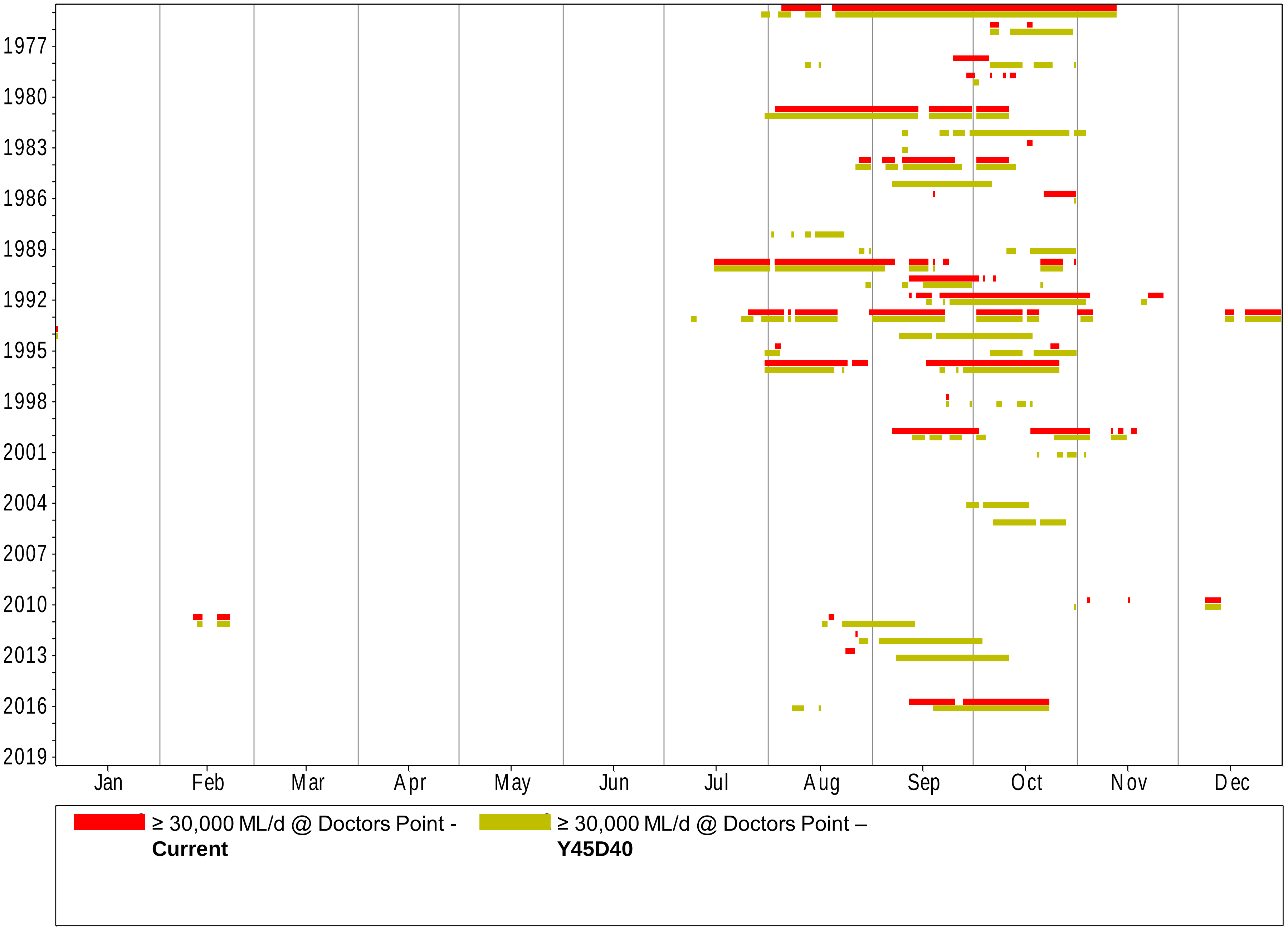
Distribution of Spells

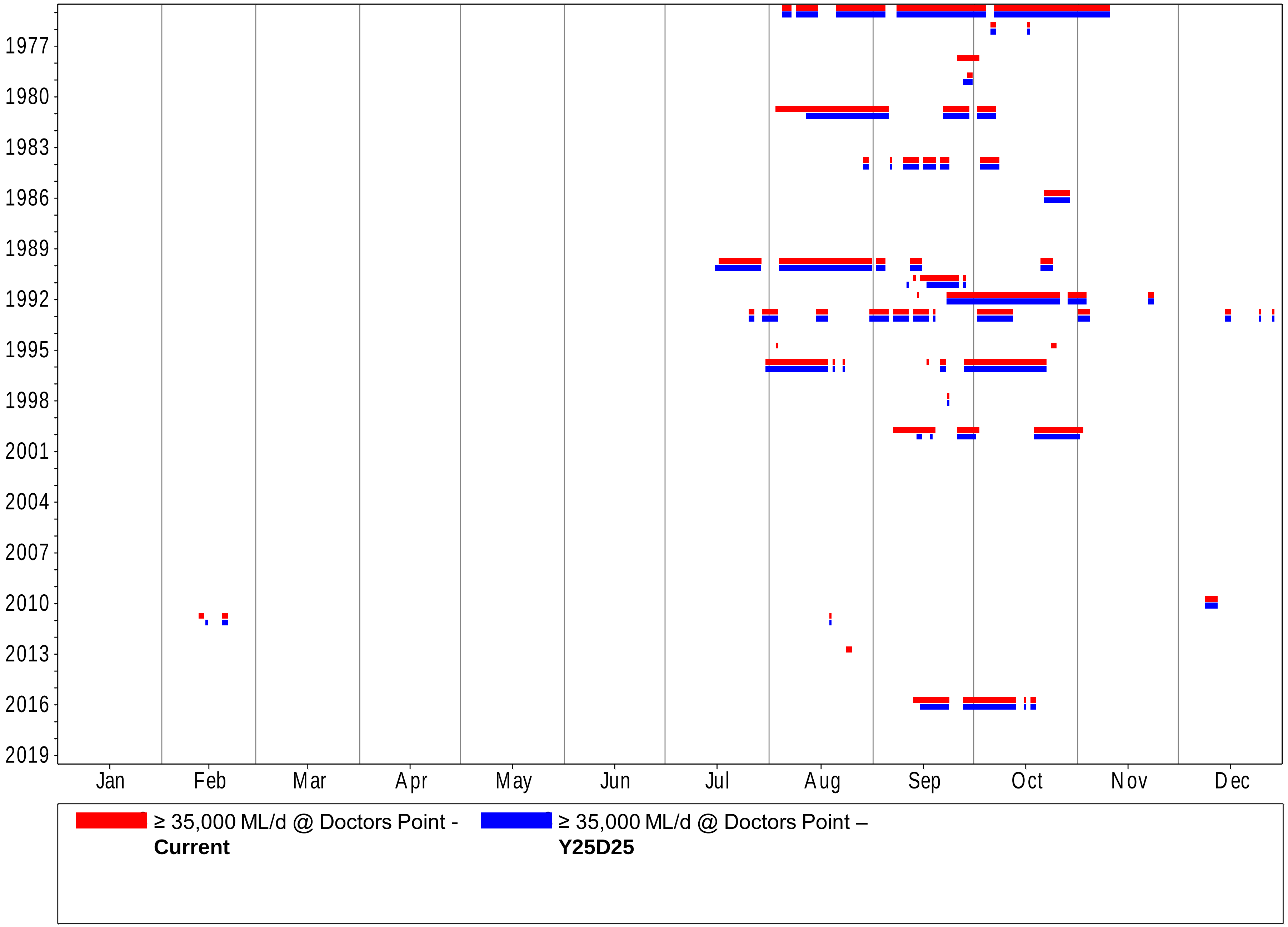


Distribution of Spells



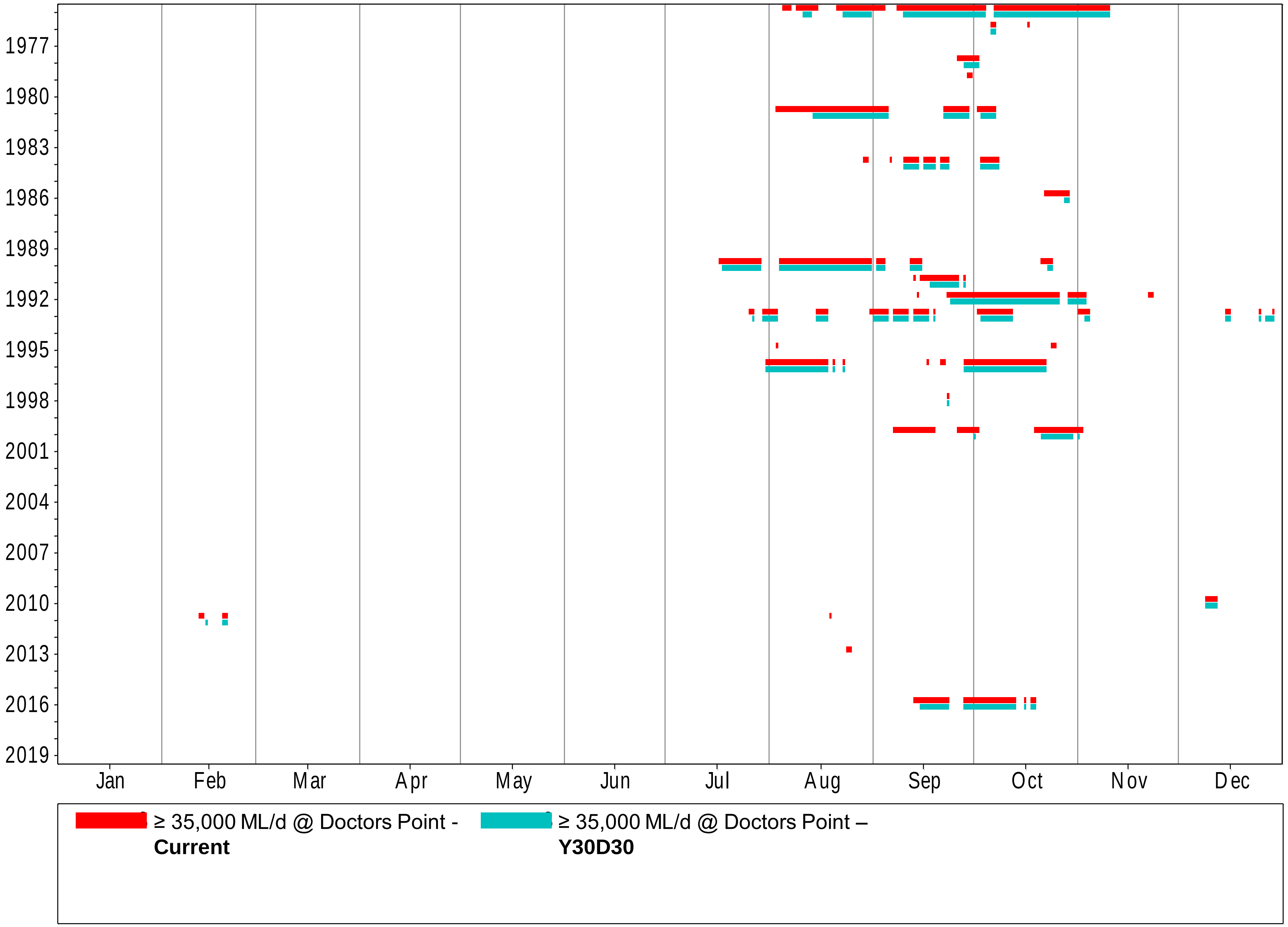
Distribution of Spells



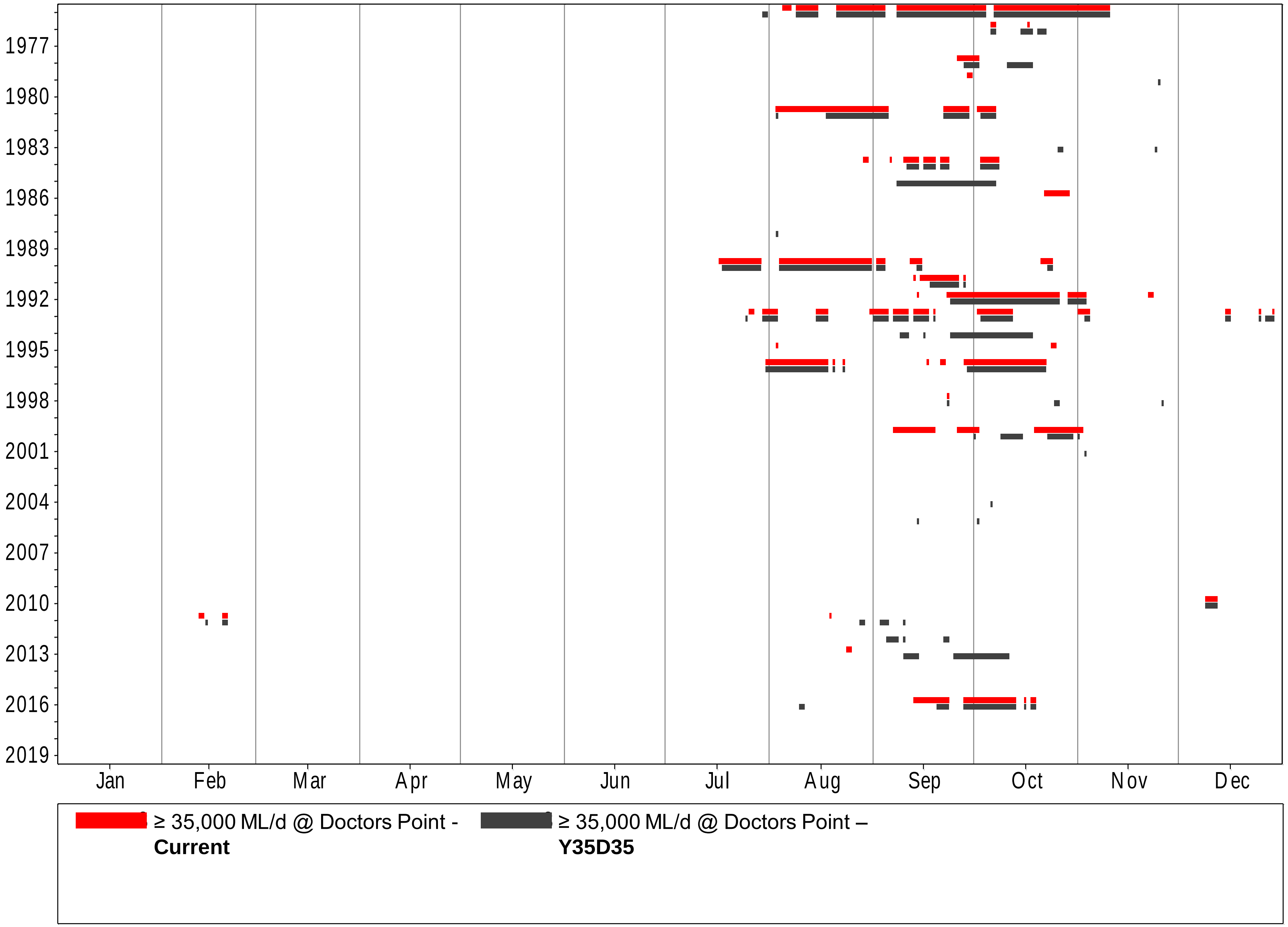


Distribution of Spells

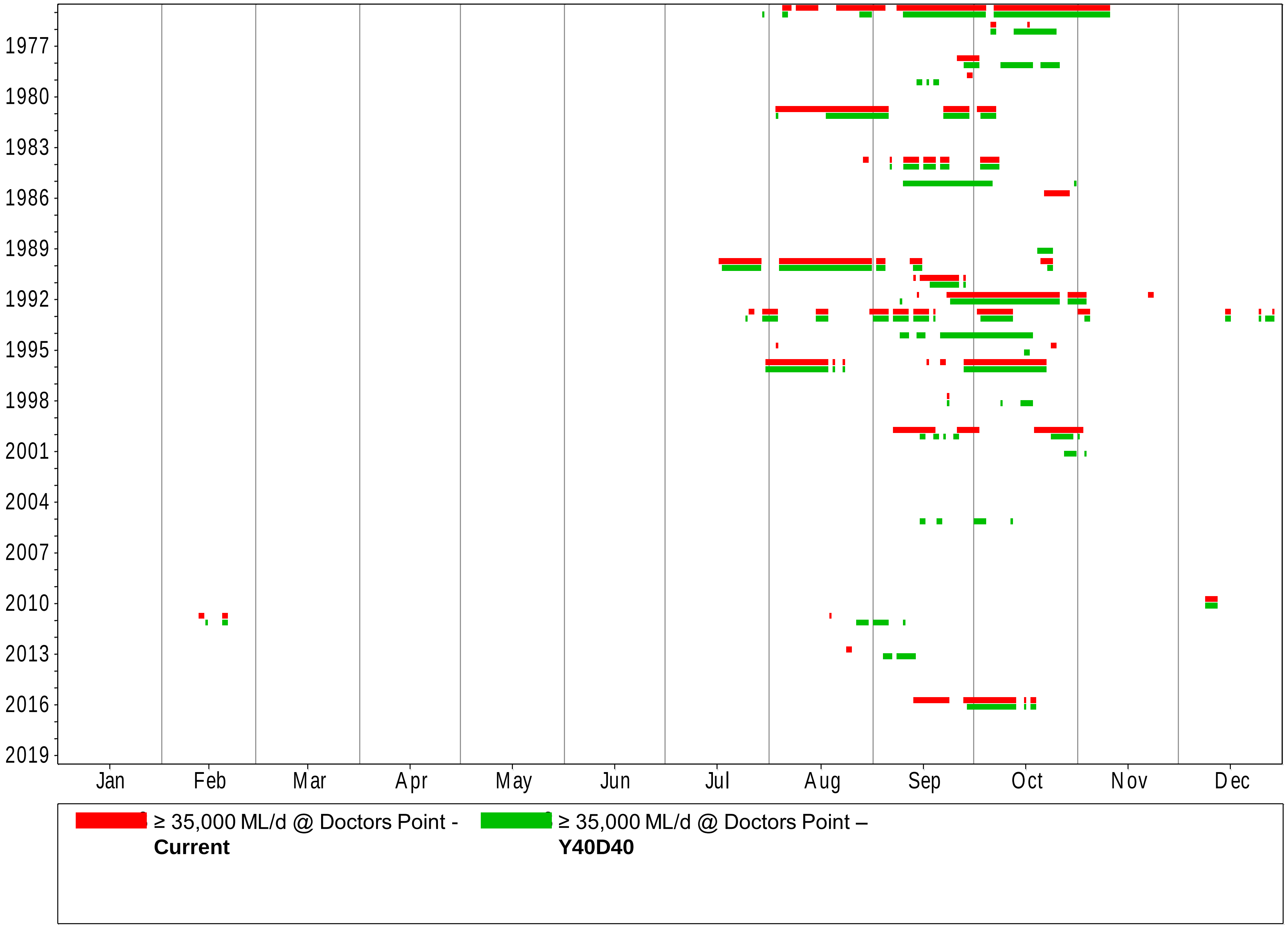
Distribution of Spells



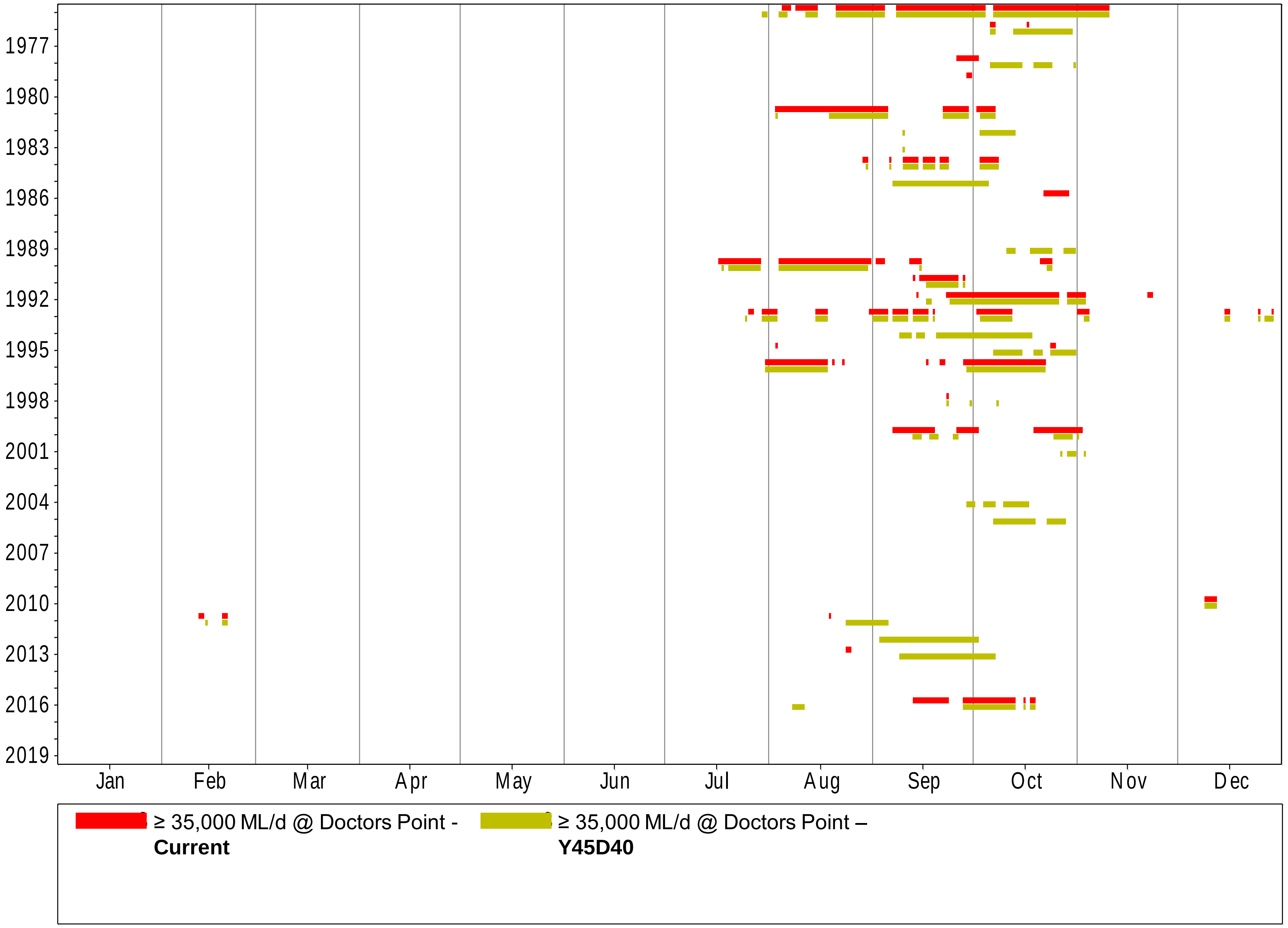
Distribution of Spells



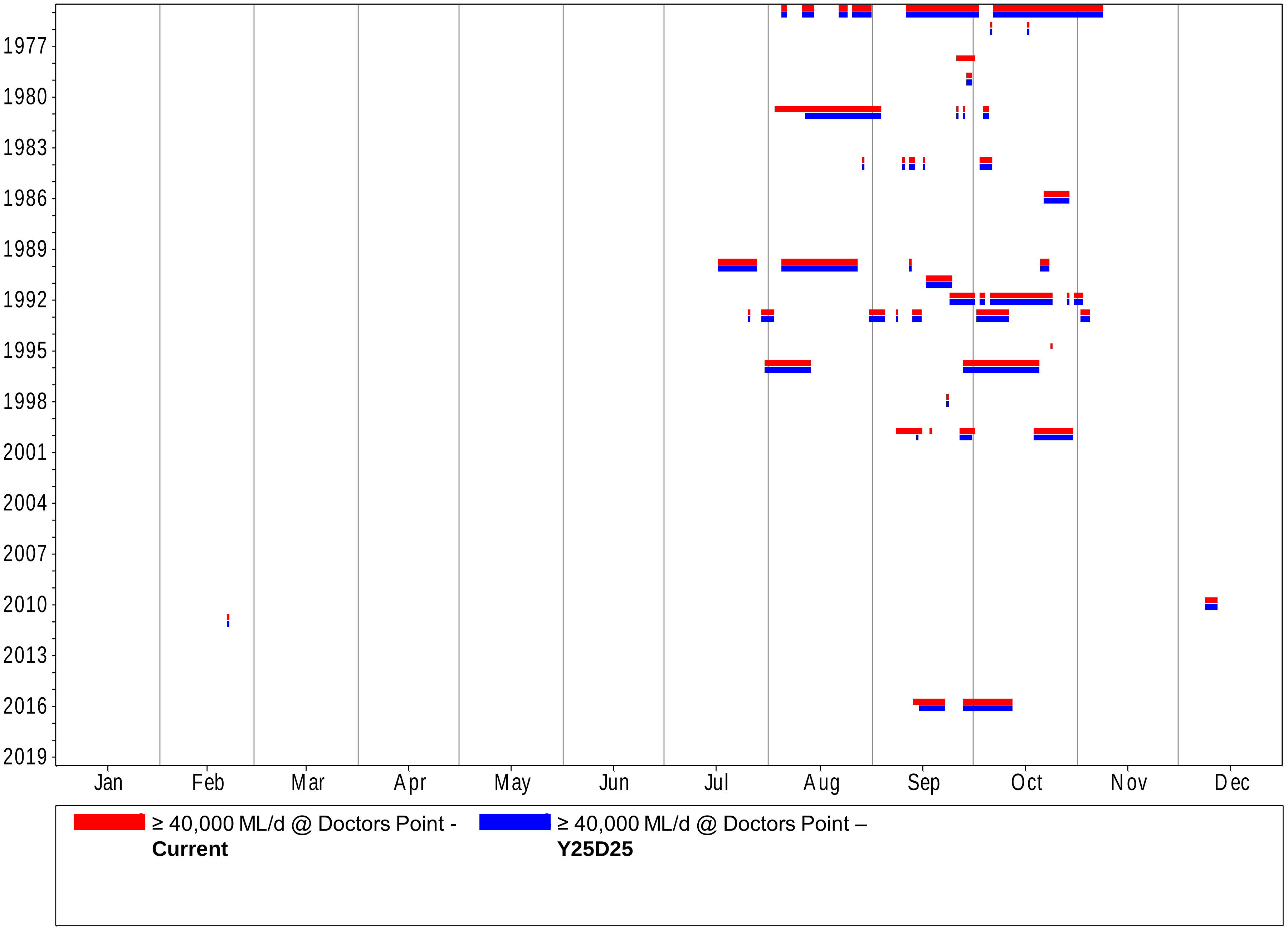
Distribution of Spells



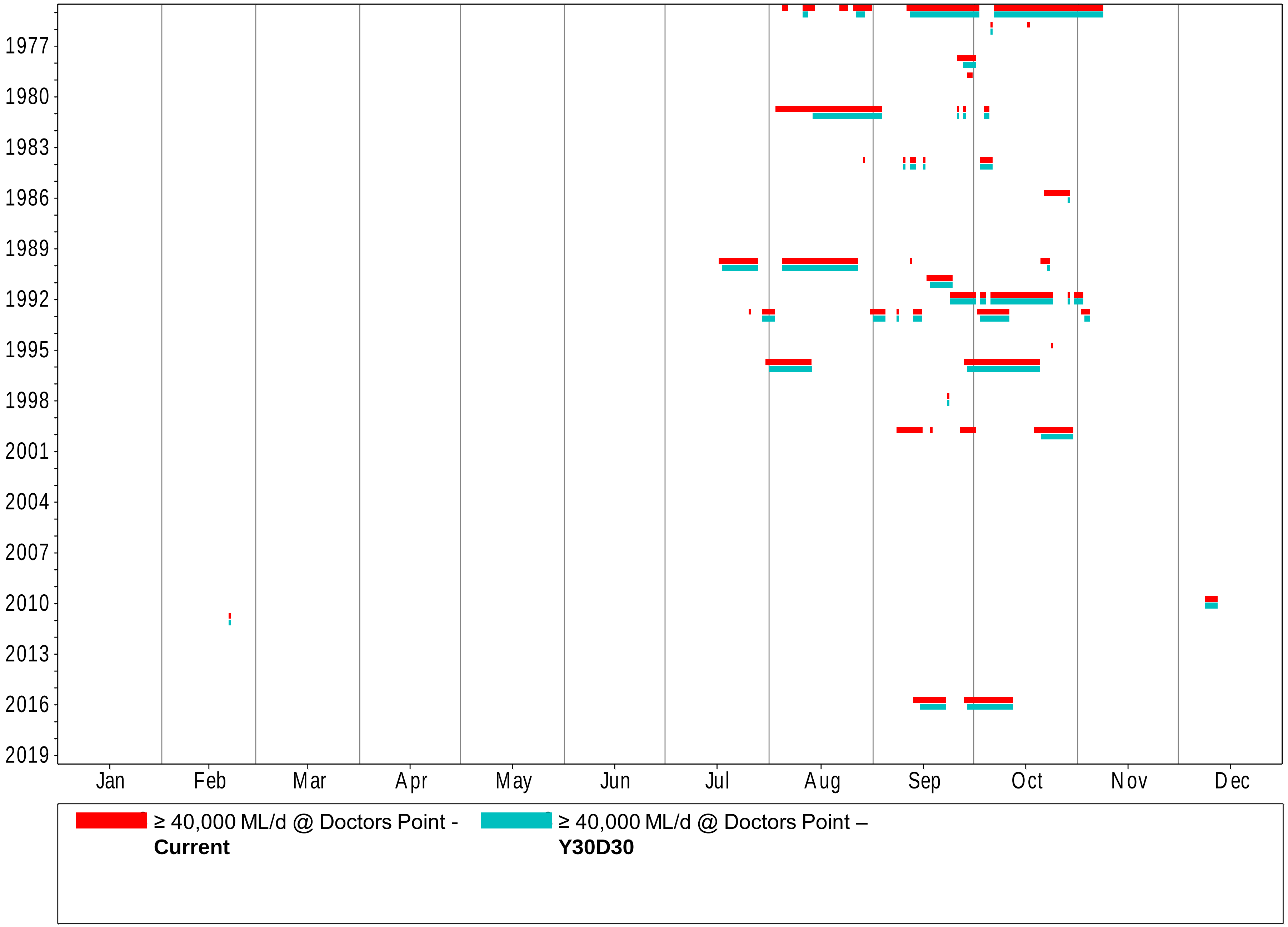
Distribution of Spells



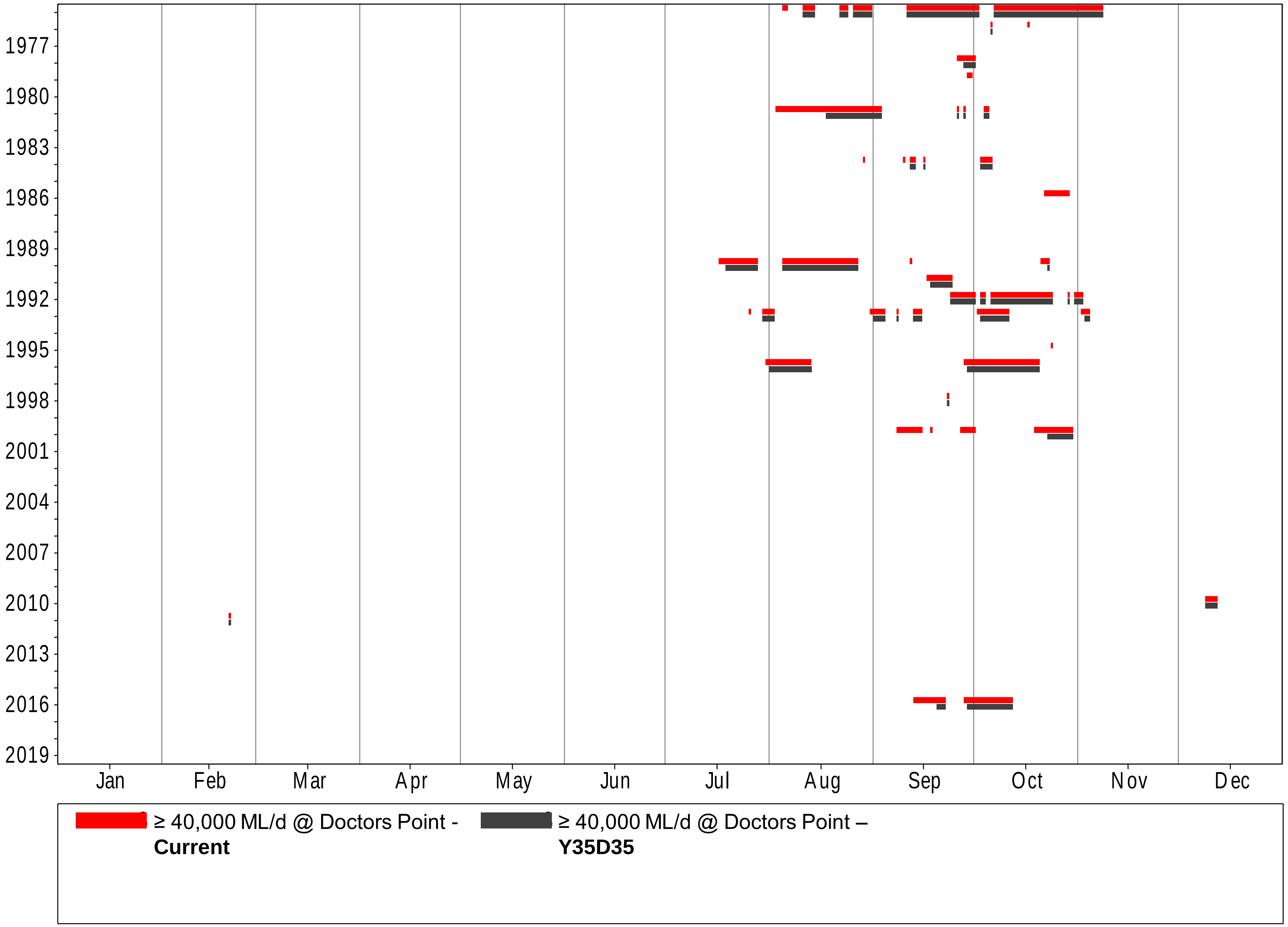
Distribution of Spells



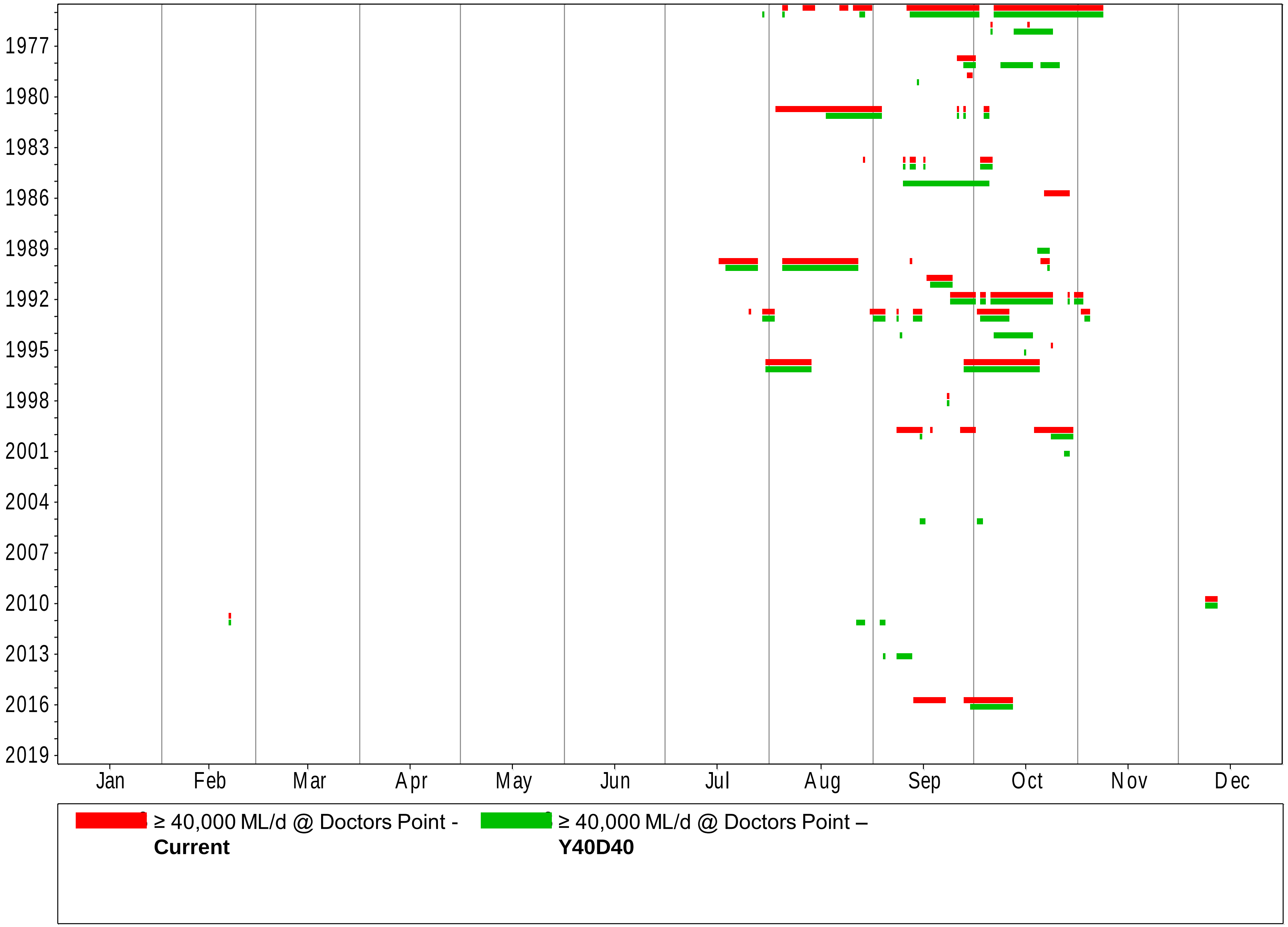
Distribution of Spells



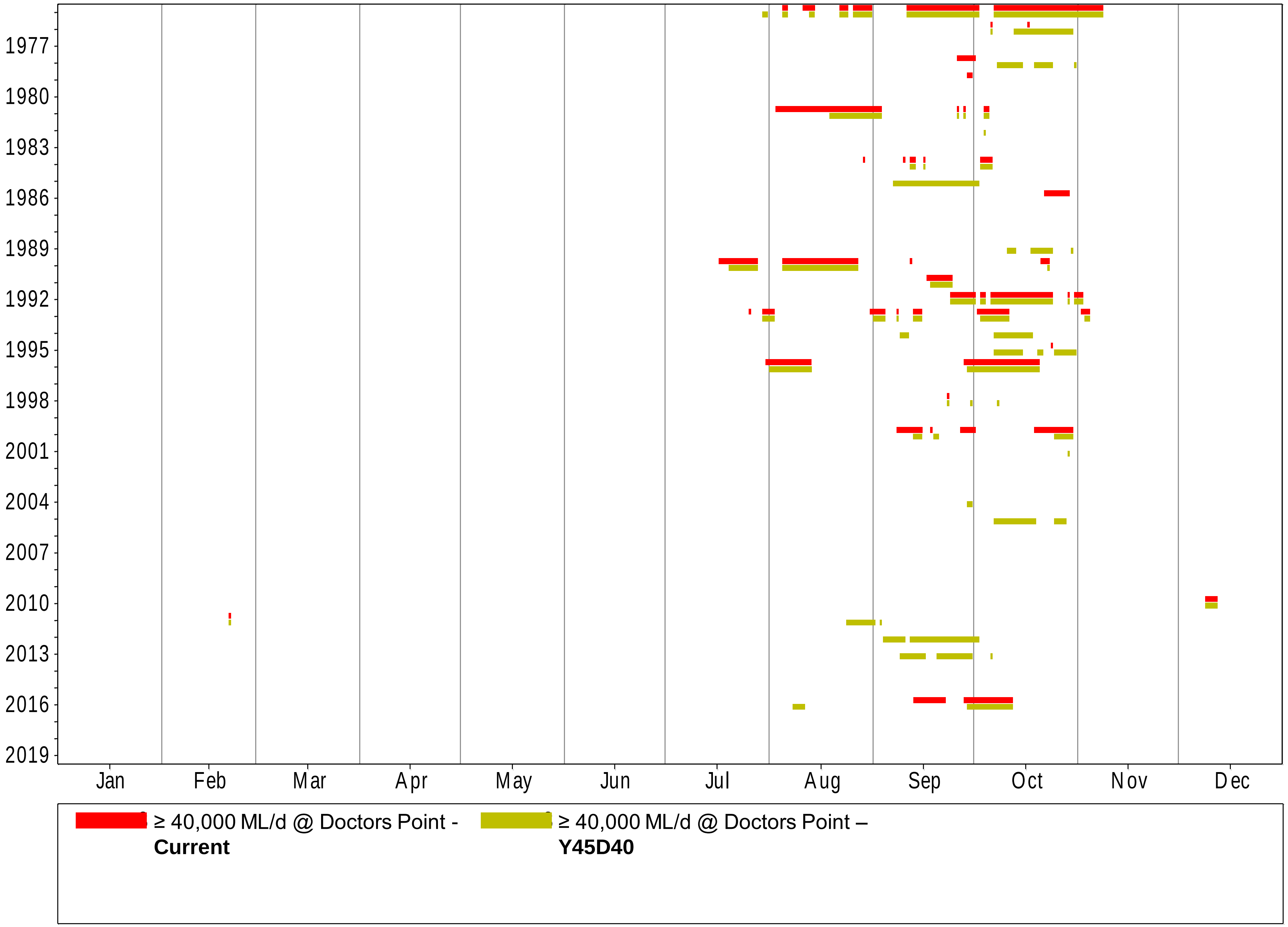
Distribution of Spells



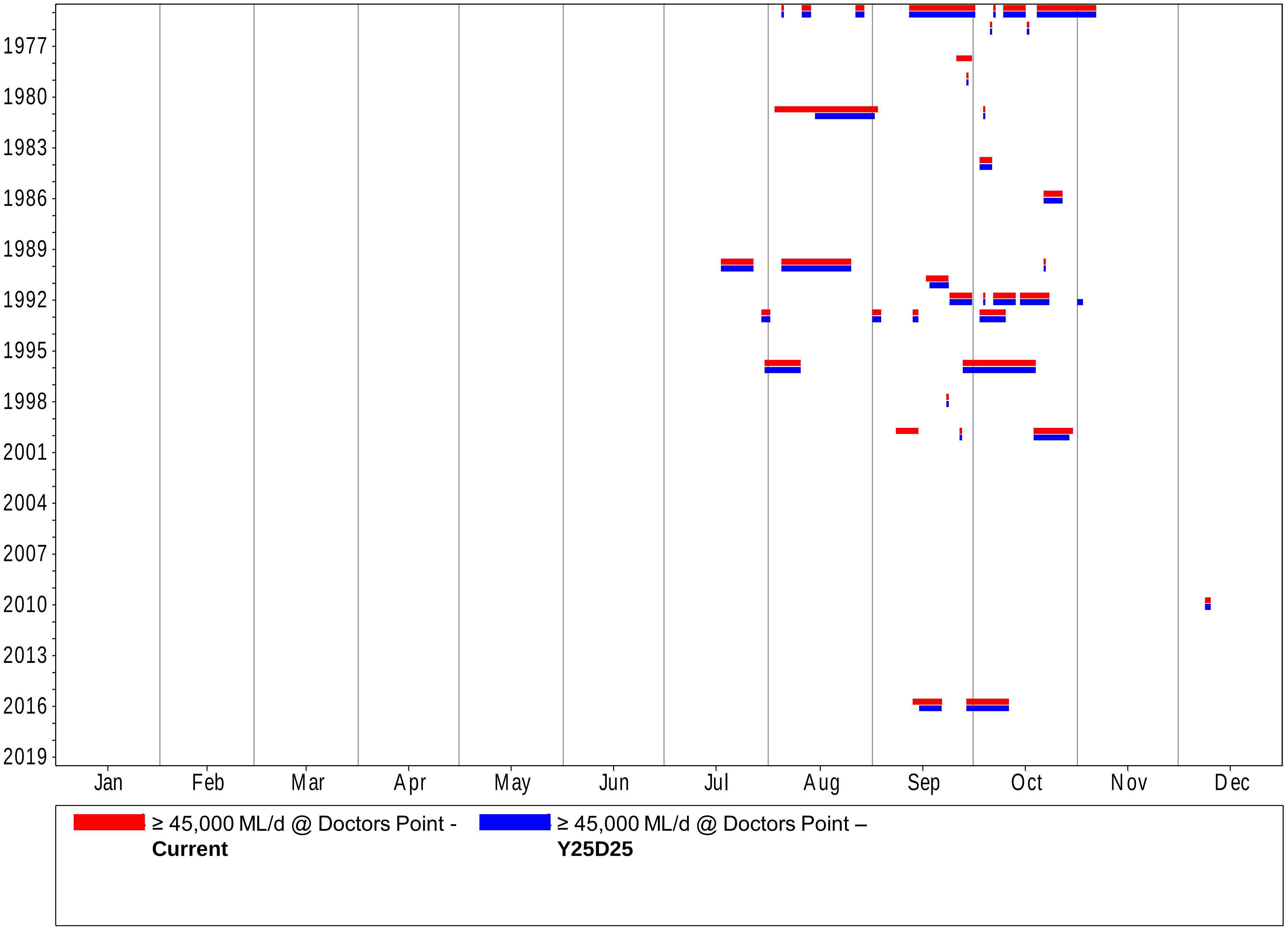
Distribution of Spells



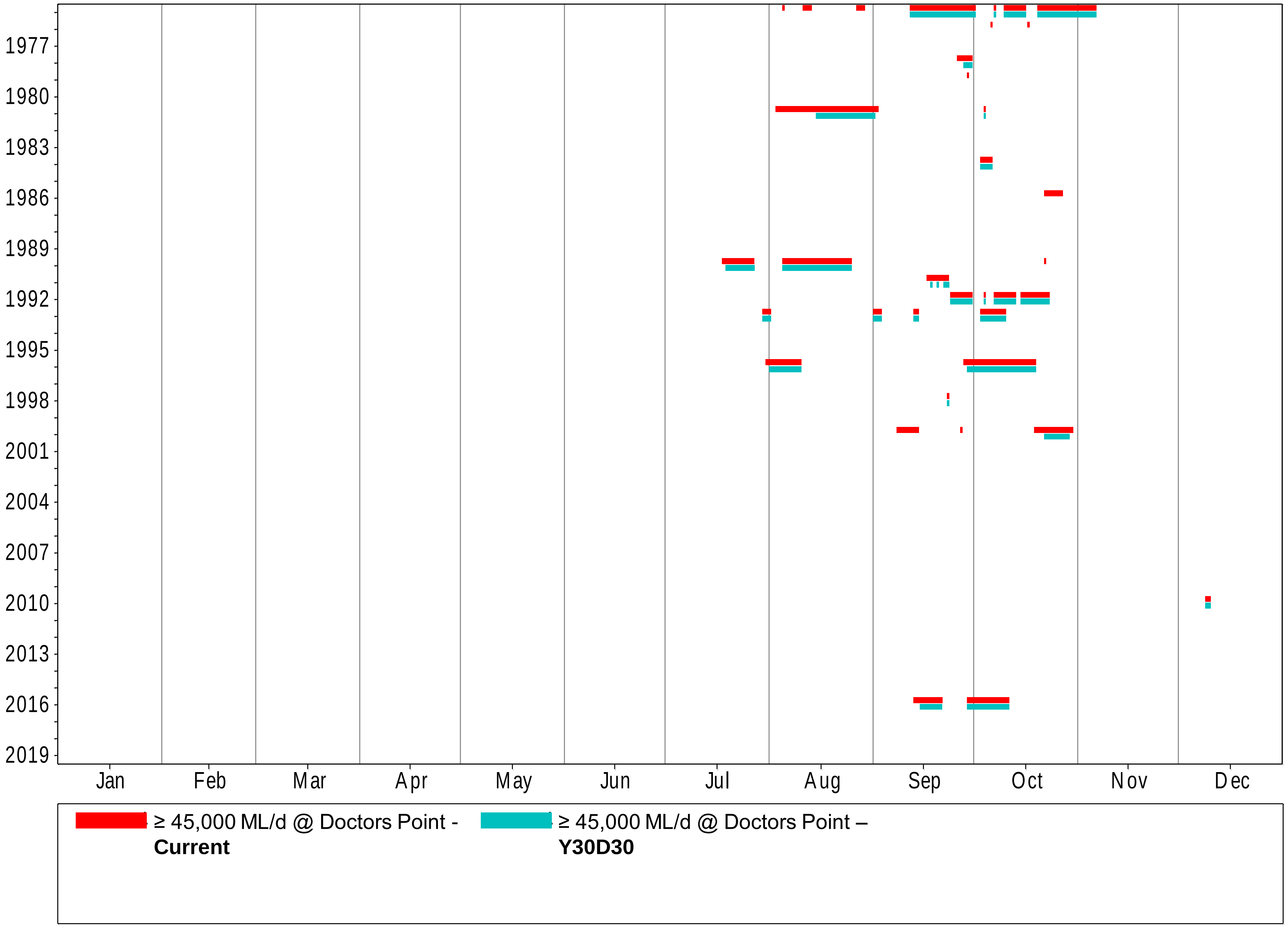
Distribution of Spells



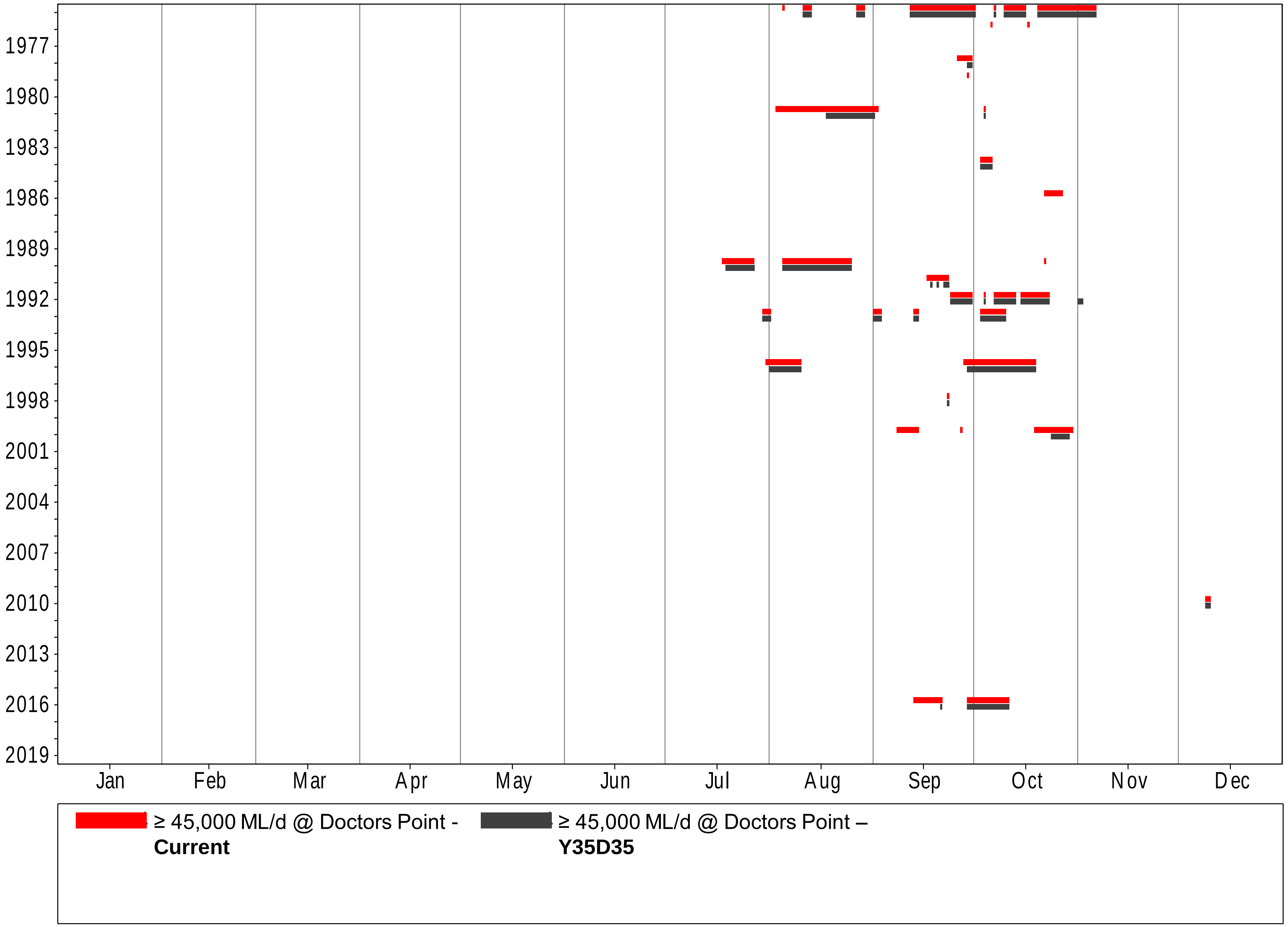
Distribution of Spells



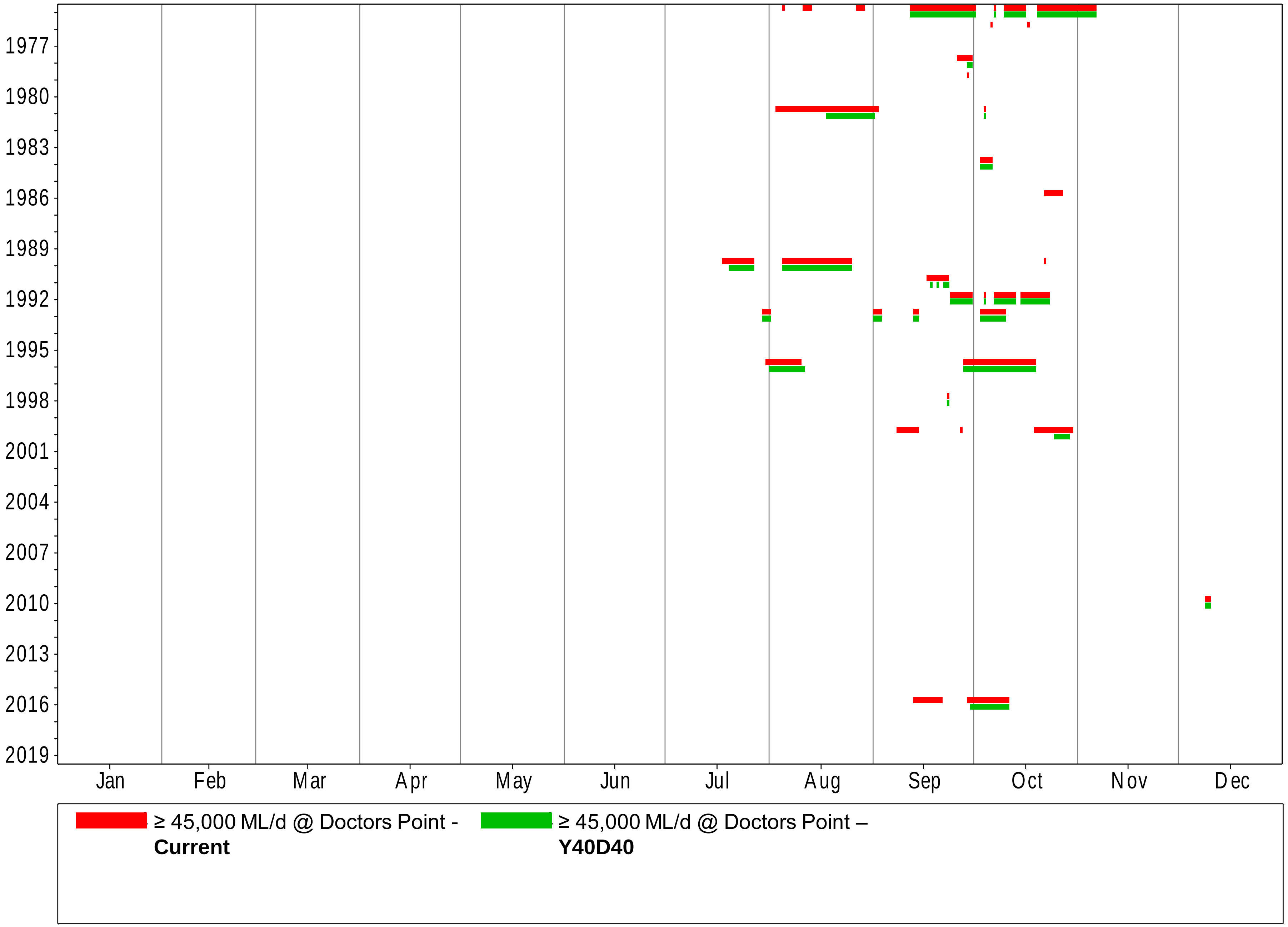
Distribution of Spells



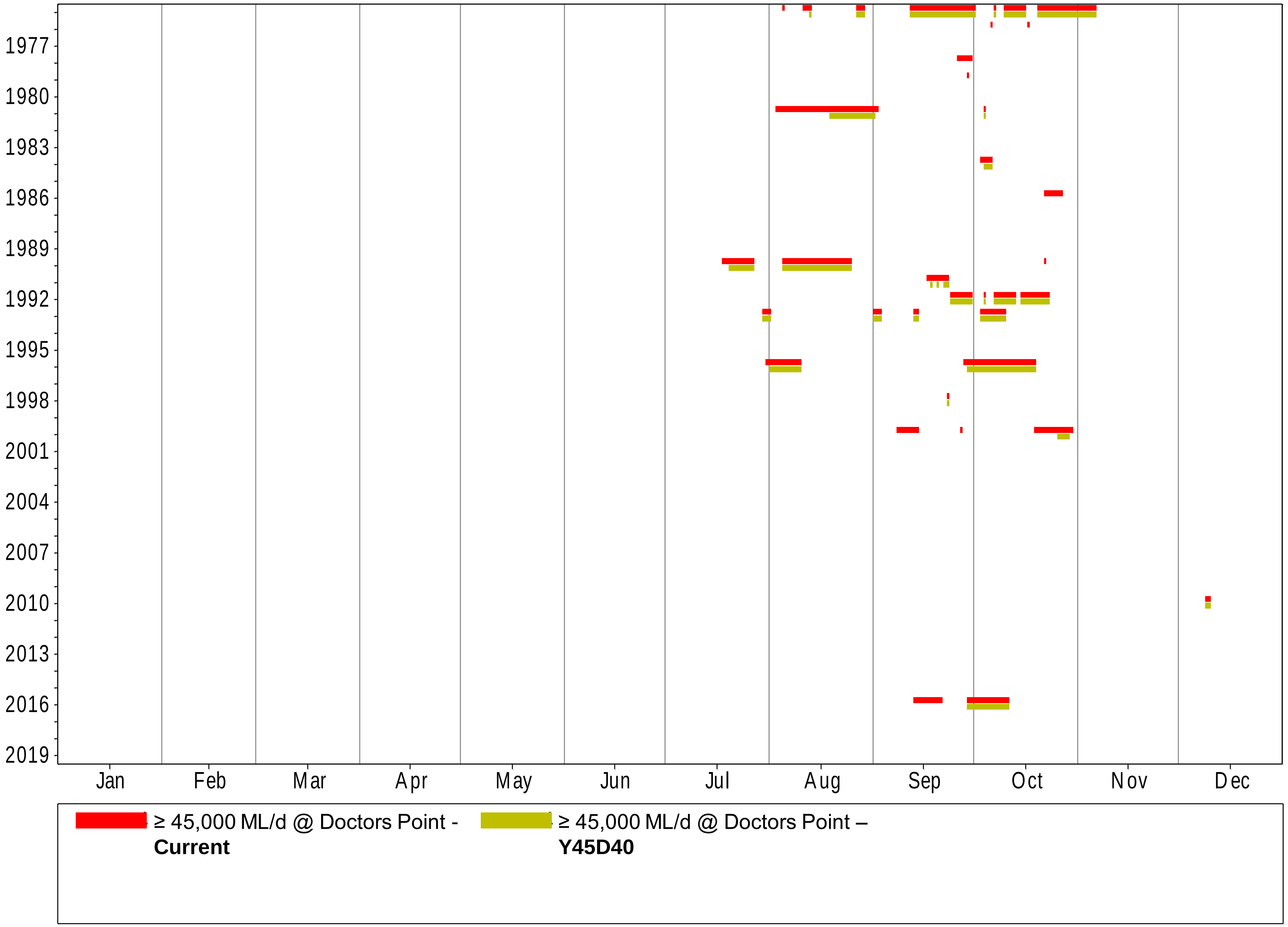
Distribution of Spells



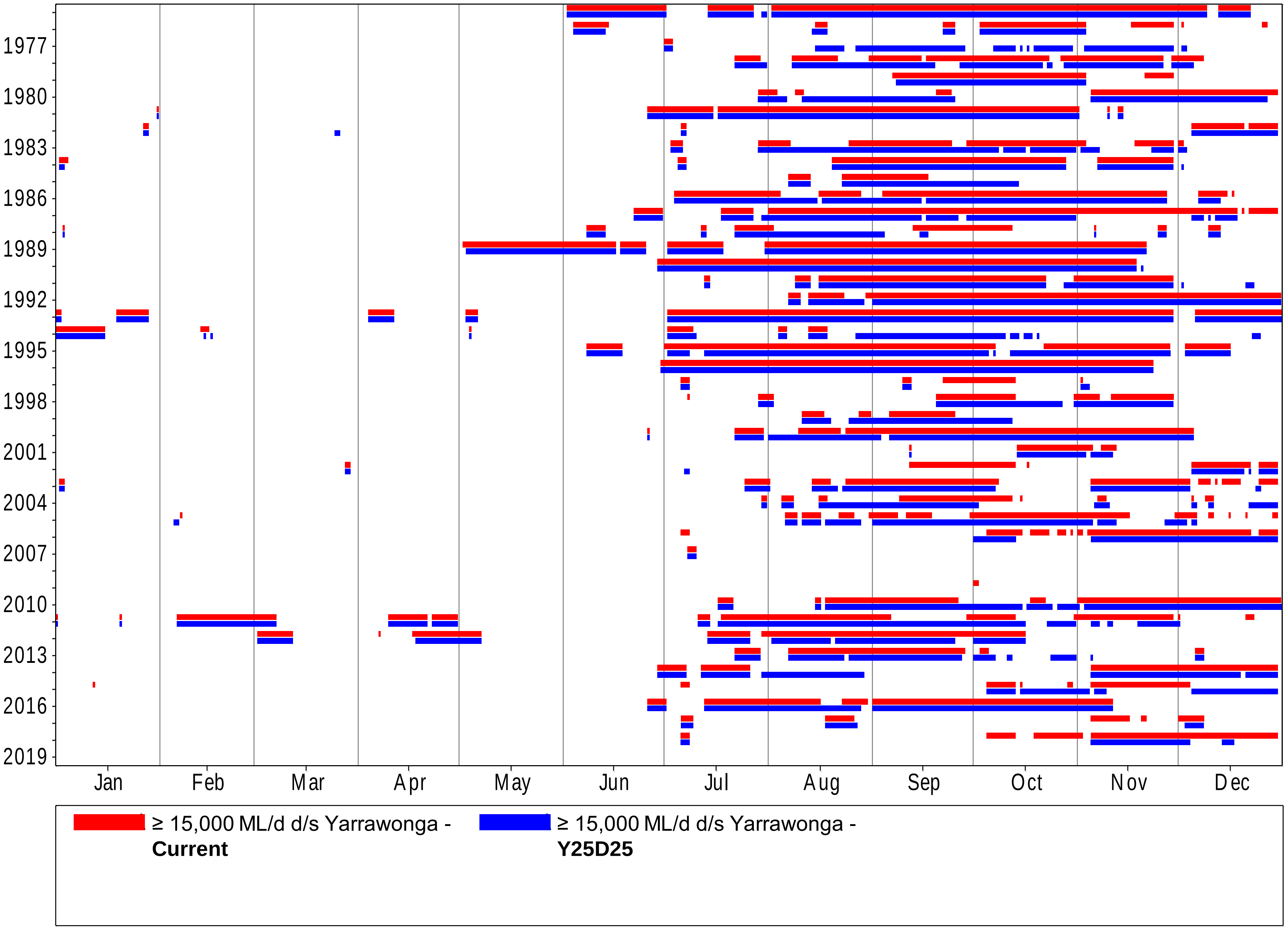
Distribution of Spells

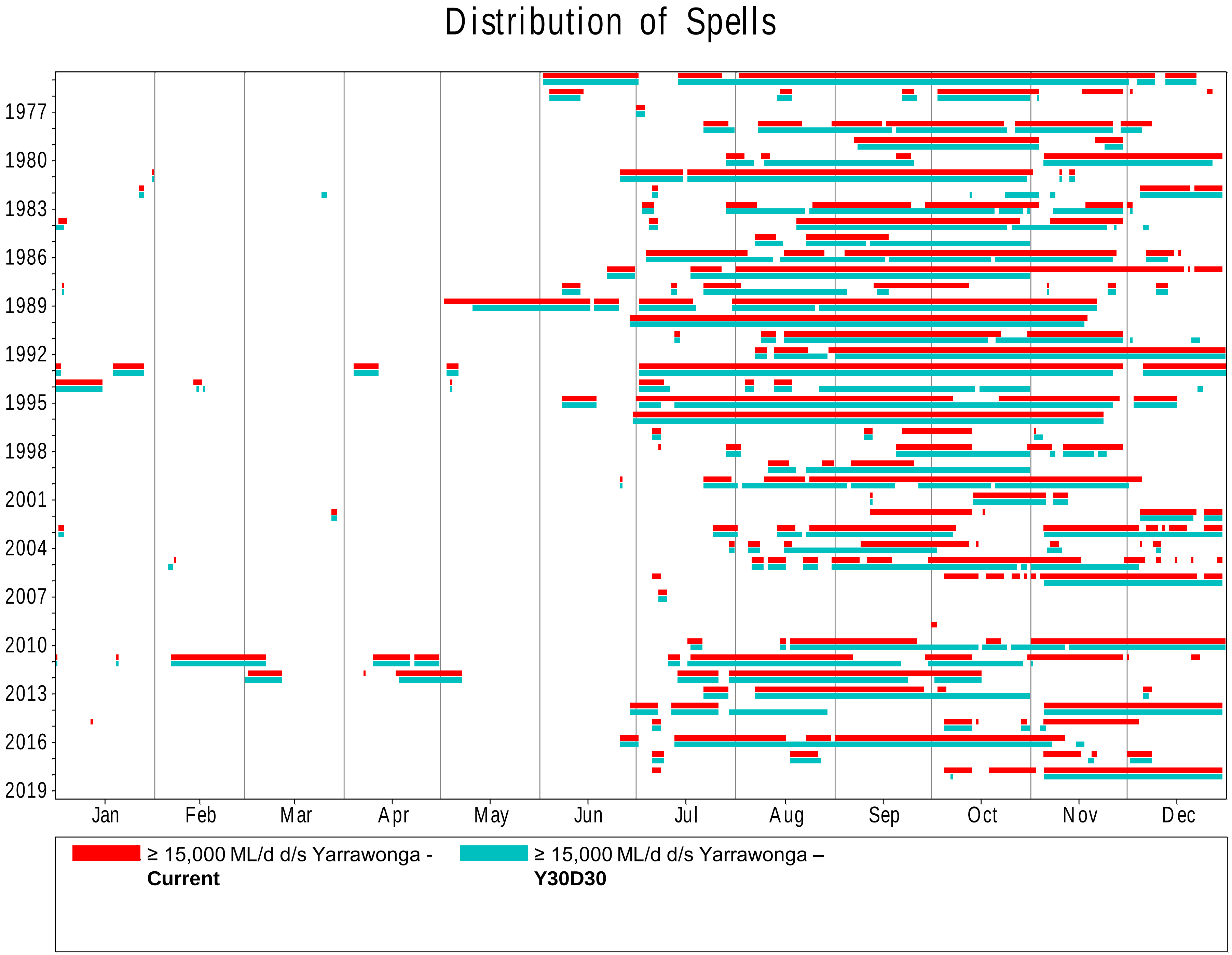


Distribution of Spells

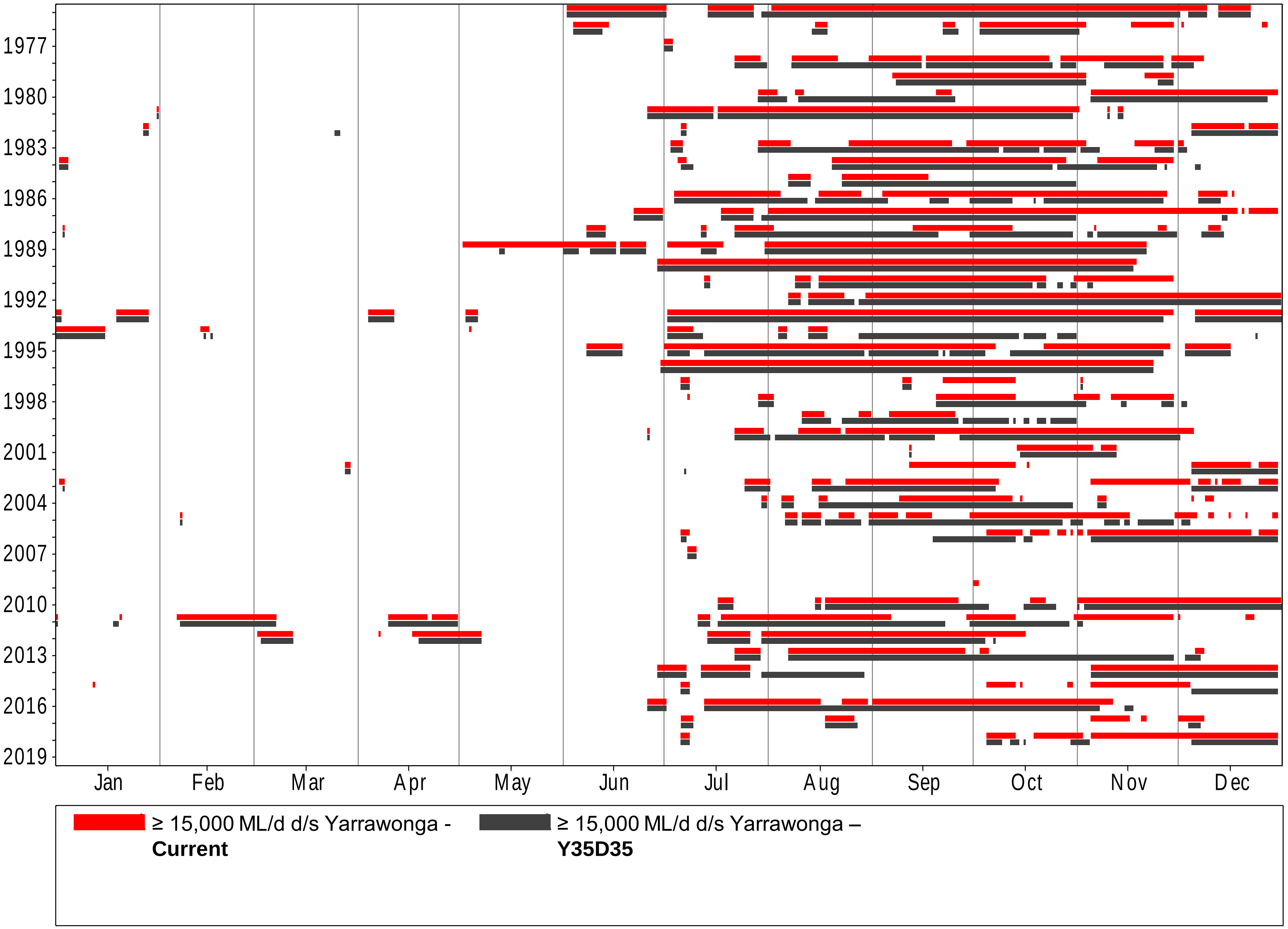


Distribution of Spells

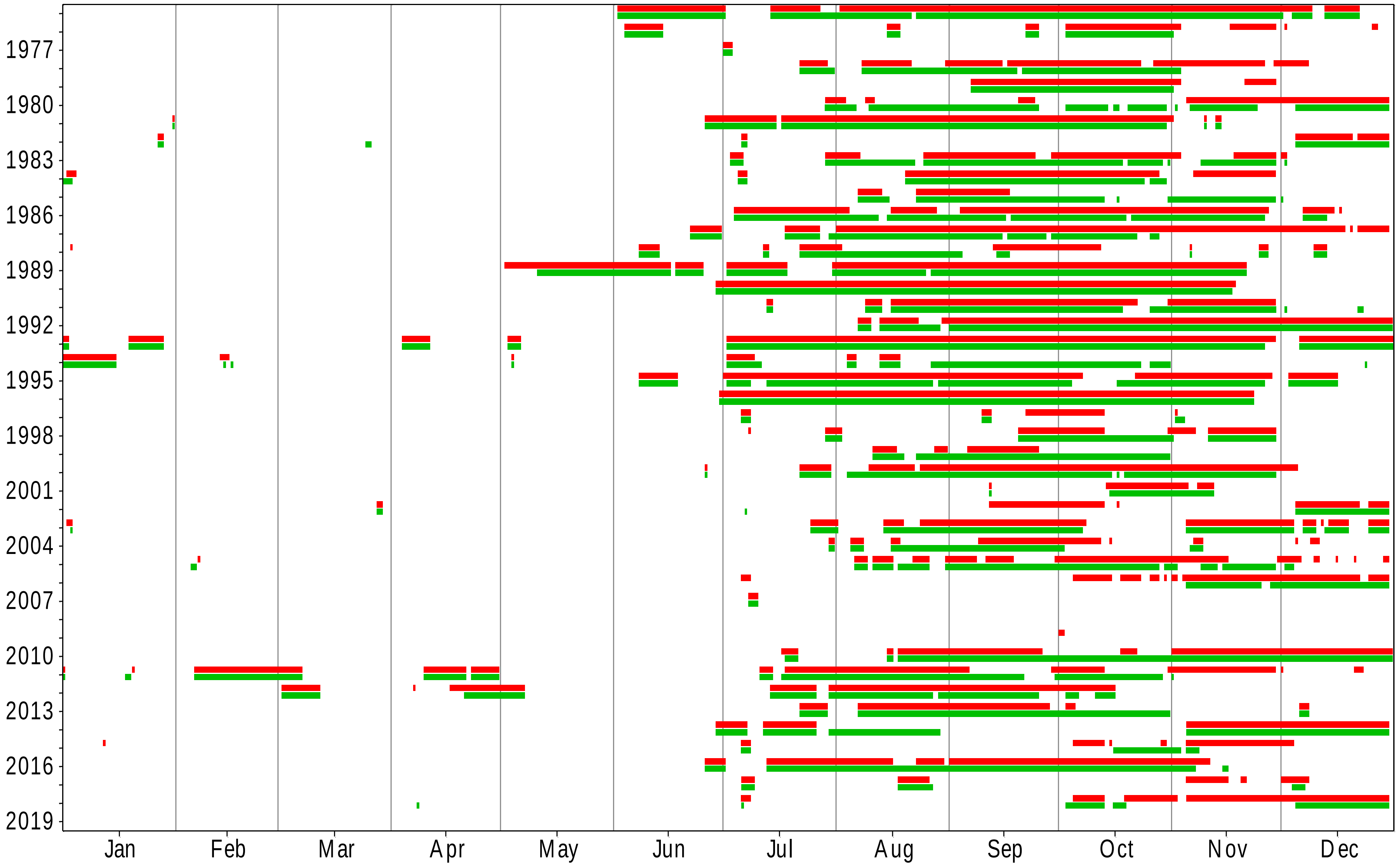



Distribution of Spells
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
2016
2019
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
≥ 15,000 ML/d d/s Yarrawonga - **Current**
≥ 15,000 ML/d d/s Yarrawonga – **Y30D30**

Distribution of Spells



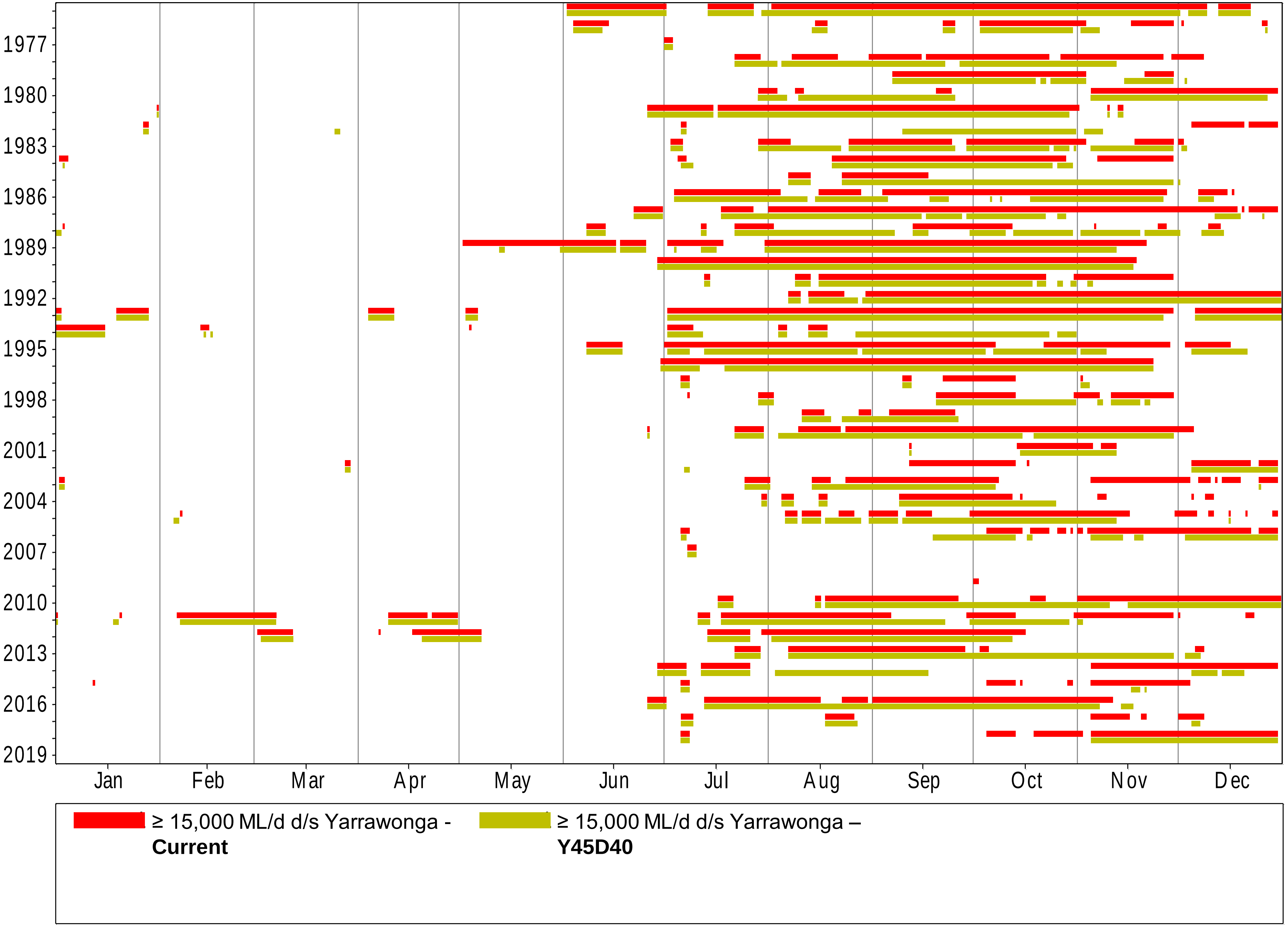
Distribution of Spells



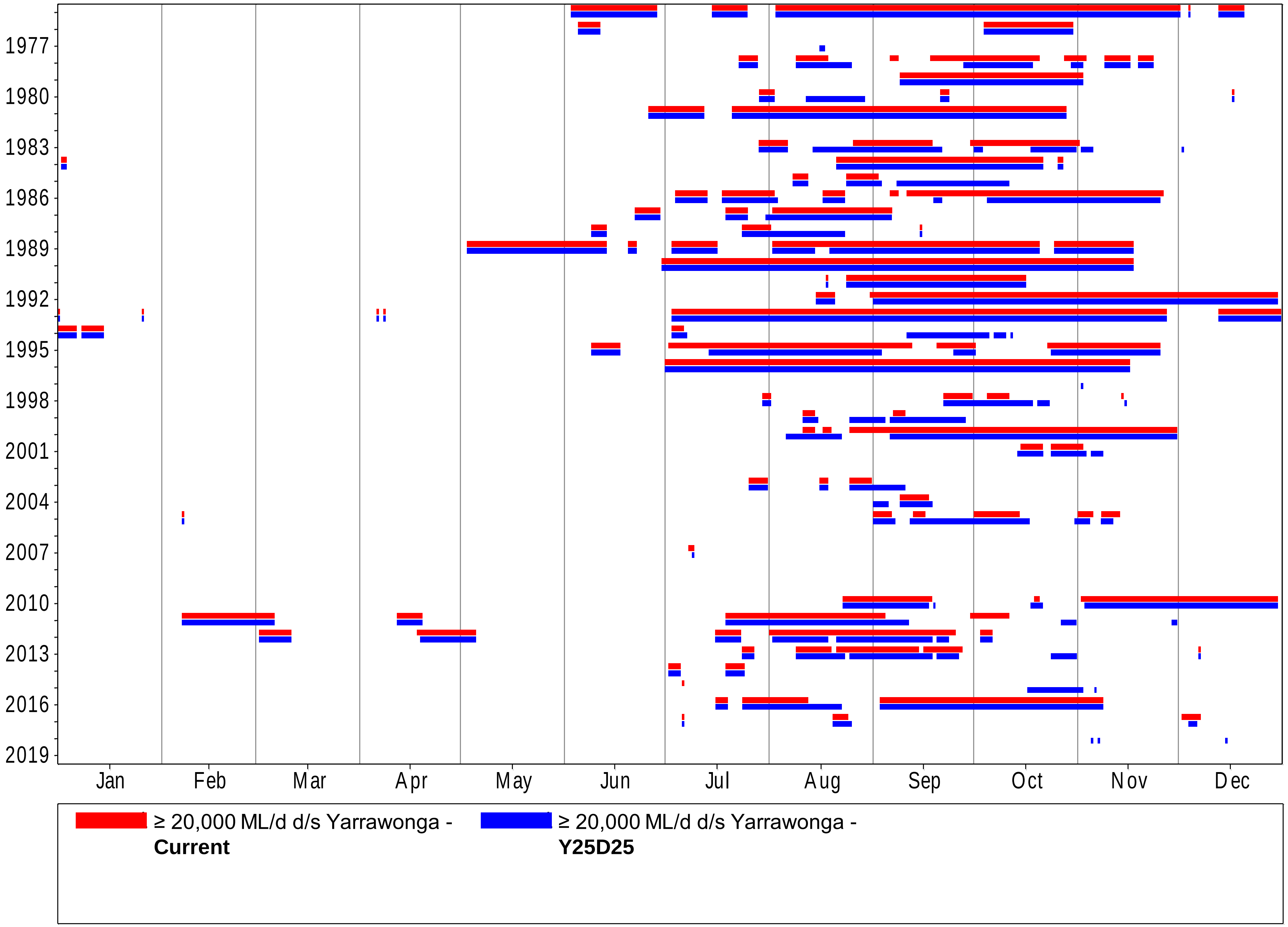
🟥 ≥ 15,000 ML/d d/s Yarrawonga - **Current**

🟩 ≥ 15,000 ML/d d/s Yarrawonga – **Y40D40**

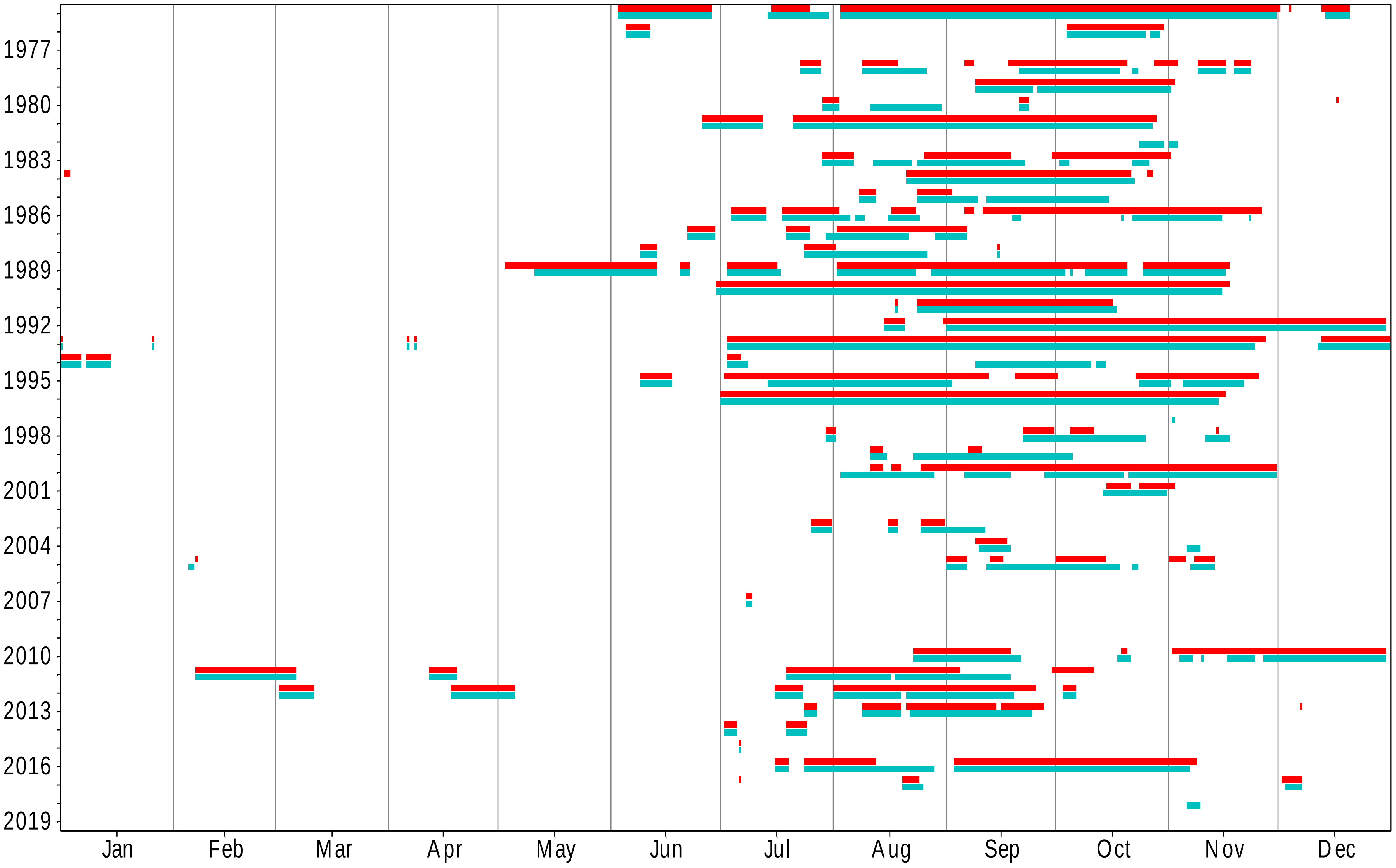
Distribution of Spells



Distribution of Spells



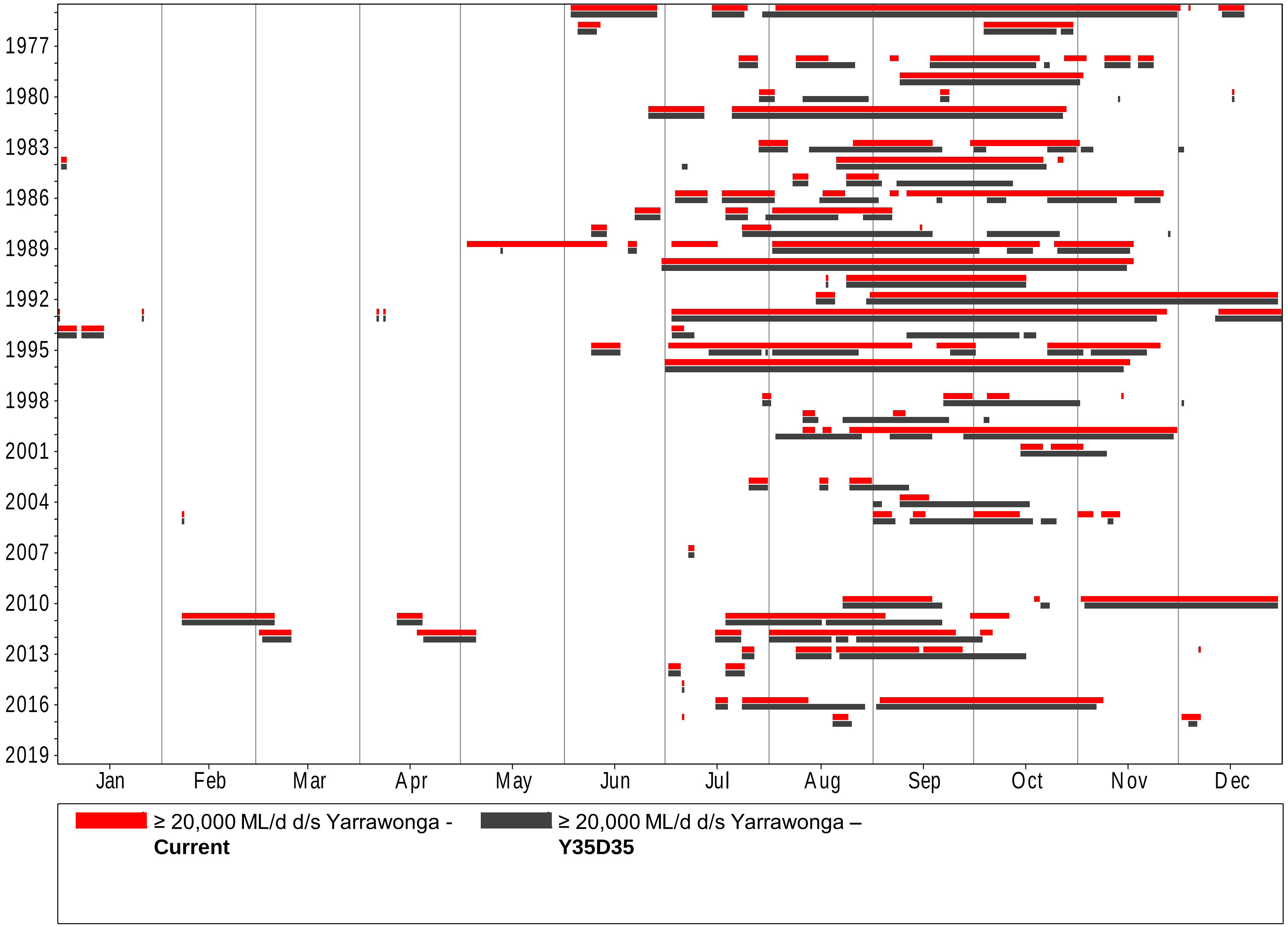
Distribution of Spells



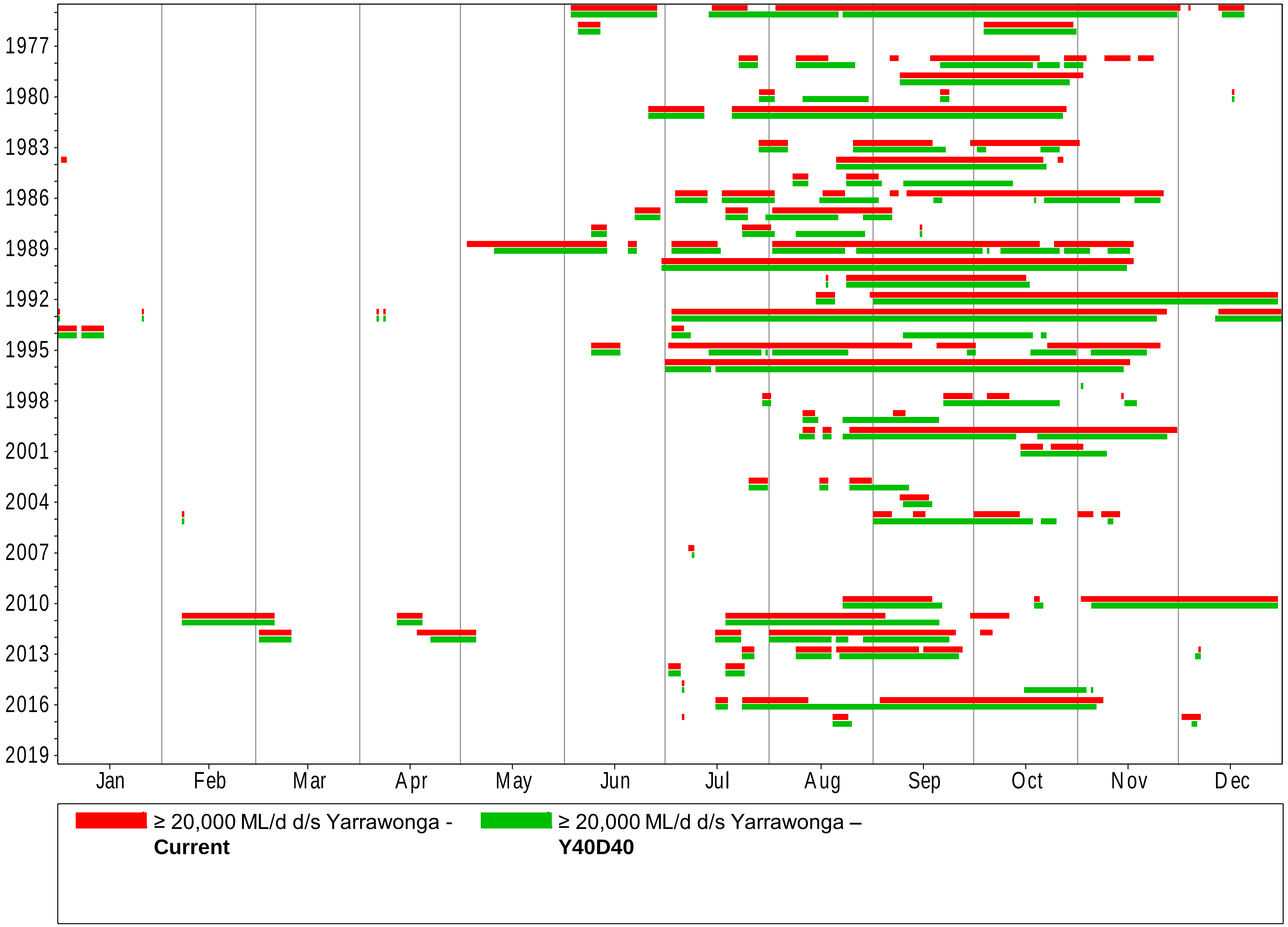
🟥 ≥ 20,000 ML/d d/s Yarrawonga - **Current**

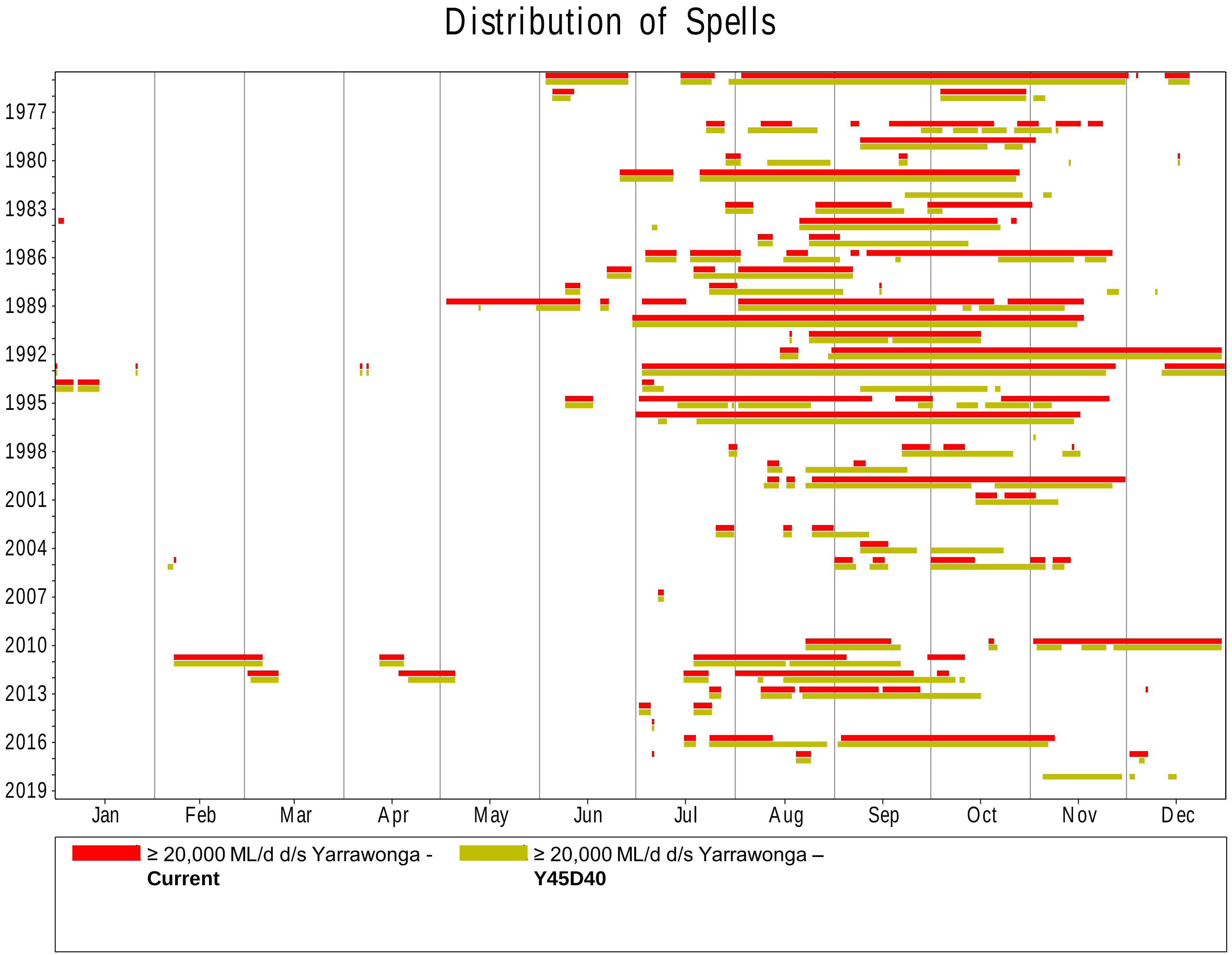
🟦 ≥ 20,000 ML/d d/s Yarrawonga – **Y30D30**

Distribution of Spells



Distribution of Spells




Distribution of Spells
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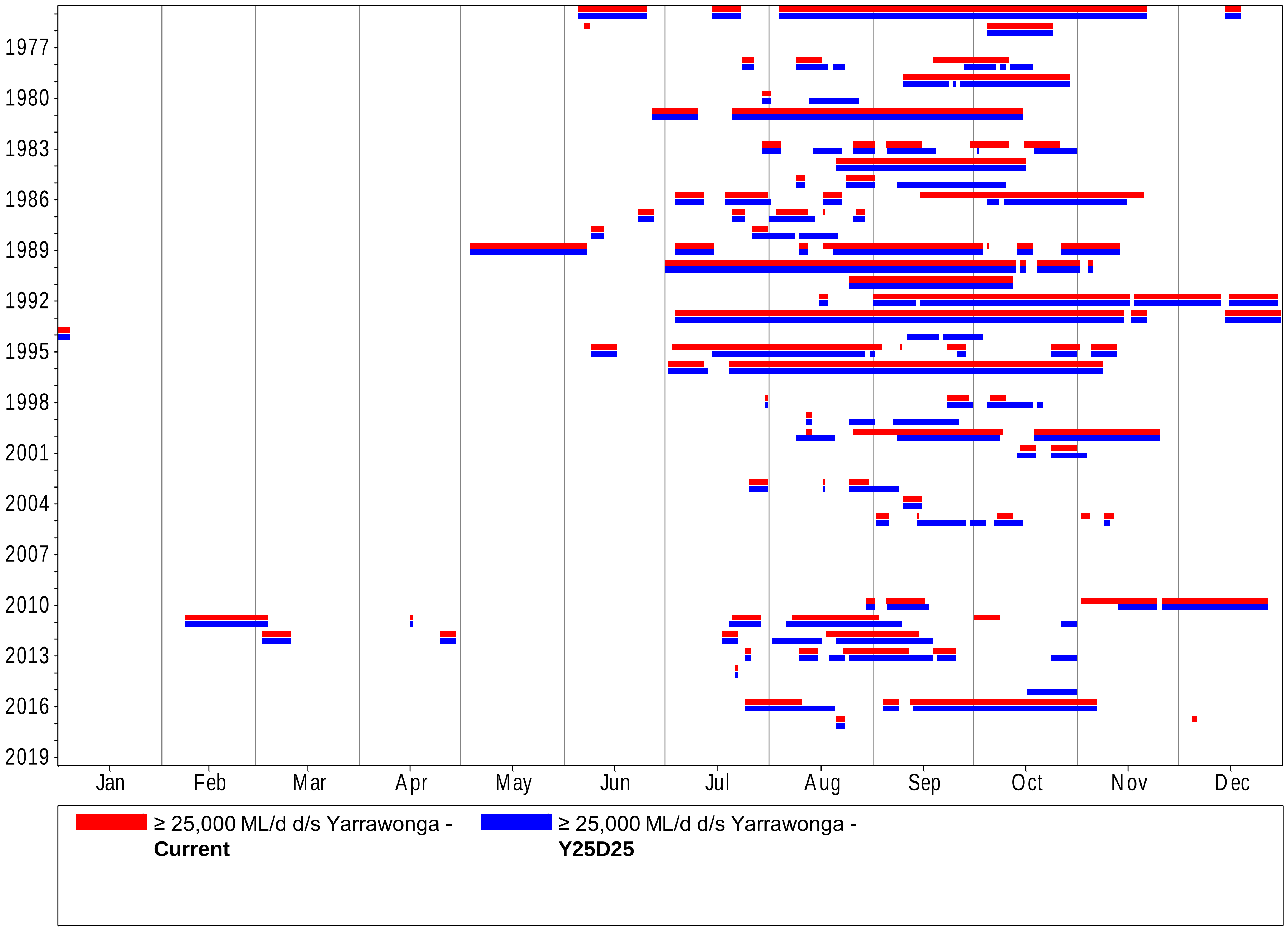
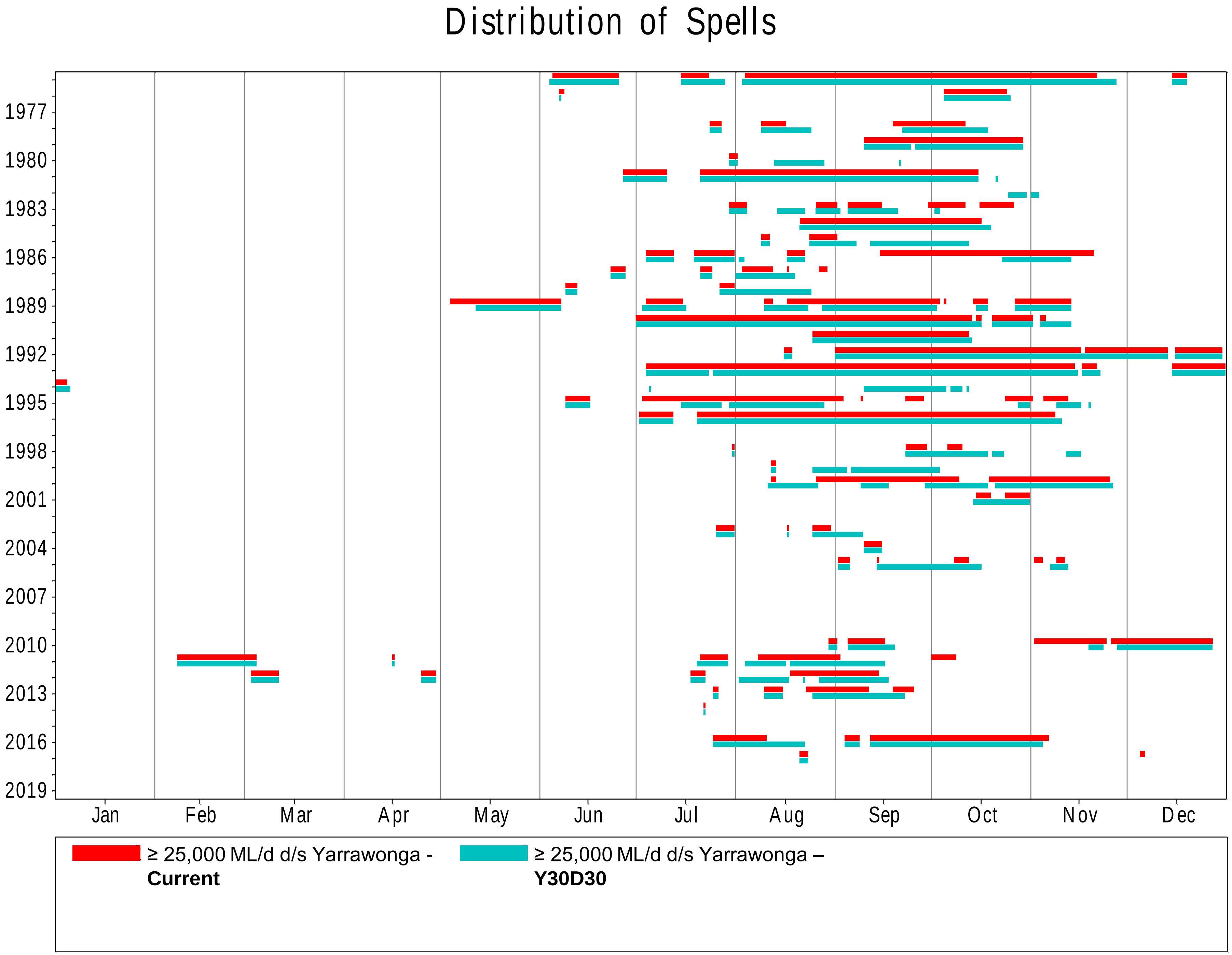
🟥 ≥ 20,000 ML/d d/s Yarrawonga - **Current**
🟨 ≥ 20,000 ML/d d/s Yarrawonga – **Y45D40**

Distribution of Spells




Distribution of Spells
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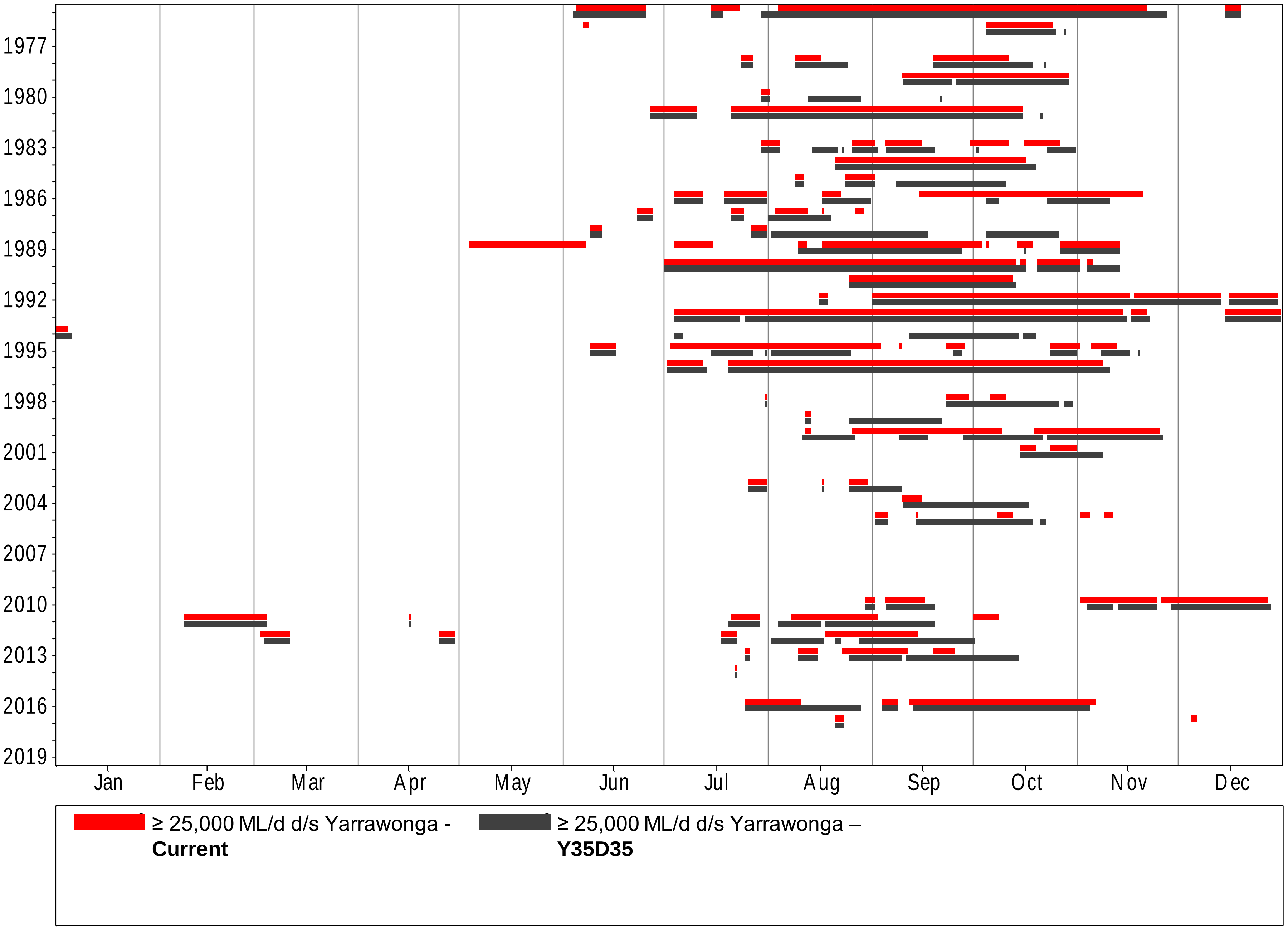
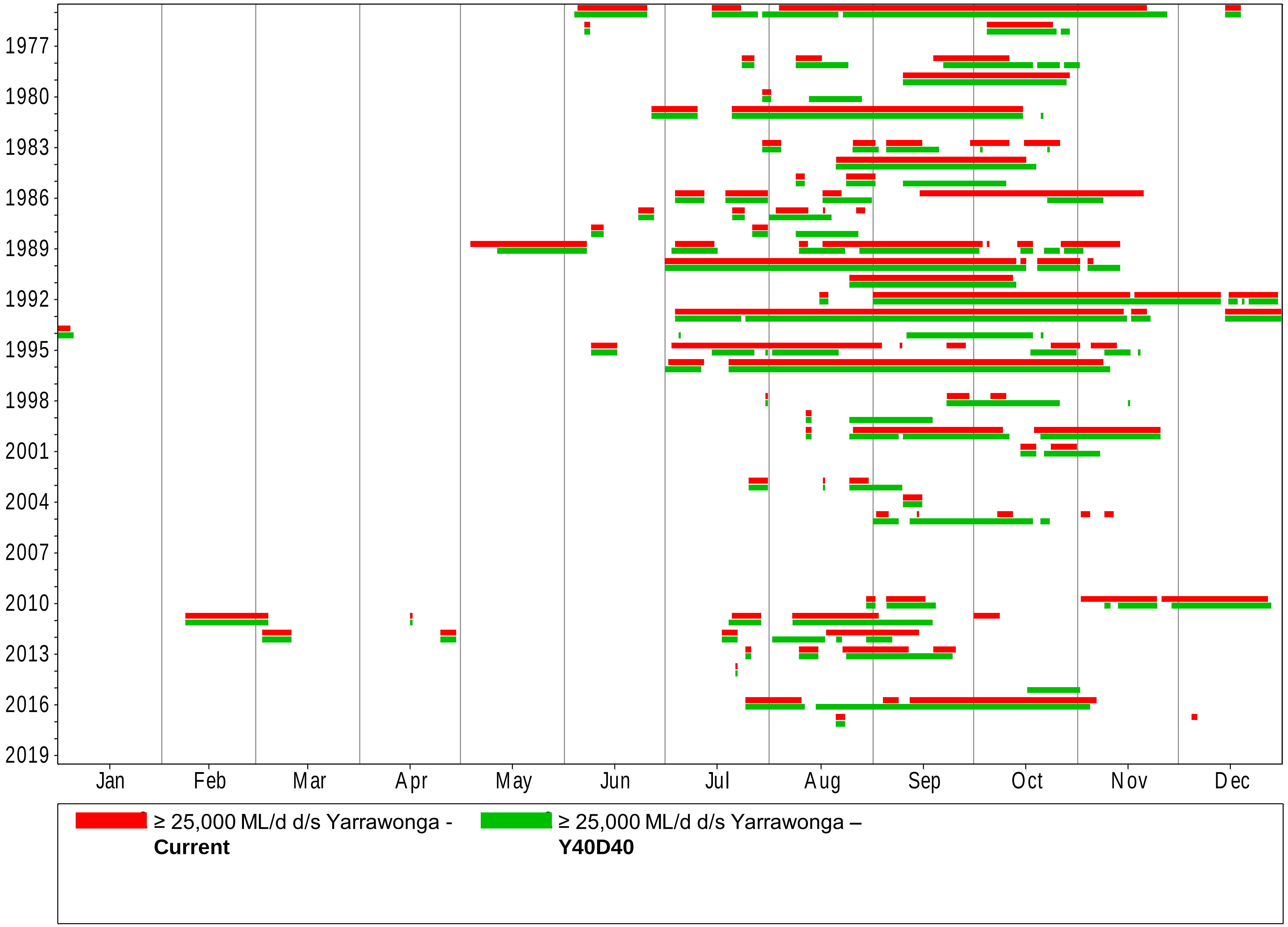
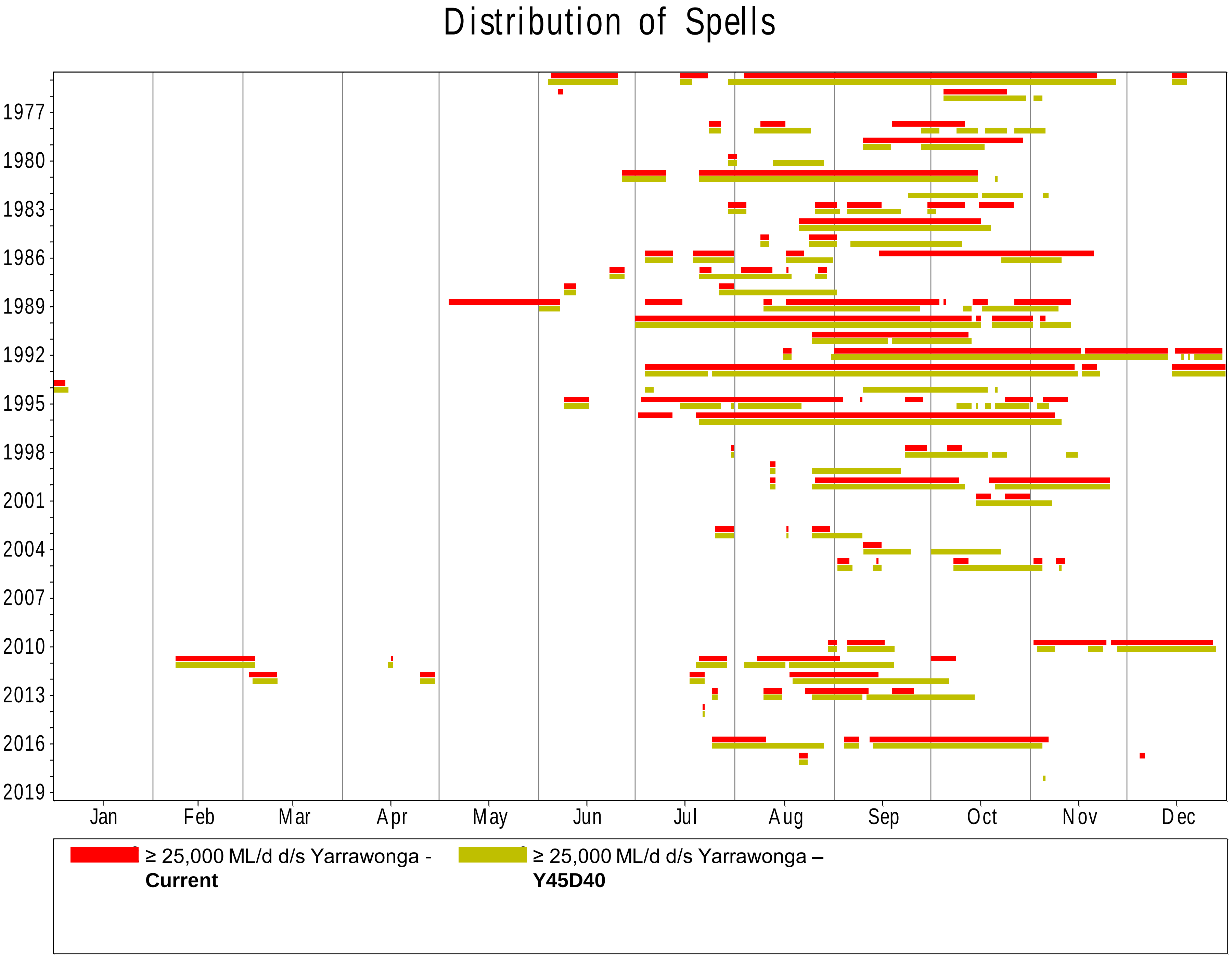
≥ 25,000 ML/d d/s Yarrawonga - Current
≥ 25,000 ML/d d/s Yarrawonga – Y30D30

Distribution of Spells



Distribution of Spells




Distribution of Spells
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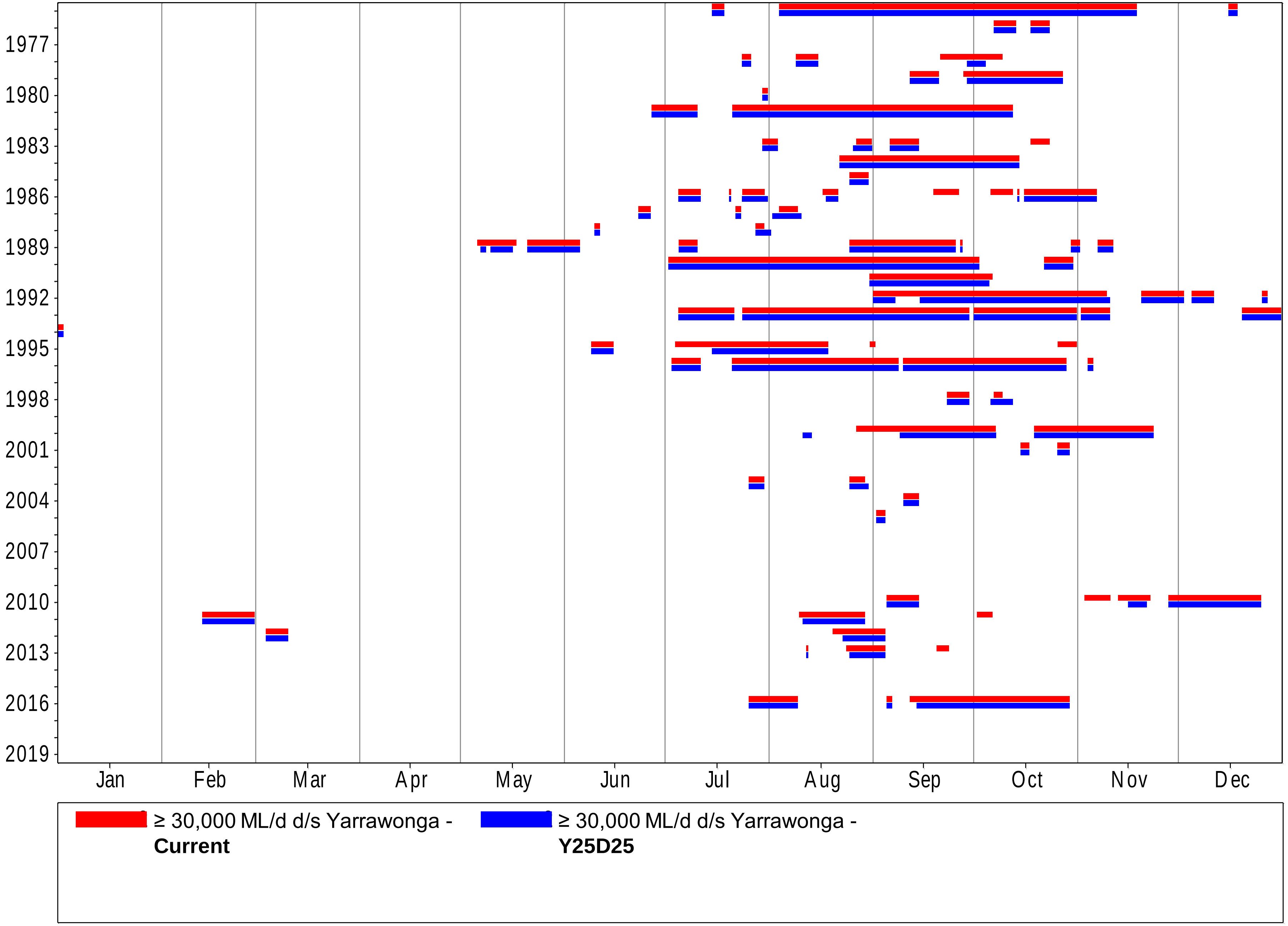
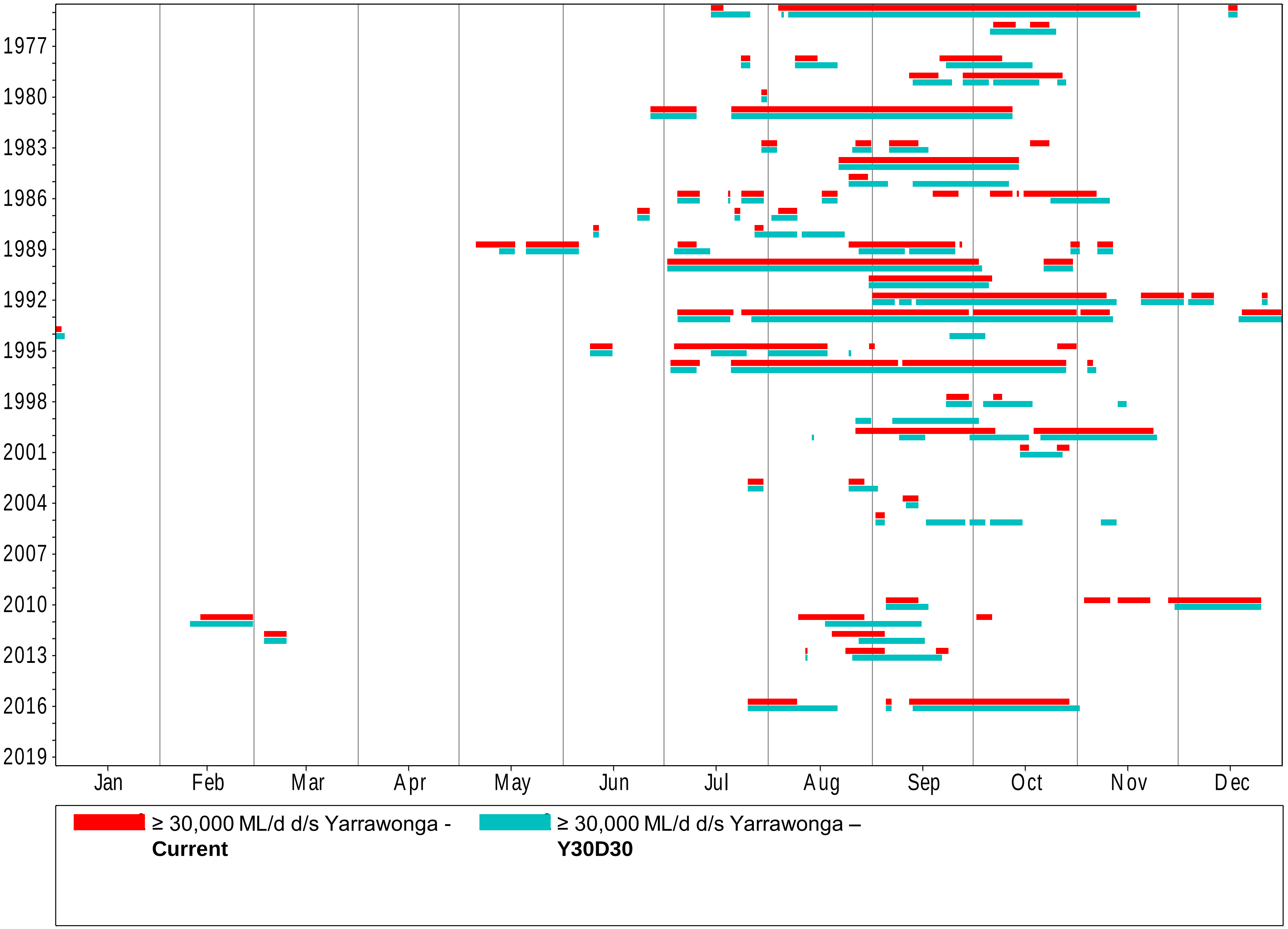
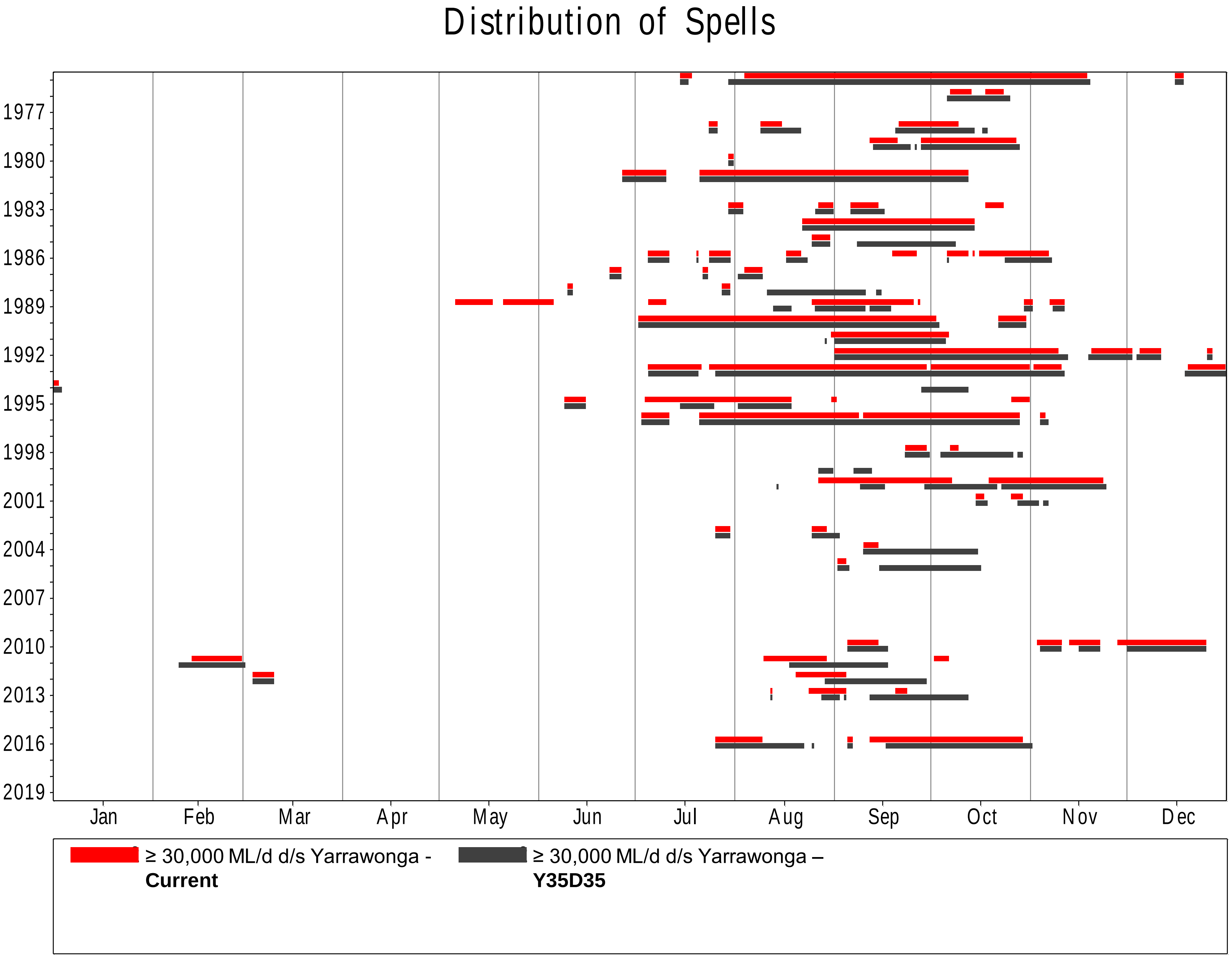
≥ 25,000 ML/d d/s Yarrawonga - Current
≥ 25,000 ML/d d/s Yarrawonga – Y45D40

Distribution of Spells



Distribution of Spells




Distribution of Spells
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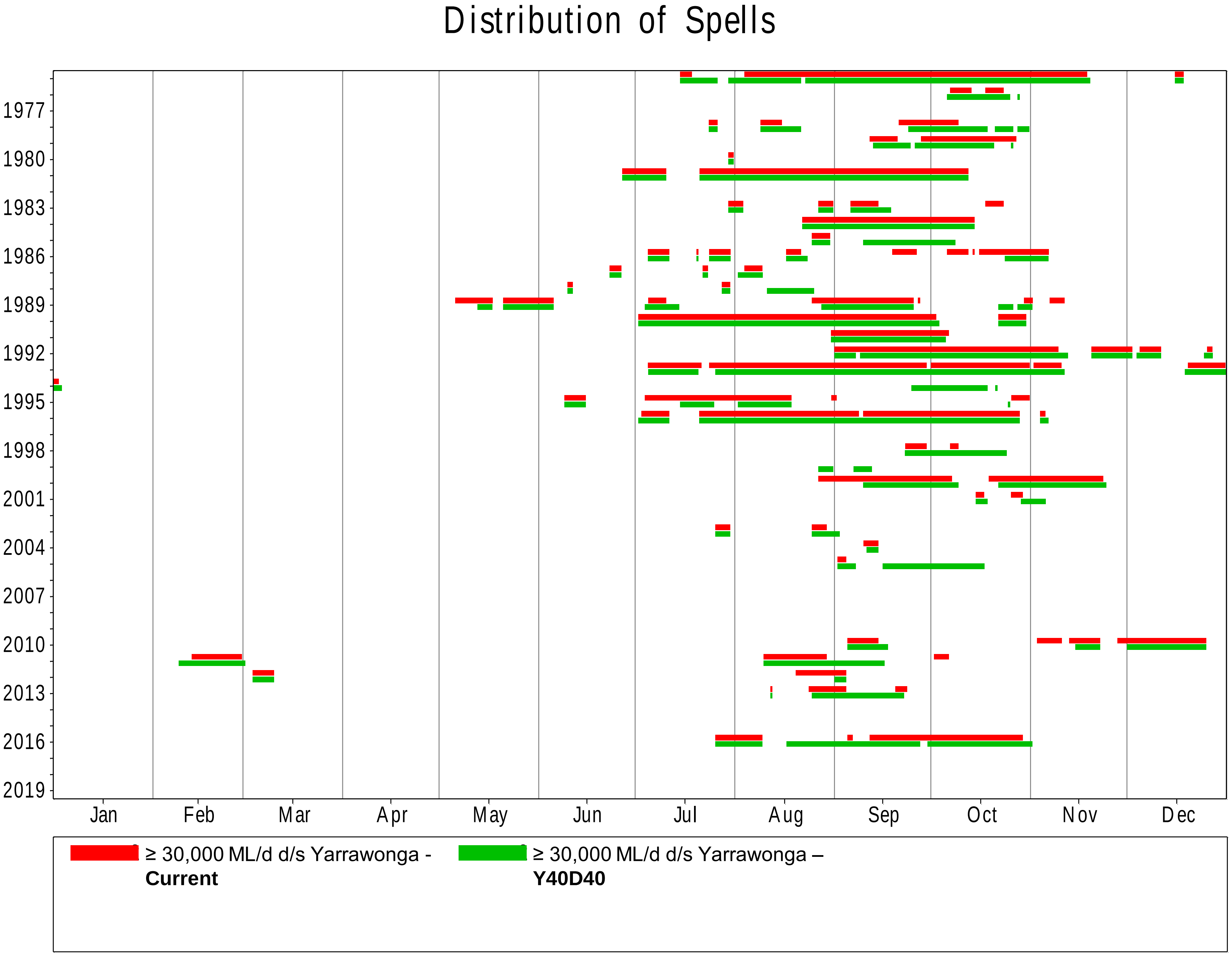
🟥 ≥ 30,000 ML/d d/s Yarrawonga - **Current**
⬛ ≥ 30,000 ML/d d/s Yarrawonga – **Y35D35**


Distribution of Spells
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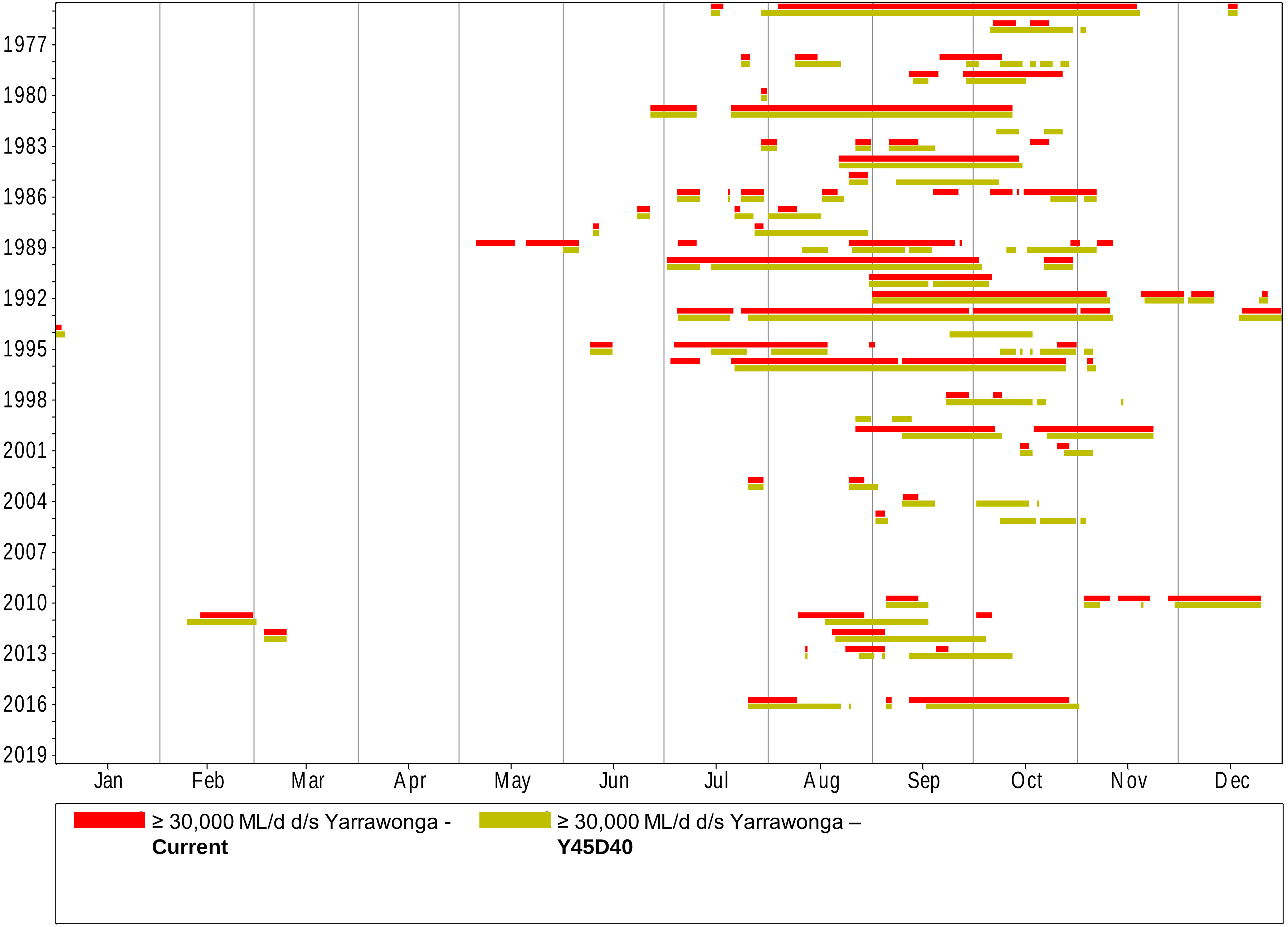
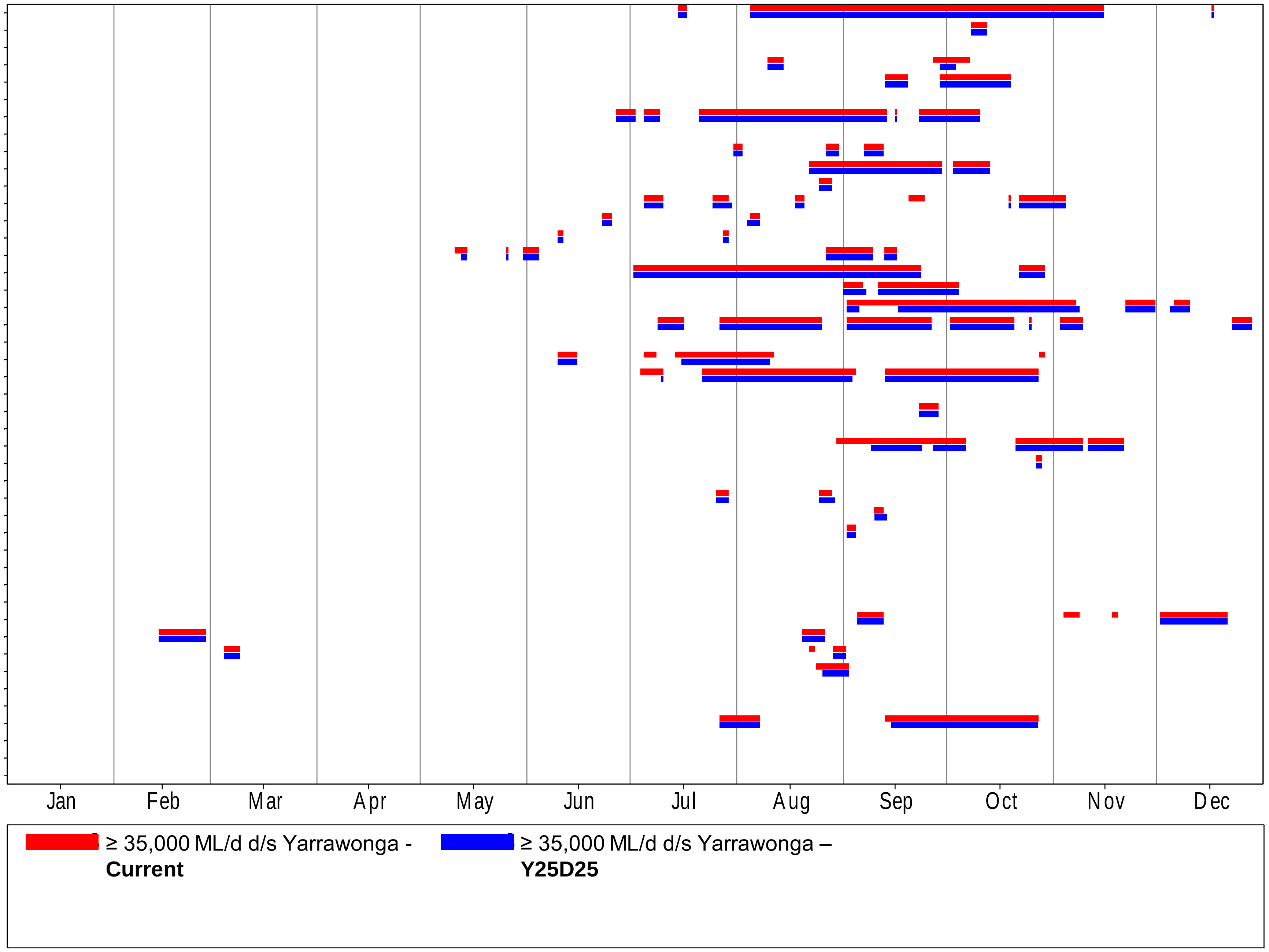
🟥 ≥ 30,000 ML/d d/s Yarrawonga - Current
🟩 ≥ 30,000 ML/d d/s Yarrawonga – Y40D40

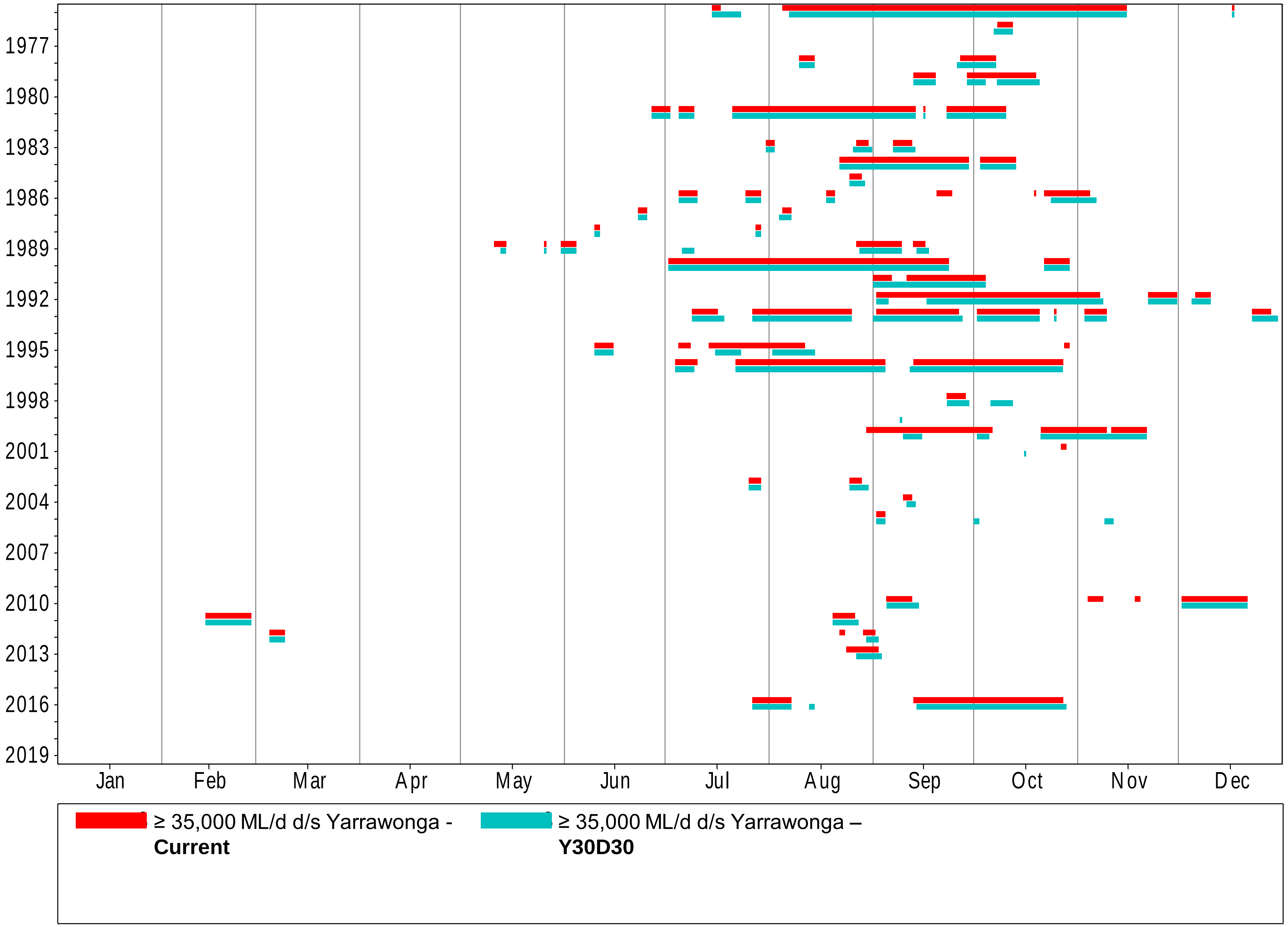
Distribution of Spells



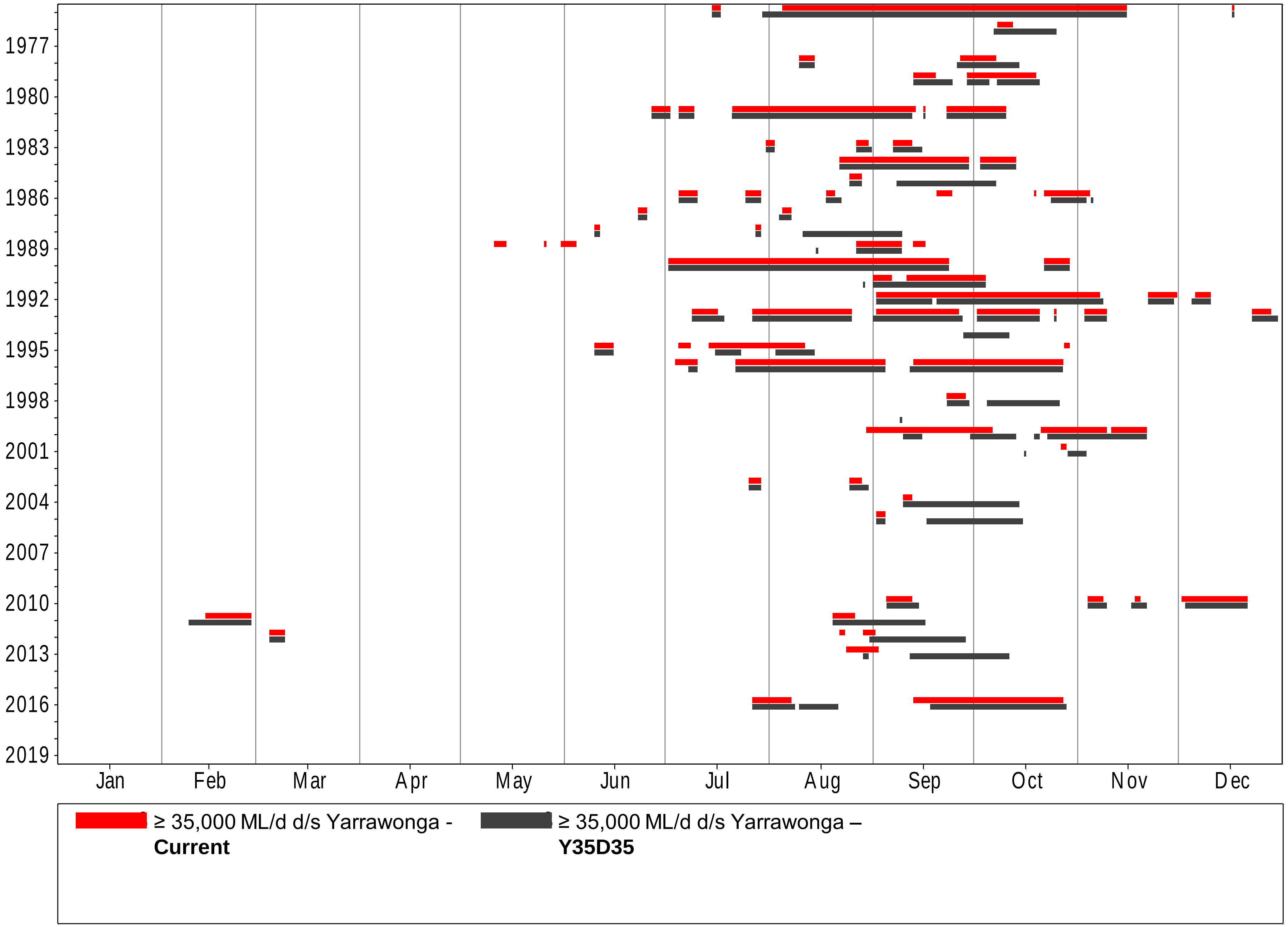
Distribution of Spells



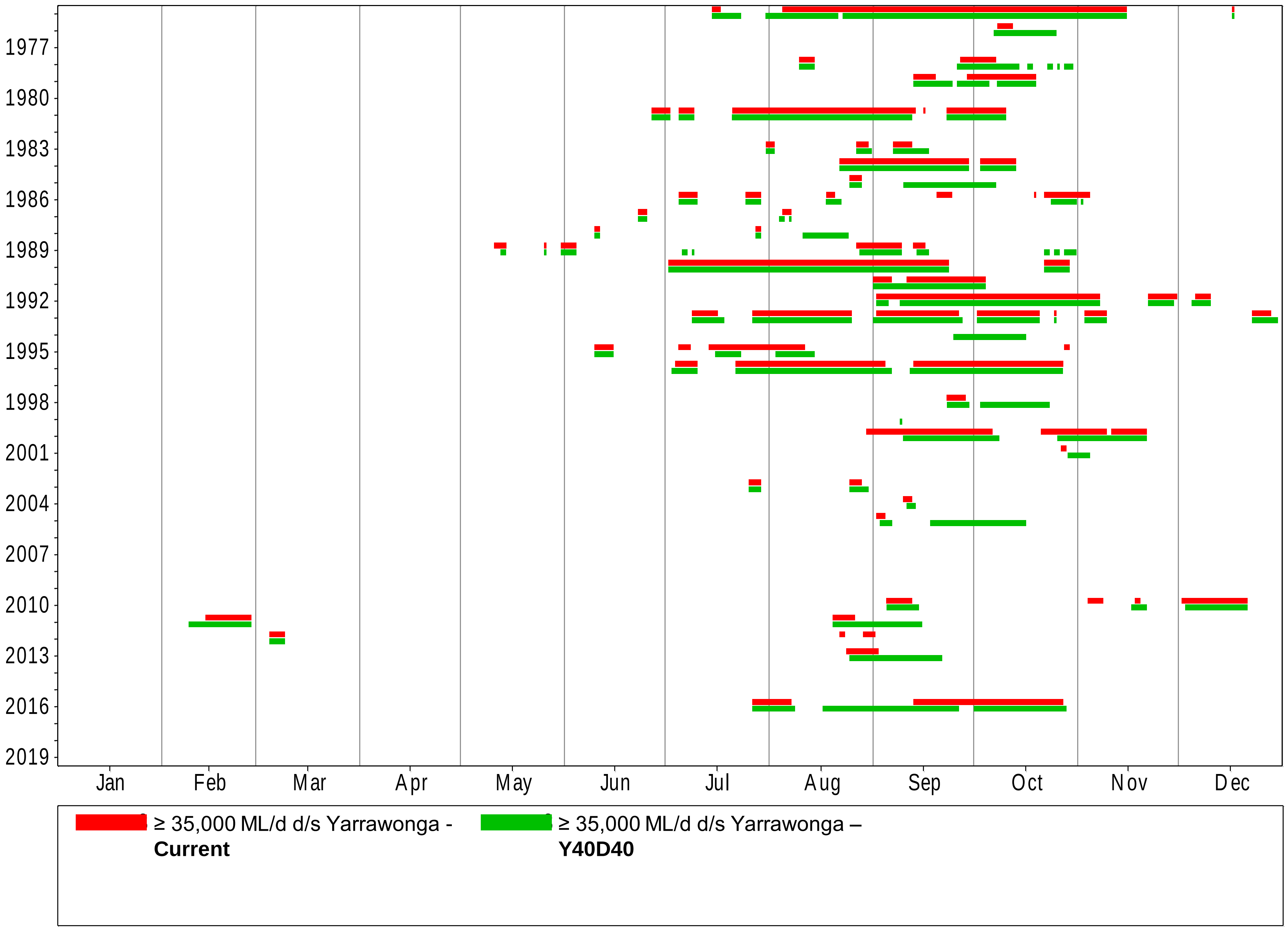
Distribution of Spells



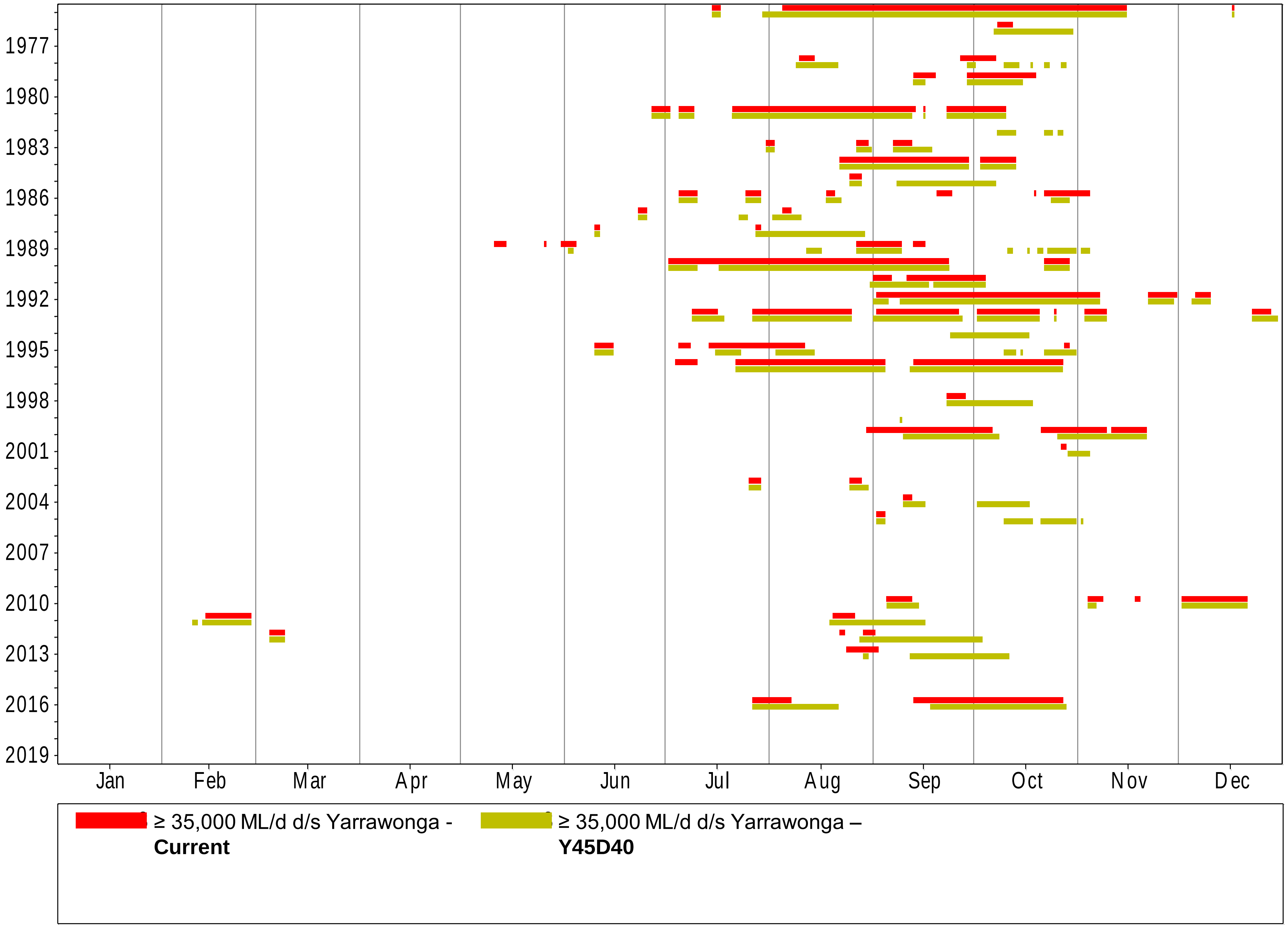
Distribution of Spells



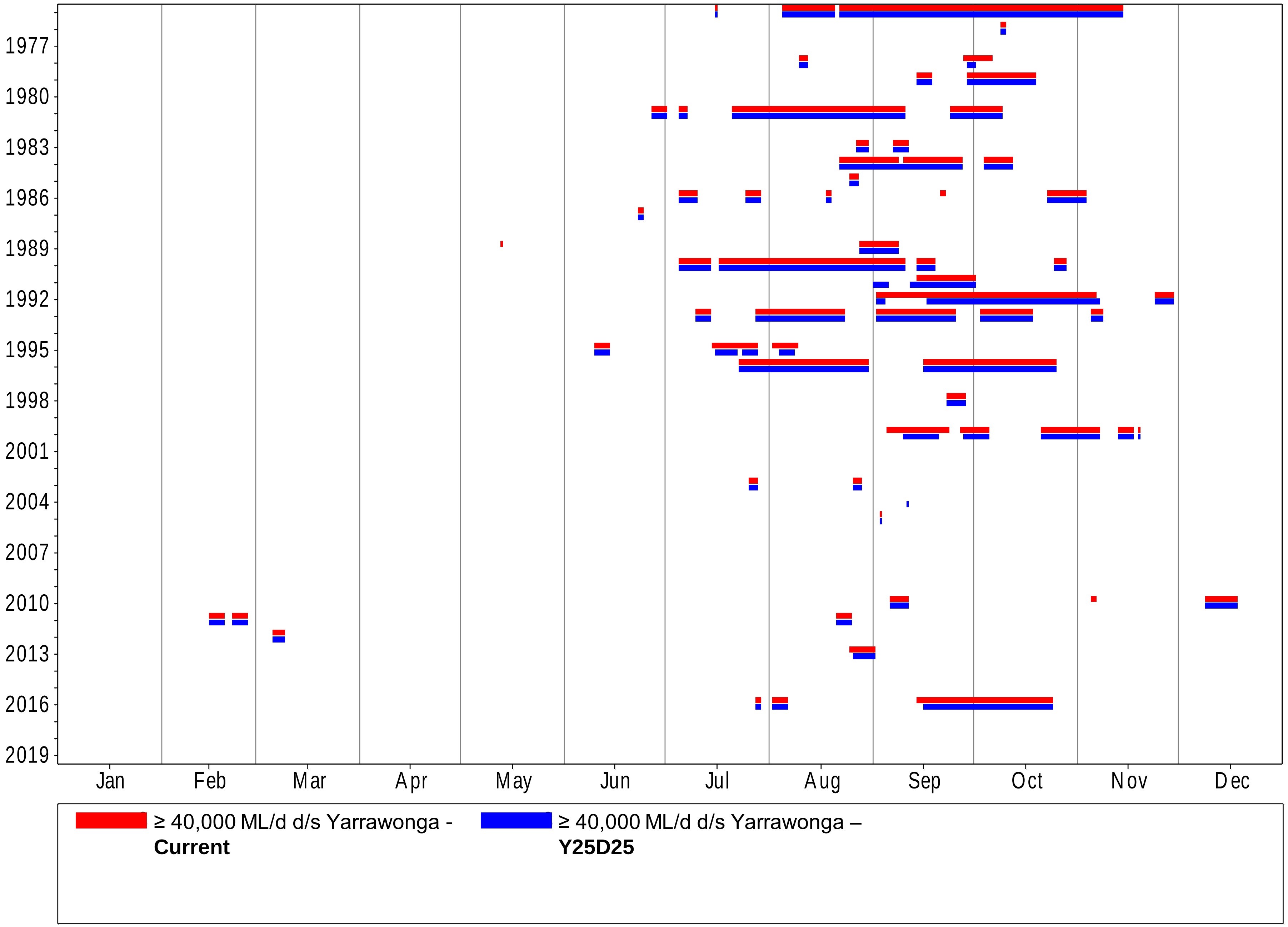
Distribution of Spells



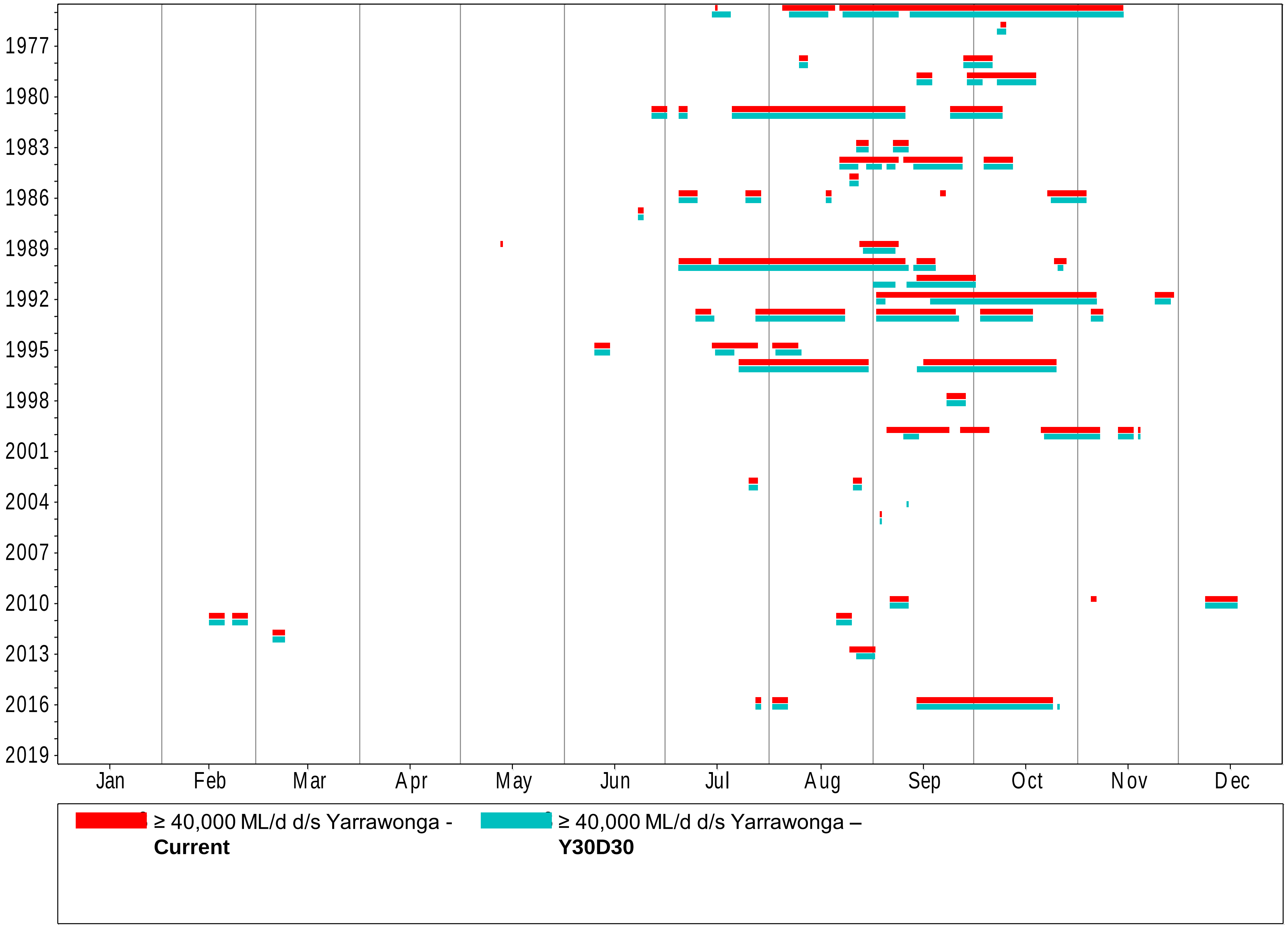
Distribution of Spells



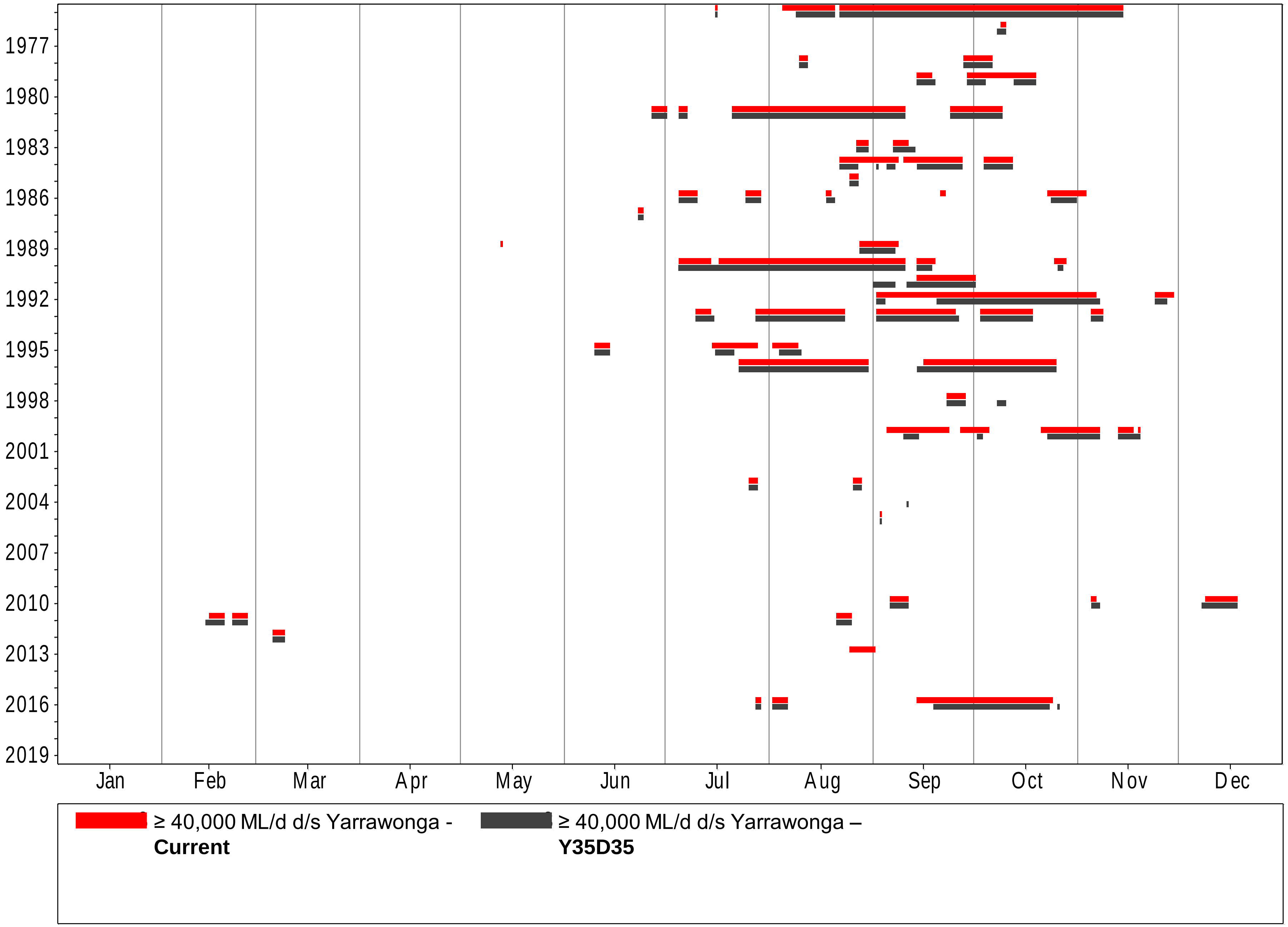
Distribution of Spells



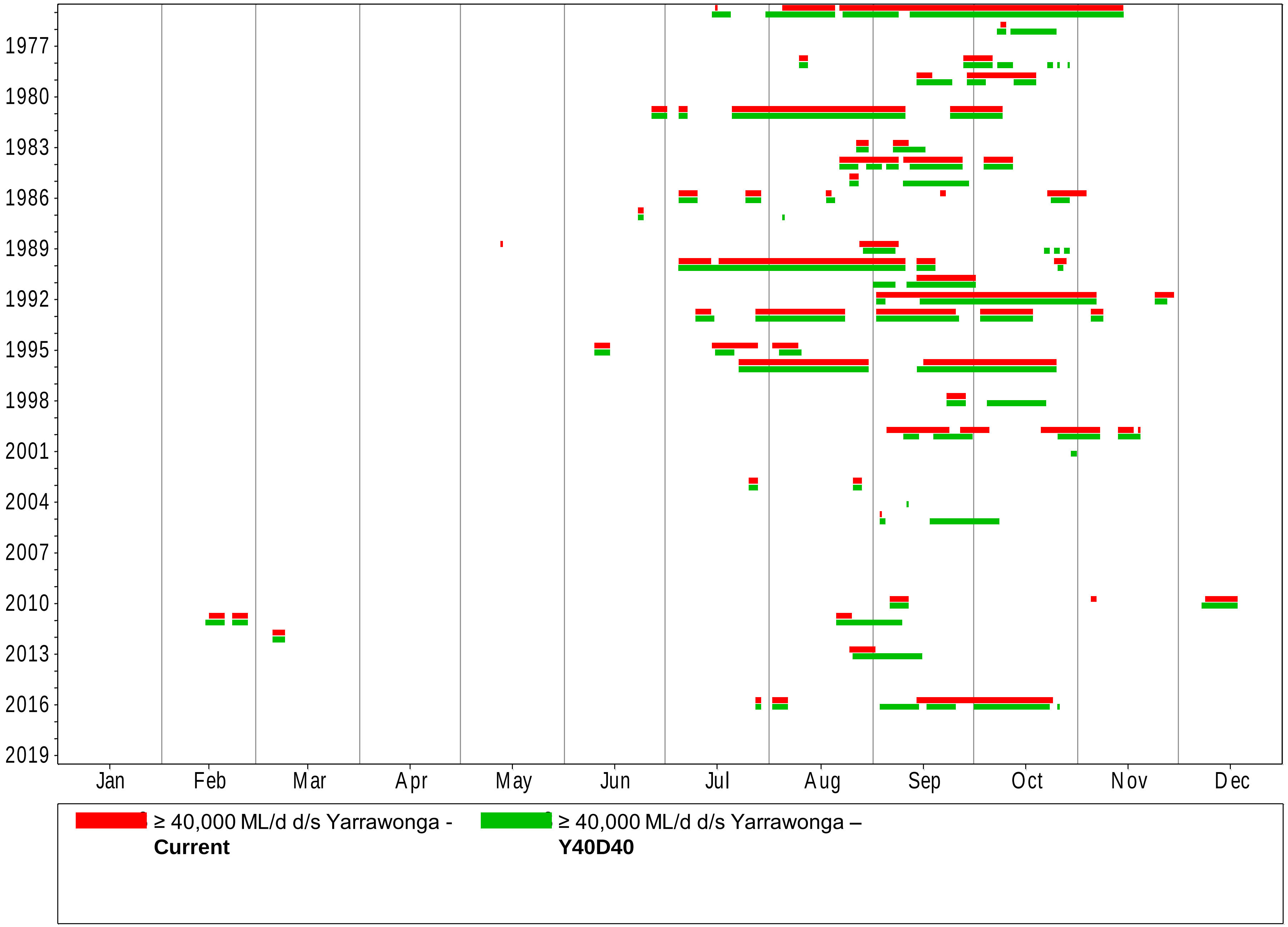
Distribution of Spells



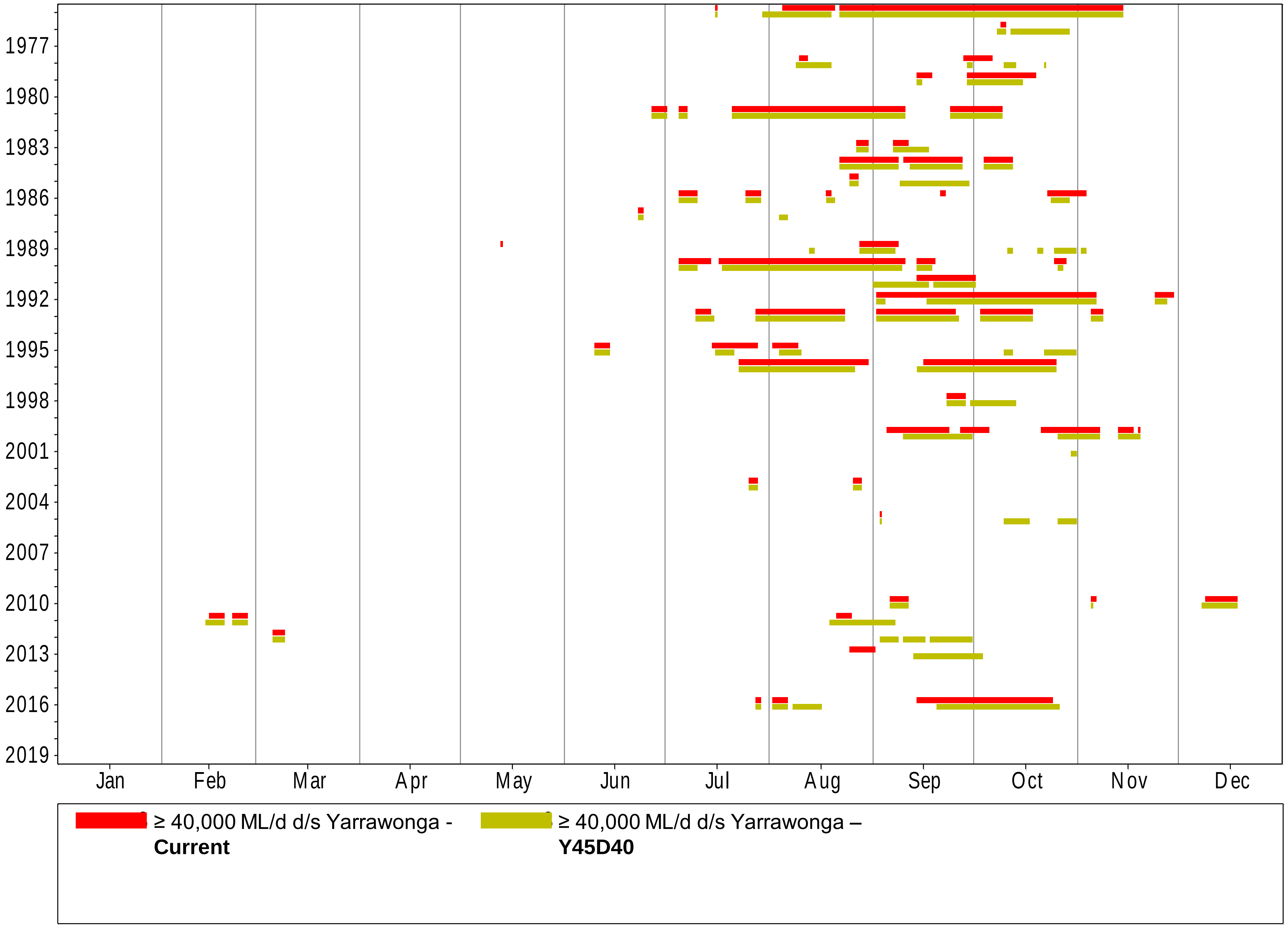
Distribution of Spells



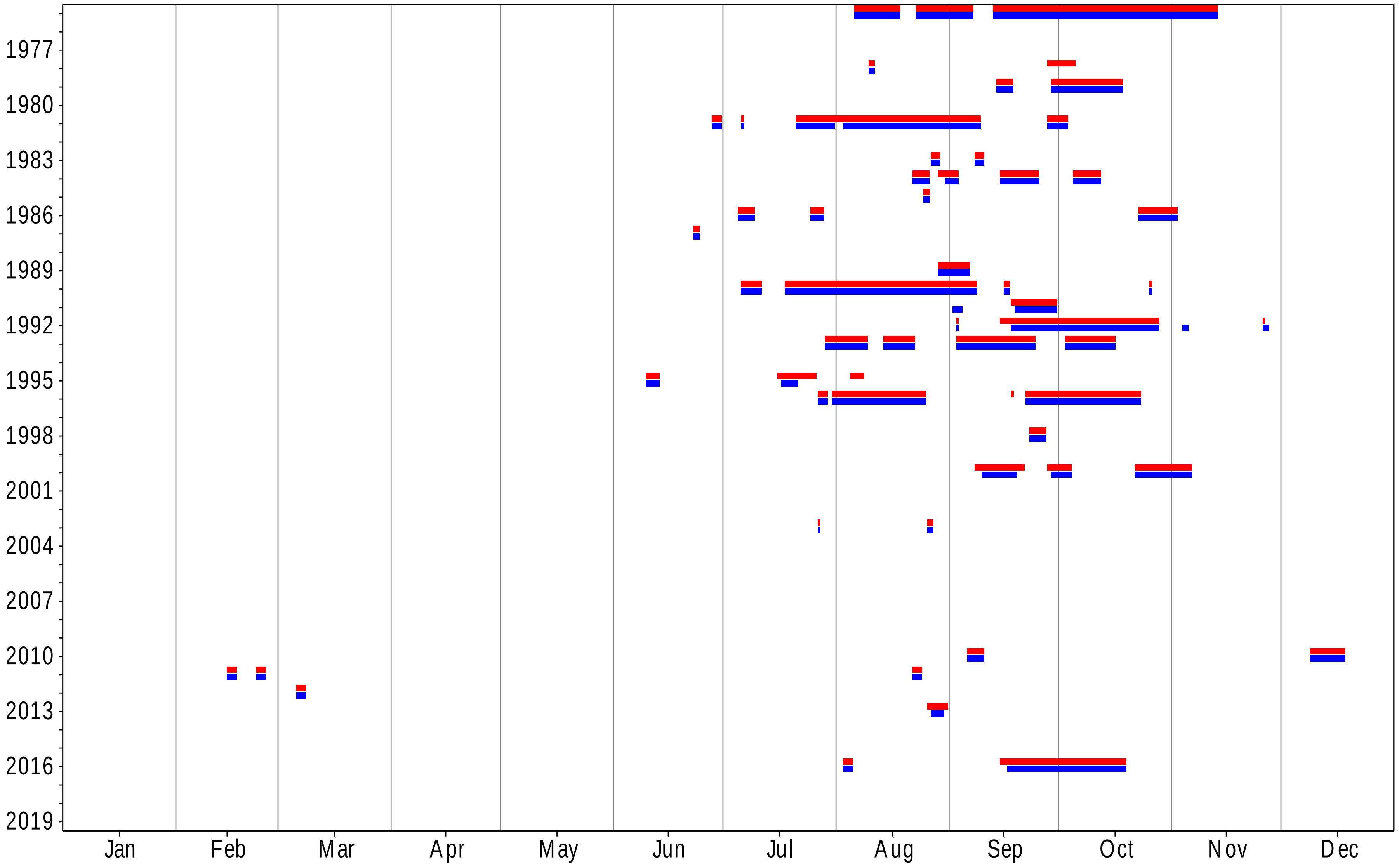
Distribution of Spells



Distribution of Spells



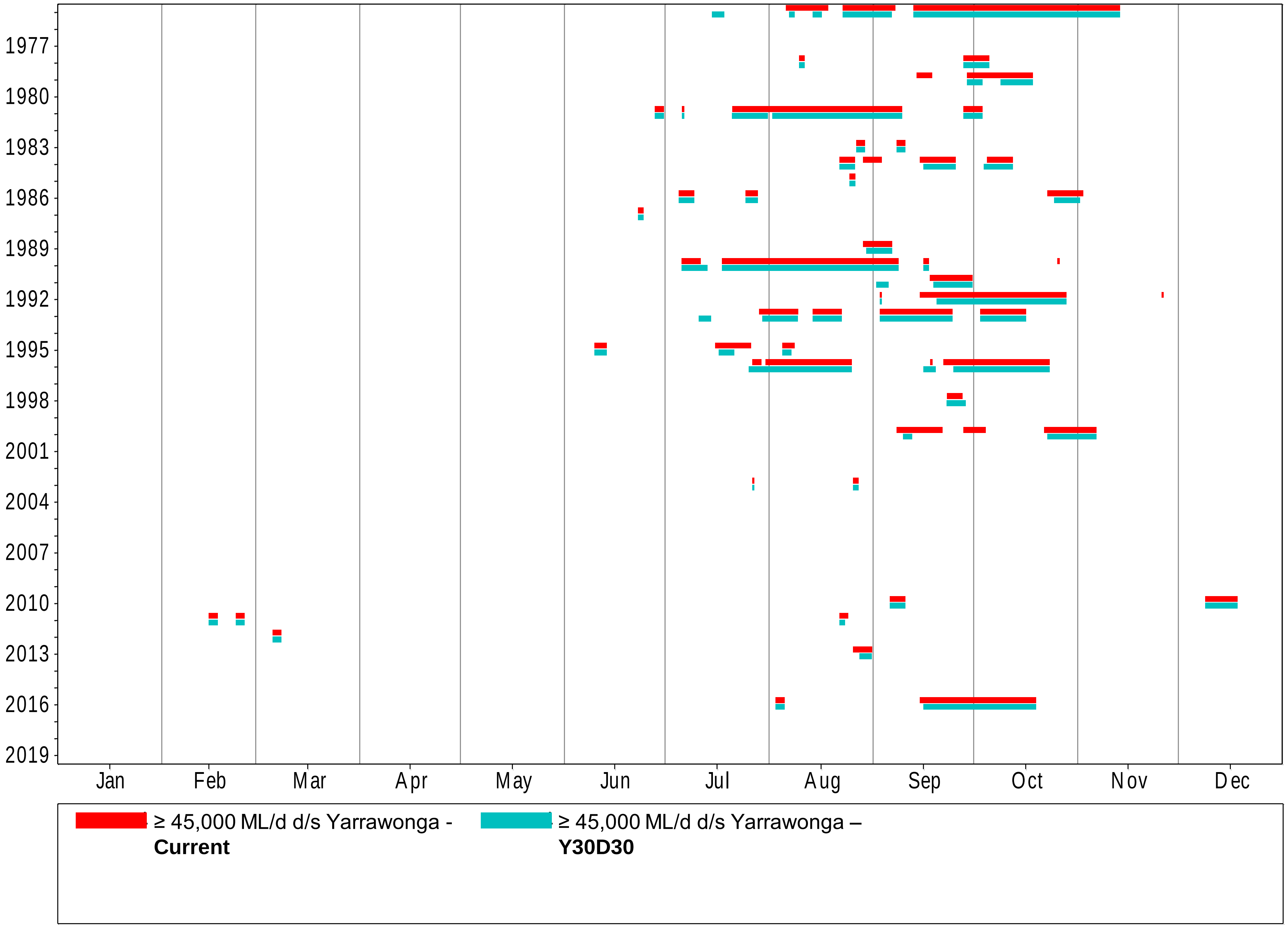
Distribution of Spells



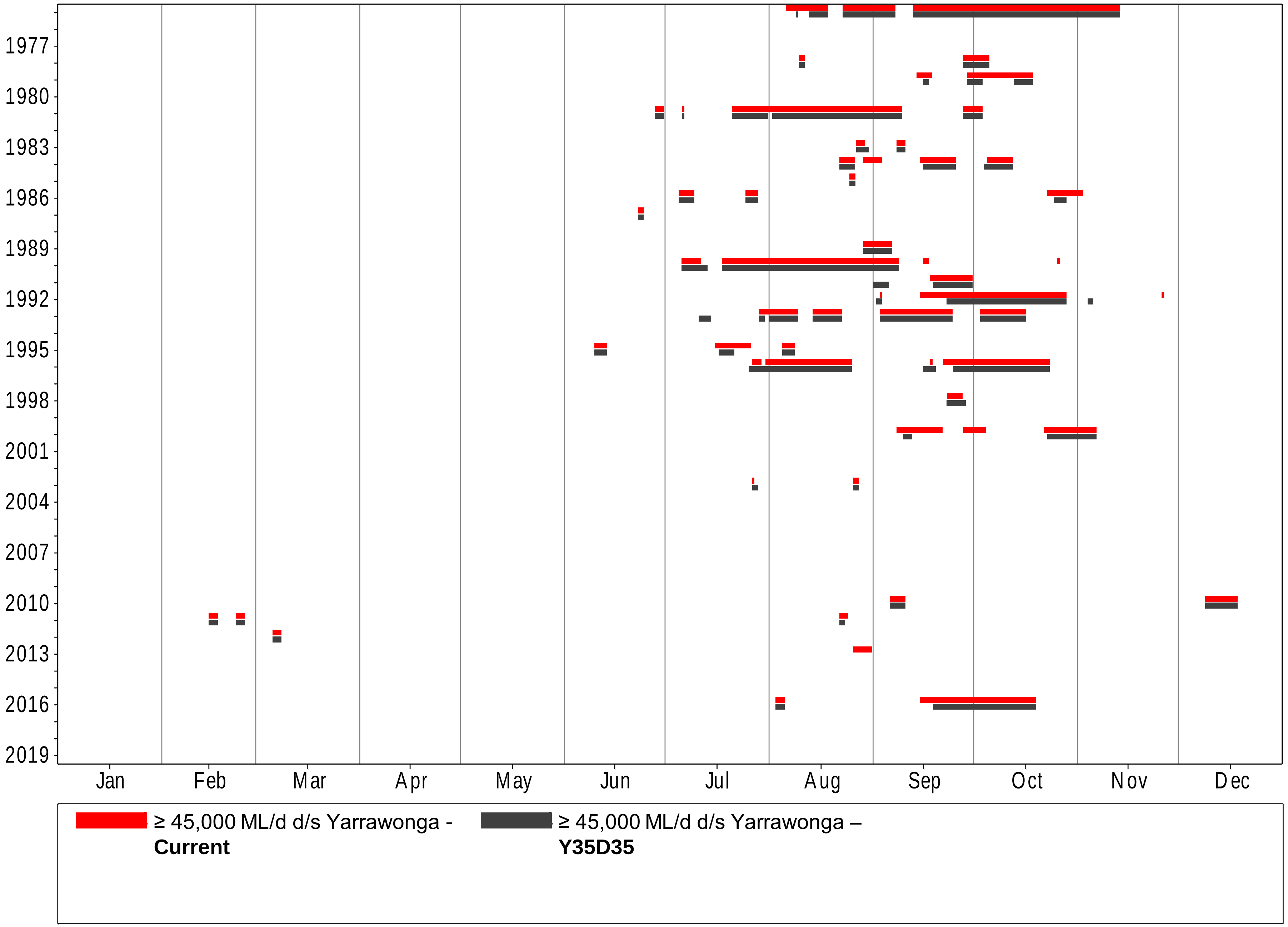
🟥 ≥ 45,000 ML/d d/s Yarrawonga - **Current**

🟦 ≥ 45,000 ML/d d/s Yarrawonga – **Y25D25**

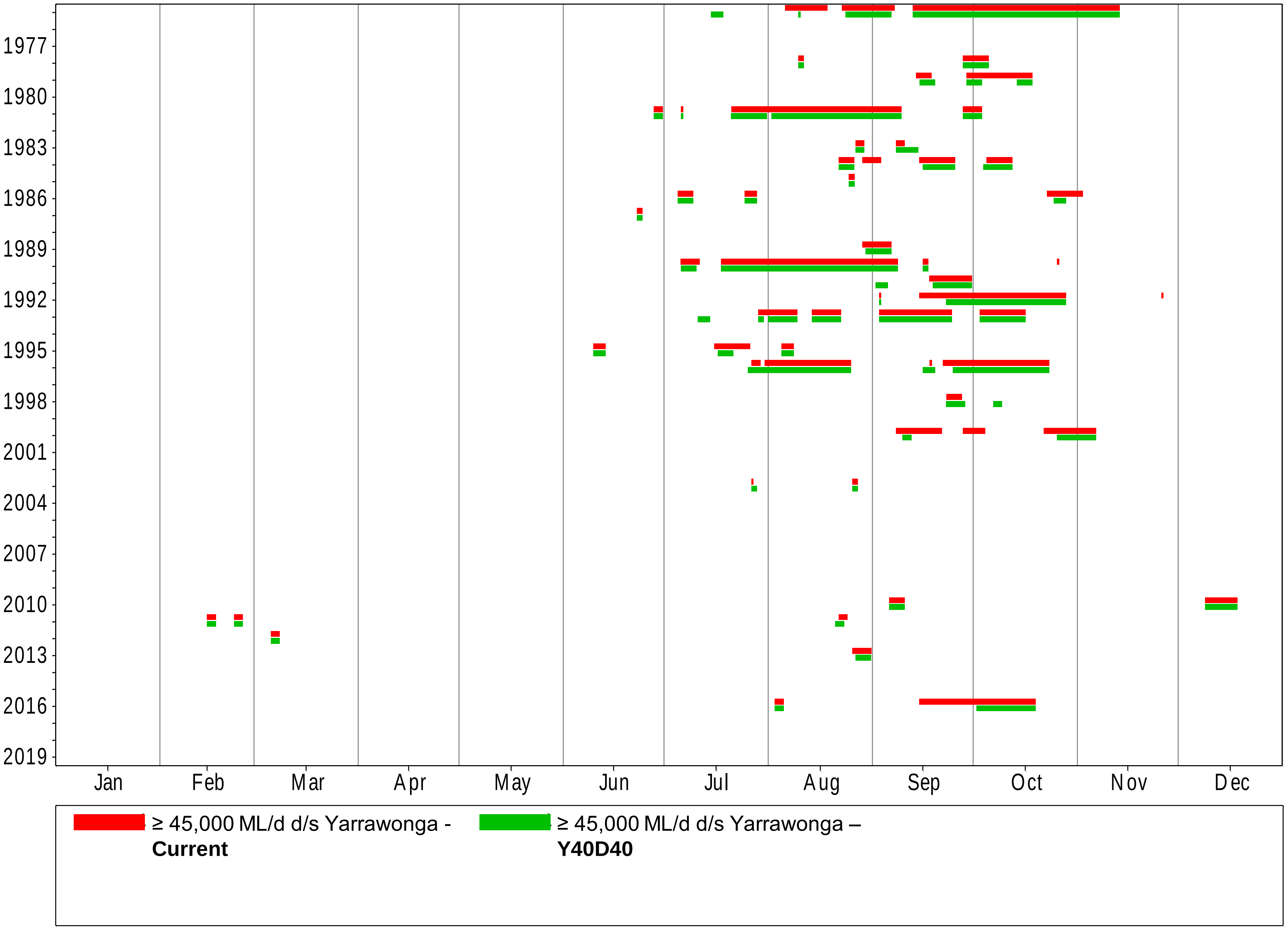
Distribution of Spells



Distribution of Spells



Distribution of Spells



Distribution of Spells