Operating options for increasing flood mitigation at Lake Eildon

Technical assessment report

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Summary Report

Introduction

This is a summary of outcomes from the technical assessment of potential operating options for increasing the flood mitigation provided by Lake Eildon. The technical assessment was commissioned by the Department of Energy, Environment and Climate Action (DEECA) following the October 2022 flood in the Goulburn River basin.

Six options were explored as part of the assessment. It was found that four of these options were not robust ways to increase the flood mitigation provided by Lake Eildon. The remaining two options did increase the flood mitigation provided by Lake Eildon; however, the cost of offsetting supply reliability impacts outweighed the avoided flood damages.

This technical summary provides background information on the project, a summary of the options investigated, and a summary of project methods and findings.

Lake Eildon

Lake Eildon was constructed in 1956 and is located on the Goulburn River, approximately 140 km north east of Melbourne. It stores water for irrigation, urban water corporations and environmental water holders. Lake Eildon holds approximately 3,334,000 ML (3,334 GL) at a full supply level (FSL) of 288.9 m AHD.

Eildon Dam consists of an earth and rockfill embankment with a concrete parapet wall, at a nominal dam crest level of 296.9 m AHD. The spillway is a concrete gravity structure controlled by three 20 m wide gates. The dam was constructed in 1955, and is owned and operated by Goulburn-Murray Water (GMW).

GMW has recorded water level in Lake Eildon on a daily basis since 1975 (Figure 2). The water level varies considerably depending on inflows, releases and other factors such as evaporation. For example, from the mid-1990s to late-2000s the effect of the Millennium Drought meant that reservoir levels were well below those observed pre-1997 and post-2011. After the Millennium Drought, Lake Eildon has been at least 99% full in four years (2011, 2012, 2022 and 2023), and releases in October 2022 were the highest since October 1993.

The Lake Eildon catchment as shown in Figure 1 encompasses an area of approximately 3,900 km^2, and the catchment area of the Goulburn River between Lake Eildon and Seymour is approximately 4,500 km^2.

The influence of releases from Lake Eildon on peak flood flows at Seymour therefore varies. For example, in October 1993 the peak outflow from Lake Eildon made a significant contribution to the peak flow at Seymour. In contrast, in October 2022 – which was the largest flood recorded at Seymour – the peak outflow from Eildon occurred after the flood peak at Seymour. The Lake Eildon releases therefore had a much smaller effect on the flood peak in Seymour in October 2022 compared with October 1993.

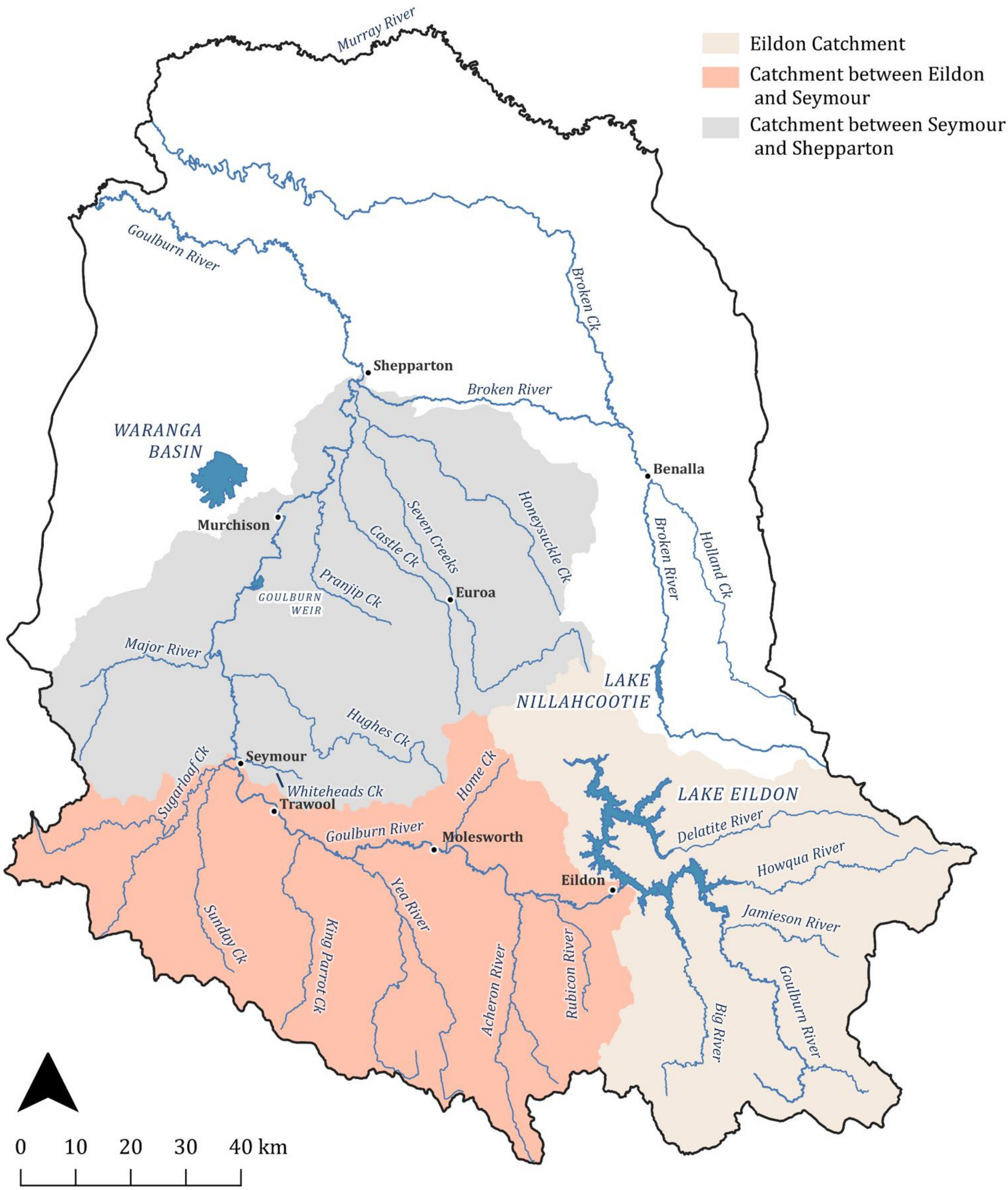

Figure 1: Overview of major river systems and catchments in the Goulburn River basin

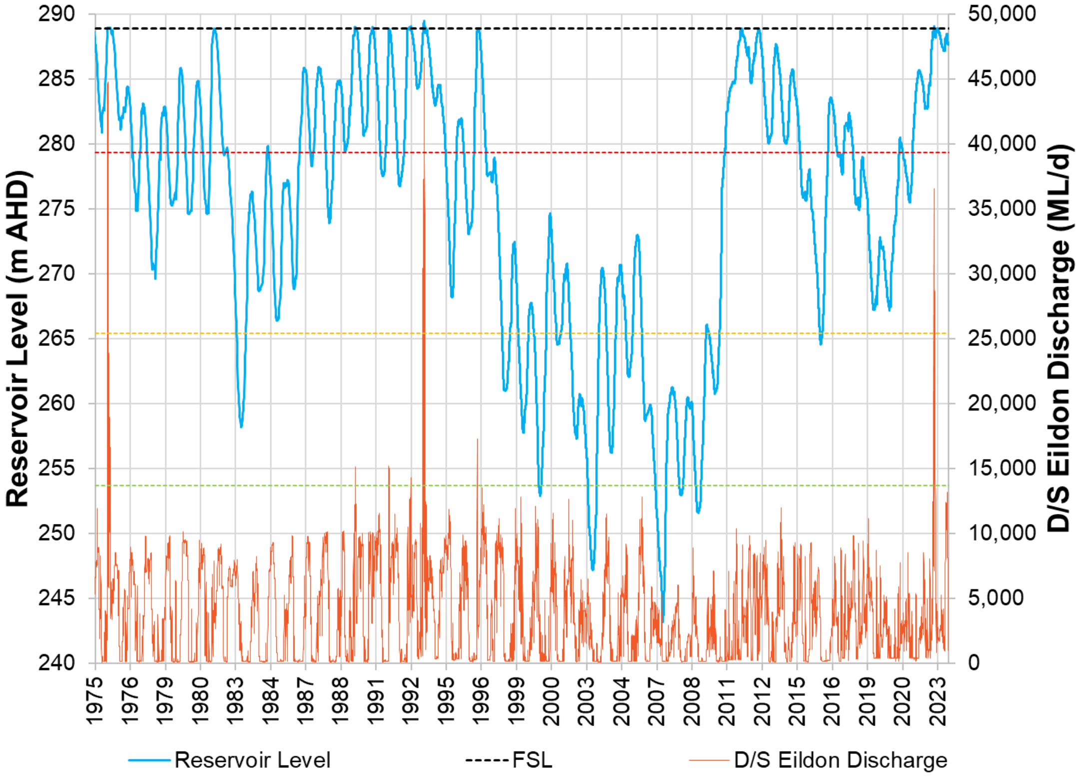

Figure 2: Recorded storage level (blue series) and releases from Lake Eildon (orange series) for the period from January 1975 to August 2023. Data supplied by GMW up until 2015 and supplemented with WMIS (https://data.water.vic.gov.au/monitoring.htm) data to 2023. The green, orange and red horizontal lines are the minor, moderate and major flood class levels downstream of Lake Eildon, respectively.

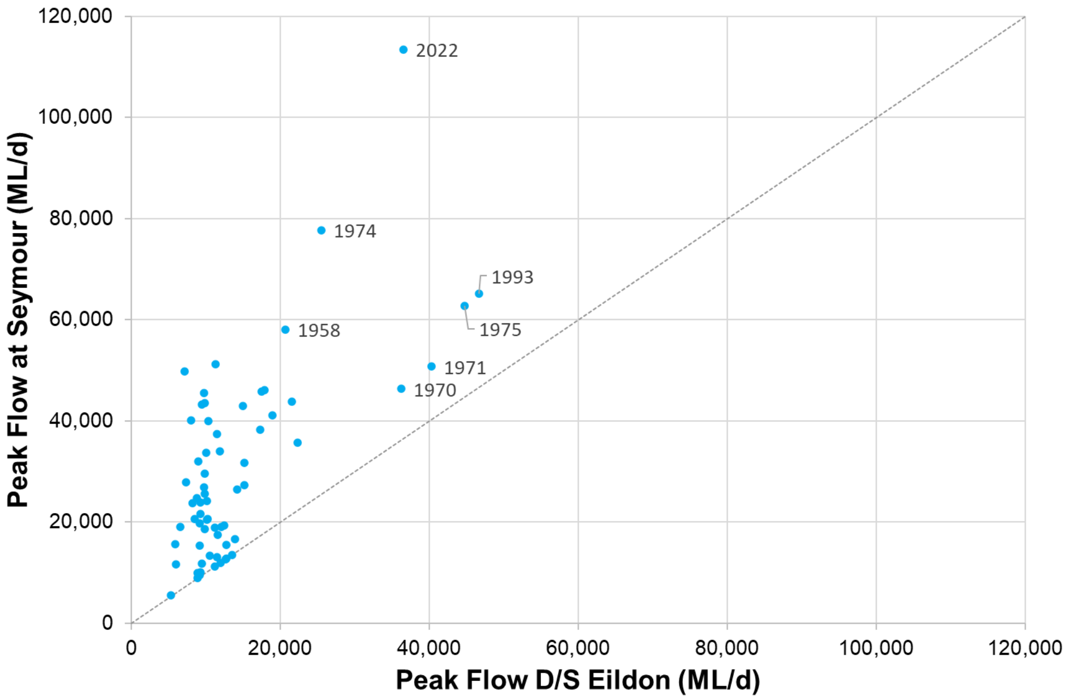

Figure 3: Peak releases from Lake Eildon versus peak flows at the Seymour for each water year, shown as an x-y scatter plot

Downstream flow constraints

The degree to which operational releases can be made from Lake Eildon depends on downstream flow constraints. The current constraints along the Goulburn River are:

- 9,500 ML/d at Eildon
- 10,000 ML/d at Molesworth (mid-Goulburn); noting though that this location does not currently have a streamflow gauge
- 9,500 ML/d at Murchison and Shepparton (lower Goulburn)

Releases above the downstream flow constraints can be made by the storage manager in order to meet the dam safety requirements in GMW's operating objectives, or if Lake Eildon is above the filling curve target and is expected to keep filling.

Options investigated for increasing the flood mitigation provided by Lake Eildon

This assessment examined six operating options for increasing the flood mitigation provided by Lake Eildon. The initial assessment (referred to as stage 1) included assessments of the water resource implications, flood frequency changes at Lake Eildon, and anticipated changes to 1993 and 2022 peak outflows from Lake Eildon (if the events were repeated) for the following options:

- Option 1 – Change the target filling curves at Lake Eildon
- Option 2 – Reduce the target storage at Lake Eildon
- Option 3 – Reduce the target storage at Lake Eildon based on climate signals that indicate 'wet' conditions
- Option 4 – Make higher pre-releases at Lake Eildon based on forecast rainfall
- Option 5 – Increase the maximum allowable surcharge level at Lake Eildon
- Option 6 – Restrict the maximum outflows from Lake Eildon

These options were selected based on a workshop with Department of Energy, Environment and Climate Action (DEECA), Goulburn-Murray Water (GMW), Goulburn Valley Water (GVW), the Goulburn Broken Catchment Management Authority (GBCMA), Melbourne Water retailers (represented by Greater Western Water), the Victorian Environmental Water Holder (VEWH), Murrindindi Shire Council, Mitchell Shire Council and Strathbogie Shire Council. Greater Shepparton City Council, Mansfield Shire Council, Coliban Water and Grampians Wimmera Mallee Water were invited to the workshop but were unable to attend.

After the stage 1 assessment, four of the six options were not progressed for further assessment, as it was found that the options were not robust ways to increase the flood mitigation provided by Lake Eildon:

- The option to reduce the target storage based on climate signals that indicated 'wet' conditions (option 3) was not a robust option because the climate signals tested were generally poor predictors of monthly inflows and storage volumes at Lake Eildon. This meant that – when combined with the influence of downstream flow constraints during wet periods – the option to reduce target storage based on climate signals was unlikely to increase the flood mitigation provided by Lake Eildon. For example, the 1993 flood occurred during El Niño conditions and during spring 2022 downstream flow constraints limited the ability to provide additional airspace.

- Increasing pre-releases from Lake Eildon based on forecast rainfall (option 4) was not deemed to be a robust option, because the uncertainty in the predicted location of where rainfall will be heaviest will constrain the degree to which storage operators can confidently make pre-releases without either reducing the water available to entitlement holders or making downstream flooding worse. Furthermore, the event-based analysis of the October 1993 and October 2022 floods showed that higher pre-releases (i.e. at the moderate flood class level flow threshold downstream of Lake Eildon), the peak flows would have increased at Seymour by up to 11%.
- The option to change the maximum surcharge (option 5) will increase the duration of Lake Eildon outflows above the minor, moderate and major flood class level flow thresholds at Eildon as floods pass through the storage, and increase the likelihood of the dam overtopping during back-to-back floods.
- The option of restricting the maximum outflow from Lake Eildon (option 6) would extend the duration of outflows above the minor, moderate or major flood class level flow thresholds at Eildon, and increase dam safety risks.

The two options which were progressed to stage 2 of the assessment were changing the target filling curve (option 1) and reducing the target storage (option 2). A brief description of each of these options is provided below.

Option 1: Change Lake Eildon target filling curve

The option to change the target filling curve involves managing the storage levels using different probability of exceedance inflows or target fill dates, so that the chance of Lake Eildon filling is reduced and/or Lake Eildon is full later in the year (e.g. January or December instead of October or November). GMW utilises the Bureau of Meteorology's seasonal streamflow forecasts for Lake Eildon and considers expected releases to help determine the target filling points. The streamflow forecasts are based on the current catchment conditions, historical inflow records and climate outlooks, and provide a range of possible inflow conditions for the months ahead.

Changes to the target filling curves would provide additional flood mitigation benefits if events occur when the storage is being held lower than under current conditions. In this technical assessment, the option to change the target filling curves considered a range of climate conditions (e.g. historical and post-1975 conditions), fill-by dates, and probabilities of exceedance for inflows was changed from 95% to 85% or 75%.

The degree to which this option reduces peak river flows diminish with increasing distance downstream of Lake Eildon, because of tributary inflows along the Goulburn River.

Option 2: Reduce Lake Eildon target storage

This option involves lowering the target storage – to the degree possible – to a defined proportion of full supply level (FSL) (e.g. 78%, 85%, 90%, 95%) all year round to provide enhanced capacity to capture flood flows.

The degree to which this option reduces peak outflows from Lake Eildon varies by event because of downstream flow constraints. For example, in 1993 and 2022 inflows in the months prior to the floods were such that the storage could not have been held at a defined target before either event without making releases in excess of the downstream flow constraint.

Assessment method

For the different filling curves (option 1) and target storages (option 2), the water resource implications, flood frequency changes, anticipated changes to 1993 and 2022 outflows from Lake Eildon (if the events were repeated), initial capital costs[1], upstream water level implications, downstream flow regime changes, and potential reductions of tangible flood damages[2] have been considered from Lake Eildon to Seymour.

The assessment was informed by applying existing water resource and flood models. Results from the technical analyses are suitable for high-level comparisons between current conditions and what is anticipated if the options were implemented. The relative differences between options are not expected to change significantly as models are updated or more work is completed, but specific values quoted in this report will become superseded.

Changes to flooding if the 1993 or 2022 events were repeated

Adopting different filling curves (option 1) or target storages (option 2) of 95%, 90% or 85% of FSL at Lake Eildon would not have significantly changed the outcomes observed in October 1993 and October 2022. The sustained inflows and downstream flow constraints in the months prior to the October 1993 and October 2022 flood events were such that the storage could not have been held at a defined target before either event. The full technical assessment report includes more detail to support these statements.

For the option to reduce the target storage to 78% of FSL, Figure 4 shows how the outflows from Lake Eildon would differ if the 1993 flood were repeated. This option would have resulted in lower outflows from Lake Eildon, and a significant reduction in peak flows at Molesworth and Seymour.

Figure 5 provides a similar analysis of the 2022 flood. In October 2022, the reduced target storage of 78% of FSL provides less additional flood mitigation downstream of Lake Eildon and at Molesworth and Seymour. Although releases from Lake Eildon are reduced this has minimal flood mitigation impact because the tributaries downstream of Lake Eildon made a much larger contribution to the flood peaks in Molesworth and Seymour in 2022 compared with 1993.

The technical assessment has therefore demonstrated that the degree to which the options will increase the flood mitigation provided by Lake Eildon will vary from event to event.

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[1] The scope of work did not include the ongoing socio-economic costs of reducing the volume of water stored in the Goulburn system.

[2] This analysis does not account for the intangible damages caused by flooding, such as mental health impacts for individuals, or unwanted changes to community dynamics as well as the duration of inundation flood damages to agricultural land uses.

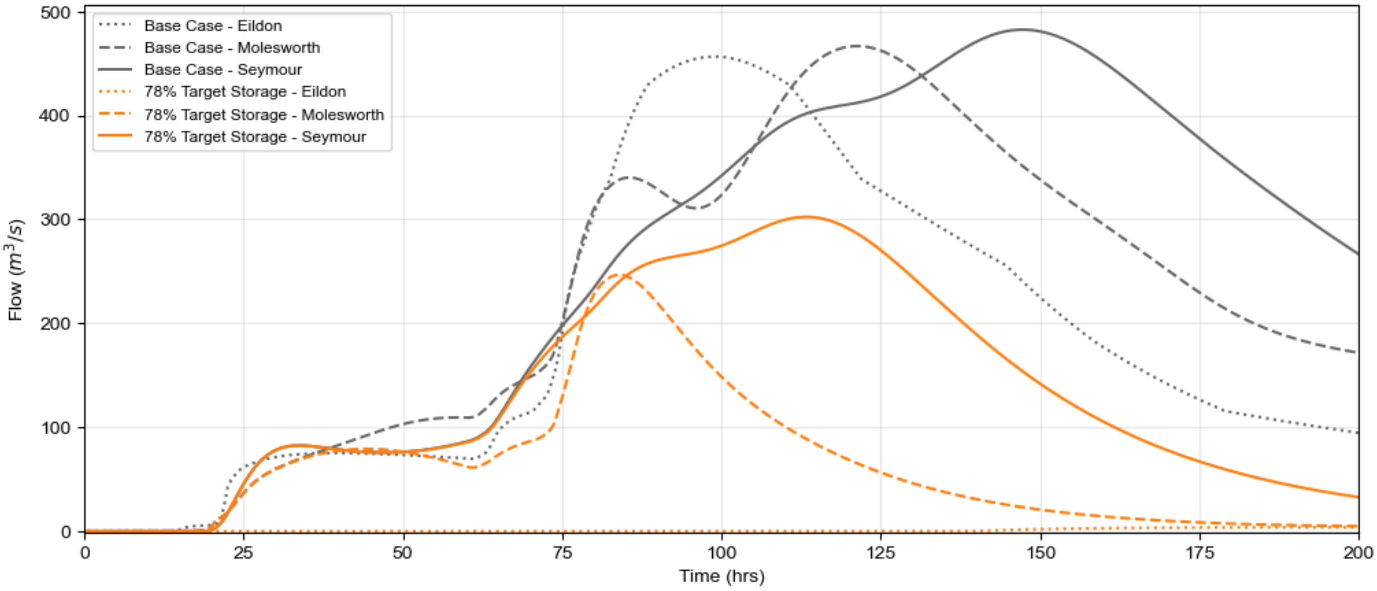

Figure 4: The modelled (in RORB) changes that 78% target storage would make to the outflows from Lake Eildon if the October 1993 flood were repeated. 1 m³/s equals 86.4 ML/d. The other target filling curve and reduced target storage options (95%, 90% and 85% of FSL) have not been plotted due to the similar hydrographs at Lake Eildon, Molesworth and Seymour.

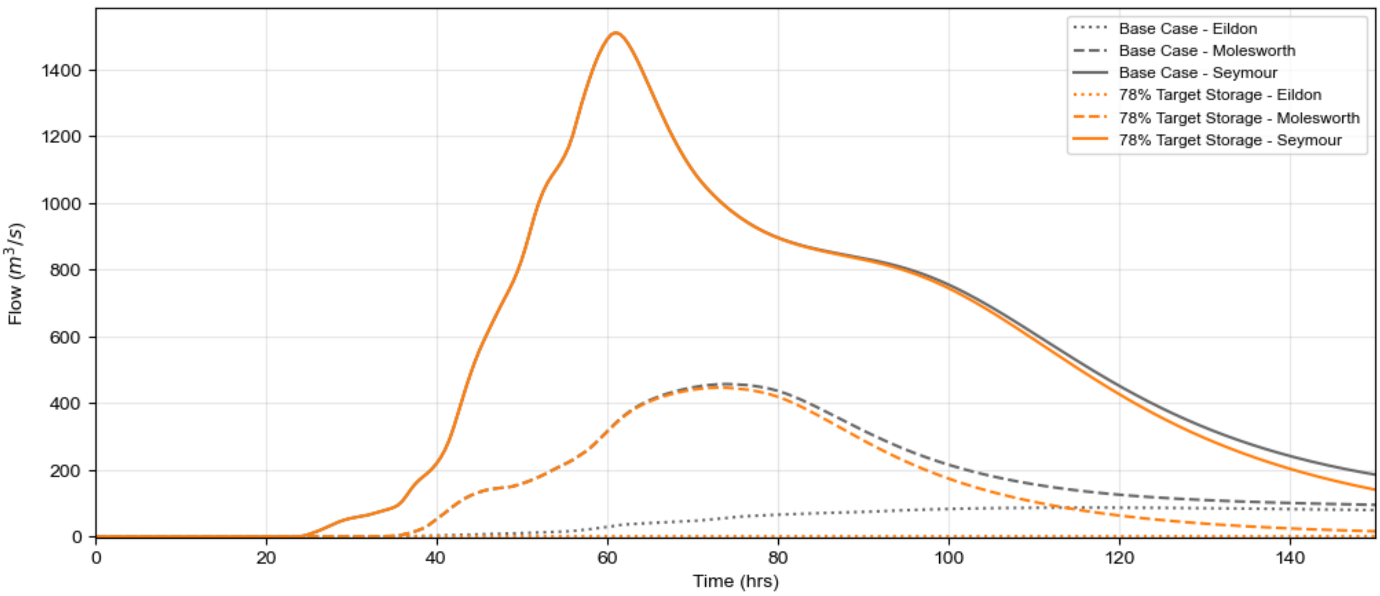

Figure 5: The modelled (in RORB) changes that various options would make to the outflows from Lake Eildon if the October 2022 flood were repeated. 1 m³/s equals 86.4 ML/d. The other target filling curve and reduced target storage options (95%, 90% and 85% of FSL) have not been plotted due to the similar hydrographs at Lake Eildon, Molesworth and Seymour.

Table 1 provides an indicative assessment of how the options would have changed flood damages from Lake Eildon to Seymour. The flood damage values combine damages estimated for buildings and contents (residential and non-residential), vehicles, road and rail, and agriculture. It should be noted that the agricultural flood damages are likely to be underestimated because they have been assessed using peak flows rather than the timing and duration of inundation. However, this is unlikely to change the conclusions of this study.

The tangible flood damages along the Goulburn River for the 2022 base case scenario was estimated to be $410 million (Table 1). The tangible flood damages in Seymour contributed to approximately 80% of the estimated total cost and the other 20% was between Lake Eildon to upstream of Seymour. For context, Deloitte (2023)[3] estimated the tangible cost of the October 2022 flood to be $432 million for the local government areas (LGAs) of Mitchell, Moira, Murrundindi and Strathbogie. Only the Mitchell and Murrundindi LGAs are within the study area for this assessment of potential options for increasing the flood mitigation provided by Lake Eildon, however, it is reassuring that the estimated tangible flood damages for the October 2022 flood are the same order of magnitude as the Deloitte (2023) estimate.

Table 1: Tangible flood damages at Lake Eildon, Molesworth and Seymour to reduced target storage options for 95%, 90%, 85% and 78% of FSL capacity if the October 1993 and October 2022 flood was repeated

Event – Option	Approximate flood damages (in millions)				
	Lake Eildon to U/S Molesworth (rounded)	Molesworth to Seymour (rounded)	Seymour (rounded)	Total (rounded)	Difference v base case
1993 – base case	$40	$20	$80	$140	-
1993 – 95% target storage	$40	$20	$80	$140	$0
1993 – 90% target storage	$40	$20	$80	$140	$0
1993 – 85% target storage	$40	$20	$80	$140	$0
1993 – 78% target storage	$20	$10	$10	$40	$100
2022 – base case	$40	$30	$340	$410	-
2022 – 95% target storage	$40	$30	$340	$410	$0
2022 – 90% target storage	$40	$30	$340	$410	$0
2022 – 85% target storage	$40	$30	$340	$410	$0
2022 – 78% target storage	$30	$30	$340	$400	$14

Water resource implications

The options that involve changing the target filling curve (option 1) or lowering the target storage at Lake Eildon (option 2) would reduce the reliability of supply to entitlement holders in the Goulburn system (Table 2). This is because less water would be held in storage (Figure 6 and Figure 7).

To return the reliability of supply to levels expected under current operating conditions, up to 10,000ML of low-reliability entitlements and water shares in the Goulburn system would need to be recovered if the target filling curve was changed by delaying the target fill date to January 1, and the probability of exceedance for inflows was changed from 95% to 75%.

For the options to reduce the target storage to 95%, 90%, 85% or 78% of FSL, a much larger volume of low reliability water shares would need to be recovered to offset the reliability of supply impacts (20,000 ML to >100,000 ML). At present, irrigators and water corporations hold

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[3] https://www.parliament.vic.gov.au/floodinquiry

approximately 65% of the low-reliability entitlements and water shares in the Goulburn system, and the environment – via the Victorian and Commonwealth environmental water holders – holds the other 35%.

The initial capital cost of offsetting the supply reliability impacts if the filling curve or target storage at Lake Eildon is changed was estimated by multiplying the volume of low-reliability water shares that would need to be recovered by $1000 / ML. This approach provides an indicative estimate of the water recovery costs, but does not account for:

- The socio-economic consequences of additional water recovery in the Goulburn system
- The reduced income to GMW from fees associated with storing water if entitlements are retired from the Goulburn system
- The foregone agricultural production if the volume of water available for consumptive use in the Goulburn system is reduced
- Any works required to adapt to the increased distance between recreational facilities (e.g. boat ramps and holiday accommodation) and the water's edge if the Lake Eildon target storage is reduced.
- Impacts to water markets and foregone productivity as a result of increased write-offs of allocation in spillable water accounts.

Table 2: Modelled average February allocations to high-reliability water shares (HRWS), low-reliability water shares (LRWS) in the Goulburn system, volumes to offset changes to reliability of supply and the approximate initial capital costs of water shares

Option	Average modelled February allocations (July 1891 – June 2022)		Volumes to offset changes to reliability of supply (ML)		Approximate initial capital costs of water shares (in millions)
	HRWS	LRWS	HRWS	LRWS	
Base case	97.7%	54.8%	-	-	-
Option 1 – Change target filling curves					
75PoE to Jan 1 (post-1891 data)	97.6%	53.9%	0	10,000	$10
75PoE to Jan 1 (post-1975 data)	97.6%	54.1%	0	7,500	$7.5
Option 2 – Reduce target storage					
95% target storage	97.6%	53.7%	0	20,000	$20
90% target storage	97.5%	51.5%	0	50,000	$50
85% target storage	97.4%	48.2%	0	^100,000	^$100
78% target storage	97.4%	42.5%	0	^155,000	^$155

^ A range of initial capital costs is provided in the full technical assessment report; however, for demonstrative purposes the middle initial capital cost was adopted for the calculation of the ratio.

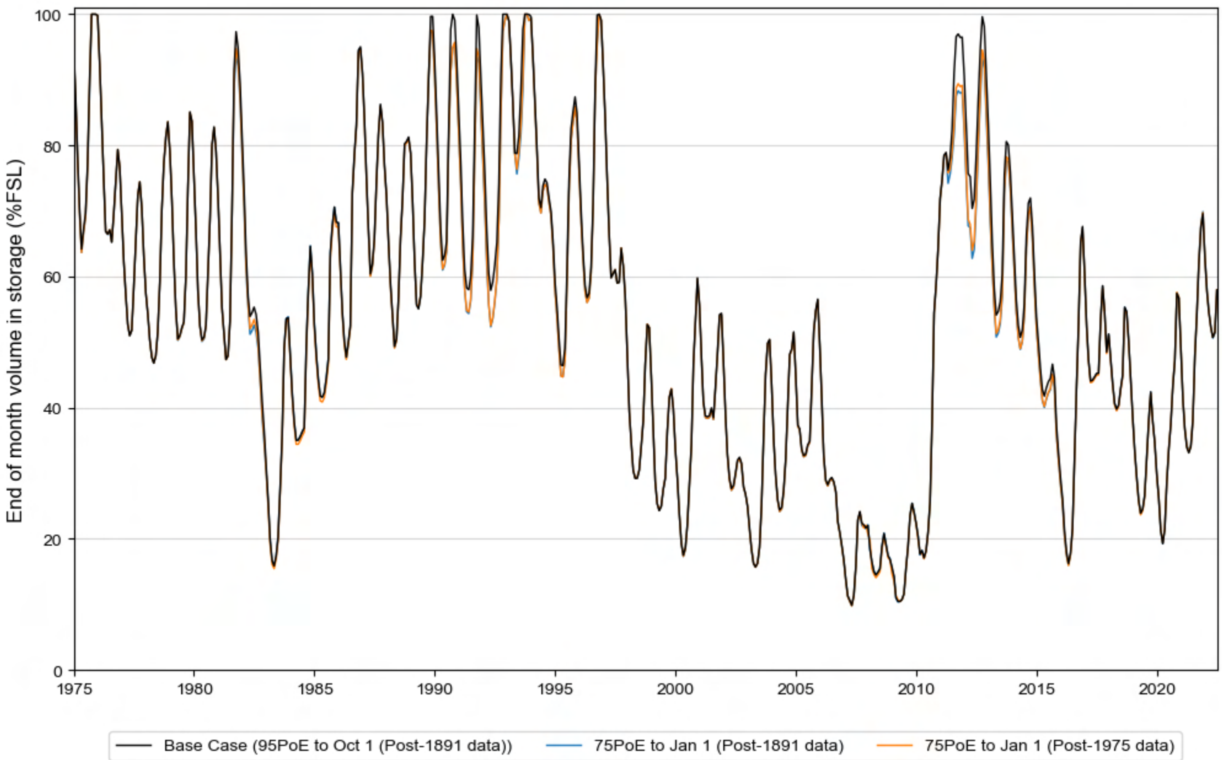

Figure 6: Monthly time-series of the modelled storage trace for Lake Eildon, from January 1975 to June 2022, for the option to change the target filling curve for 75PoE target filling curves (the figures for the 95PoE and 85PoE target filling curves are presented in the full technical assessment report)

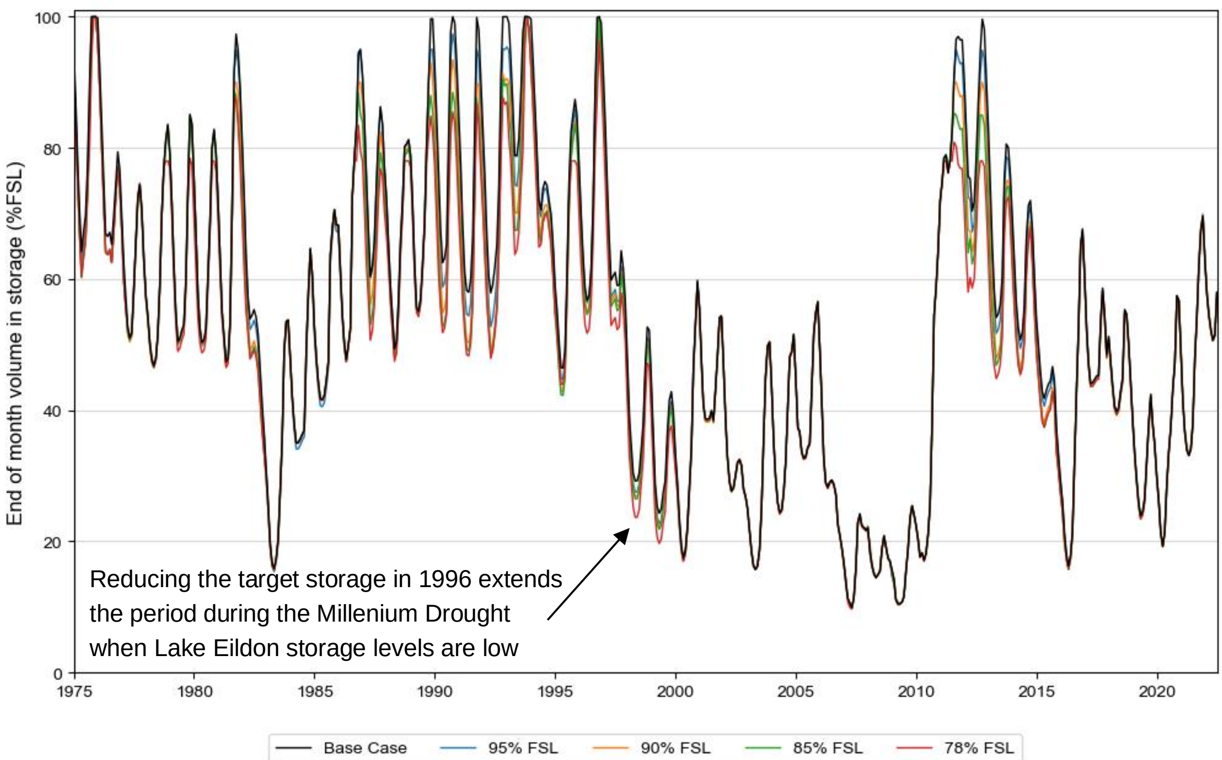

Figure 7: Monthly time-series of the modelled storage trace for Lake Eildon, from January 1975 to June 2022, for the option to reduce target storage to 95%, 90%, 85% or 78% of FSL

Changes to flood frequencies

Although changing the target filling curve (option 1) or lowering the target storage at Lake Eildon (option 2) may not make a difference to some floods – as discussed above for 1993 and 2022 – it will reduce the peak outflow from Lake Eildon during other events, and hence reduce flood frequencies downstream of the storage (Figure 8). However, the degree of peak flow reduction will decrease the further downstream the flood frequencies are assessed. That is, the degree of difference between the flood frequency curves for the base case and options investigated reduces by Molesworth (Figure 9) and is minor at Seymour (Figure 10).

This happens because the tributary flows downstream of Eildon from the Rubicon River and Acheron River influence the peak flows at towns such as Molesworth, and inflows from the Yea River, King Parrot Creek, Sugarloaf Creek and Sunday Creek influence the peak flows at towns such as Seymour. This means that changes to operations at Eildon have less influence on peak flows as the distance from the dam increases.

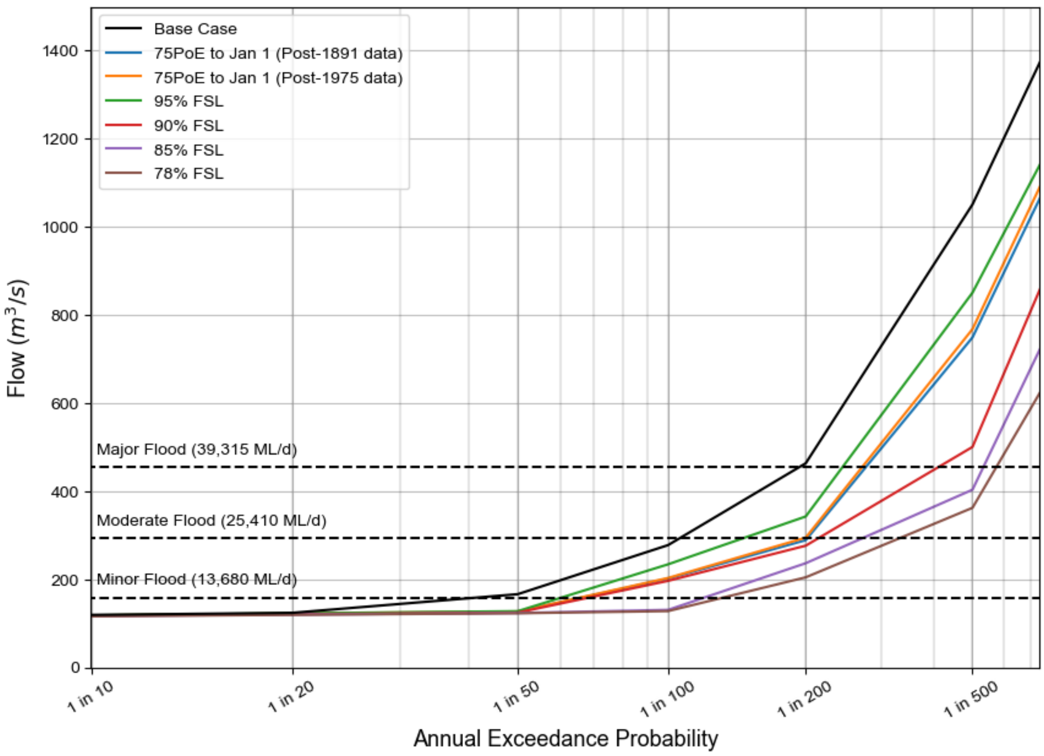

Figure 8: RORB model estimates of Lake Eildon peak outflow AEPs for the options that involve a target filling curve based on 75PoE inflow conditions and a target storage of 78%, 85%, 90% and 95% of FSL

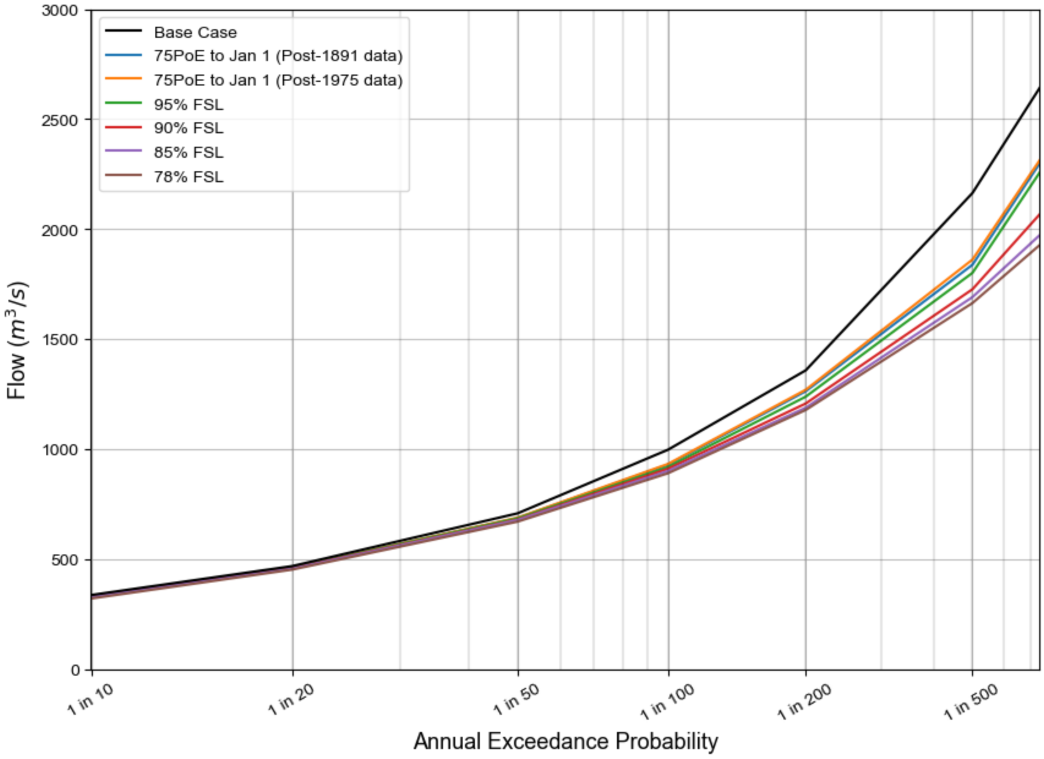

Figure 9: RORB model estimates of peak flow at Molesworth for the options that involve a target filling curve based on 75PoE inflow conditions and a target storage of 78%, 85%, 90% and 95% of FSL

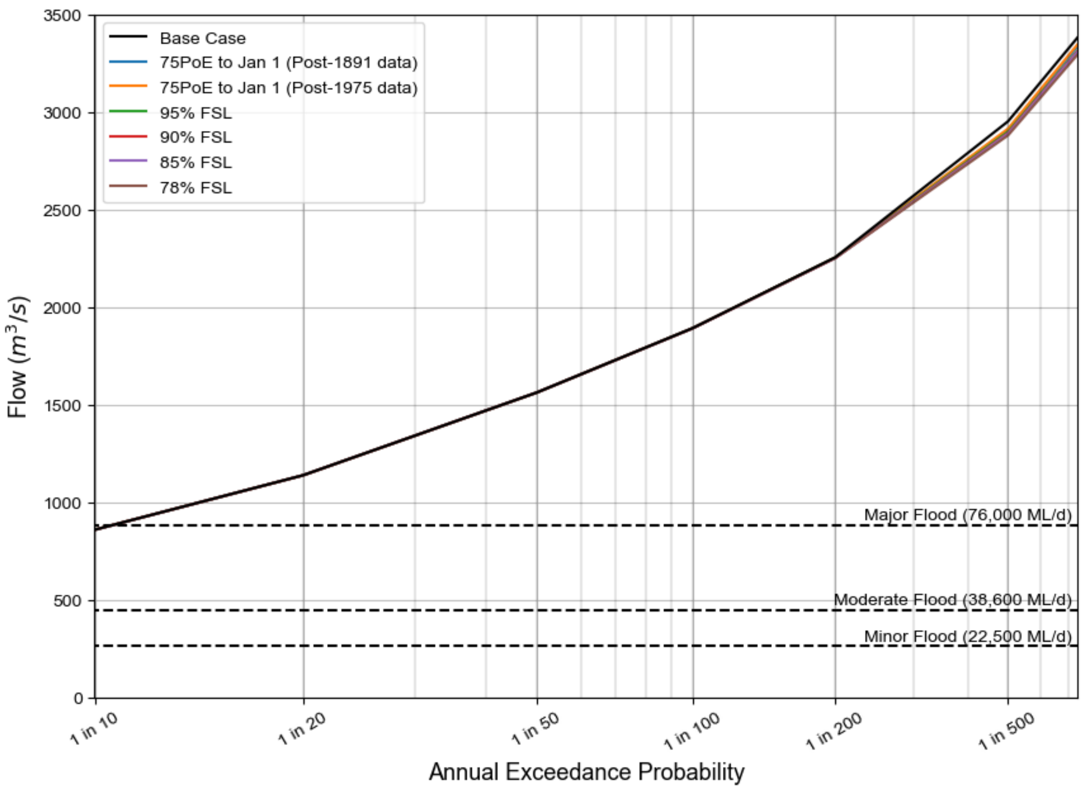

Figure 10: RORB model estimates of peak flow at Seymour for the options that involve a target filling curve based on 75PoE inflow conditions and a target storage of 78%, 85%, 90% and 95% of FSL

Downstream daily flow regime

If the Lake Eildon target filling curve is changed by delaying the target fill date to January 1, and fill is achieved in 75% of years, there will be a reduction of downstream flows in winter and an increase in autumn. This is because the May target filling point for Lake Eildon will be lower than currently the case, and therefore more flows will be passed in the lead-up, and there will be fewer spills in the subsequent months.

If the target storage at Lake Eildon is reduced, there will be generally lower flows from August to October, and higher flows in the months either side. This is because there will be fewer spills from Lake Eildon in the generally wet months, but higher flows in the shoulder months because higher releases will be required to maintain the target storage below FSL. This is likely to be a negative outcome for the environment, because the flow regime would be shifted further away from that which would have been observed under natural (unregulated) conditions. However, further investigations would be required to test this. The impact of the options on Traditional Owner values has not yet been assessed.

Flood damages

Modelled flood frequencies were combined with estimates of how flood damages vary according to peak flows along the Goulburn River to estimate the average annual damages for the base case and options 1 and 2. The differences between these values are the estimates of avoided flood damages.

Table 3 shows how the avoided flood damages if the options were in place compare with the initial capital cost of water recovery. The results show that all options have a benefit to cost ratio less than one. The estimates of avoided flood damages included in this report are approximate. This is because:

- The relationship between peak outflows from Lake Eildon and flood damages from Lake Eildon to Seymour is approximate, and has been interpolated from a steady-state assessment of flow along the Goulburn River
- The assessment of agricultural damages was based on expected changes in peak flows, rather than duration of inundation
- Flood damages downstream of Seymour were not considered.
- The estimates of average annual damage may also change once the hydraulic modelling is finalised as part of the ongoing Goulburn and Broken Rivers Flood Study, which includes calibration of the hydraulic model to inundation extents observed during the October 1993 and October 2022 floods.

For the reasons discussed above, the benefit to cost ratios are approximate and will change if the options are investigated in more detail. The options to change the target filling curve for other percentages of exceedance are not shown because they provide lesser degrees of flood mitigation downstream of Lake Eildon.

These points do not however, invalidate the results of the analysis. The ratios of avoided damages to the initial capital cost of recovering water shares would have to shift by a substantial amount to make a difference to the outcomes of this technical assessment.

Table 3: Estimates of avoided damages vs initial capital costs.

Option	Approximate benefit-cost ratio (50 years, 6% discount)		
	Avoided damages ($ m)^	Initial capital cost ($ m)*	Ratio
Option 1 – Change target filling curves			
Change target filling curves (75PoE to Jan 1 (post-1891 data))	3.1	10	0.3 : 1
Change target filling curves (75PoE to Jan 1 (post-1975 data))	2.9	7.5	0.4 : 1
Option 2 – Reduce target storage			
95% target storage	2.6	20	0.1 : 1
90% target storage	4.7	50	< 0.1 : 1
85% target storage	5.9	†100	< 0.1 : 1
78% target storage	6.7	†155	< 0.1 : 1

* For the estimates of costs:

- The costs associated with offsetting the supply reliability impacts are approximate.
- The ongoing socio-economic costs associated with reducing the volume of water stored in the Goulburn system (if the target storage at Lake Eildon is reduced) are not included.

† For the initial capital costs for 78% and 85% reduced target storage:

- A range of initial capital costs were estimated, however, the benefit-cost ratio is a similar order of magnitude if the high or low estimates of initial capital costs are used instead.

Sensitivity test

The outflow flood frequencies at Lake Eildon, and the degree of low-reliability water shares that would need to be recovered to offset reliability impacts if additional airspace is provided, are likely to be underestimated when based on the Goulburn Simulation Model (GSM) made available by DEECA for this technical assessment. This is because the GSM predictions of water level are lower than observed water levels over the recent period of record. Therefore, the differences in downstream flood frequencies and water recovery costs were also estimated using the University of Melbourne's Stochastic Goulburn Environmental Flow Model (SGEFM) model to test the sensitivity of the study outcomes to the type of model used. As expected, using the SGEFM produced different estimates of avoided flood damages and the cost of offsetting the reduced reliability of supply to water shares. However, the ratio between the avoided flood damages and initial capital cost of water recovery was similar when estimated using the SGEFM (Table 4). Therefore, the study outcomes were not sensitive to whether the GSM or SGEFM model was applied to simulate the long-term storage trace for Lake Eildon under current conditions and the options investigated.

Table 4: Estimates of avoided damages vs initial capital costs – sensitivity testing^

Option	Approximate benefit-cost ratio (50 years, 6% discount)					
	GSM			SGEFM		
	Avoided damages ($ m)^	Initial capital cost ($ m)*	Ratio	Avoided damages ($ m)^	Initial capital cost ($ m)*	Ratio
Option 1 – Change target filling curves						
Change target filling curves (75PoE to Jan 1 (post-1891 data))	3.1	10	0.3 : 1	8.4	60	0.1 : 1
Change target filling curves (75PoE to Jan 1 (post-1975 data))	2.9	7.5	0.4 : 1	7.0	50	0.1 : 1
Option 2 – Reduce target storage						
95% target storage	2.6	20	0.1 : 1	10	80	0.1 : 1
90% target storage	4.7	50	< 0.1 : 1	12	170	< 0.1 : 1
85% target storage	5.9	†100	< 0.1 : 1	16	270	< 0.1 : 1
78% target storage	6.7	†155	< 0.1 : 1	20	460	< 0.1 : 1

^ The caveats for Table 3 also apply to the estimates presented in this table

Findings

After the initial assessment, it was found that four of the six options were not robust ways to increase the flood mitigation provided by Lake Eildon. These options were:

- Option 3 – Reduce the target storage at Lake Eildon based on climate signals that indicate 'wet' conditions
- Option 4 – Make higher pre-releases at Lake Eildon based on forecast rainfall
- Option 5 – Increase the maximum allowable surcharge level at Lake Eildon
- Option 6 – Restrict the maximum outflows from Lake Eildon

The other two options which were progressed to the detailed technical assessment were changing the target filling curve (option 1) and reducing the target storage (option 2). These options did increase the flood mitigation provided by Lake Eildon; however, the cost of offsetting supply reliability impacts outweighed the avoided flood damages.

The main reason for the low benefit to cost ratio is that the flood mitigation benefits provided by the changes to target filling curve (option 1) and reduced target storage (option 2) diminish the further downstream the flood frequencies are assessed.

This is because the tributary flows downstream of Lake Eildon from the Rubicon River, Acheron River, Yea River, King Parrot Creek, Sugarloaf Creek and Sunday Creek influences the peak flows at towns such as Seymour. To explain this in an alternative way, the catchment area of the Goulburn River between Lake Eildon and Seymour (i.e. downstream of Lake Eildon) is approximately 4,500 km² while the Lake Eildon catchment area is approximately 3,900 km². This means that changes to operations at Eildon have less influence on reducing the overall avoided damages downstream. In contrast, the approximate initial capital cost of water shares to implement these options ranges from $7.5 million to $266 million.

When looking at the 1993 and 2022 floods, the only option that would have made a difference to what was actually observed during these floods would have been aiming to hold the storage to 78% of FSL prior to the events. If option 1 or any other target storage within option 2 was implemented, there would have been no material difference to the flows observed downstream of Lake Eildon, Molesworth and Seymour for these historic events.

The assessment also looked at other impacts from changing the filling curve (option 1) and reducing the volume of water stored in Lake Eildon (option 2). Both options would change the downstream flow regime in the Goulburn River, by reducing flows in generally wetter months and increasing them in drier months. This may have negative environmental impacts, however further investigations would be required to confirm this.

For option 2, there would also be some recreational impacts, because the water body would be smaller and the distance between community and recreational facilities (e.g. holiday accommodation) and the water's edge would increase.

Further work could be done to improve aspects of this technical assessment. This includes:

- Using long-term time series of modelled flows from the daily Goulburn-Broken-Campaspe-Coliban-Loddon-Source model to characterise the expected change in the timing and duration of flooding, and how this will impact agricultural losses.
- Assessing the costs and benefits of different potential ways for recovering water shares.
- Refining the initial assessments of the expected costs and benefits to existing recreational and environmental values around Lake Eildon and downstream.
- A more detailed assessment of how potential future climate change is likely to influence flood frequencies downstream of Lake Eildon.

However, doing additional work is not recommended because it is not expected to change the conclusion that the cost of offsetting reliability of supply changes will be greater than the avoided flood damages for the Lake Eildon operating options considered in this study.

1. Introduction

1.1 Project scope

This report summarises the outcomes of the technical assessment of potential operating options for increasing the flood mitigation provided by Lake Eildon. The assessment was completed in two stages, and this report covers both.

Stage 1 included:

- A literature review of previous studies into options considered for increasing flood mitigation at Lake Eildon.
- A workshop with the Department of Energy, Environment and Climate Action (DEECA), and stakeholders including Goulburn-Murray Water (GMW), Goulburn Valley Water (GVW), the Goulburn Broken Catchment Management Authority (GBCMA), Melbourne Water retailers (represented by Greater Western Water), the Victorian Environmental Water Holder (VEWH), Murrindindi Shire Council, Mitchell Shire Council and Strathbogie Shire Council, to identify operating options to investigate in this study. Greater Shepparton City Council, Mansfield Shire Council, Coliban Water and Grampians Wimmera Mallee Water were invited to the workshop but were unable to attend.
- Modelling the anticipated changes to seasonal determinations (i.e. allocations) for water shares, and flood frequencies downstream of Lake Eildon, if the options were implemented.
- Modelling the anticipated changes the options would have made to outflows from Lake Eildon for design flood events and/or historic events.
- A high-level assessment of how the options would change flood frequencies at Molesworth and Seymour.

Stage 2 included:

- Assessing how the daily flow regime downstream of Lake Eildon could change under the options investigated.
- Using the Goulburn and Broken Rivers Flood Study underway for the Goulburn River reach from Lake Eildon to Seymour to characterise expected changes to flood behaviour and damages if the options are implemented.
- Assessing the potential impacts for recreational users of Lake Eildon and upstream landholders.
- Providing commentary on how a warming climate may change the flood characteristics at Lake Eildon and downstream, and how this might impact on the effectiveness of operating options for increasing the flood mitigation provided by Lake Eildon.

1.2 Project context

This study was commissioned by DEECA – to begin in July 2023 – following the October 2022 floods in the Goulburn River basin. Information about the October 2022 floods has been summarised by Goulburn-Murray Water (GMW) on the website https://www.g-mwater.com.au/customer-services-resources/flood-recovery/floods-in-focus-goulburn-river-system.

Key facts from this website include that:

- Inflows to Lake Eildon peaked at 145,000 ML/d while releases from Lake Eildon were able to be maintained at a peak of 38,000 ML/d.
- The peak flow at Seymour (estimated at 140,000 ML/d) occurred prior to the increased releases from Lake Eildon arriving at Seymour.
- The peak flow at Shepparton (estimated at 192,000 ML/d) was primarily made up of tributary inflows between Eildon and the Goulburn Weir, plus inflows from the Broken River and Seven Creeks.
- Releases from Lake Eildon contributed approximately 6% of the peak experienced at Shepparton.

The increase of releases from Lake Eildon from 12,400 ML/d - prior to the flood - to 38,000 ML/d started at 11 pm on 13 October, with releases increased by 2,500 ML/d every hour. Releases were then held at 38,000 ML/d for 9 days.

The October 2022 floods along the mid-Goulburn to the lower Goulburn reaches affected many individuals and families, businesses, primary producers and community organisations. The impacts of the flood can be found in the database of flood inquiry submissions[4].

1.3 This report

In this report:

- Section 2 includes information about Lake Eildon.
- Section 3 summarises the outcomes of previous relevant studies.
- Section 4 describes the options assessed in this study to increase the flood mitigation provided by Lake Eildon.
- Section 5 outlines the water resource implications of the options investigated.
- Section 6 outlines the expected flood frequency changes at Lake Eildon if the options were implemented.
- Section 7 includes an assessment of how the options would have potentially changed the outflows from Lake Eildon during the October 1993 and October 2022 floods.
- Section 8 includes the estimated costs of recovering water from the Goulburn system to offset the anticipated changes to the reliability of supply.
- Section 9 discusses the potential impacts for recreational users of Lake Eildon and upstream landholders.
- Section 10 provides an assessment of how the daily flow regime downstream of Lake Eildon could change under the options investigated.

[4] https://www.parliament.vic.gov.au/floodinquiry

- Section 11 includes information on potential flood frequency changes between Lake Eildon and Seymour, and the associated flood damages.
- Section 12 provides some concluding remarks, including comments on the further work that would be required to progress options beyond the concepts considered in this report.

1.4 Models used

This assessment of potential operating options for increasing the flood mitigation provided by Lake Eildon was informed by applying several existing models:

- The Goulburn Simulation Model (GSM), which is owned by DEECA, was used to assess the water resource implications of the options investigated. The 'base case' version available for this study simulates the period from July 1891 to June 2022 on a monthly time-step, and represents the application of current infrastructure and system operation rules under long-term historic climate conditions, with consumptive and environmental water demands as per Victoria's water resource plans[5]. More detail on the GSM is included in Section 5.1.
- The RORB model of the Lake Eildon catchment and dam, which is owned by GMW, was applied to simulate how the options would change flood frequencies immediately downstream of the storage. The RORB model was first developed by SKM (1998) and was last updated by HARC (2017). It simulates runoff from rainfall events ranging in burst durations from 12 hours to 168 hours. Refer to Section 6 for more detail.
- The RORB model of the Goulburn and Broken Rivers catchment, which is owned by the Goulburn Broken Catchment Management Authority, was applied to simulate how the options would change flood frequencies at Molesworth and Seymour. This model simulates floods using rainfall space-time patterns developed for complete storms for the 24 hour and 48-hour durations. Refer to Section 6 and Section 7 for more detail.
- The preliminary TUFLOW model of the Goulburn River catchment, which is owned by Goulburn Broken Catchment Management Authority, was applied to estimate how the options would change the inundation extents for the flood damages assessment downstream of Lake Eildon. The TUFLOW model is currently being calibrated to historic flood events for the Goulburn and Broken Rivers Flood Study therefore elements of this work will be superseded when the hydraulic modelling is finalised. Refer to Section 11 for more detail.
- The Stochastic Goulburn Environmental Flow Model (SGEFM), developed by the University of Melbourne (John, 2021), was used to investigate expected changes to the daily flow regime downstream of Lake Eildon. The SGEFM simulates the distribution of water resources at a monthly time-step – as does the GSM – but then disaggregates the results to a daily time-step using anticipated reservoir release patterns and streamflow patterns derived from historic gauge records of tributary flows. More detail on the SGEFM is included in Section 10.

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[5] https://www.water.vic.gov.au/our-programs/murray-darling-basin/water-resource-plans

Given the time available for this study, these existing models were used as available. They are fit-for-purpose for this technical assessment, as demonstrated in the sections referenced in the dot-points above, when used to make high-level comparisons between current conditions (i.e. the base case) and what is anticipated if the options were implemented. Although the relative differences between options are not expected to change significantly as further investigations are completed, specific values quoted in this report will become superseded:

- When the DEECA daily Goulburn-Broken-Campaspe-Coliban-Loddon Source model replaces the GSM in the near future.
- When hydrologic and hydraulic modelling for the Goulburn and Broken Rivers Flood Study is completed.

If any of the potential operating options for increasing the flood mitigation provided by Lake Eildon is simulated using the hydrologic and hydraulic models that are being applied to update the Goulburn Broken Regional Floodplain Management Strategy 2018-2028.

1.5 Terminology

In this report, for simplicity the term FSL has been used to refer to the full supply level and the volume of water held in storage when the reservoir is at FSL. Therefore, terms such as 95%, 90%, 85% or 78% of FSL refer to the volume of water held in storage (i.e. 95%, 90%, 85% or 78% of the volume stored when Lake Eildon is at FSL), rather than 95%, 90%, 85% or 78% of the full supply level measured in m AHD.

2. Lake Eildon

2.1 Storage information

Lake Eildon was constructed in 1956 and is located on the Goulburn River, approximately 140 km north east of Melbourne. It stores water for irrigation, urban water utility providers and environmental water holders.

Lake Eildon holds approximately 3,334,000 ML (3,334 GL) at a full supply level (FSL) of 288.9 m AHD. The main embankment consists of a central clay core and dumped rockfill shoulders separated by filter layers. The nominal crest level of the embankment is 295.7 m AHD. There is also a 1.2 m high parapet wall on the embankment, which raises the crest level to 296.9 m AHD.

The Lake Eildon spillway structure is a reinforced concrete gravity dam controlling a constructed spillway channel. The structure is separated from the left abutment of the embankment by natural high ground. The spillway itself is an ogee crest at an elevation of 282.81 m AHD. The weir has a 59.9 m clear opening and is 65.53 m with piers. The spillway is controlled by three 20 m wide vertical lift gates.

Key aspects of the reservoir, main embankment, spillway and outlet works is summarised in Table 5.

Table 5: Key aspects of the spillways and embankments at Lake Eildon

Component	Value
Reservoir	
Catchment area	3,885 km²
Surface area	13,832 ha at FSL
Full supply level	288.90 m AHD
Target filling curve	Set based on current conditions
Full supply volume	3,334,158 ML
Dead storage volume	84,244 ML
Reservoir type	Online (Goulburn River)
Main embankment	
Embankment type	Earth and rockfill dam
Embankment height	84.45 m including parapet wall.
Embankment crest level (average)	EL 295.70 m AHD at crest and 296.90 at top of parapet
Embankment crest length	1080 m
Spillway	
Spillway type	Ogee crest, concrete gravity structure gated spillway
Spillway gates	3 vertical lift gates (19.96 x 6.40 m) on spillway. Maximum opening 9296 mm.
Spillway crest level	EL 282.814 m AHD
Spillway crest length	59.89 m clear opening, total length 65.53 m including piers
Spillway bridge	Deck level 294.38 m AHD

Component	Value
Spillway chute	Reinforced concrete chute, with variable slope, 416 m long x 65.5 m wide (upstream end) and 91.4 m wide (downstream end). Reinforced concrete dissipater 66 m long x 91.4 m wide, c/w concrete baffle piers Dissipator sill level 211.03 m AHD
Spillway irrigation outlet	2 x Roller type Service Gates, 2.13 x 3.96 m high 2 x 1.83 m diameter x 23 m long steel lined conduit. Invert level 254.39 m AHD 2 x 1,980 mm FCD regulating valves Maximum outlet capacity 5,300 ML/d per outlet
Outlet works	
Intake tower	Wet intake tower, 7.8 m internal diameter, reinforced concrete. 72 m high. 10 No. inlet ports approx. 1.64 m wide x 3.66 m high with inlet sill level at 237.09 m AHD ▪ Top of tower level 309.20 m AHD. ▪ Operating deck level 295.62 m AHD. 7.01m dia. x 7.0 m high (42 tonnes), cylinder type guard gate located at base of tower. Tower includes10 No. Bulkheads 2.62 m wide x 4.64 m high (7.5 tonnes) Access bridge, single span, steel girder, concrete deck, 51.8 m long x 3.0 m clear width
Penstock/outlet conduit	7.01 m dia. x 21.45 m high vertical concrete riser from outlet conduit invert at 215.64 m AHD to tower inlet sill level. 7.01 m dia. X 377 m long steel lined outlet tunnel to trifurcation upstream of power station. Trifurcation provides: ▪ 3.96 m dia. branch to Power Station small turbines and Low-Level Outlet Valve ▪ 2 additional branches, 4.45 m dia., supply to Power Station large turbines.
Low level outlet valve	1,980 mm FCD valve. Maximum discharge 8,600 ML/d

A two-lane roadway is constructed on the dam crest. The spillway is a gated, concrete gravity structure. The outlet system includes a concrete tower and access bridge, a steel outlet conduit with regulating cone valve, and a steel penstock to a hydro-electric power station situated at the downstream toe of the right abutment.

In 2005 the dam was upgraded as part of the GMW Dam Improvement Program (DIP) which included:

- Construction of an embankment filter buttress and composite (embankment and parapet wall) raise of 5.25 m to achieve Probable Maximum Flood (PMF) flood capacity for the main dam.
- Repair of the spillway chute slab joints.
- Strengthening of the chute slabs at the toe of the spillway structure by anchoring and strengthening of the spillway chute walls.
- Improvements to the spillway gate operating gear.

The dam features a large capacity outlet tunnel connected to a power station, the latter being owned and operated by AGL Hydro. The tailwater discharge from the power station passes through a constructed channel into a separate structure on the Goulburn River immediately downstream of Lake Eildon, called Eildon Pondage. Also, there is a small hydro power station, owned by Pacific Hydro, through which regulated releases from the pondage are passed. The pondage is designed to regulate outflows from the dam, including power station discharges, irrigation releases and spillway flows, and is controlled by a gated ogee crest structure identical to the Lake Eildon spillway. The storage capacity of the pondage is approximately 5,200 ML.

2.2 Goulburn-Murray Water's operating objectives

Goulburn-Murray Water (GMW) are the appointed storage manager for the Broken System, the Ovens System, the Bullarook System, the Goulburn System, the Lake Eppalock Headworks System and the Loddon Headworks System.

The primary purpose of Victoria's water storages is to provide a secure and safe water supply for irrigators, towns and the environment. However, in undertaking the role of storage manager, storage managers are required to also weigh up other considerations set out in legislation and associated instruments.

The functions of the storage manager for Lake Eildon (GMW) are set out in section 122ZL(1) of the *Water Act* (Victoria, 1989), and primary functions and obligations are conferred on the storage manager under bulk entitlements. The bulk entitlements set out how the storage manager must manage the system to harvest water and supply this water to entitlement holders.

The storage manager must have regard to not only the four items under s. 122ZL(2) but also any other relevant mandates associated with any other part of the *Victorian Water Act 1989* or associated instruments, including the *Statement of Obligations for Victorian Water Corporations* (Minister for Environment Climate Change and Water Victoria, 2015) and obligations in bulk entitlements. The storage manager must consider:

- Dam safety, per Part 5-3 of the Statement of Obligations and the link to Part 5/ s. 80 of the *Water Act*
- Water supply, per s. 122ZL (2)(b) of the *Water Act* and the link to Part 8, as well as per bulk entitlements
- Flood mitigation where possible, per s. 122ZL (2)(d) of the *Water Act* and the link to Parts 5-2.2 and 7-2.4 of the Statement of Obligations, and the link to Div. 4 of Part 10 of the *Water Act*, and
- Environmental protection, per s. 122ZL (2)(a) and (c) of the *Water Act*.

The storage manager has some discretion as to how the system is managed, but when undertaking its functions must have regard to matters set out in section 122ZL(2) such as protecting the reliability and quality of water supply, and mitigating flooding where possible.

The GMW (2022) board policy published on the website (https://www.g-mwater.com.au/news-updates/reports-and-publications/policies) outlines the priorities for GMW in routing floods through its large water storages. These priorities, which are consistent with GMW's obligations as storage manager, are to:

1. Protect the structural integrity of the dam, as failure of the structure would be catastrophic.
2. As far as practicable, reduce the risk to human life downstream of the dam by routing flood flows through the storages, pre-releasing and/or surcharging where possible, and providing timely notification of high downstream releases.
3. Optimise water harvesting so the storage is at full supply (or filling target level) when the flood event concludes.
4. Reduce downstream flooding impacts on properties, livestock and the environment where possible.

2.3 Catchment details

The catchment above Lake Eildon is approximately 3,900 km² and is generally mountainous. It is enclosed by the Great Dividing Range to the south and east and the Strathbogie Ranges to the north. The highest elevation in the catchment is Mt Buller at EL 1,804 m AHD while the reservoir FSL is EL 288.90 m AHD.

The main waterways within the catchment are the Jamieson River, Big River, Goulburn River, Howqua River and Delatite River (Figure 11). The maximum stream distance from source to the Eildon outlet is about 120 km, including the submerged portion of the stream channel. Tributaries are generally hydraulically steep and flow within well-defined valleys. Most of the catchment is covered in native forest with only about a quarter of the area cleared for agricultural or township needs. The cleared area is principally on the lower parts of the Ford Creek around Mansfield, and the Delatite River below Sawmill Settlement has also been cleared. Mean annual rainfall ranges from approximately 560 mm to 1500 mm across the catchment, with an average of approximately 1100 mm.

The catchment area of the Goulburn River between Lake Eildon and Seymour (i.e. downstream of Lake Eildon) is approximately 4,500 km² which is similar to the Lake Eildon catchment area of 3,900 km². For the catchment from Lake Eildon to Seymour the mean annual rainfall is approximately 900 mm. Tributaries in this reach between Lake Eildon and Seymour include:

- Rubicon River (catchment area 175 km²)
- Acheron River (catchment area 731 km²)
- Yea River (catchment area 908 km²)
- King Parrot Creek (434 km²)
- Sunday Creek (331 km²)
- Sugarloaf Creek (609 km²)

The Goulburn River catchment area between Seymour and Shepparton is 7,500 km². This region is downstream of the area focused on – i.e. Lake Eildon to Seymour – for this technical assessment of potential operating options for increasing the flood mitigation provided by Lake Eildon.

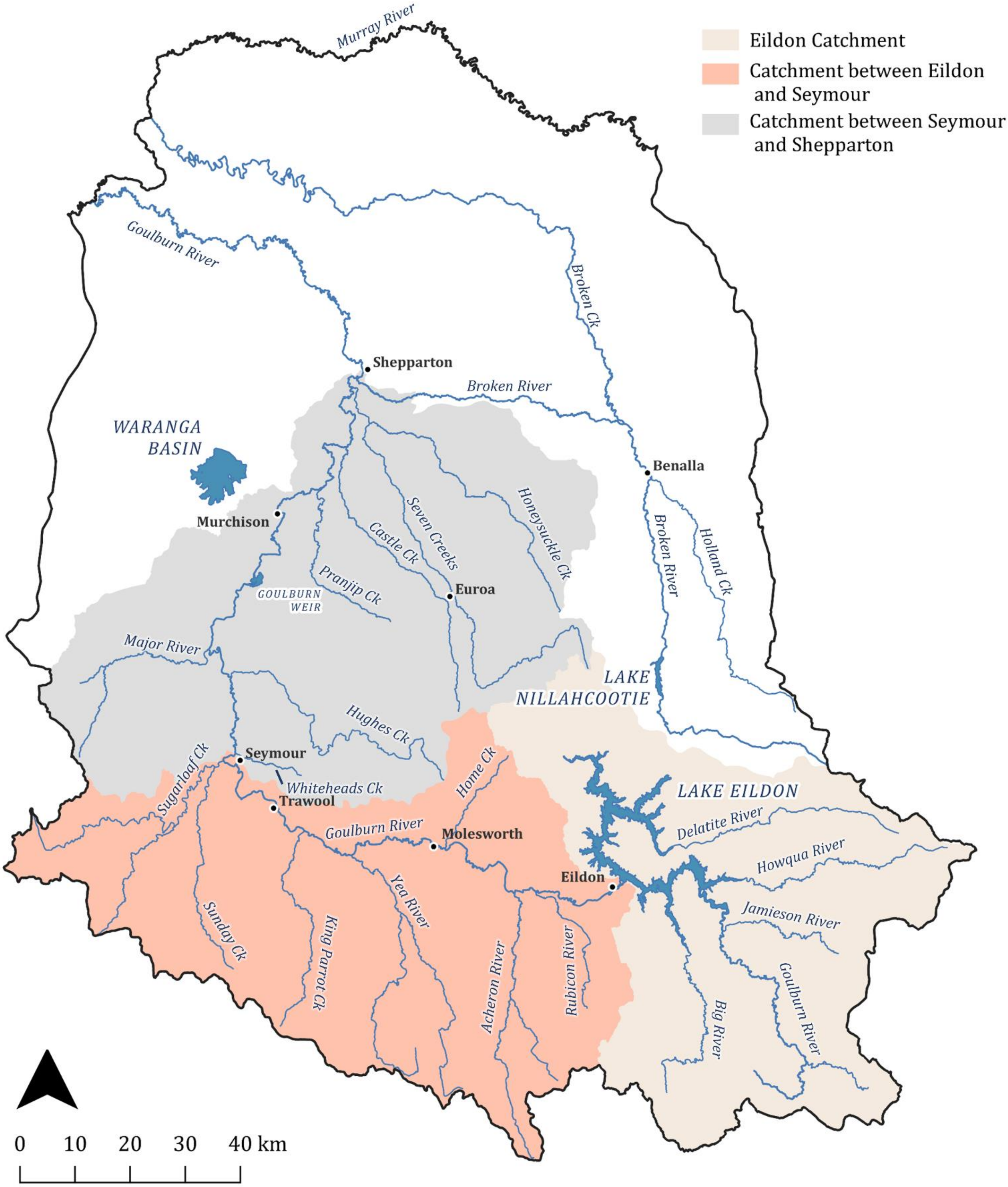


Figure 11: Overview of major river systems and catchments in the Goulburn River basin

2.4 Target filling curve

Bulk entitlements and environment entitlements are legal rights to water granted by the Minister for Water under the Victorian *Water Act 1989.* Schedule 5 of the bulk entitlement for Eildon – Goulburn Weir says that, *subject to receiving sufficient inflow, the storage manager (GMW) must operate Lake Eildon from May to October inclusive each year such that it targets filling the storage to capacity by 1 October or 1 November each year assuming inflow conditions of 95% probability of exceedance*.

Storage levels historically decrease from November onwards due to increased demands for water and reduced inflows. There are therefore no filling targets from November until the end of the irrigation season. However, if releases from Lake Eildon are required to meet the 1 May target these can occur between December and May.

The filling targets seek to protect the reliability of water entitlements, while offering some flood mitigation. This means the target filling curve is relatively high throughout the May to November period and a probability of exceedance of 95% is used which means that only in 5% of years will the storage not reach FSL by the end of the target filling curve. GMW utilises the Bureau of Meteorology's seasonal streamflow forecasts for Lake Eildon and considers expected releases to help determine the target filling points (Figure 12). The streamflow forecasts are based on the current catchment conditions, historical inflow records and climate outlooks, and provide a range of possible inflow conditions for the months ahead.

The target filling points are formally reviewed and updated by GMW at the start of each month, but the catchment conditions, inflows and demands which inform the target filling curve are continuously monitored.

An alternative to having a target filling curve would be to fill the storage as soon as possible, then maintain the storage at or near FSL until demands exceed inflows (with the exception of releases made when forecast inflows are anticipated to return the storage to FSL). This is the case at other storages in northern Victoria, such as Lake Eppalock.

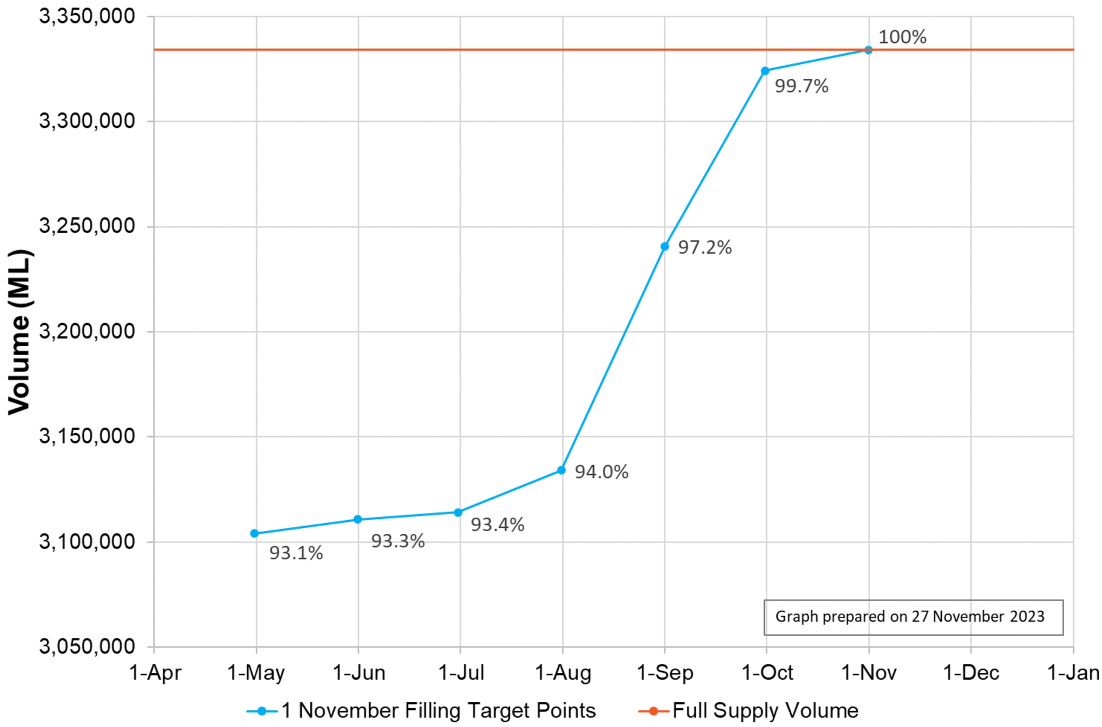


Figure 12: Target filling arrangement for Lake Eildon published on the GMW website at December, 2023

2.5 Downstream flow constraints

The degree to which operational releases can be made from Lake Eildon depends on downstream flow constraints. The current constraints along the Goulburn River are:

- 9,500 ML/d at Eildon
- 10,000 ML/d at Molesworth (mid-Goulburn); noting though that this location does not currently have a streamflow gauge
- 9,500 ML/d at Murchison and Shepparton (lower Goulburn)

Releases above the downstream flow constraints can be made by the storage manager in order to meet the dam safety requirements in GMW's operating objectives (Section 2.2), or if Lake Eildon is above the filling curve target and is expected to keep filling (e.g. see June-July of 2023 in Figure 14 below).

Further details on how these operational constraints are represented in the water resources model of the Goulburn River system are included in Section 5.1, and commentary on the influence that downstream flow constraints have at Lake Eildon reservoir levels and outflows is provided in Section 5.3.

2.6 Historic storage behaviour

Figure 13 shows from January 1975 onwards the recorded volume stored at Lake Eildon and releases made from storage, and how the releases have compared with flow thresholds corresponding to minor, moderate and major flood class levels for the Goulburn River downstream of Eildon (13,680 ML/d, 25,410 ML/d and 39,315 ML/d respectively)[6]. The period post-1975 is shown because it is more representative of current climate conditions in Victoria compared with pre-1975[7].

Figure 14 shows the same data, but in a different way that highlights when Lake Eildon has been more than 90%, 95%, 97.5% or 99% full (top) and when releases have been greater than 8,000 ML/d, 10,000 ML/d, 12,000 ML/d, 14,000 ML/d or 20,000 ML/d (bottom).

Figure 13 and Figure 14 demonstrate that from the mid-1970s to mid-1990s Lake Eildon was full (99% or higher) in 8 years, including 6 of 8 years from the late-1980s to mid-1990s. Releases were above the major flood class level at Eildon in September 1975 and October 1993.

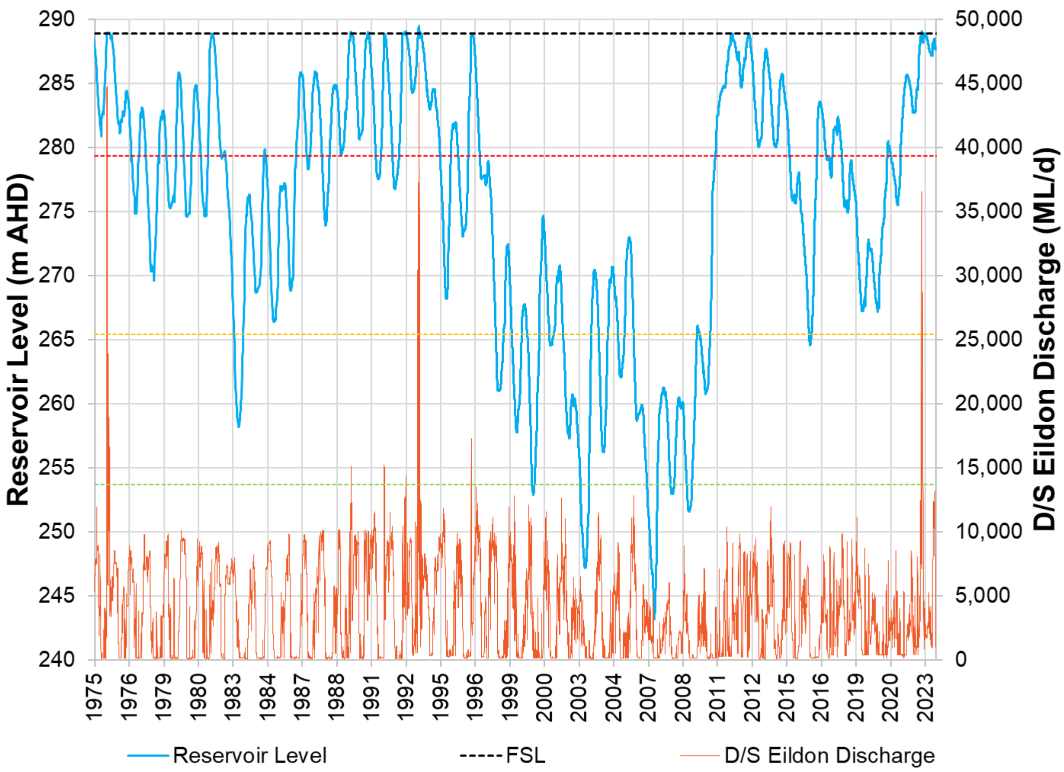


Figure 13: Recorded storage level (blue series) and outflows from Lake Eildon (orange series) for the period from January 1975 to August 2023. Data supplied by GMW up until 2015 and supplemented with WMIS to 2023. The green, orange and red horizontal lines are the minor, moderate and major flood class levels downstream of Lake Eildon, respectively.

[6] Flood class level flow thresholds provided by GMW, based on data for gauge 405203 from http://www.bom.gov.au/vic/flood/floodclass_north.shtml and https://data.water.vic.gov.au/

[7] https://www.water.vic.gov.au/our-programs/climate-change-and-victorias-water-sector/climate-change-water-resources/water-availability-climate-change-guidelines

From the mid-1990s to late-2000s the effect of the Millennium Drought is seen in the Lake Eildon storage trace, with reservoir levels well below those observed pre-1997 and post-2011. Lake Eildon has been at least 99% full in four of the years after the Millennium Drought (2011, 2012, 2022 and 2023), and releases in October 2022 were the highest since October 1993.

Two other things are apparent from Figure 14:

- Even though significant releases were made from storage in June and July 2023, 2023 is the first time in the post-1975 record where Lake Eildon has remained ≥ 90% full in all months of the calendar year. As shown on Figure 15, inflows to Lake Eildon in the water year July 2022 to June 2023 were the equal highest with 1974-75 in the period of record considered.
- In the latter part of the historic record, releases from Lake Eildon in summer / autumn have been less compared with the earlier part of the record. The buyback of water shares[8], reduced losses in irrigation distribution systems[9] and limits on inter-valley trade[10] are contributing factors to the reduction of releases from storage in summer / autumn.

[8] https://www.water.vic.gov.au/__data/assets/pdf_file/0033/669426/social-and-economic-impacts-of-basin-plan-water-recovery-in-victoria.pdf
[9] https://www.water.vic.gov.au/for-agriculture-and-industry/irrigation/investment-in-irrigation-efficiency/independent-audit-of-water-recovery-gmw-connections-project
[10] https://www.waterregister.vic.gov.au/about/news/377-long-term-goulburn-to-murray-trade-rule-to-take-effect-from-1-july-2022

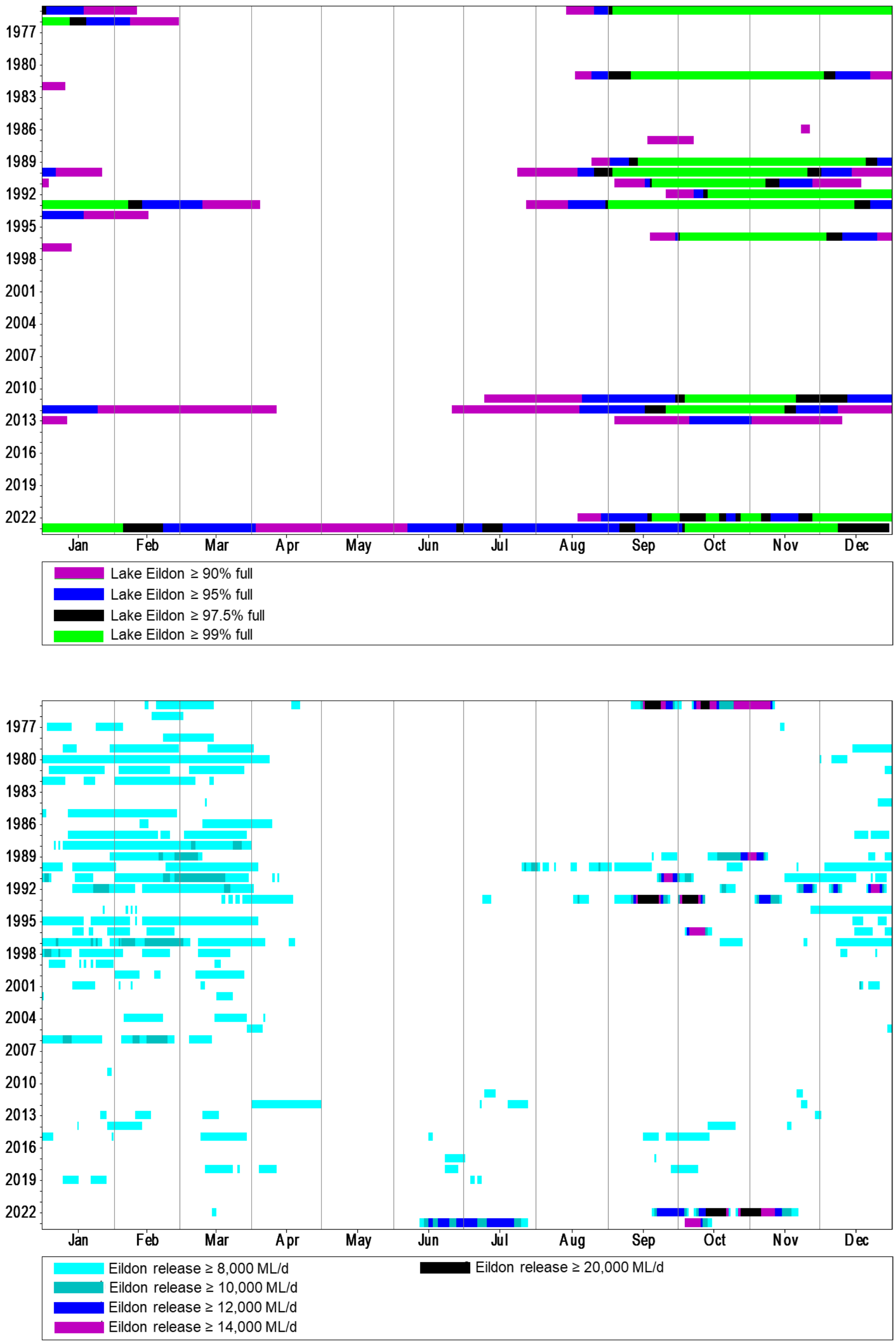


Figure 14: Distribution of Lake Eildon storage capacity (top) and releases (bottom) from January 1975 to December 2023

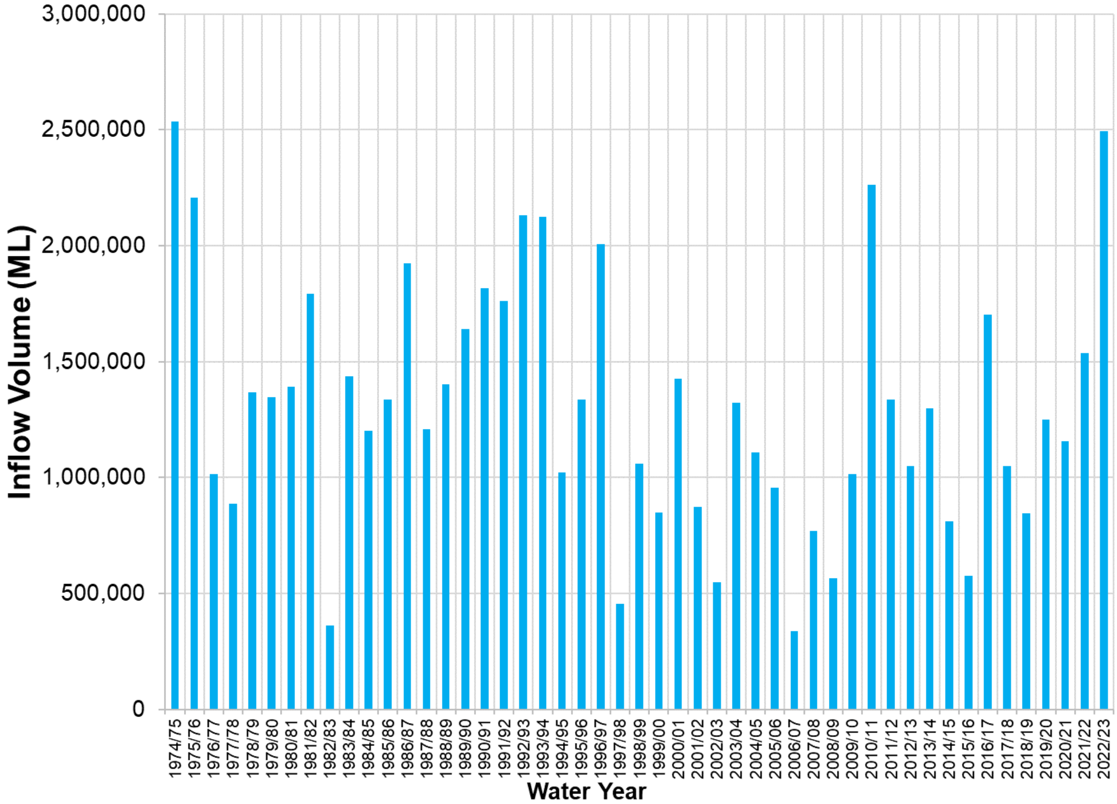


Figure 15: Lake Eildon inflows for water years (July-June) from 1974/75 to 2022/23

2.7 Influence on Seymour floods

For July to June water years post-1957, Figure 16 compares the peak release from Lake Eildon with the peak flow recorded at Seymour (gauge 405202), both as a time-series (top) and an x-y scatter plot (bottom). This figure demonstrates that the correlation between the peak release from Lake Eildon and the peak flow at Seymour varies. That is, there are a significant number of years in the data when the releases made from Eildon had little to no impact on the peak flows recorded at Seymour. For instance, the peak flow at Seymour in October 2022 was significantly above the major flood class level flow threshold for gauge 405202 (76,000 ML/d[11]), however, the peak release from Lake Eildon – which was between the moderate and major flood class level flow threshold at Eildon – occurred at a similar time to the peak flow at Seymour and due to the travel time between Eildon and Seymour, did not contribute to the peak flow at Seymour. This comparison has not been repeated at Molesworth because there is no gauged information at Molesworth because there currently is no operational streamflow gauge.

There are, however, other years (e.g. 1971, 1974 and 1993) where the peak release from Lake Eildon was a bigger contributor to the peak flow at Seymour, as shown by the smaller gap between the orange and blue series in Figure 16. The variation in the correlation between the peak release from Lake Eildon and peak flows at Seymour occurs because of the variability in where rain falls during large events (i.e. in the dam catchment or the downstream tributary

[11] http://www.bom.gov.au/vic/flood/floodclass_north.shtml and https://data.water.vic.gov.au/

catchments). This variation in where rain falls means that increasing the flood mitigation provided by Lake Eildon will not always reduce flood peaks further downstream. The four largest floods recorded at Seymour was the May 1974, September 1975, October 1993 and October 2022 events.

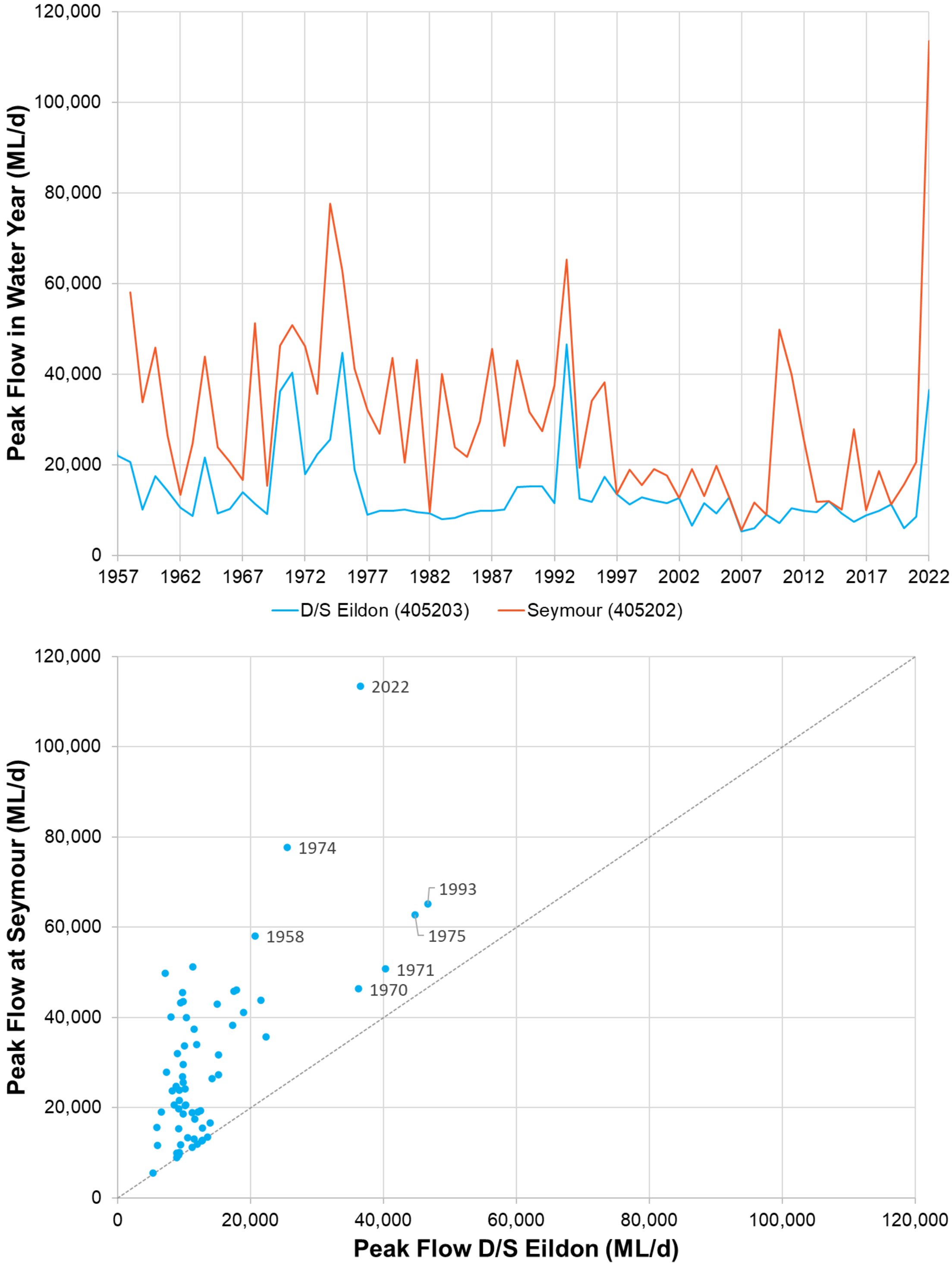


Figure 16: Peak releases from Lake Eildon versus peak flows at the Seymour for each water year, shown as a time-series (top) and x-y scatter plot (bottom)

3. Previous studies

Before considering options to increase the flood mitigation provided by Lake Eildon, several previous studies were reviewed. These were:

- SKM (2006). Flood Surcharge of Gated Storages. Report prepared for GMW.
- SKM (2007). Preliminary Surcharge Modelling for Eildon Dam. Memorandum prepared for GMW.
- SKM (2010). Eildon Surcharge Investigation. Report prepared for GMW.
- SKM (2011). Review of Lake Eildon Filling Arrangements. Report prepared for GMW.
- HARC (2017). GMW Dams PRA Hydrology Review; Lake Eildon. Report prepared for GMW.
- HARC (2019). GMW Dams PRA Project Risk Assessment; Lake Eildon. Report prepared for GMW.

The outcomes of these studies are summarised below.

3.1 SKM (2006)

Flood Surcharge of Gated Storages	
Purpose of study	This study explored the issues relating to flood surcharge of gated storages with particular emphasis on Lake Eildon
Main conclusion	Increasing the target surcharge could reduce the likelihood of spillway damage but could extend the duration in which higher downstream flows are sustained. Furthermore, there is a potential for an increased likelihood of a flood overtopping the dam if the reservoir was initially surcharged prior to the occurrence of an extreme flood.
Relevance to current investigation	This study provides information relevant to Option 5 – Change maximum surcharge

This investigation explored the issues relating to flood surcharge of gated storages, with particular emphasis on Lake Eildon. A workshop was held to explore the viability of developing recommendations for allowable surcharge and was attended by a range of stakeholders to identify a range of issues relating to surcharging. A brief description and significance were assigned for each of the identified issues which reflected its perceived importance. The issues were divided into three groups, namely general policy and technical constraints, potential benefits of surcharging, and potential adverse consequences of surcharging.

The investigation included some preliminary modelling to assess the impact of surcharging on the Eildon reservoir outflow frequency curves (Figure 17), and the approximate annual exceedance probability (AEPs) of outflows exceeding 1,000 m^3/s (Table 6). The target surcharge levels were chosen based on risk assessments undertaken prior to the Lake Eildon upgrade completed in 2005. The 1,000 m^3/s (86,400 ML/d) outflow was based on an Eildon Alliance (2006) analysis which identified that the spillway chute slabs could become unstable if outflows exceed this threshold.

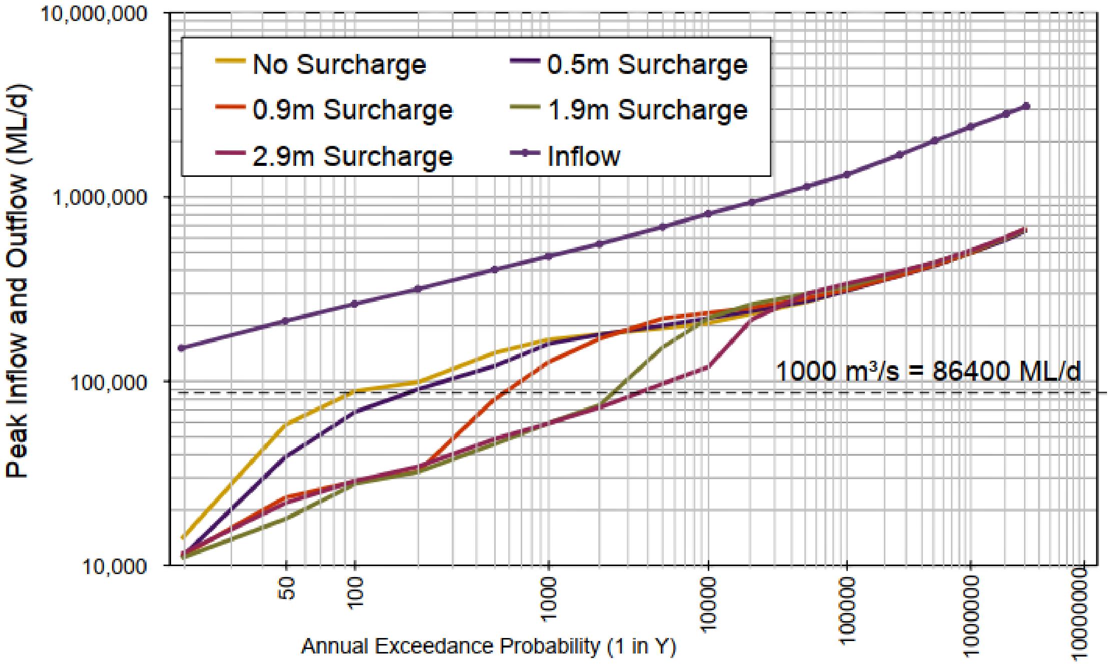


Figure 17: Preliminary Eildon outflow frequency curves for different surcharge levels (SKM, 2006)

The results in Table 6 show a decreased likelihood of outflows exceeding 1,000 m³/s as the allowable surcharge increases. However, while increasing the target surcharge could reduce peak outflows, it would also increase the duration of downstream flooding, by increasing the time required to return the reservoir level to FSL after an event. The increased duration of flooding could adversely impact on agricultural production and disrupt the road transport and communications. but this trade-off between the peak and duration of flooding was not investigated (SKM, 2006).

Table 6: Approximate AEPs of Eildon outflows exceeding 1,000 m³/s for different surcharge levels (SKM, 2006)

Target Surcharge	AEP (1 in Y)
0.0	1 in 100
0.5	1 in 180
0.9	1 in 560
1.9	1 in 2400
2.9	1 in 3500

The SKM (2006) study also investigated whether the likelihood of the spillway chute slab becoming unstable (at reservoir level 294.0 m AHD) or the dam overtopped (at reservoir level 296.4 m AHD) changes if the reservoir is surcharged when a flood arrives. This involved a simplified analysis where the level frequency curve for Lake Eildon was modelled assuming the reservoir was already surcharged prior to an extreme rainfall event (Figure 18). As shown in Table 7, the AEP of reaching the key reservoir levels mentioned above increased as the starting level was increased. However, further work would be required to assess the probability of back-to-back floods occurring, and therefore the likelihood the reservoir would be surcharged before an extreme rainfall event.

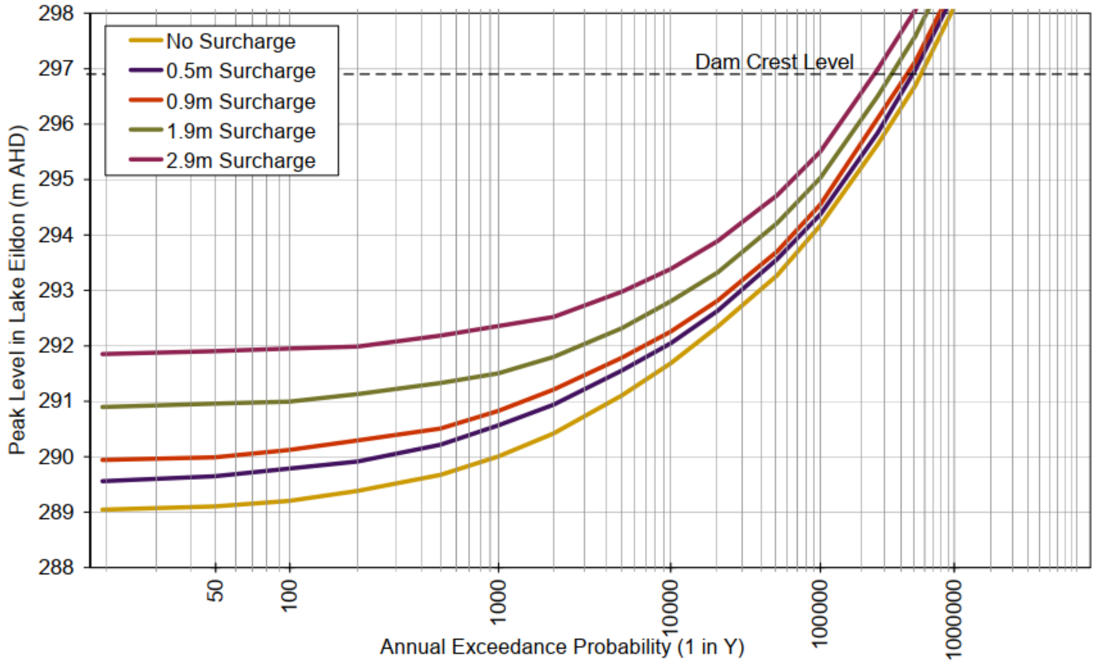


Figure 18: Impact of starting surcharge level on Eildon level frequency curve (SKM, 2006)

Table 7: Approximate probability of reservoir levels for different starting levels (SKM, 2006)

Initial Reservoir Level	AEP of exceeding level	
	294.0 mAHD	296.9 mAHD
FSL	1 in 88,000	1 in 550,000
FSL + 0.5 m	1 in 73,000	1 in 480,000
FSL + 0.9 m	1 in 64,000	1 in 430,000
FSL + 1.9 m	1 in 40,000	1 in 330,000
FSL + 2.9 m	1 in 23,000	1 in 250,000

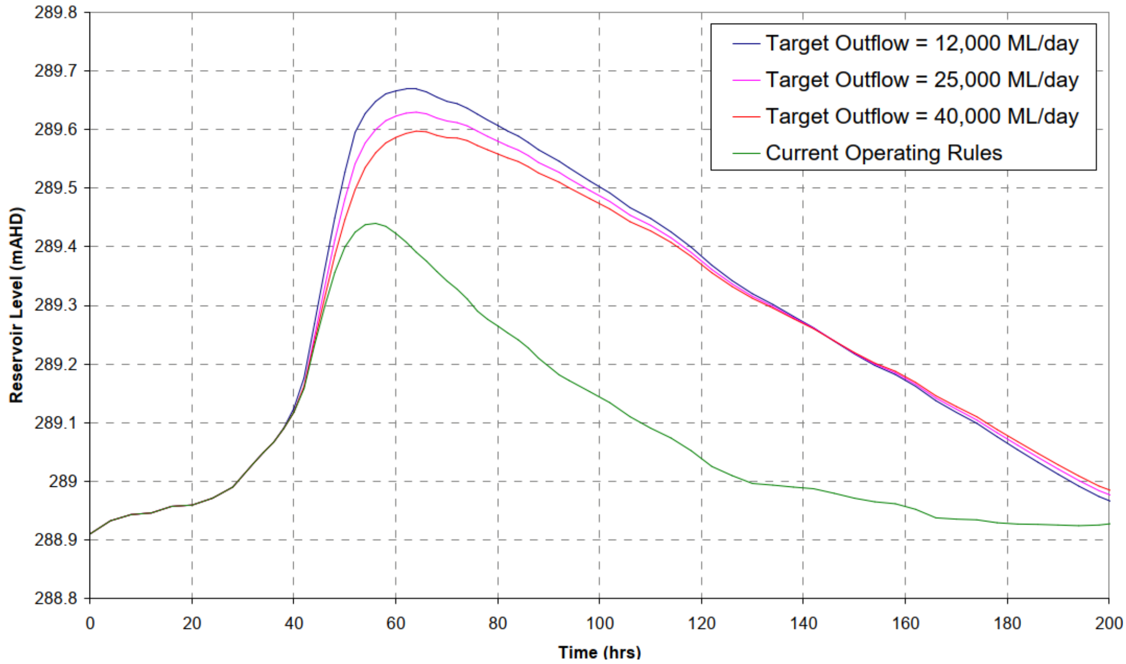
3.2 SKM (2007)

Preliminary Surcharge Modelling for Eildon Dam	
Purpose of study	This study modelled the impact of limiting the peak outflow from the dam to minor (12,000 ML/d), moderate (25,000 ML/d) and major (40,000 ML/d) flood class level flow thresholds, using an event-based analysis
Main conclusion	Limiting the outflow from Lake Eildon (therefore surcharging the storage) only decreases the peak outflow, and therefore has positive flood mitigation effects, for events more common than the 10% AEP.
Relevance to current investigation	This study provides information relevant to Option 6 – Restrict maximum outflows

As part of this study, a spreadsheet model of gate operations was developed. This spreadsheet was used to simulate the changes to peak reservoir levels during historic floods if the peak outflow was restricted. The target outflows for flood mitigation purposes were defined by the Bureau of Meteorology minor, moderate and major flood class level flow thresholds downstream of Lake Eildon.

The results presented in Figure 19 show that limiting the outflow from Lake Eildon (therefore surcharging the storage) only decreased the peak outflow (i.e. had a positive flood mitigation benefit) for October 1993 flood event by a small amount. This was due to the ability to mitigate outflows being constrained by the need to ensure that adequate freeboard was maintained to the top of the spillway gates.

The gate operating conditions that were modelled as part of this study have since been updated as part of the HARC (2017) flood hydrology study. However, the results from the 2007 study still provide useful context for this assessment of potential operating options for increasing the flood mitigation provided by Lake Eildon.



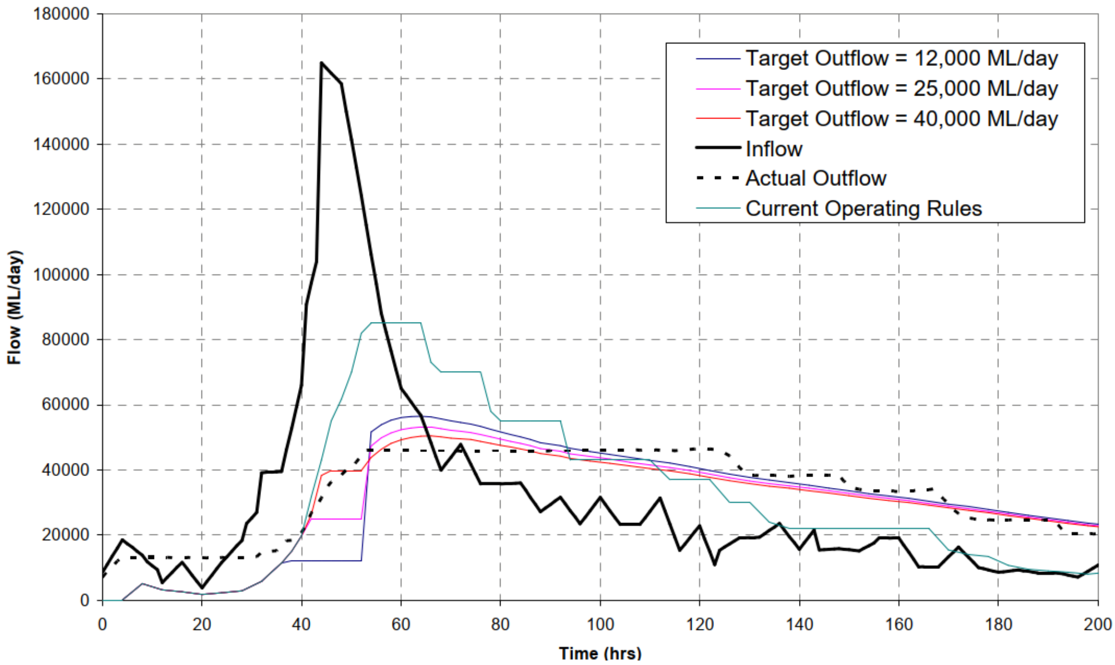


Figure 19: Simulations of the 1993 flood – showing reservoir level (top) and outflow (bottom) – assuming the reservoir is initially at FSL, appropriate freeboard is maintained, and different maximum outflows are targeted (SKM, 2007)

3.3 SKM (2010)

Eildon Surcharge Investigation	
Purpose of study	This study built on the previous SKM (2006 & 2007) investigations to assess in more detail the impacts of surcharging Lake Eildon
Main conclusions	▪ There are flood mitigation benefits for events more frequent than the 1 in 1,000 AEP event when 600 mm of surcharging is allowed. This benefit also increases when the target surcharge increases. ▪ The initial reservoir drawdown plays a significant role in the likelihood of key levels and outflows being reached. When the initial reservoir level is assumed to be at FSL, the AEP of the DCF is approximately 3.5 times more likely compared with the AEP estimated when the expected reservoir drawdown is accounted for.
Relevance to current investigation	This study provides more detailed information relevant to Option 5 – Change maximum surcharge

After the SKM (2006 & 2007) investigations, a gate operations module was developed for the Lake Eildon RORB (hydrology) model. The gate operations module enabled the impact of potential surcharge policies to be better quantified.

Figure 20 is a key outcome of the SKM (2010) study and shows that for events more frequent than about 1 in 1,000 AEP, surcharging the reservoir by 600 mm or greater lowers peak outflows compared with having no surcharge. For example, with 600 mm of surcharging the likelihood of an event resulting in a peak flow of 46,000 ML/d reduced from 1 in 40 to 1 in 110 AEP. This reduced further to 1 in 140 AEP with 1200 mm of surcharging.

Figure 20 also shows the impact on the likelihood of reaching a flow of 1,000 m³/s (86,400 ML/d) through the spillway. This was highlighted in SKM (2006) as being a flow at which the spillway chute slabs could become unstable, resulting in a significant repair cost. The likelihood of reaching this flow is three times less likely with 600 mm surcharging, and six times less likely with 1200 mm surcharging.

For events between the 1 in 1,000 and the 1 in 10,000 AEP, surcharging results in larger peak outflows. This is because to pass very rare events the gates need to be fully opened, which means that the outflows are no longer controlled by the gates but rather the head of water above the spillway crest. If less water is released at the start of the event – i.e. because of surcharging the reservoir – the water level and outflow at the peak of the event increases. For events rarer than 1 in 10,000 AEP, this effect is less noticeable, but still does increase the likelihood of a flood overtopping the dam.

A summary of the likelihood of key thresholds being exceeded under the no surcharge, 600 mm, 900 mm and 1200 mm surcharge scenarios is provided in Table 8. The results show that increasing the surcharge depth has positive flood mitigation benefits for more common events, but this reverses for extreme floods. The SKM (2010) study did not assess how the duration of outflows from Lake Eildon above minor, moderate, major flood levels, etc change under different surcharging scenarios.

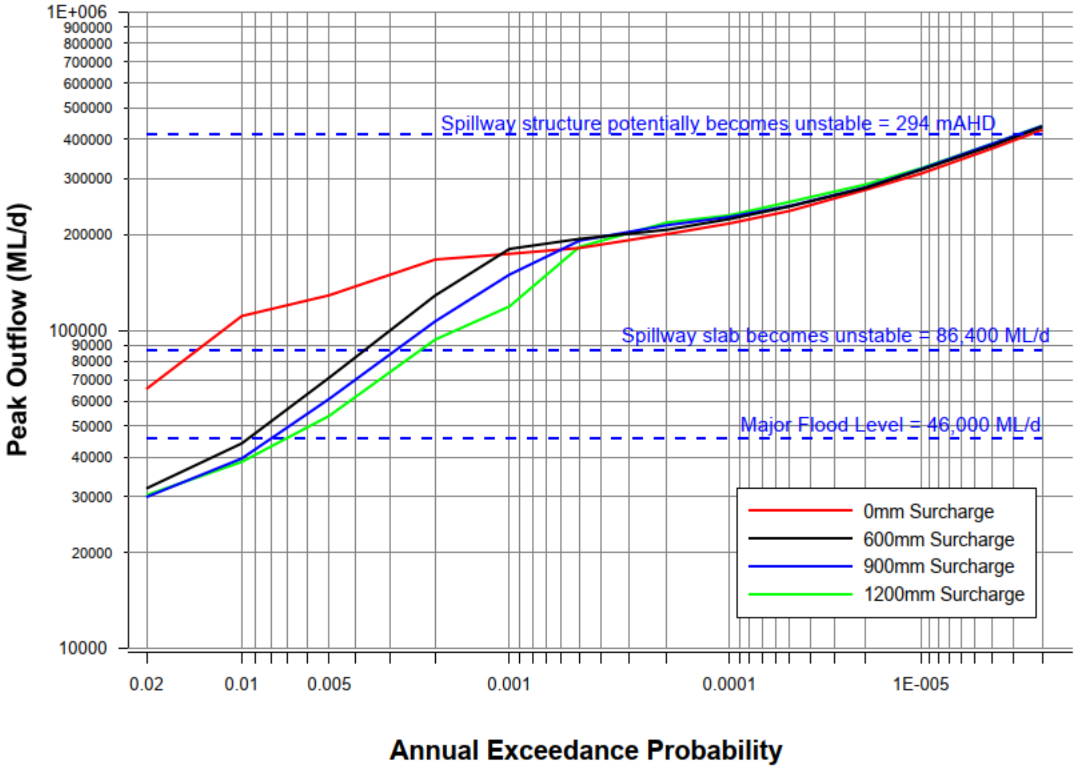


Figure 20: Outflow frequency curves for different gate operating rules, assuming the initial reservoir is sampled in the Monte Carlo framework (SKM, 2010)

Table 8: Annual Exceedance Probability (AEP) (1 in Y) of key events occurring given different surcharge policies assuming current gate operating rules and initial reservoir level is sampled in the Monte Carlo framework (SKM, 2010)

Event	0mm Surcharge	600mm Surcharge	900mm Surcharge	1200mm Surcharge
Approximate reservoir level causing spillway structure instabilities (294 mAHD)	380,000[1]	370,000[1]	360,000[1]	360,000[1]
Reservoir outflows causing spillway slab instabilities (86,400 ML/d)	70	270	350	440
Reservoir outflows at Major Flood Level (46,000 ML/d)	40	110	130	140

[1] These results have been extrapolated past the AEP of the Probable Maximum Precipitation (1 in 260,000 AEP) and hence are only indicative.

3.4 SKM (2011)

Review of Lake Eildon Filling Arrangements	
Purpose of study	This study assessed the impact on water resources and outflow flood frequencies if different filling curves were used for Lake Eildon.
Main conclusion	There were no discernible differences in the outflow flood frequency curves and February allocations to Goulburn system irrigators between the different options investigated.
Relevance to current investigation	This study provides information relevant to Option 1 – Change target filling curve

The target filling arrangements in Schedule 5 of the Bulk Entitlement (Eildon-Goulburn Weir) Conversion Order 1995 (Goulburn BE) were updated following a revision of the capacity table (i.e. elevation – storage) for Lake Eildon, and a re-assessment of the target points required to maintain a 95% probability of filling the storage (Figure 21). GMW then commissioned SKM to explore whether the updated filling curve made a material difference to the flood mitigation provided by Lake Eildon, or the reliability of supply to entitlement holders.

The SKM (2011) study found that:

- Over a long-term period of record, the potential different filling arrangements made no significant difference to the modelled reliability of supply.
- Over a long-term period of record, outflow flood frequencies were not noticeably different under the various filling curves tested.
- Over the short-term (i.e. the next 12 months from the time of the study), the updated filling curves slightly increased the AEP of a major flood outflow (i.e. from 1 in 14 to 1 in 13).

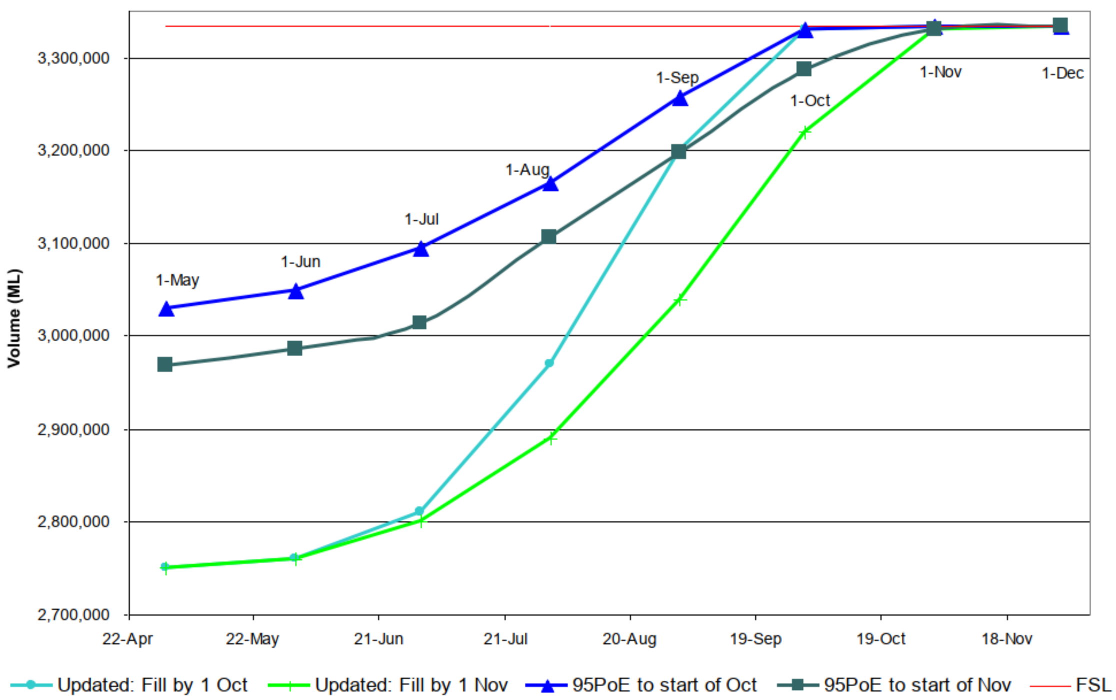


Figure 21: The influence of returning to the 95% probability of exceedance (95PoE) intent of the Lake Eildon filling arrangements, after updating the current filling curves based on the revised capacity table (SKM, 2011)

3.5 HARC (2017 & 2019)

GMW Dams PRA Hydrology Review and Risk Assessment – Lake Eildon	
Purpose of study	These studies involved updating the design flood hydrology modelling for Lake Eildon with a focus on extreme floods in the Lake Eildon catchment, and revising the dam safety risk assessment
Main conclusion	The design flood hydrology inputs and frequency curves were updated, by building on previous SKM studies (2006, 2007, 2010 and 2011). Likewise, the dam safety risk assessment for Lake Eildon built on the Eildon Alliance (2006) analysis of dam safety.
Relevance to current investigation	The revised design flood hydrology inputs have been used as part of the flood modelling in Section 6, and the most recent understanding of the dam safety risks are also referred to in Section 6.2.

The most recent reviews of the design flood hydrology and dam safety of Lake Eildon were completed by HARC in:

- May 2017: *GMW Dams PRA Hydrology Review; Lake Eildon*
- September 2019: *GMW Dams PRA Project; Risk Assessment: Lake Eildon*

The HARC 2017 and 2019 studies were focused on the ability of Lake Eildon dam to withstand extreme floods (i.e. of the type not experienced in the historic record). The conclusion of these studies was that the individual and societal risks posed by Lake Eildon were below the ANCOLD (2022) limit of tolerability for existing dams.

Outputs from these 2017 and 2019 studies have been used in this assessment of the potential operating options for increasing the flood mitigation provided by Lake Eildon. In particular:

- The flood hydrology (RORB) model of the catchment updated in 2017 informs the assessment of expected flood frequency changes at Lake Eildon (Section 6).
- An appreciation of the critical potential failure modes identified as part of the risk assessment informs the comments made in Section 6.2.5.

4. Options investigated

4.1 Selection method

A workshop with Department of Energy, Environment and Climate Action (DEECA), Goulburn-Murray Water (GMW), Goulburn Valley Water (GVW), the Goulburn Broken Catchment Management Authority (GBCMA), Melbourne Water retailers (represented by Greater Western Water), the Victorian Environmental Water Holder (VEWH), Murrindindi Shire Council, Mitchell Shire Council and Strathbogie Shire Council was held in Nagambie, on September 11, to discuss potential operating options for increasing the flood mitigation provided by Lake Eildon. Greater Shepparton City Council, Mansfield Shire Council, Coliban Water and Grampians Wimmera Mallee Water were invited to the workshop but were unable to attend.

Based on the outcomes from this workshop, six options for increasing the flood mitigation provided by Lake Eildon were included as part of this investigation. The options are briefly described in the sub-sections below. Below each option, a subjective rating against the six elements that were considered important during the initial option selection has also been provided. These elements are:

- **Potential to reduce the peak outflow from Lake Eildon**
  i.e. the expected effect the option would have on reducing flood peaks immediately downstream of Lake Eildon
- **Reduced water share reliability**
  i.e. the expected reduction to how often high-reliability water shares (HRWS) and low-reliability water shares (LRWS) in the Goulburn system would receive a 100% allocation
- **Dam safety risk**
  i.e. the relative degree to which implementing the option could compromise the structural integrity of the dam
- **Operational risk**
  i.e. the relative degree to which implementing the option would increase the risks borne by storage operators during flood events
- **Environmental impact**
  i.e. the potential impact to environmental assets at Lake Eildon, and the Goulburn River downstream
- **Recreational impact**
  i.e. the potential impact to recreational activities around Lake Eildon

The subjective rating excludes consideration of socio-economic impacts of reduced water availability, such as the reduction in agricultural production.

4.2 Option 1 - Change target filling curves

The filling arrangements for Lake Eildon are specified in the Bulk Entitlement (Eildon – Goulburn Weir) Conversion Order 1995, and were last updated in 2012 (Bulk Entitlement (Eildon – Goulburn Weir) Amendment Order 2012). The original and all amendments can be found on the Victorian Water Register. The option to change the target filling curve involves managing the storage levels using different probability of exceedance inflows or target fill dates, so that the chance of Lake Eildon filling is lower and/or Lake Eildon is full later in the year (e.g. January or December instead of October or November). Variations of this option were considered by SKM in 2011, based on recorded and modelled inflows for historical climate conditions.

It was agreed with the workshop participants that this option would be considered as part of this technical assessment, and that a greater range of climate conditions (e.g. historical and post-1975 conditions) and probability of exceedance inflows of filling Lake Eildon (e.g. to 75% or 85% instead of 95%) would be assessed.

The subjective ratings for this option that were discussed and agreed in the workshop are shown in Table 9.

Table 9: Subjective ratings for the option to reduce the Lake Eildon target storage

Element	Subjective Rating
Potential to reduce peak outflow from Eildon	Low
Reduced water share reliability	Low – Medium
Dam safety risk	Low
Operational risk	Low – Medium
Environmental impact	Low
Recreational impact	Low

4.3 Option 2 - Reduce target storage

This option involves lowering the target storage to a defined proportion of full supply level (FSL) (e.g. 78%, 85%, 90%, 95%), rather than allowing Lake Eildon to fill to the current FSL. The additional airspace in Lake Eildon could further reduce flood peaks as events passed through the storage.

This option has not explicitly been considered in past studies. However, this option could provide flood mitigation benefits, at the expense of the reliability of HRWS and LRWS held in the Goulburn system. The degree to which the storage could be held at a target below FSL will also depend on the operational constraints downstream of Lake Eildon, in that reservoir levels will rise if inflows are greater than the maximum possible releases under regulated flow conditions.

The subjective ratings for this option that were discussed and agreed in the workshop are shown in Table 10.

Table 10: Subjective ratings for the option to reduce the Lake Eildon target storage

Element	Subjective Rating
Potential to reduce peak outflow from Eildon	Medium – High
Reduced water share reliability	Medium – High
Dam safety risk	Low
Operational risk	Low – Medium
Environmental impact	Low – Medium
Recreational impact	Medium

4.4 Option 3 - Reduce target storage based on climate signals

This option involves lowering the target storage to a defined proportion of FSL (e.g. 85%, 90%, 95%), based on climate signals. A range of different climate signals were investigated that could be used to inform the operation of Lake Eildon which included:

- The Southern Oscillation Index (SOI) (http://www.bom.gov.au/climate/enso/soi/), a measure of the observed sea level pressure (SLP) differences between Tahiti and Darwin, Australia. The SOI gives an indication of the development and intensity of El Niño or La Niña events in the Pacific Ocean. Sustained positive values are indicative of La Niña conditions (increased chance of above average winter-spring rainfall in eastern Australia) (http://www.bom.gov.au/climate/about/australian-climate-influences.shtml?bookmark=enso).
- The Indian Ocean Dipole (IOD) (https://psl.noaa.gov/gcos_wgsp/Timeseries/DMI/), a measure of difference in the sea surface temperature (SST) between the western equatorial Indian Ocean and the south eastern equatorial Indian Ocean. A sustained negative IOD typically results in above-average winter-spring rainfall over parts of southern Australia (http://www.bom.gov.au/climate/iod/).
- The Tripole Index for the Interdecadal Pacific Oscillation (TPI) (https://psl.noaa.gov/data/timeseries/IPOTPI/), a measure based on the difference between the sea surface temperature anomaly (SSTA) averaged over the central equatorial Pacific and the average of the SSTA in the Northwest and Southwest Pacific. The TPI is another indicator for the El Niño or La Niña conditions with negative values indicating an increased change of above-average rainfall (https://link.springer.com/article/10.1007/s00382-015-2525-1).

The historic index data for the SOI, IOD and TPI is plotted against the monthly inflows to Lake Eildon – as extracted from the water resources model described in Section 5 – in Figure 22, Figure 23 and Figure 24 respectively.

Figure 22 shows that although there is a weak positive correlation between the SOI and monthly inflows, there is significant variability. Furthermore, the 1974 flood event occurred during 'weak' La Niña conditions and the 1975 and 2022 flood events occurred during 'moderate; to 'strong' La Niña conditions, however, the 1993 flood event occurred during 'weak' El Niño conditions.

Figure 23 shows that there is low negative correlation between the IOD and monthly inflows. For IOD index values that are less than -1, the inflows into Eildon varied between 130,000 ML and 770,000 ML per month. However, the 1974, 1975, 1993 and 2022 flood events which resulted in significant flooding downstream of Eildon did not coincide with very negative IOD conditions.

Figure 24 shows that there is a weak negative correlation between the TPI and monthly inflows. For TPI values that are less than -1, the inflows into Eildon varied quite significantly, from very low inflows to the maximum monthly inflow in the modelled period of record (930,000 ML). Furthermore, while the 1974, 1975 and 2022-flood events coincided with negative TPI values, the TPI value during the 1993 flood event was positive.

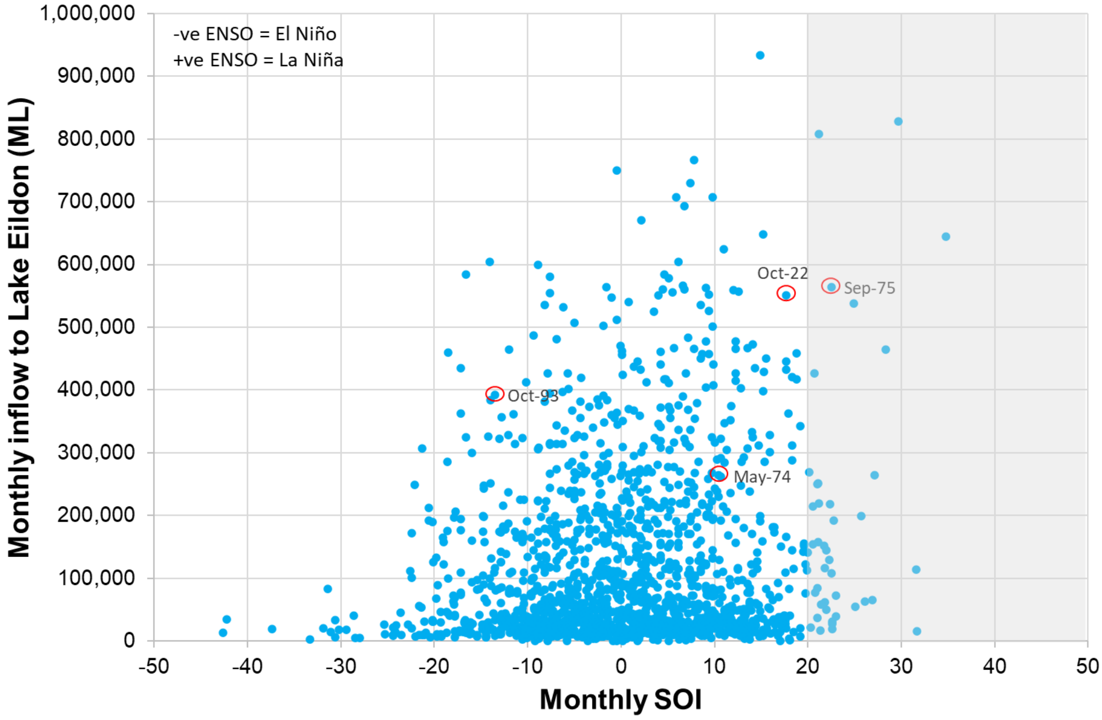


Figure 22: Monthly SOI plotted against the monthly inflow volumes into Lake Eildon

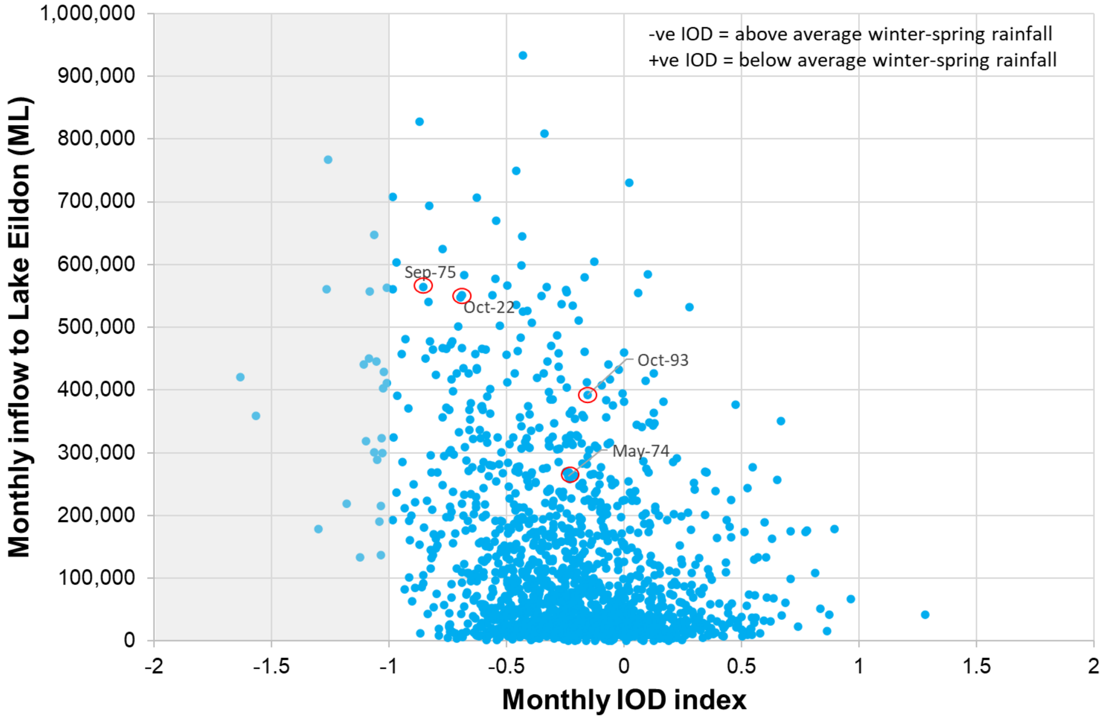


Figure 23: Monthly IOD index plotted against the monthly inflow volumes into Lake Eildon

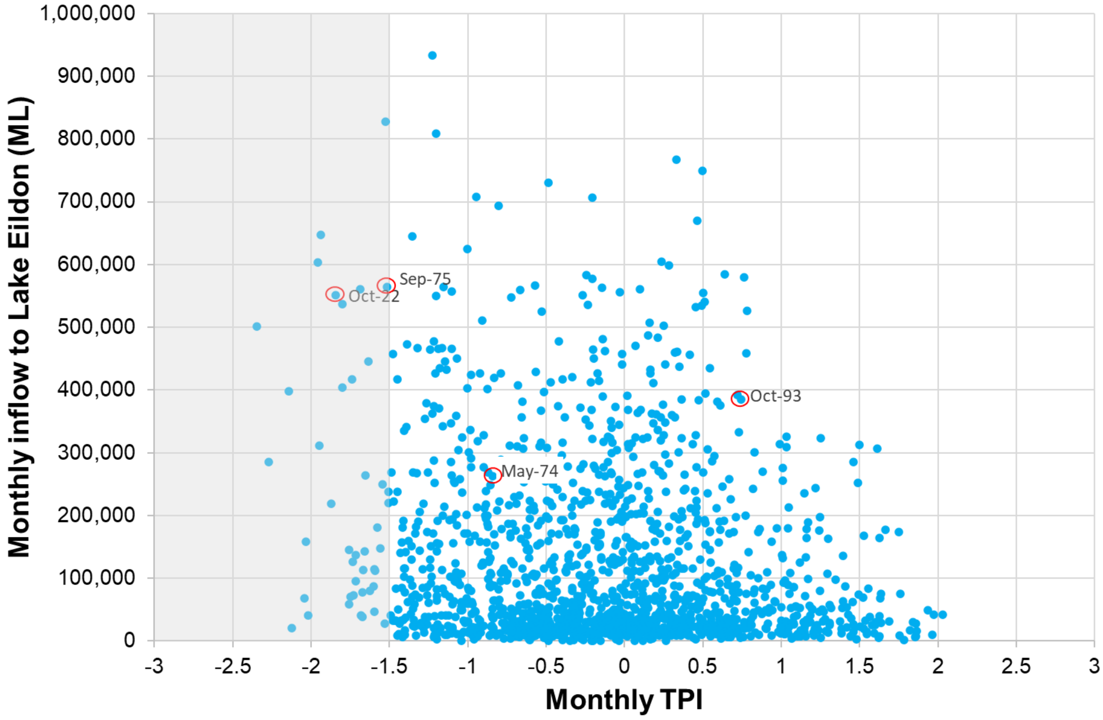


Figure 24: Monthly TPI plotted against the monthly inflow volumes into Lake Eildon

GMW use climate indices such as these to inform the management of the filling curve at Lake Eildon. Climate indices are also used by other Australian agencies to inform decision making. For example, in response to the La Niña conditions, the Queensland Government implemented a temporary reduced FSL of approximately 80% of water supply capacity for Wivenhoe Dam in October 2022. However, below average wet season rainfall in the dam catchment occurred, and thus the dam level continued to decline over 2023, decreasing to approximately 62% of water supply capacity in December 2023. The decision to impose a temporary reduced FSL prior to the 2022/23 wet season resulted in a significant decrease in water supply capacity without offering any appreciable flood mitigation benefit.

This option was progressed to the technical assessment based on the feedback provided by the workshop participants. The subjective ratings that were discussed and agreed are shown in Table 11.

Table 11: Subjective ratings for the option to reduce the Lake Eildon target storage based on climate signals

Element	Subjective Rating
Potential to reduce peak outflow from Eildon	Low – Medium
Reduced water share reliability	Medium – High
Dam safety risk	Low
Operational risk	Medium – High
Environmental impact	Low – Medium
Recreational impact	Medium

4.5 Option 4 - Pre-release based on forecast rainfall

Pre-releasing means releasing water from storage, to reduce the reservoir level prior to forecast rainfall and resulting inflows, and thus reduce peak flows downstream of the storage. As Lake Eildon exists primarily to harvest and store water for entitlement holders, a main consideration for pre-releasing water is the level of confidence that the water can be recovered. Releasing more water than is received from inflows would have a negative impact on the availability of water for entitlement holders. Another key consideration is whether pre-releasing water will increase downstream flooding, by adding releases to inflows from downstream tributaries.

It is almost impossible to know how much water will flow into storages based on rainfall forecasts. Catchment conditions, differences between forecast and actual rainfall, and how quickly and where rain falls, all contribute to how much water flows into Lake Eildon. GMW currently considers pre-releasing when it expects inflows to be greater than the available airspace and releases may be required to pass the flood safely based on the flood operations policy[12] (GMW, 2022). This can reduce the magnitude and duration of downstream flooding flows and associated impacts, however, it can increase the risk to system reliability.

The option considered here is varying the current flood operations policy (GMW, 2022) by making more significant pre-releases from Lake Eildon – i.e. up to the minor or moderate flood class level flow thresholds – based on forecast rainfall in the dam catchment 3 to 4 days in advance. Examples of available datasets to inform pre-release decision making, such as the Bureau of Meteorology Australian Digital Forecast Database (ADFD) grids, and forecast rainfall from different global models, were presented during the workshop.

This option was progressed to the technical assessment, by modelling the impacts of increased pre-releases on peak flows at Seymour if the October 1993 and October 2022 floods were repeated.

The subjective ratings for this option that were discussed and agreed in the workshop are shown in Table 12.

[12] https://www.g-mwater.com.au/news-updates/reports-and-publications/policies

Table 12: Subjective ratings for the option to pre-release Lake Eildon based on forecast rainfall

Element	Subjective Rating
Potential to reduce peak outflow from Eildon	Low
Reduced water share reliability	Medium – High
Dam safety risk	Low
Operational risk	High
Environmental impact	Low
Recreational impact	Low

4.6 Option 5 - Change maximum surcharge

Surcharging is a condition where the water level in a storage inadvertently or deliberately rises above the designed or agreed FSL. To protect the structural integrity of the water storage, the reservoir level should not exceed FSL for any longer than necessary. Minor unavoidable surcharging may occur during flood routing due to operational constraints. Storage safety implications, flood mitigation benefits and water harvesting objectives of storage surcharging must also be reconciled through operational procedures (GMW, 2022).

Surcharging is expected to reduce the peak magnitude of downstream flooding, however may increase the duration of flooding above a certain level or flow threshold.

The current Maximum Allowable Surcharge Level (MASL) at Lake Eildon is 610 mm above the FSL (MASL of 289.51 m AHD). This option considered here involves increasing the MASL above 610 mm. This option was progressed to the technical assessment, so that the trade-off between the potential reduction in downstream flood frequencies and the impacts on the dam safety could be investigated in more detail.

The subjective ratings for this option that were discussed and agreed in the workshop are shown in Table 13.

Table 13: Subjective ratings for the option to change the maximum surcharge at Lake Eildon

Element	Subjective Rating
Potential to reduce peak outflow from Eildon	Low – Medium
Reduced water share reliability	Low
Dam safety risk	High
Operational risk	Medium
Environmental impact	Low
Recreational impact	Low

4.7 Option 6 - Restrict maximum outflows

This option involves restricting the outflows to the minor, moderate or major flood class level flow thresholds from Lake Eildon, and allowing the reservoir to surcharge to any depth provided an appropriate freeboard from the top of the gates is maintained.

This option was previously investigated by SKM (2007). However, SKM (2007) found that the necessary freeboard could not be maintained while restricting outflows to minor, moderate or major flood class level flow thresholds during a repeat of the 1993 flood or for the 1% AEP design flood.

This option was progressed to the technical assessment to provide further detail on the risks involved in restricting the outflows to the minor, moderate or major flood class level flow thresholds downstream of Lake Eildon.

The subjective ratings for this option that were discussed and agreed in the workshop are shown in Table 14.

Table 14: Subjective ratings for the option to restrict the maximum outflows from Lake Eildon

Element	Subjective Rating
Potential to reduce peak outflow from Eildon	Medium
Reduced water share reliability	Low
Dam safety risk	High
Operational risk	High
Environmental impact	Low
Recreational impact	Low

5. Water resource implications

5.1 Method

The Goulburn Simulation Model (GSM) provided by DEECA was used to assess the water resource implications of the options described in Section 4 that included modified target filling curves, a reduced target storage, and reducing target storage based on climate signals (i.e. the first three options). The GSM is a water resource allocation model (REALM) that operates on a monthly time-step, and simulates the river systems of the Goulburn, Broken, Campaspe and Loddon basins, including the volumes stored in Lake Eildon and flows in the Goulburn River. The 'base case' version available for this study simulates the period from July 1891 to June 2022, and represents the application of current infrastructure and system operation rules under historic climate conditions, with consumptive and environmental water demands as per Victoria's water resource plans[13].

If future work is done on the potential operating options for increasing the flood mitigation provided by Lake Eildon, DEECA should use the daily Goulburn Broken-Campaspe-Coliban-Loddon Source model to assess the water resource and downstream flow regime implications, rather than continuing to use the monthly GSM that was made available for this study. This is because the daily time-step results from the Source model would provide more useful information about how the timing and duration of Goulburn River flows above important thresholds for downstream communities would be expected to change if the operations of Lake Eildon were modified. If the daily time-step Source model was used instead of the GSM, it would also mean that results from the simulations of potential options to increase the flood mitigation provided by Lake Eildon could be more easily compared with Source modelling results for scenarios considered in Stage 1A of the Victorian Constraints Measures Program[14].

Figure 25 shows how the Lake Eildon storage trace modelled by the GSM compares with the historical record. In general, there is a reasonable match between the two time-series, though in more recent times the GSM has predicted a greater drawdown of Lake Eildon compared with what has been observed. Further comment on this is provided in Section 8.

[13] https://www.water.vic.gov.au/our-programs/murray-darling-basin/what-is-the-murray-darling-basin-plan

[14] https://www.water.vic.gov.au/our-programs/murray-darling-basin/victorian-constraints-measures-program

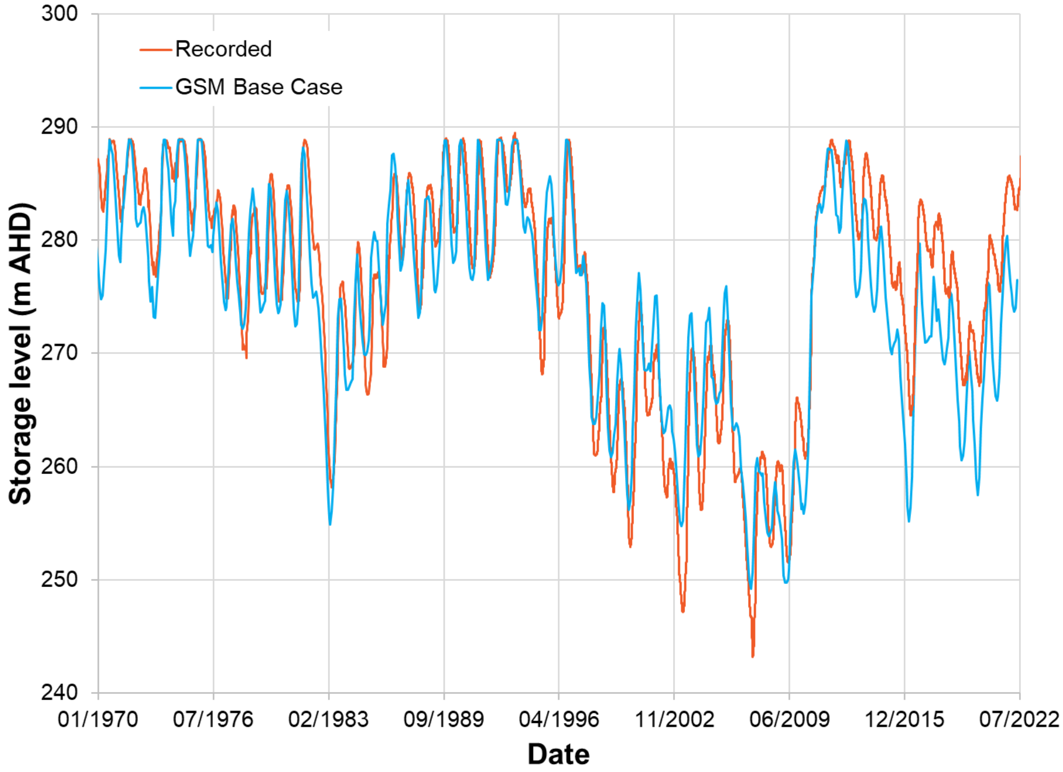


Figure 25: A comparison between the Lake Eildon storage trace as recorded over time, and modelled in the GSM base case available for this study

The base case scenario modelled for this assessment was provided by DEECA. The base case includes a target filling curve for Lake Eildon that is calculated with 95% probability of exceedance inflows which means that only in 5% of years will the storage not reach FSL by 1 October. This base case does not necessarily match the actual operation of the storage by GMW from year-to-year, but does provide a useful basis for comparing with potential operating options for increasing the flood mitigation at Lake Eildon.

To calculate these filling curves based on PoE inflows, the GSM's modelled inflow into Eildon was used. For months from May to the target fill month, the total inflow of each month to the target fill month was calculated (e.g. if the aim was to fill by 1 Oct, for July the total inflow would be the sum of inflows from July, August, and September). The percentile of these total inflows was then calculated, and converted to a target storage by subtracting it from Lake Eildon's total storage capacity.

The base case scenario was modified to simulate the options in Section 4 that included a modified target filling curve or reduced target storage by:

- Revising the GSM's target filling curves for Lake Eildon from the base case (fill by 1 Oct 95% of the time) to represent different percentage of exceedance (PoE) inflows (75% and 85%, calculated for post-1891 conditions and post-1975 conditions) and different target fill dates (1 Nov, 1 Dec and 1 Jan) (Figure 26, Figure 27 and Figure 28).
- Revising the target storage to 95%, 90%, 85% and 78% of FSL at Lake Eildon. If the target storage was above the base case filling curve, the filling curve was adopted (Figure 29). If the modelled volume held in storage was above the target storage (e.g. during wet periods

when inflows exceeded outflow constraints), the volume above the target storage was excluded from the GSM calculations of allocations to entitlement holders.

- Introducing new rules to the GSM that simulated the release of water from Lake Eildon to the Goulburn River based on historic climate signals. If the climate signal threshold was reached the target storage was reduced to 85% of FSL. A threshold of above 20, below -1, and below -1.5 was modelled for the SOI, IOD, and TPI climate signals, respectively (see Section 4.4, Figure 22, Figure 23 and Figure 24).

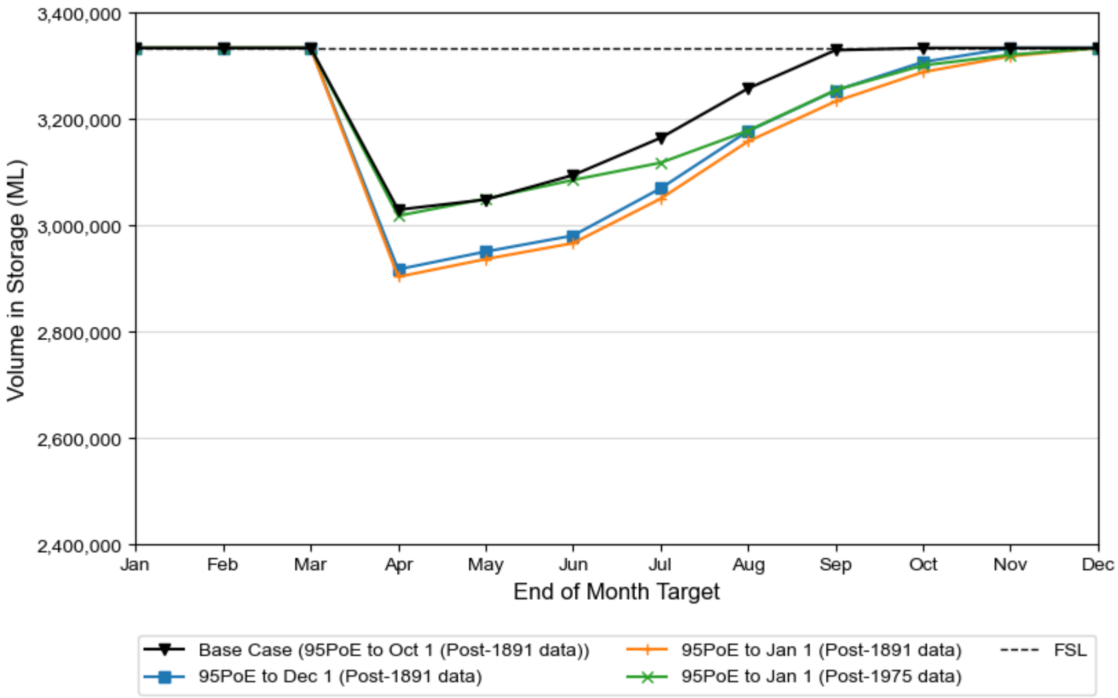


Figure 26: Selected target filling curves adopted for reducing the target storage with percentage of exceedance (PoE) inflows set to 95%

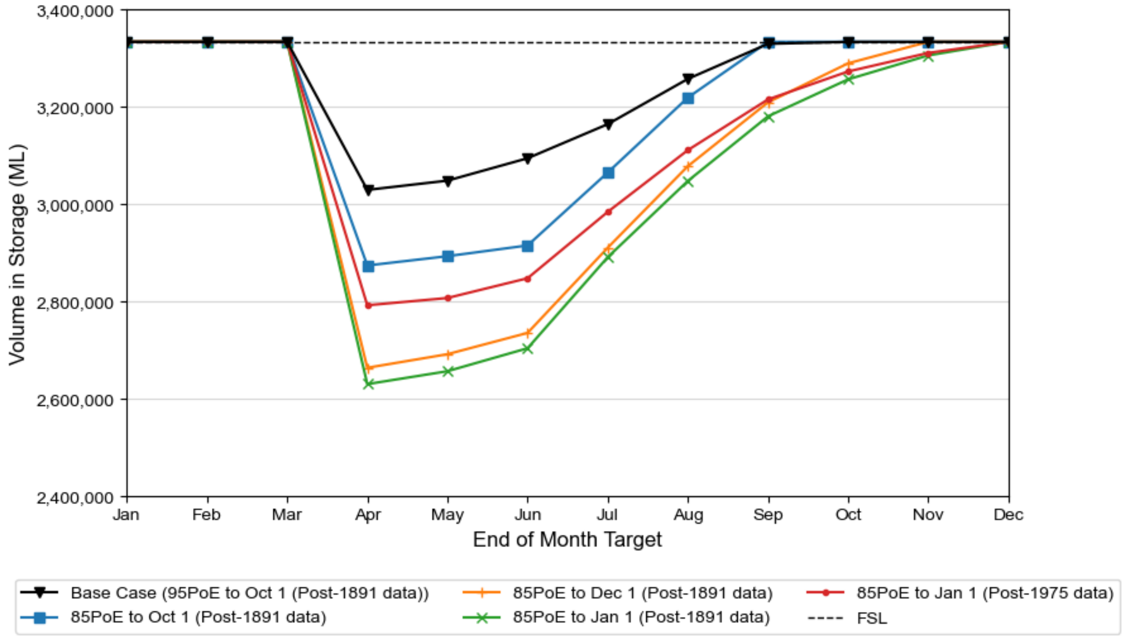


Figure 27: Selected target filling curves adopted for reducing the target storage with percentage of exceedance (PoE) inflows set to 85%

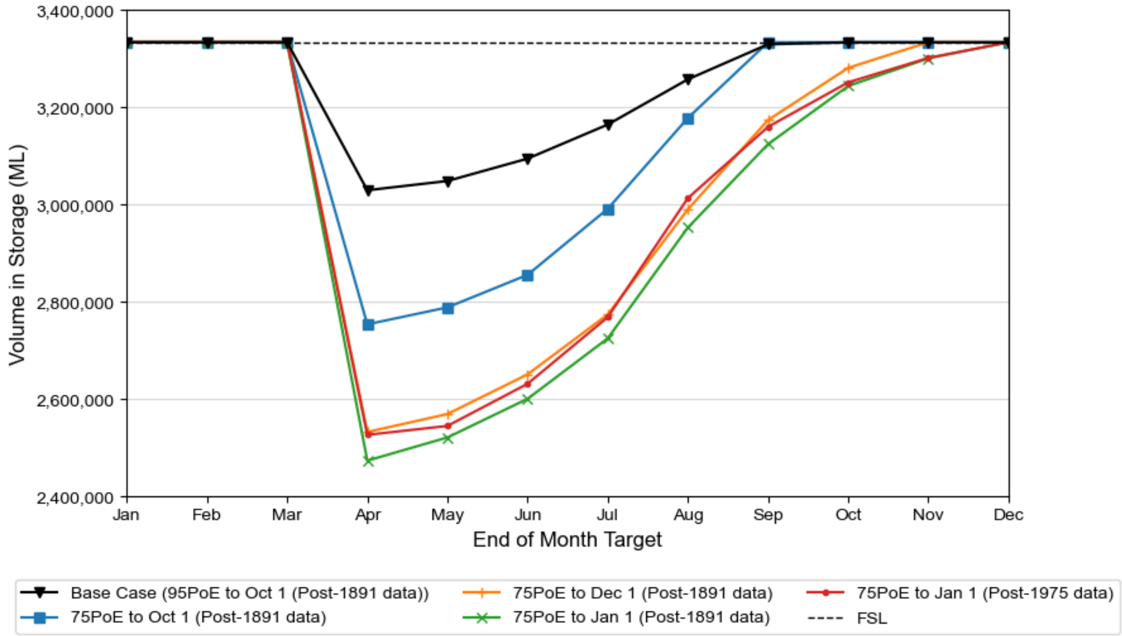


Figure 28: Selected target filling curves adopted with percentage of exceedance (PoE) inflows set to 75%

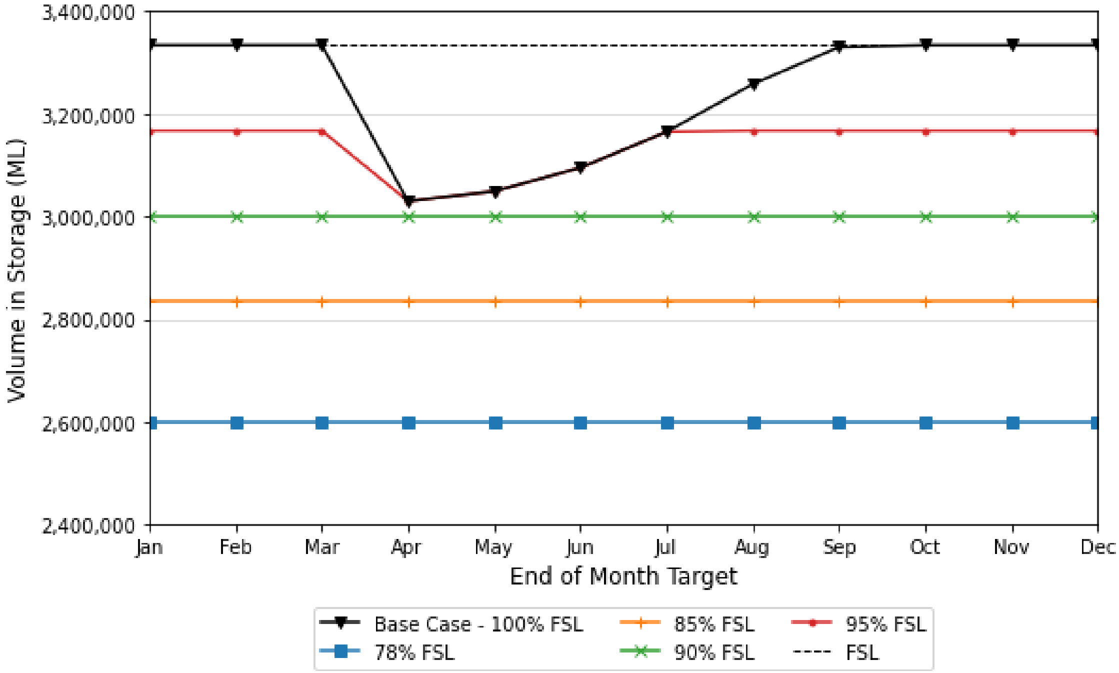


Figure 29: Modified target filling curves adopted for reducing the target storage

The changes to the storage level and volume as a result of the reduced target storage option is shown in Figure 30.

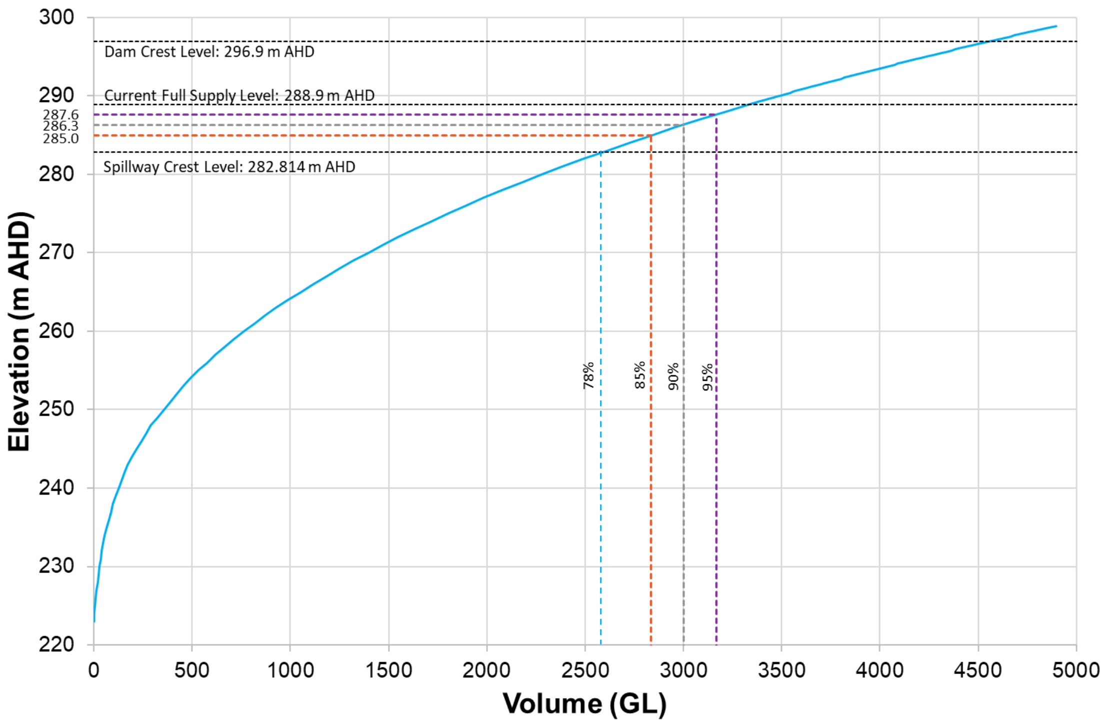


Figure 30: Lake Eildon storage (GL) vs reservoir level (m AHD)

5.2 Results

5.2.1 Storage exceedance curves

Figure 31 to Figure 35 show monthly time-series of the simulated storage trace for Lake Eildon under the options trialled. The period January 1975 to June 2022 is shown – rather than the whole period modelled – so that the plots are easier to interpret. The period post-1975 is also more representative of current climate conditions in Victoria compared with pre-1975[15].

Specifically:

- Figure 31, Figure 32 and Figure 33 contains the storage traces for the options to modify the target filling curve to be based on 95%, 85% or 75% percentage of exceedance inflow conditions, or to fill the storage by 1 Dec or 1 Jan.
- Figure 34 contains the storage traces for the options to reduce target storage to 78%, 85%, 90% or 95% of FSL.
- Figure 35 compares the storage traces for the options to reduce target storage to 85% of FSL by releasing of water from Lake Eildon to the Goulburn River based on historic climate signals that predict 'wet' years. Several different climate indices (IOD, SOI and TPI) were used to assess the impact on the storage trace.

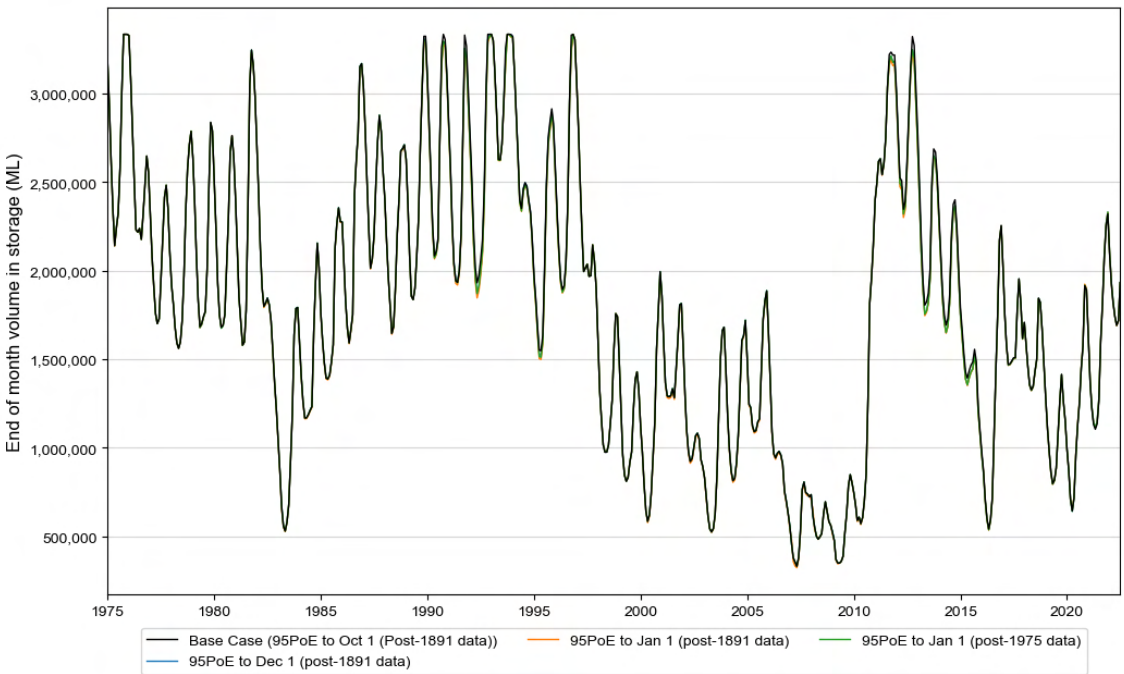


Figure 31: Monthly time-series of the modelled storage trace for Lake Eildon, from January 1975 to June 2022, for 95PoE target filling curves.

[15] https://www.water.vic.gov.au/climate-change/adaptation/guidelines

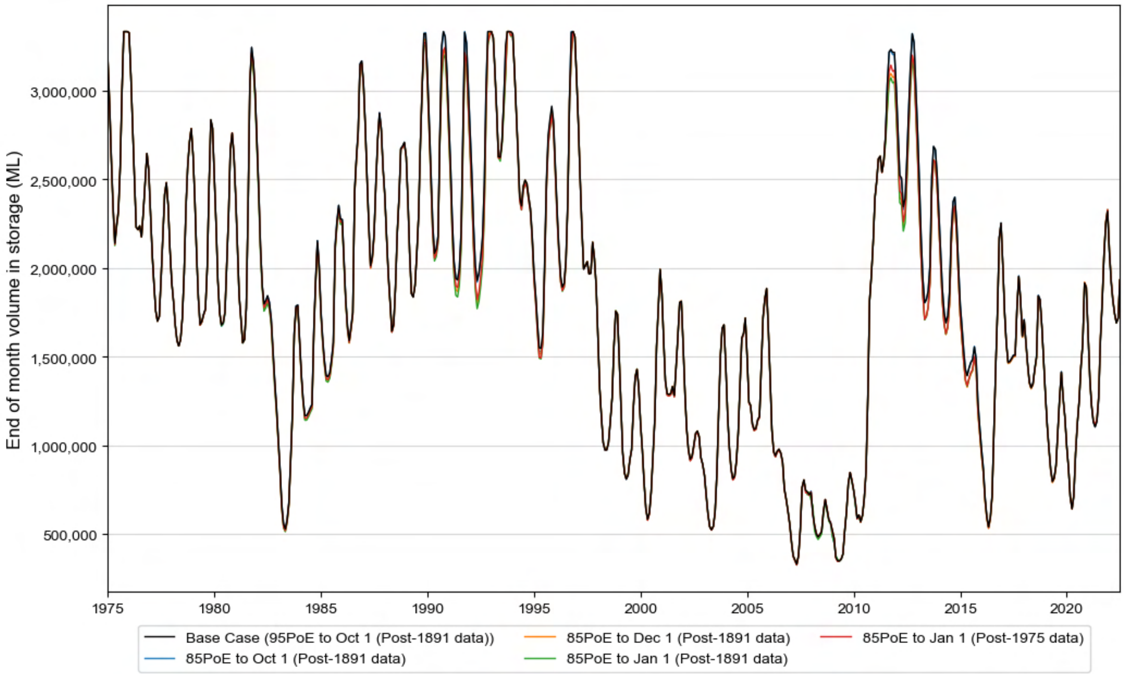


Figure 32: Monthly time-series of the modelled storage trace for Lake Eildon, from January 1975 to June 2022, for 85PoE target filling curves.

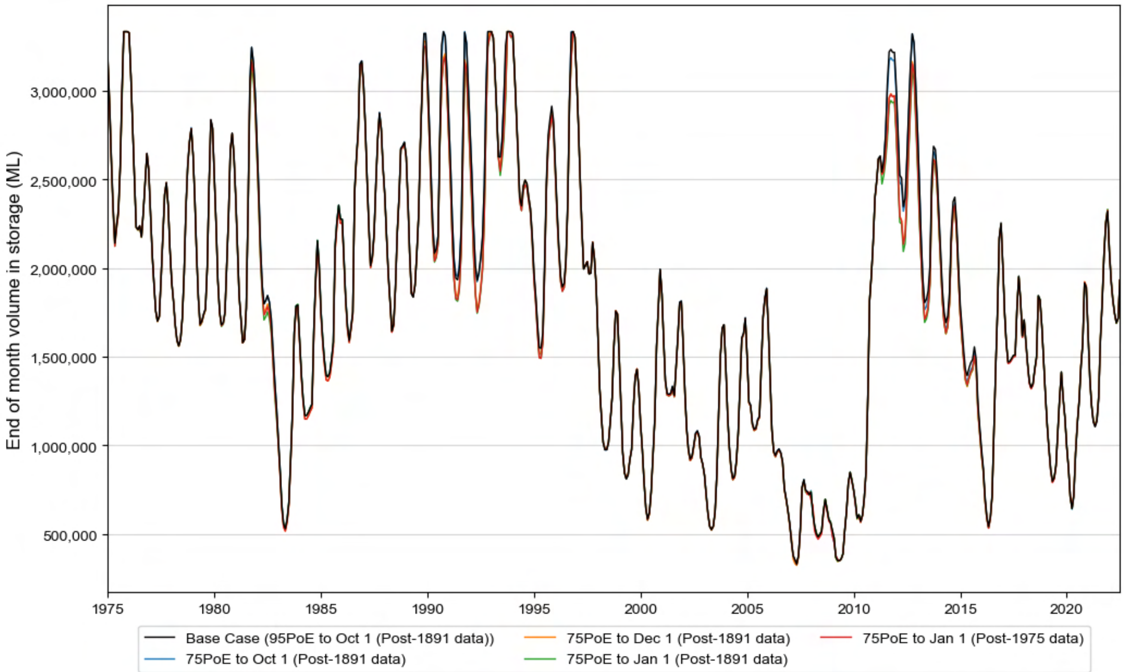


Figure 33: Monthly time-series of the modelled storage trace for Lake Eildon, from January 1975 to June 2022, for 75PoE target filling curves.

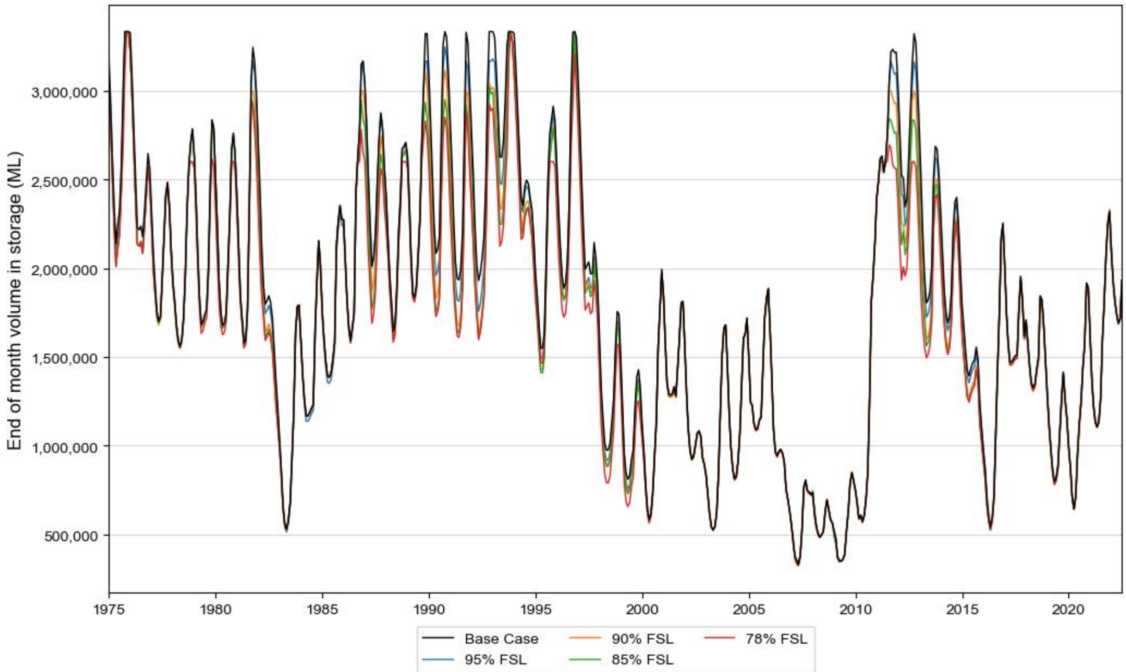


Figure 34: Monthly time-series of the modelled storage trace for Lake Eildon, from January 1975 to June 2022, for the options to reduce target storage to 78%, 85%, 90% and 95% of FSL.

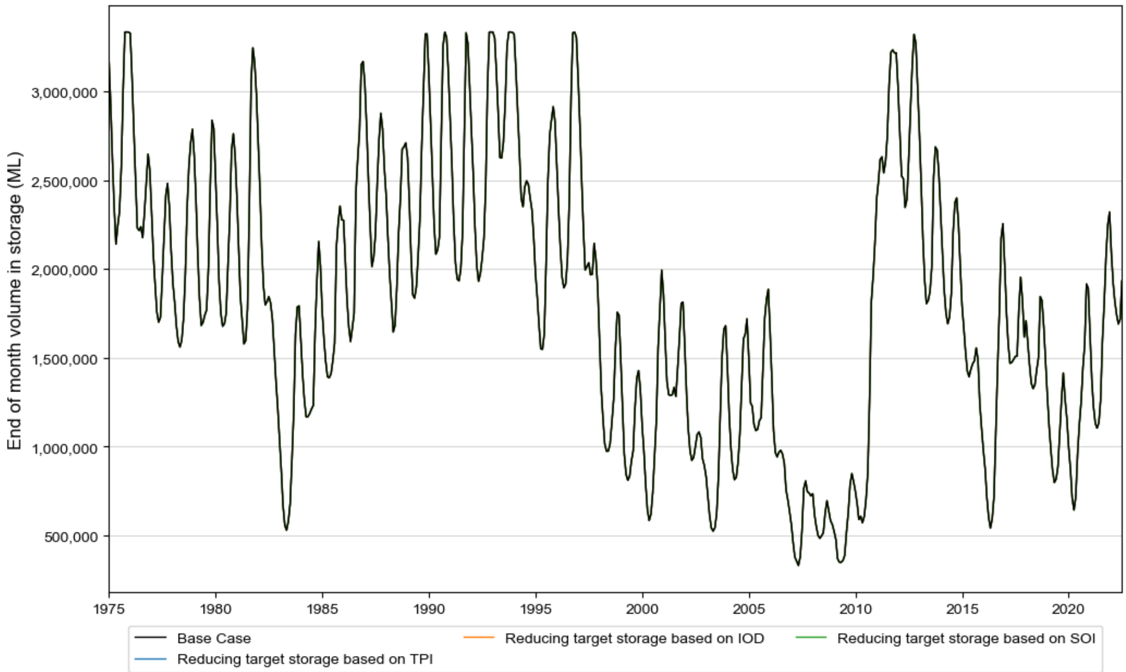


Figure 35: Monthly time-series of the modelled storage trace for Lake Eildon, from January 1975 to June 2022, for the options to reduce target storage to 85% of FSL based on climate signals that predict 'wet' years.

These time-series – for the whole modelled period – were plotted as time of exceedance curves in Figure 36 to Figure 40. These curves are the key outputs from the water resource modelling used to simulate the expected flood frequency changes immediately downstream of Lake Eildon

(Section 6). The degree to which curves plot to the left of the base case demonstrate the degree of additional airspace provided in Lake Eildon.

The time-series and time of exceedance curves demonstrate that:

- The differences between the target filling curve options and the base case are minor. Only the option with a 75% PoE and target fill date of 1 Jan shows a slight shift in the time of exceedance curve compared with the base case (black to red or green curve in Figure 38).
- The largest differences between the modelled storage traces were attributable to the proportion of FSL used to set the target storage – i.e. 78%, 85%, 90% or 95% of FSL. As the target storage is reduced, the amount of airspace in Lake Eildon increases more often over the modelled period of record.
- The effectiveness of target storage options is sometimes limited by the downstream flow constraints in the mid-Goulburn (see Section 2.5). That is, holding the lake at levels at a lower FSL may not always be possible if the preceding inflows into Lake Eildon are greater than the downstream flow constraints for a prolonged period of time. See Section 5.3 for a more detailed explanation.
- There were minimal differences compared with the base case if the target storage at Lake Eildon was reduced to 85% of FSL based on selected IOD, SOI and TPI thresholds (see Section 4.4 for how these thresholds were selected). The differences are minimal because of the very weak correlation between the climate indices and the monthly Lake Eildon inflow volumes. This result suggests the option to reduce the target storage only when climate indices suggest inflows is not a reliable method to increase the flood mitigation provided by Lake Eildon. See Section 5.4 for a more detailed explanation.
- If additional airspace provided when the storage is close to full, this can reduce the volume held in storage in subsequent years when the storage is less full.

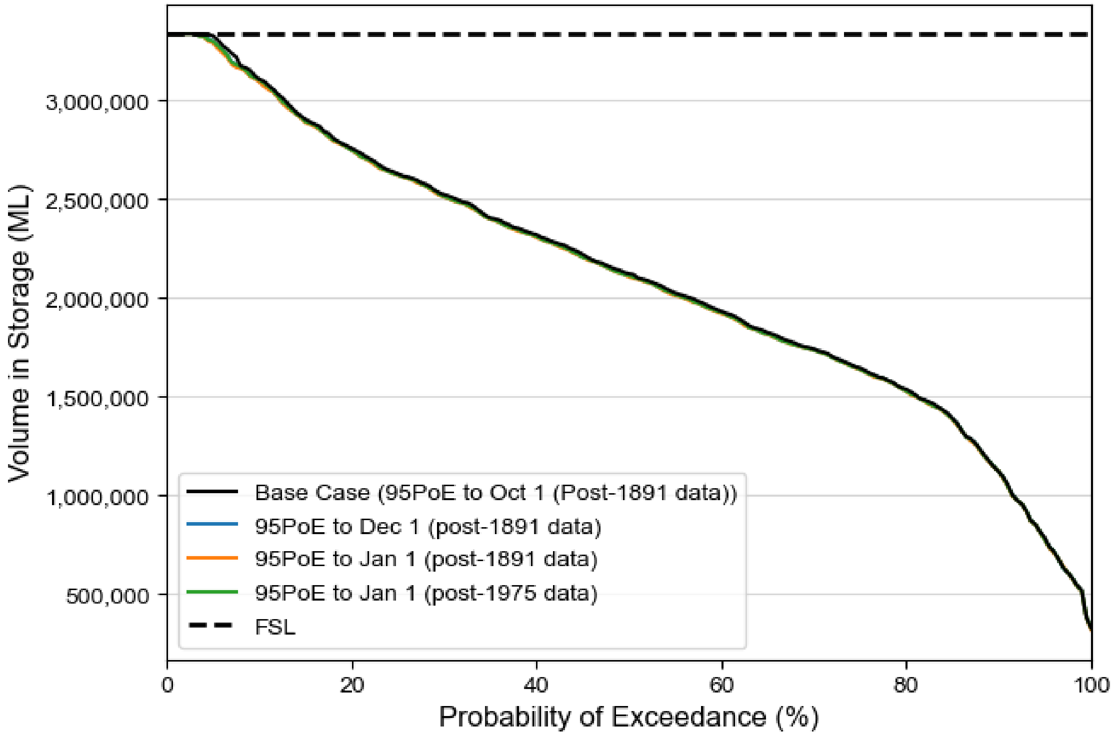


Figure 36: Modelled time of exceedance curves for 95PoE inflow conditions under different target fill dates and period of climate data

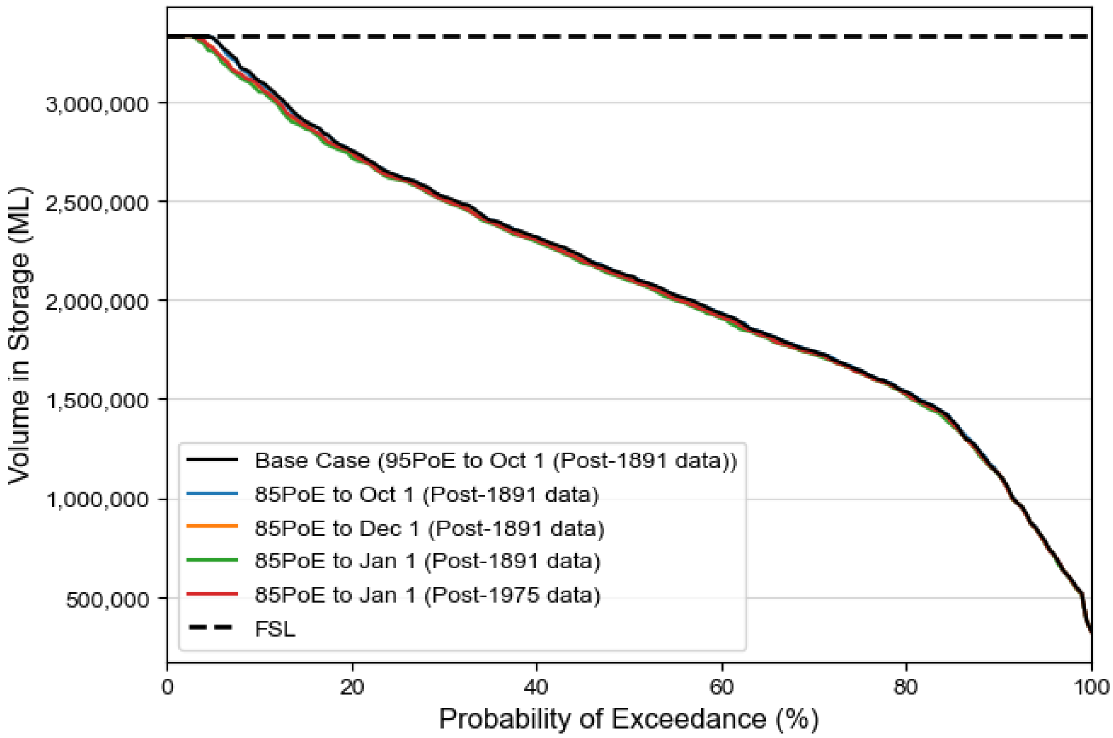


Figure 37: Modelled time of exceedance curves for 85PoE inflow conditions under different target fill dates and period of climate data

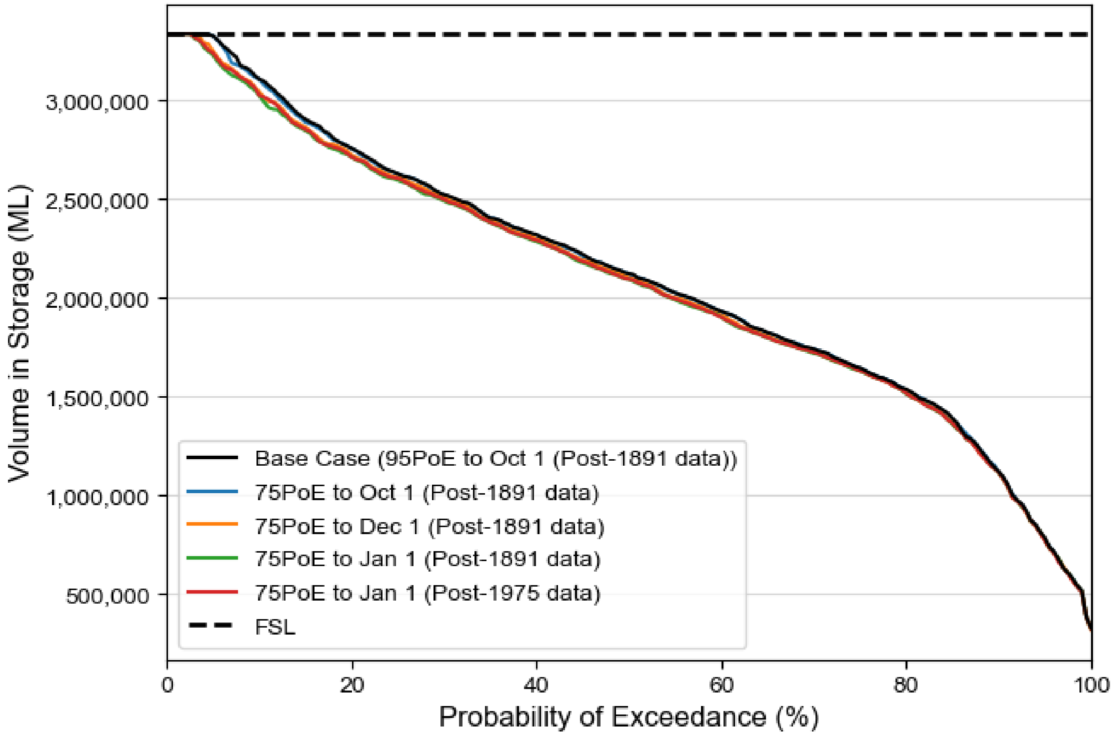


Figure 38: Modelled time of exceedance curves for 75PoE inflow conditions under different target fill dates and period of climate data

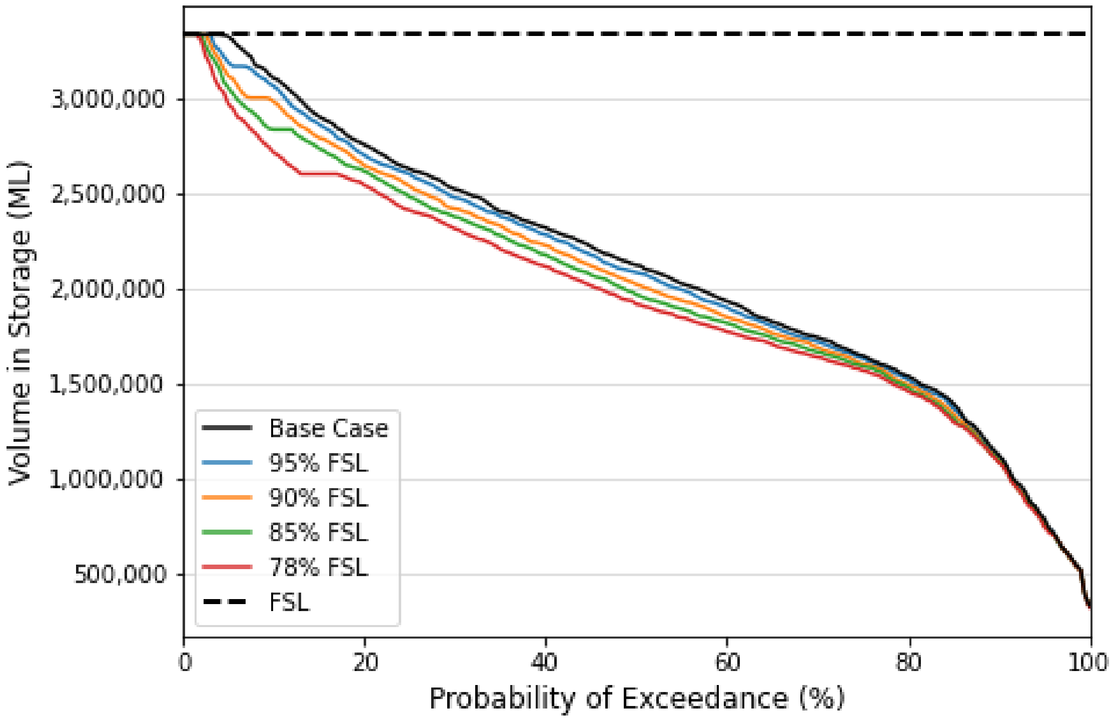


Figure 39: Modelled time of exceedance curves for the options to reduce target storage to 78%, 85%, 90% and 95% of FSL

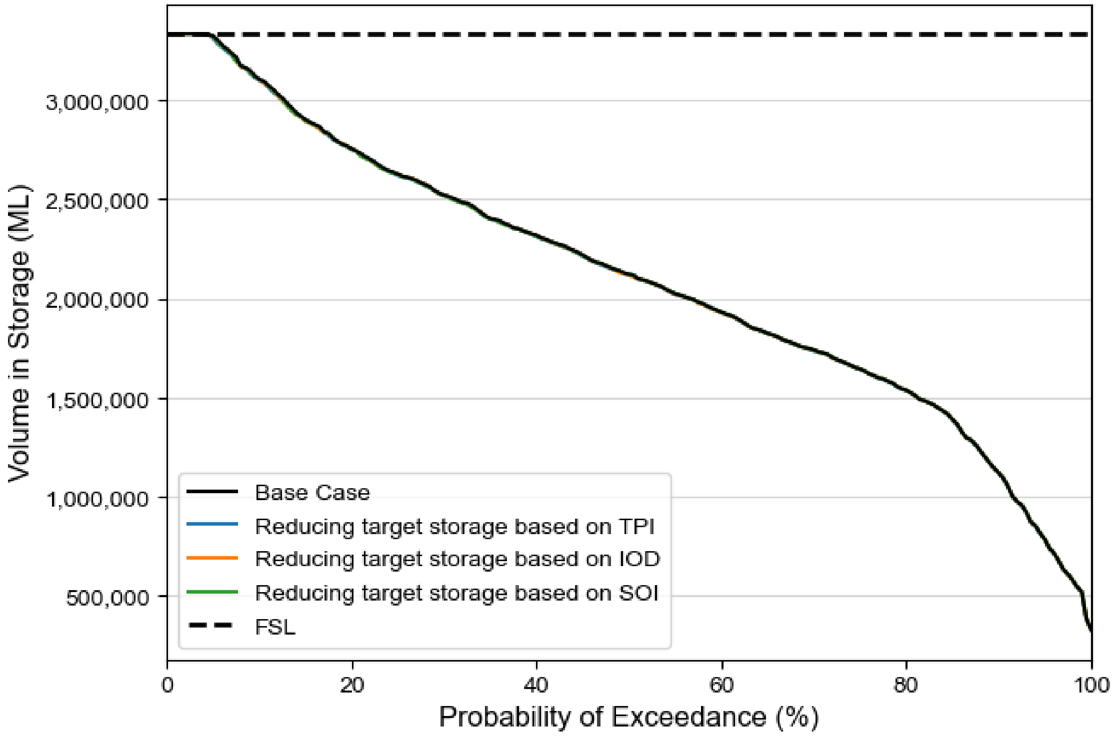


Figure 40: Modelled time of exceedance curves for the options to reduce target storage to 85% of FSL based on climate signals that predict 'wet' years

5.2.2 February allocations for entitlement holders

The modelled February allocations to the HRWS and LRWS in the Goulburn system is shown in Table 15 to Table 19 and in Figure 41 to Figure 49 and demonstrate that:

- Staying with the 95PoE inflows to define the filling curve but delaying the target fill date to December 1 or January 1, or basing the filling curve on post-1975 rather than historic inflows, has no impact on the reliability of February HRWS and LRWS allocations.
- Changing the target filling curve to be based on the 85PoE inflow conditions, and delaying the target fill date or changing the period of historic data, will have an impact on February LRWS allocations. For example, the average February allocations to HRWS was unchanged, and the average February LRWS allocations were simulated to decrease by approximately 0.2 – 0.4%. The average February HRWS allocations generally remain unchanged.
- Changing the target filling curve to be based on the 75PoE inflow conditions, and delaying the target fill date or changing the period of historic data, has an impact on average February LRWS allocations. The costs to offset this reduced reliability of supply are discussed in Section 8. For example, the average February LRWS allocations are simulated to decrease by approximately 0.9% with a delayed target fill date (Jan 1). The average February HRWS allocations generally remain unchanged.
- Providing more airspace by drawing down Lake Eildon to target storages less than FSL decreases the reliability of supply to HRWS and LRWS in the Goulburn River system (Table 18). For example, average February allocations to HRWS are modelled to decline by up to 0.3% if the target storage is reduced to 95%, 90%, 85% or 78% of the current

FSL, and average February LRWS allocations are simulated to decrease by approximately 1.1%, 3.3%, 6.6% and 12.3% respectively.

- During the Millennium Drought (between 1997 and 2010) there was little to no change to average February HRWS allocations for the target filling options, but up to 0.4% difference for the target storage options. The worst case was that February HRWS allocations in 2003 were 1% lower with changes to the target filling arrangements, and February HRWS allocations in 2000 were 11% lower with the target storage reduced to 78% of FSL.
- Using climate signals to reduce the target storage to 85% of FSL (Table 19 and Figure 49) had little to no impact on the HRWS and LRWS allocations in the Goulburn system. However, as indicated by Figure 40 this option is also an unreliable way to increase the flood mitigation provided by Lake Eildon.

Table 15: Modelled average February allocations (July 1891 – June 2022) to HRWS and LRWS in the Goulburn system, for different 95PoE target filling curve options.

Option	HRWS*	LRWS*
Base Case (95PoE to Oct 1 (Post-1891 data))	**97.7%**	**54.8%**
95PoE to Dec 1 (post-1891 data)	97.7%	54.9%
95PoE to Jan 1 (post-1891 data)	97.7%	54.8%
95PoE to Jan 1 (post-1975 data)	97.7%	54.8%

*Average February allocations based on post-1975 climate data are presented in Appendix A.

Table 16: Modelled average February allocations (July 1891 – June 2022) to HRWS and LRWS in the Goulburn system, for different 85PoE target filling curve options.

Option	HRWS*	LRWS*
Base Case (95PoE to Oct 1 (Post-1891 data))	**97.7%**	**54.8%**
85PoE to Oct 1 (post-1891 data)	97.7%	54.6%
85PoE to Dec 1 (post-1891 data)	97.7%	54.6%
85PoE to Jan 1 (post-1891 data)	97.6%	54.4%
85PoE to Jan 1 (post-1975 data)	97.7%	54.6%

*Average February allocations based on post-1975 climate data are presented in Appendix A.

Table 17: Modelled average February allocations (July 1891 – June 2022) to HRWS and LRWS in the Goulburn system, for different 75PoE target filling curve options.

Option	HRWS*	LRWS*
Base Case (95PoE to Oct 1 (Post-1891 data))	**97.7%**	**54.8%**
75PoE to Oct 1 (post-1891 data))	97.7%	54.8%
75PoE to Dec 1 (post-1891 data)	97.6%	54.4%
75PoE to Jan 1 (post-1891 data)	97.6%	53.9%
75PoE to Jan 1 (post-1975 data)	97.6%	54.1%

*Average February allocations based on post-1975 climate data are presented in Appendix A.

Table 18: Modelled average February allocations (July 1891 – June 2022) to HRWS and LRWS in the Goulburn system, for different target storage options.

Option	HRWS*	LRWS*
Base Case	**97.7%**	**54.8%**
95% FSL	97.6%	53.7%
90% FSL	97.5%	51.5%
85% FSL	97.4%	48.2%
78% FSL	97.4%	42.5%

*Average February allocations based on post-1975 climate data are presented in Appendix A..

Table 19: Modelled average February allocations (July 1891 – June 2022) to HRWS and LRWS in the Goulburn system, for different options to reduce target storage to 85% of FSL.

Option	HRWS*	LRWS*
Base Case	**97.7%**	**54.8%**
Reducing target storage based on TPI	97.7%	54.8%
Reducing target storage based on IOD	97.7%	54.8%
Reducing target storage based on SOI	97.7%	54.7%

*Average February allocations based on post-1975 climate data are presented in Appendix A.

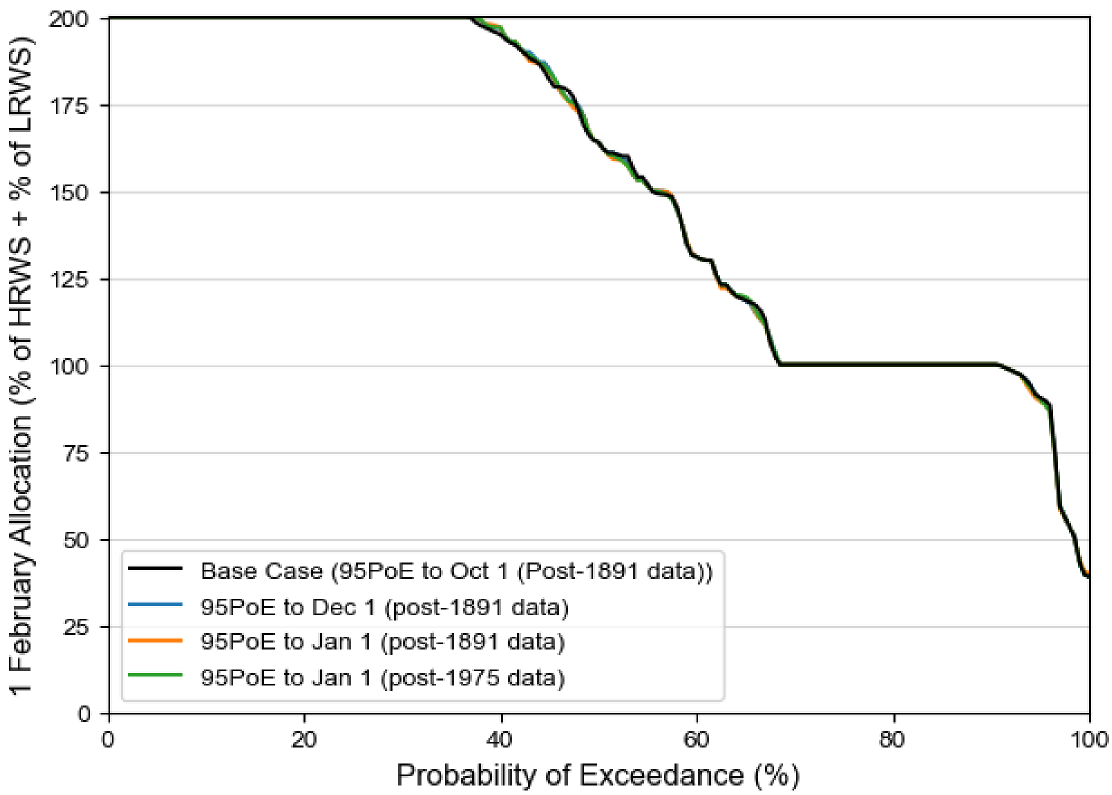


Figure 41: Modelled February allocations for different 95PoE target filling curve options.

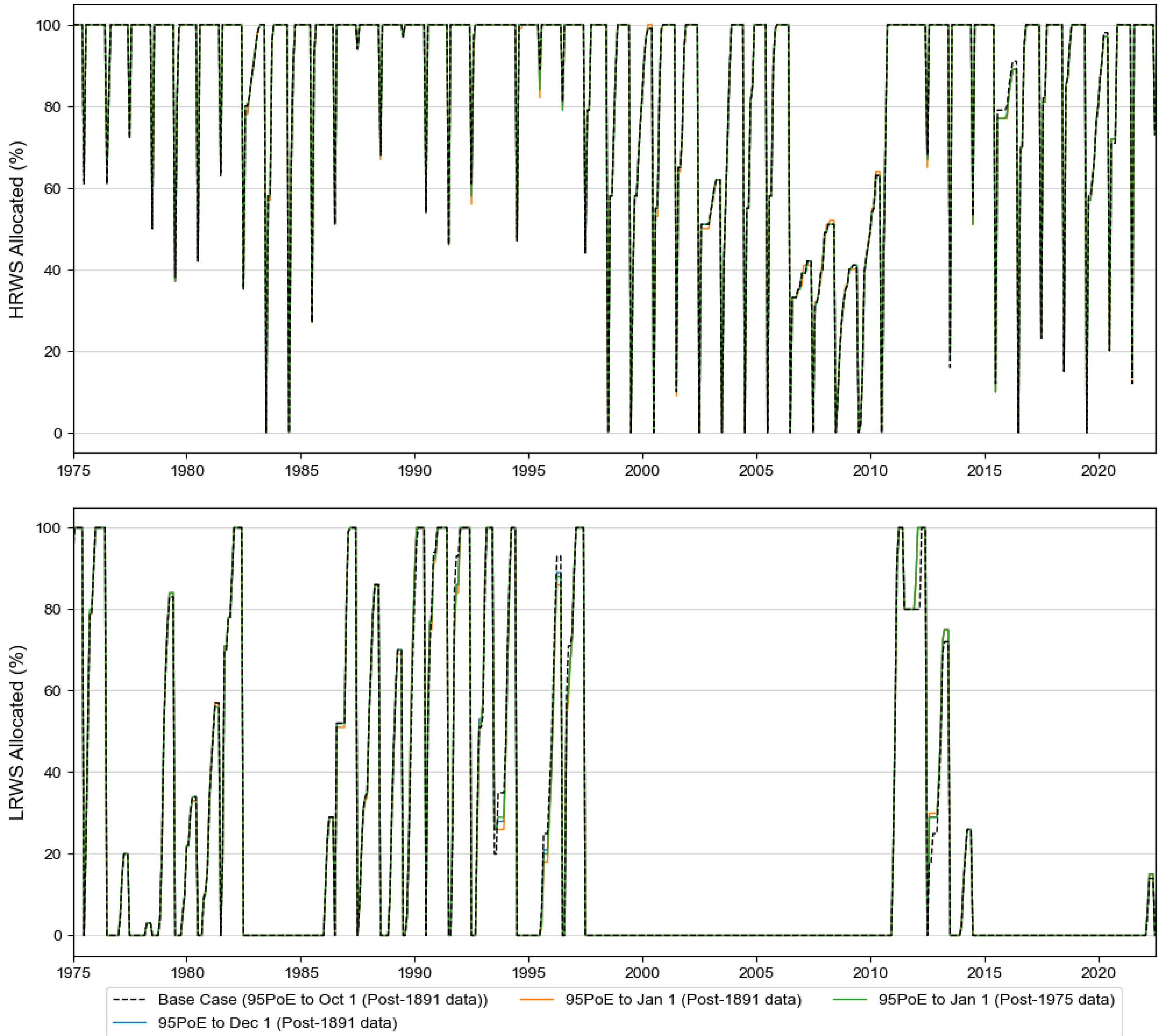


Figure 42: Modelled time series of allocations to HRWS (top) and LRWS (bottom) in the Goulburn system, for different 95PoE target filling curve options (showing January 1975 to June 2022)

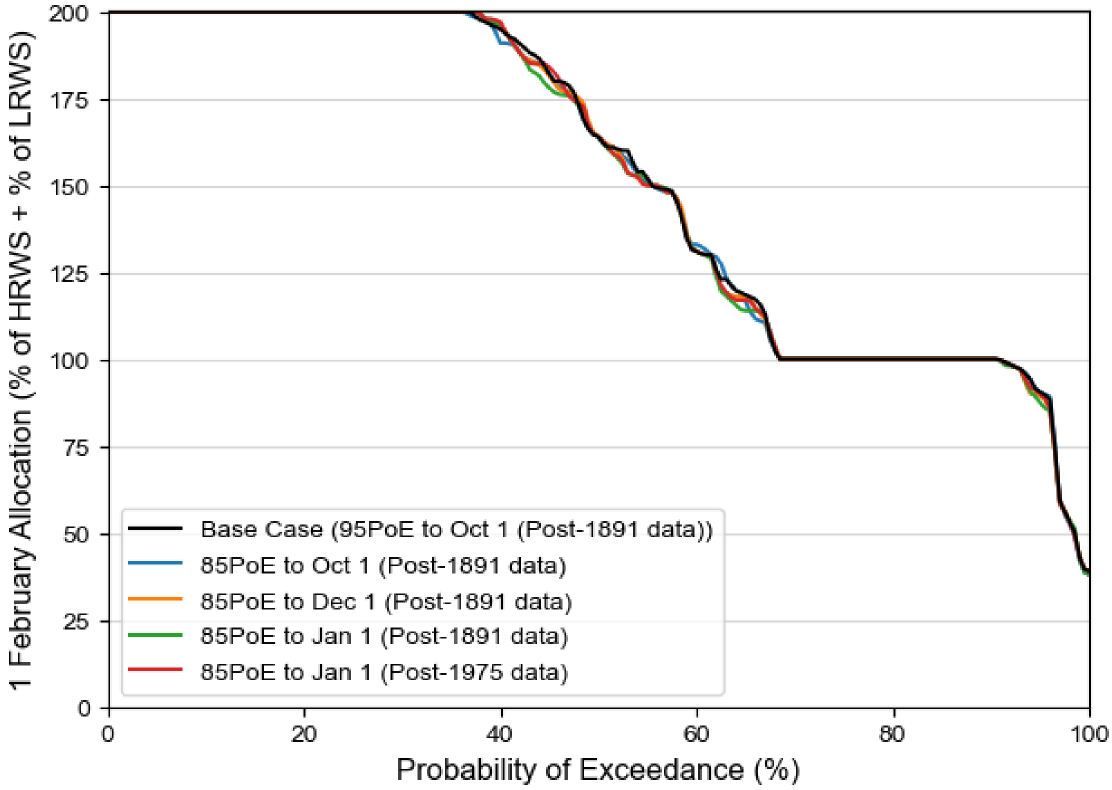


Figure 43: Modelled February allocations for different 85PoE target filling curve options.

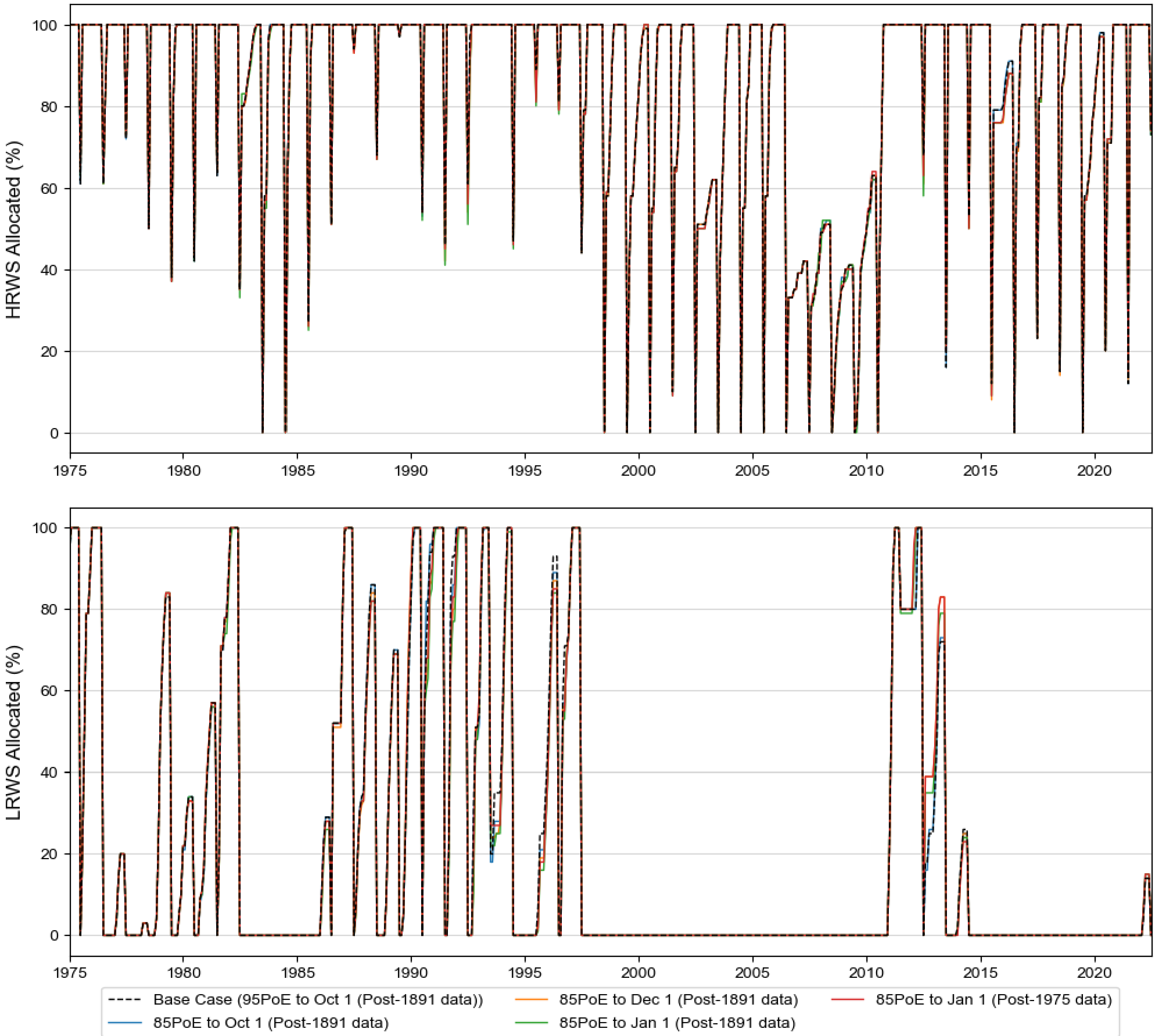


Figure 44: Modelled time series of allocations to HRWS (top) and LRWS (bottom) in the Goulburn system, for different 85PoE target filling curve options (showing January 1975 to June 2022)

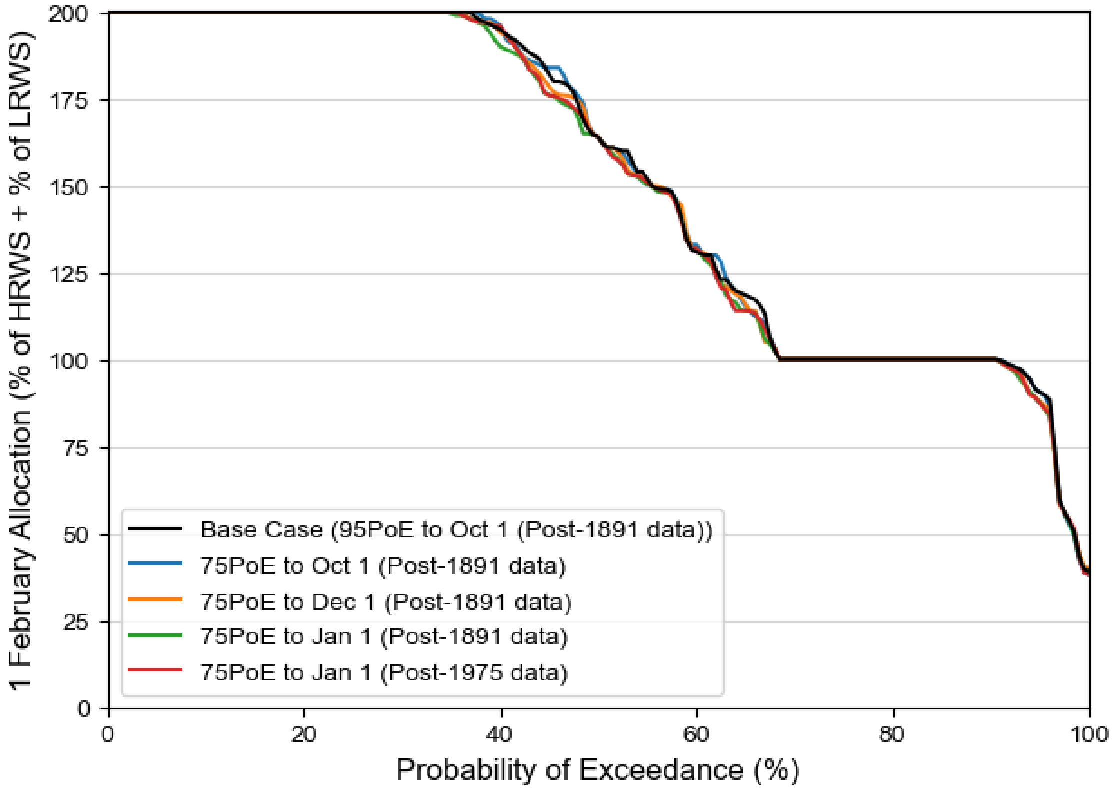


Figure 45: Modelled February allocations for different 75PoE target filling curve options.

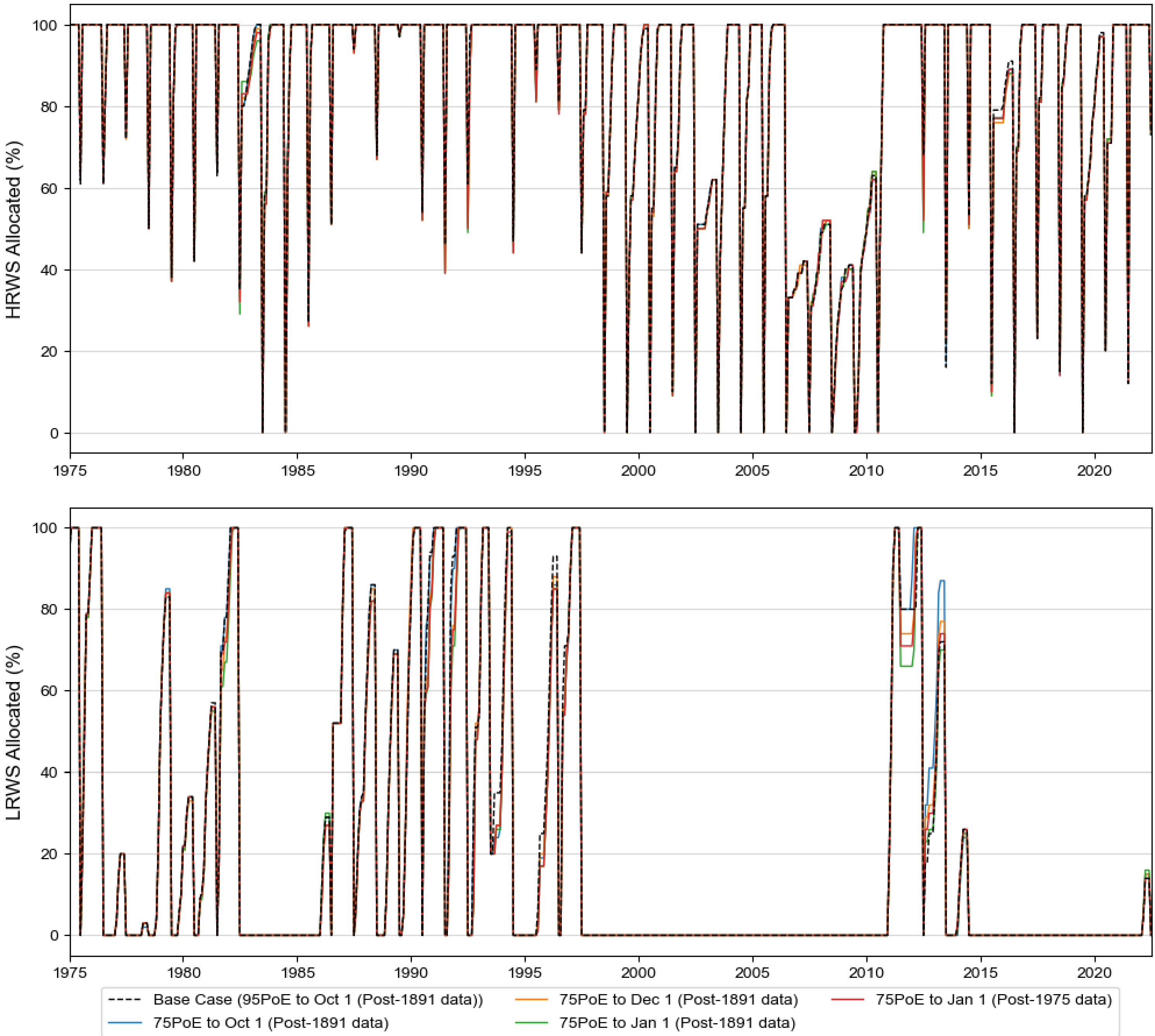


Figure 46: Modelled time series of allocations to HRWS (top) and LRWS (bottom) in the Goulburn system, for different 75PoE target filling curve options (showing January 1975 to June 2022)

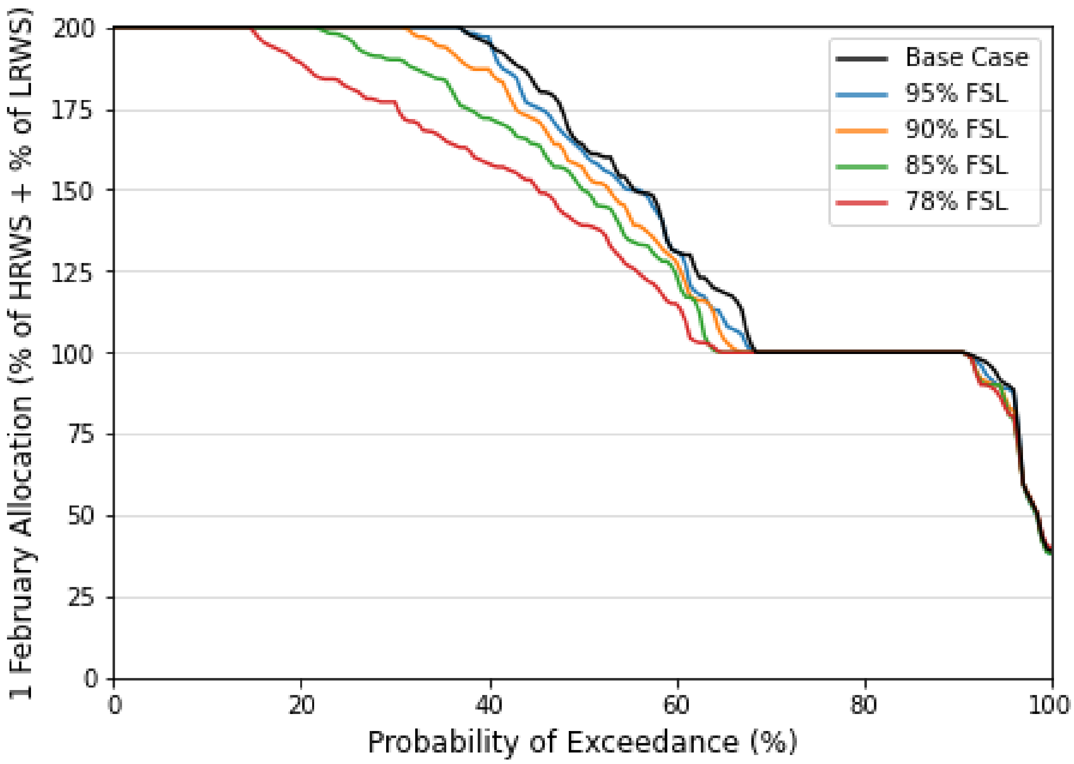


Figure 47: Modelled February allocations for the options to reduce target storage to 78%, 85%, 90% and 95% of FSL.

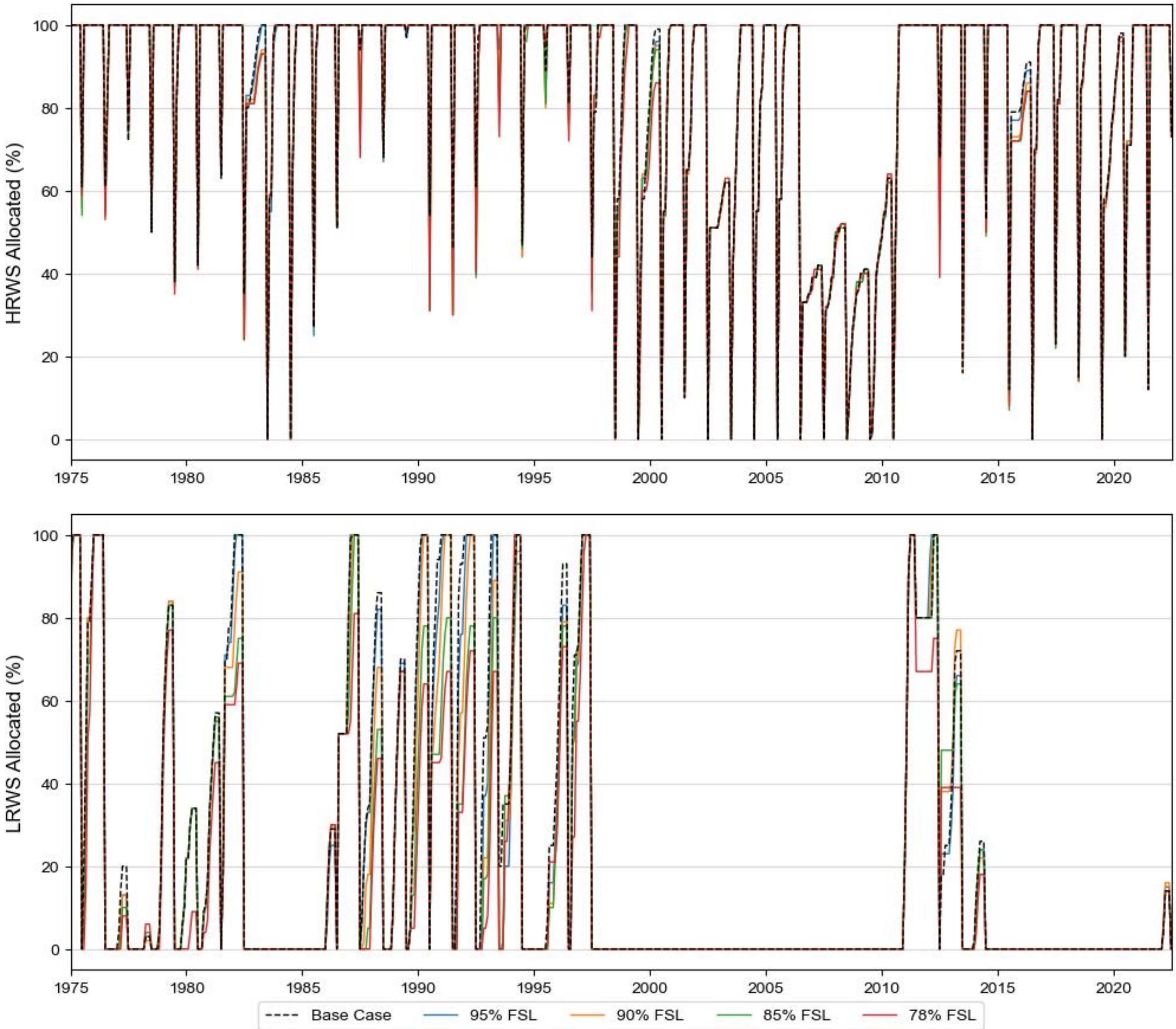


Figure 48: Modelled time series of allocations to HRWS (top) and LRWS (bottom) in the Goulburn system, for the options to reduce the Lake Eildon target storage to 78%, 85%, 90% and 95% of FSL (showing January 1975 to June 2022)

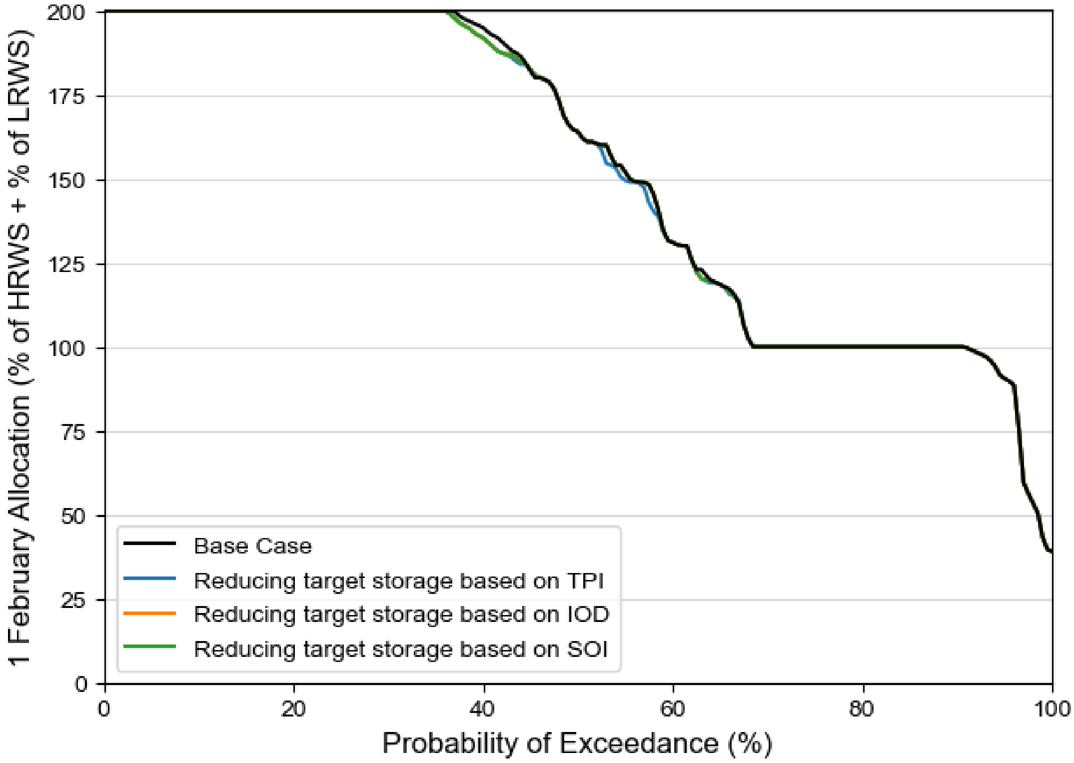


Figure 49: Modelled February allocation for the options to reduce target storage to 85% of FSL based on climate signals that predict 'wet' years.

5.2.3 Cumulative pre-releases and spills from Lake Eildon

The GSM results were also used to calculate the cumulative monthly pre-releases and spills from Lake Eildon between 1891 and 2022 for the options that change the target filling curve or reduce the target storage. All of the options considered increase the cumulative volume of modelled pre-releases and spills, and would thus increase the amount of water lost from spillable water accounts. The additional deductions from spillable water accounts will mean less water available for consumptive water users. The cumulative pre-releases and spills, as presented in Figure 50 to Figure 53 and summarised in Table 20 and Table 21, demonstrate that:

- The probability of exceeding a certain pre-release and spill volume in a given year increases under the various filling curve and target storage options. For example, the probability pre-releases and spills exceed 500 GL increases by up to 2% for the filling curve options and up to 23% for the target storage options.
- The options to change the target filling curves result in fewer pre-releases and spills compared with the reduced target storage options.
- The cumulative pre-releases and spills from Lake Eildon for the options to reduce the target storage noticeably increase as the target storage is reduced from 95% to 78% of FSL. For the 78% of FSL target storage option, the cumulative pre-releases and spills from Lake Eildon over the modelled period of record are 3 times those simulated for the base case.

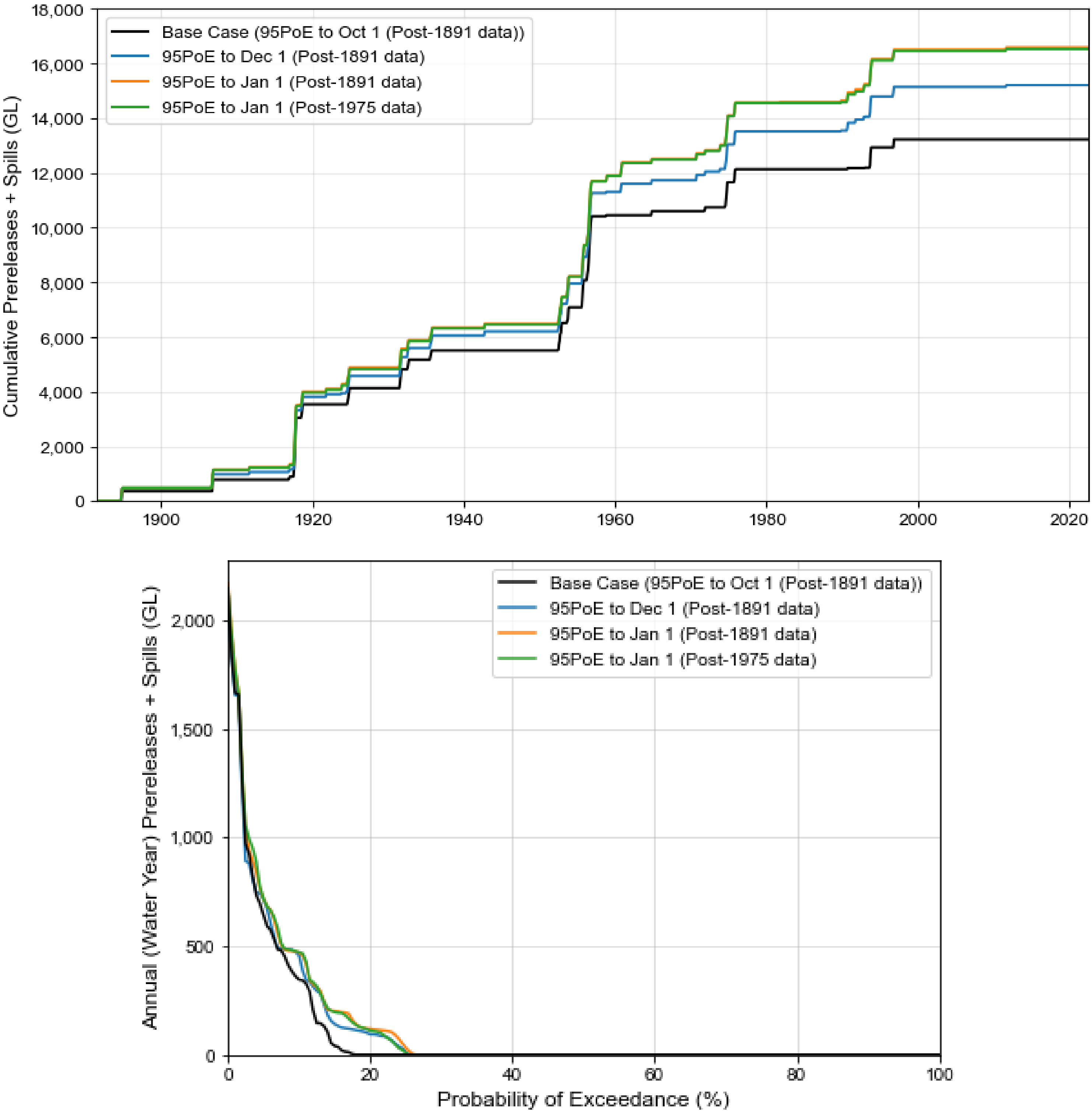


Figure 50: Modelled cumulative (top) and probability of exceedance in a water year (bottom) of pre-releases and spills from Lake Eildon between 1891 and 2022 for the 95PoE target filling curve options.

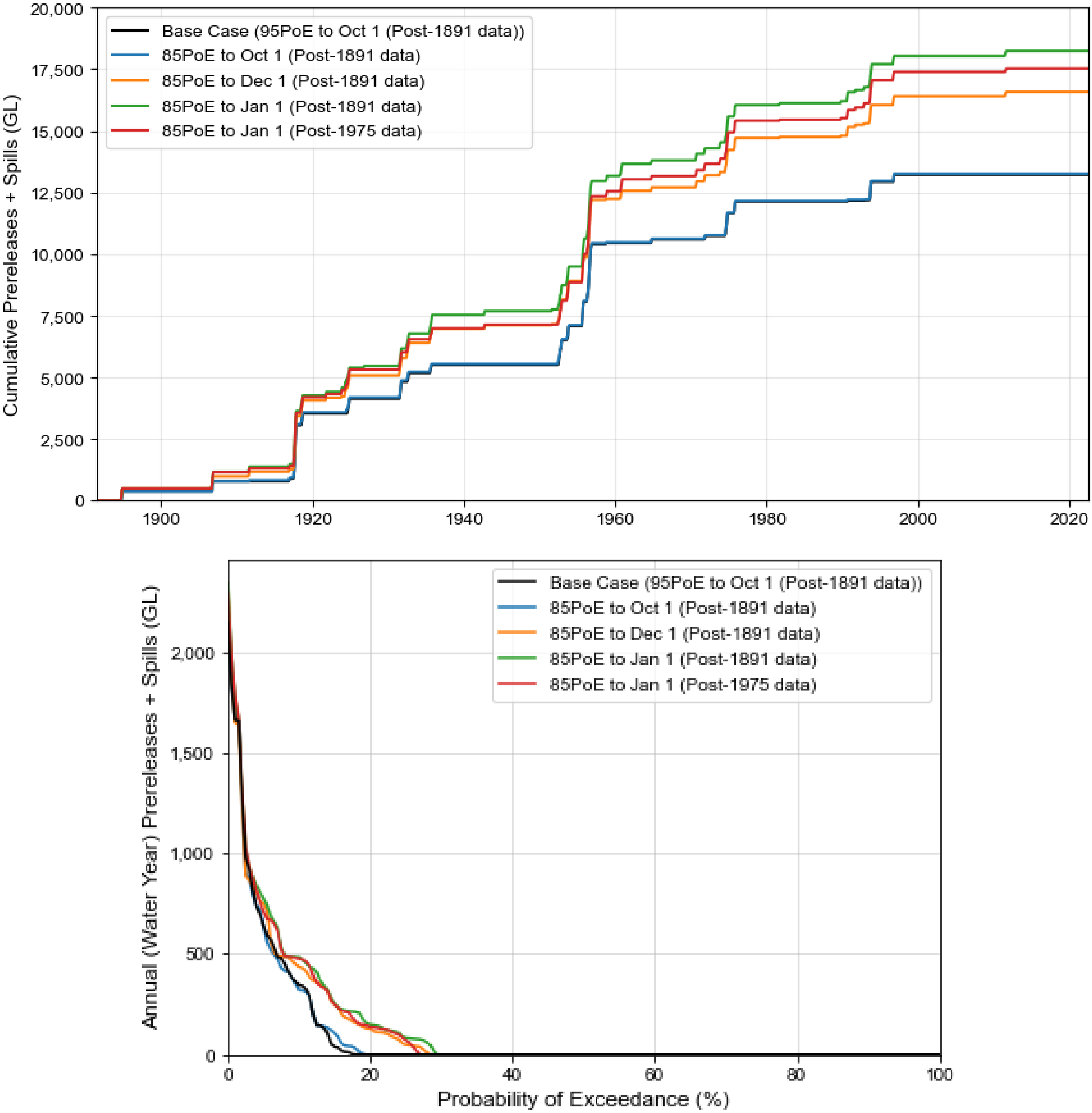
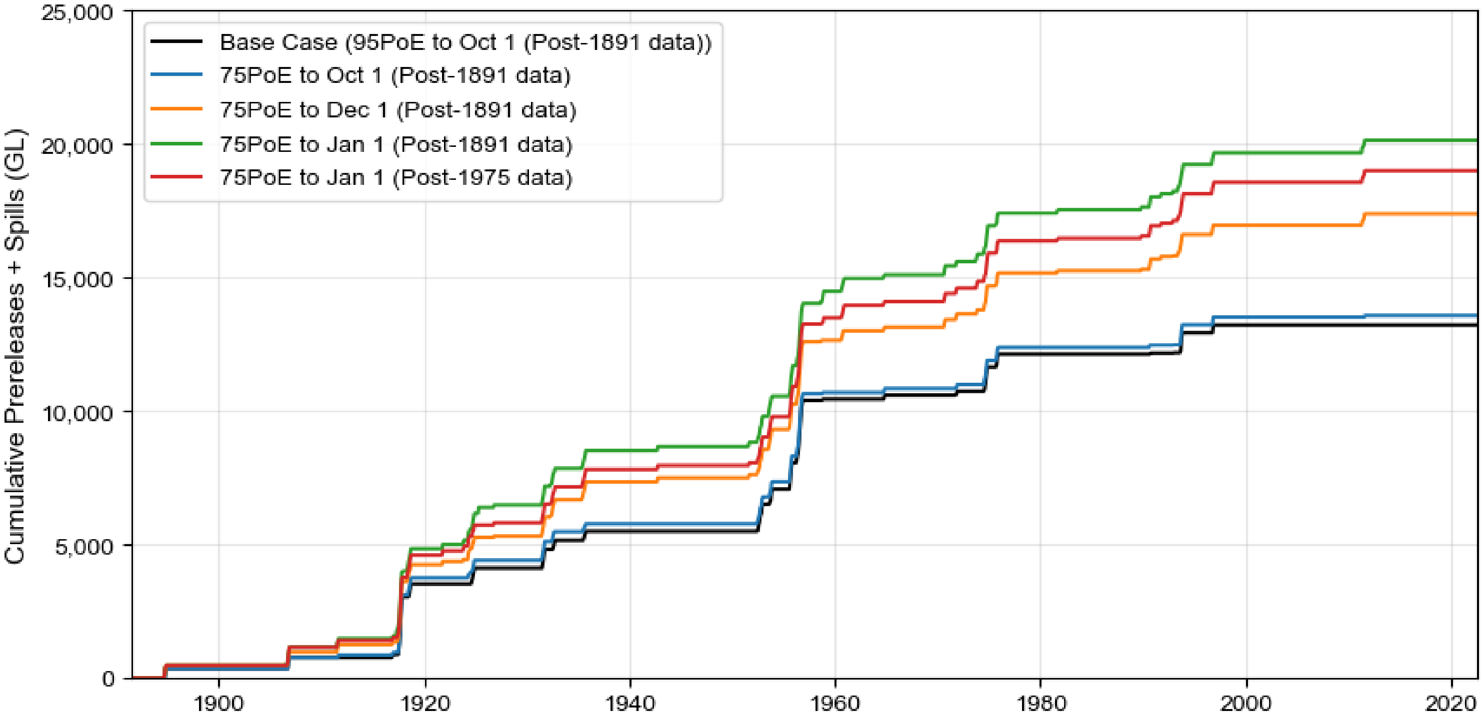


Figure 51: Modelled cumulative (top) and probability of exceedance in a water year (bottom) of pre-releases and spills from Lake Eildon between 1891 and 2022 for the 85PoE target filling curve options.



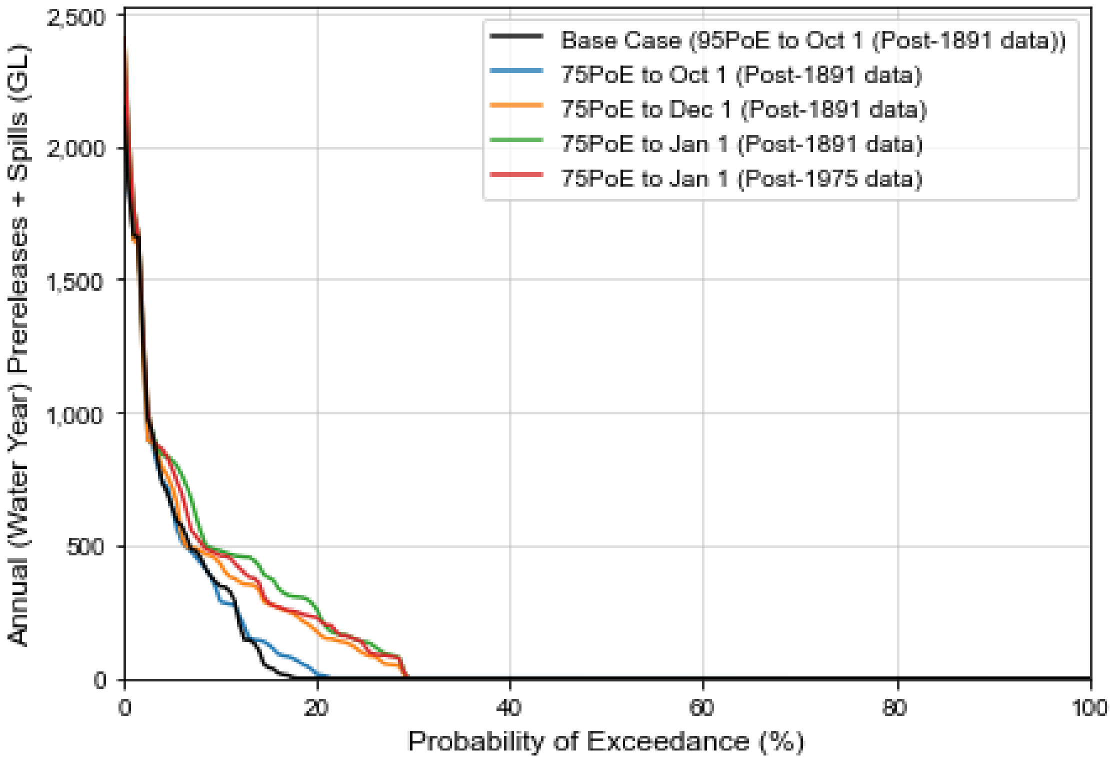


Figure 52: Modelled cumulative (top) and probability of exceedance in a water year (bottom) of pre-releases and spills from Lake Eildon between 1891 and 2022 for 75PoE target filling curve options.

Table 20: Elements of the cumulative pre-releases and spills shown in Figure 50 to Figure 52

Option	Cumulative pre-releases + spills from Lake Eildon (GL)	Cumulative difference at June 2022 to base case (GL)	Average annual pre-release + spill from Lake Eildon (GL/year)
Base Case (95PoE to Oct 1 (Post-1891 data))	13,220	-	101
95PoE to Dec 1 (post-1891 data)	15,210	1,990	116
95PoE to Jan 1 (post-1891 data)	16,580	3,360	127
95PoE to Jan 1 (post-1975 data)	16,520	3,300	126
85PoE to Oct 1 (post-1891 data))	13,260	40	101
85PoE to Dec 1 (post-1891 data)	16,580	3,360	127
85PoE to Jan 1 (post-1891 data)	18,240	5,020	139
85PoE to Jan 1 (post-1975 data)	17,530	4,310	134
75PoE to Oct 1 (post-1891 data))	13,570	350	104
75PoE to Dec 1 (post-1891 data)	17,390	4,170	133
75PoE to Jan 1 (post-1891 data)	20,140	6,290	154
75PoE to Jan 1 (post-1975 data)	19,000	5,780	145

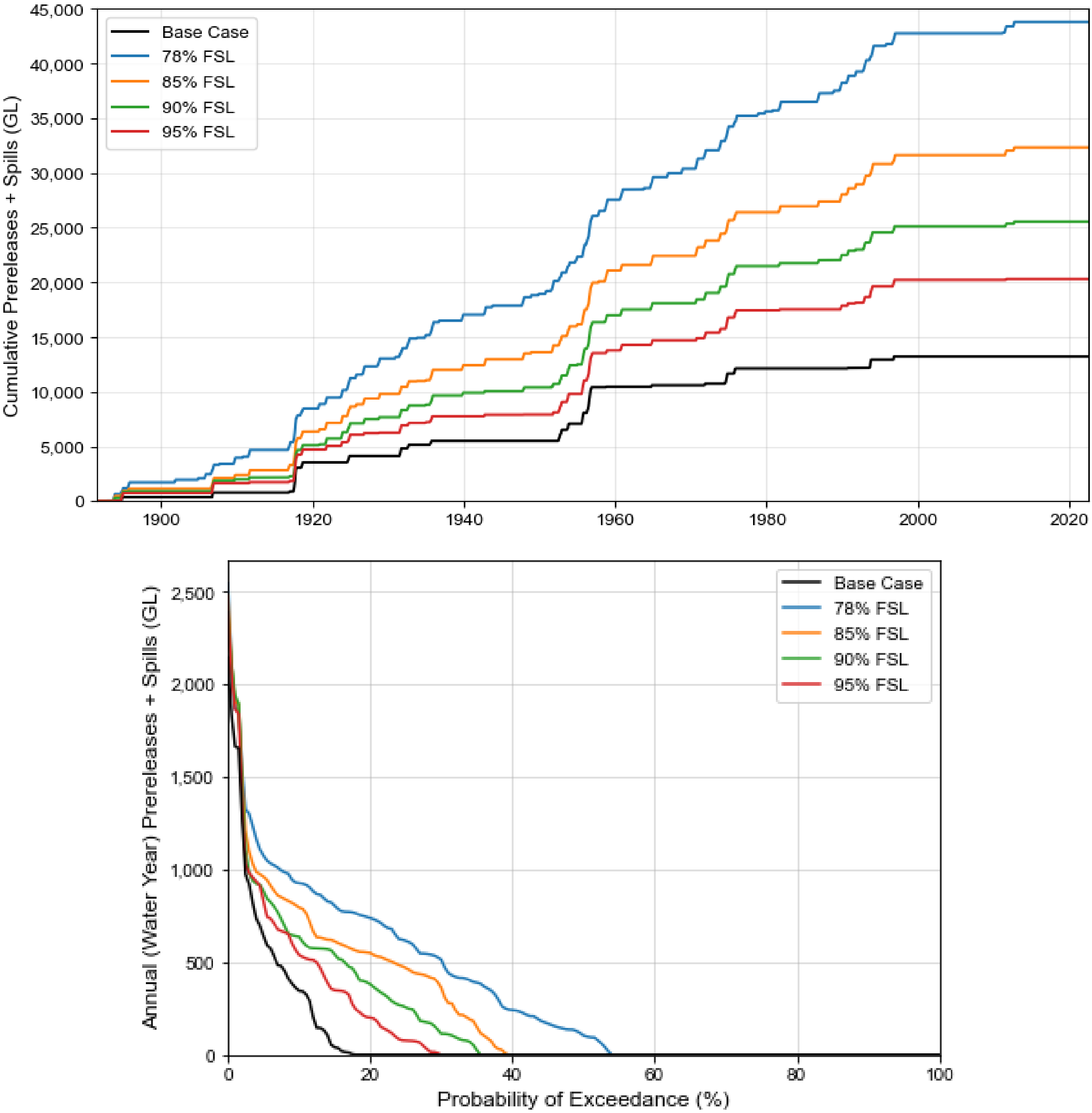


Figure 53: Modelled cumulative (top) and probability of exceedance in a given water year (bottom) of pre-releases and spills from Lake Eildon between 1891 and 2022 for the options to reduce target storage.

Table 21: Elements of the cumulative pre-releases and spills shown in Figure 53

Option	Cumulative pre-releases + spills from Lake Eildon (GL)	Cumulative difference at June 2022 to base case (GL)	Average annual pre-release + spill from Lake Eildon (GL/year)
Base Case	13,220	-	101
95% FSL	20,290	6,440	155
90% FSL	25,540	11,690	195
85% FSL	32,320	18,480	247
78% FSL	43,780	29,930	334

5.3 Influence of downstream flow constraint on storage drawdown

To illustrate the impact that downstream flow constraints have on the ability to maintain Lake Eildon at a reduced target storage, selected results from the monthly[16] GSM model were extracted for the period 1992-1995 and 2022-2023[17] for the 90%, 85% and 78% reduced target storage options, and plotted in Figure 54 and Figure 55. The 95% target storage option was not included in this analysis because the results are similar to the 90% target storage option. The storage drawdown is influenced by the downstream flow constraints because it is not always possible to hold the storage at reduced levels if releases are constrained. Therefore, if downstream flow constraints were to increase, the impacts on storage drawdown caused by reducing the target storage would also increase.

The figures presented below show the downstream flow constraint modelled in the GSM as the dashed black line. The line is dependent on the inflows simulated between Lake Eildon and Molesworth; therefore, the maximum operational releases that can be made vary as the downstream tributary inflows vary. There are however exceptions where the outflows from Lake Eildon (grey line) exceed the dashed black line because Lake Eildon spills as a result of reaching (or exceeding) FSL.

These figures demonstrate several key points:

- For the option which reduces the target storage to 90% of FSL during 1993 to 1995 (top plot in Figure 54), the storage volume was able to be maintained at or below that target storage except for during October and November 1993. In these months Lake Eildon reached 100% (FSL) because of the high inflows and downstream flow constraints.
- For the same option during 2022 to 2023[18] (top plot in Figure 55), the reservoir level was not able to be maintained at the target storage because of the high inflows and downstream flow constraints. Therefore, even if a target storage of 85% of FSL (middle plot

[16] Using DEECA's daily Goulburn-Broken-Campaspe-Coliban-Loddon Source model would show more detailed results, but it was not available for this study.

[17] For the purposes of this exercise, the period of record in the GSM was extended to June 2023, using model inputs that became available from GMW towards the end of the study

[18] It is noted that the peak outflows from Lake Eildon as simulated at the GSM occur later than observed (i.e. December 2022 vs October 2022). However, the simulations available for this period of high inflows are still useful for demonstrating the concepts involved.

of Figure 55) had been in place, Lake Eildon would have been at 100% of FSL prior to the 2022 floods.

- For the options which reduce the target storage to 78% or 85% of FSL during 1993 to 1995 (middle and bottom plot of Figure 54), the reservoir rose above the target storage in both the spring of 1992 and 1993, including to 100% (FSL) in November 1993. However, the modelled outflows in spring 1993 were lower compared with the 90% target storage option, because the modelled storage in the lead-up to the event (i.e. May-September 1993) was lower. Therefore, even if a target storage of 90% or 85% of FSL had been in place, Lake Eildon would have been at 100% of FSL prior to the 1993 floods.
- For the same options to reduce the target storage during 2022 to 2023 (middle and bottom plot of Figure 55), the reservoir was not able to be maintained at the target storage because of the high inflows and downstream flow constraints. For the 85% of FSL target storage option, the outflows were similar to the 90% option. For the 78% option, the modelled outflows were lower.

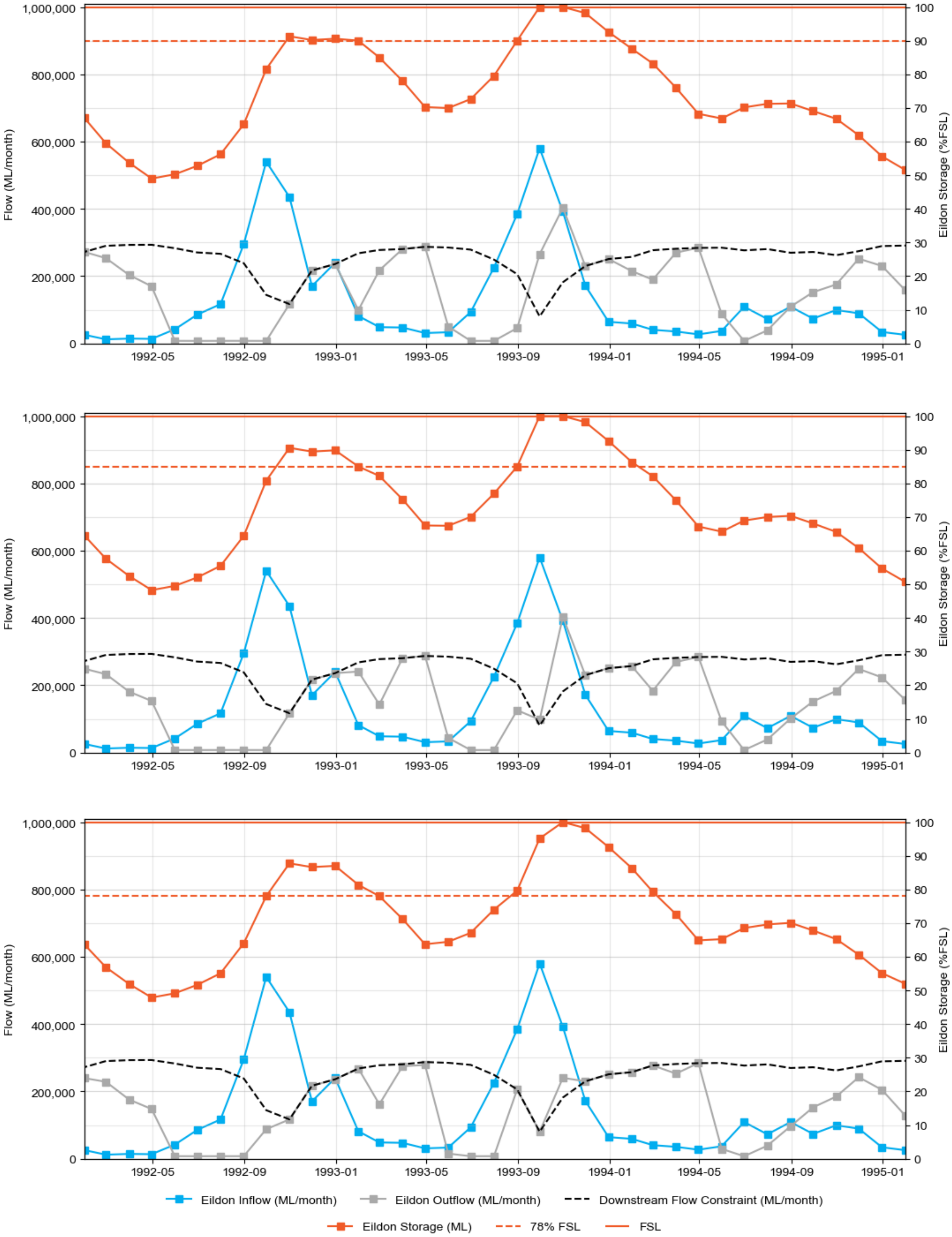


Figure 54: Simulated inflow, outflow and downstream flow constraint (primary axis) and storage as a % of FSL (secondary axis) for the options to reduce the target storage to 90% (top), 85% (middle) or 78% (bottom) of FSL – results extracted from the GSM for the period between 1992 and 1995

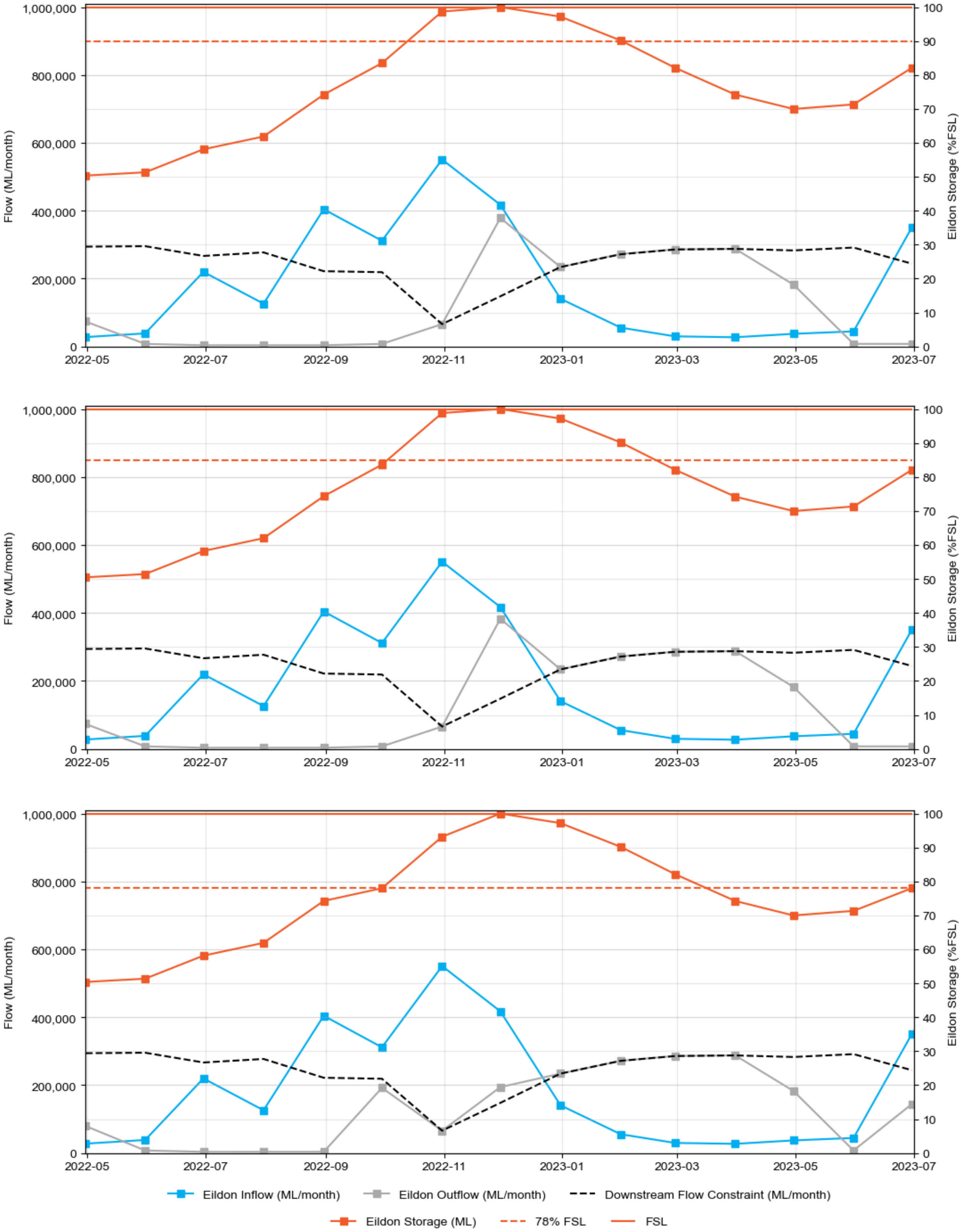


Figure 55: Simulated inflow, outflow and downstream flow constraint (primary axis) and storage as a % of FSL (secondary axis) for the options to reduce the target storage to 90% (top), 85% (middle) or 78% (bottom) of FSL – results extracted from the GSM for the period between 2022 and 2023

To illustrate the impact the downstream flow constraint has on the ability to maintain Lake Eildon at a reduced target storage, the downstream flow constraint was hypothetically doubled (upward shift of the dashed black line). Selected results from the GSM were extracted for the period 1992-1995 and 2022 to 2023 for the 78% reduced target storage options and plotted in Figure 56 and Figure 57.

The figures below demonstrate that:

- In the scenario where the target storage was reduced to 78% of FSL but the downstream flow constraint was hypothetically doubled, the target storage was able to be maintained for a longer period of time between 1992 and 1995. For example, the storage volume only exceeded the target storage for October and November in 1993, and was always below 90% FSL. However, the outflows from Lake Eildon in this scenario (grey line) were generally higher than in Figure 54.
- A target storage of 78% of FSL would be able to be maintained for a longer period of time between 2022 and 2023 if the downstream flow constraint was hypothetically doubled. For example, the storage volume only exceeded the target storage for November and December in 2022, and was always below 90% FSL. However, the outflows from Lake Eildon in this scenario (grey line) were generally higher than in Figure 55.

The findings from this analysis show the interplay between target storage reductions and downstream flow constraints[19], and that the existing constraint will at times limit the storage operator's ability to hold Lake Eildon at a target storage below FSL. This is one of the main reasons why the impact of the modelled time of exceedance curves in Section 5.2 is not as significant as initially anticipated in Table 10 of Section 4.3.

[19] The costs and benefits of relaxing operational constraints downstream of Lake Eildon for environmental purposes is being assessed by DEECA via the Victorian Constraints Measures Program, which is described at https://www.water.vic.gov.au/our-programs/murray-darling-basin/victorian-constraints-measures-program

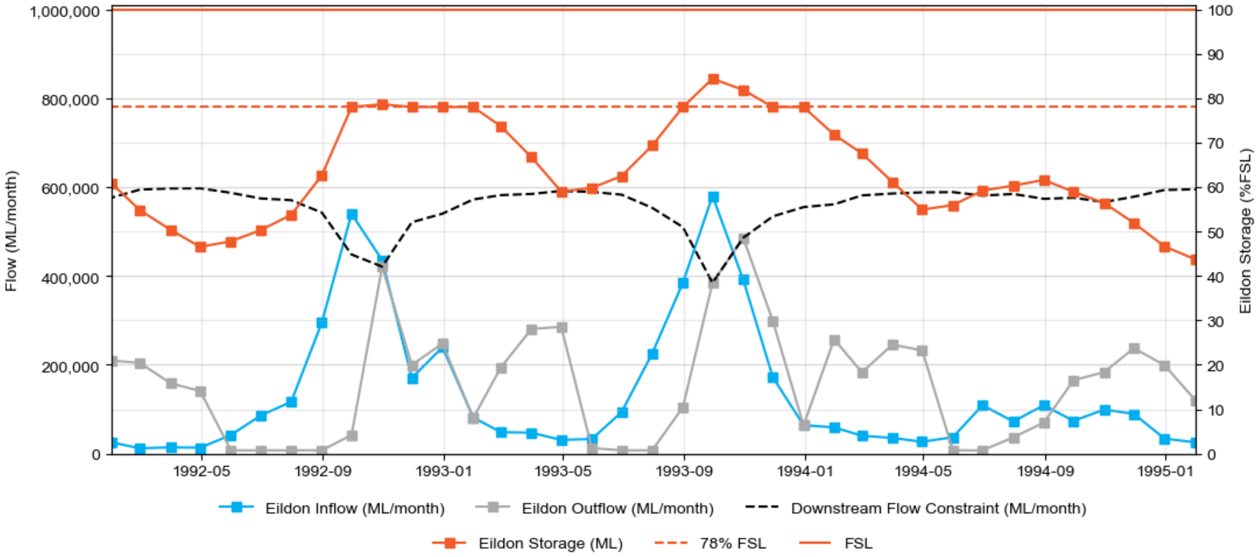


Figure 56: Simulated inflow, outflow and hypothetically doubled downstream flow constraint (primary axis) and storage as a % of FSL (secondary axis) for the reduced target storage of 78% between 1992 and 1995 extracted from the GSM

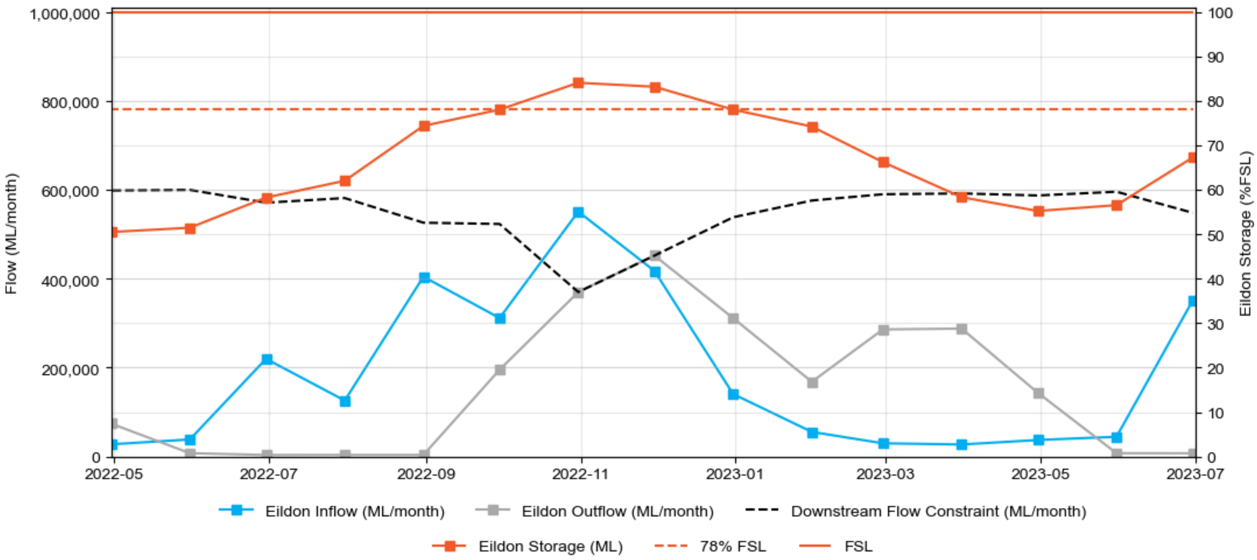


Figure 57: Simulated inflow, outflow and hypothetically doubled downstream flow constraint (primary axis) and storage as a % of FSL (secondary axis) for the reduced target storage of 78% between 2022 and 2023 extracted from the GSM

5.4 Influence of climate signal on drawdown and allocation

The results in Section 5.2 show that there was little impact on the modelled Lake Eildon drawdown or Goulburn system allocations as a result of reducing the target storage to 85% of FSL based on climate signals that indicate 'wet' conditions.

To demonstrate this further, case studies have been extracted from the water resource modelling to highlight the challenges of using climate signals ENSO and TPI as a reliable method to reduce Lake Eildon reservoir levels.

Figure 58 and Figure 59 show monthly time-series of four datasets:

- Modelled storage levels for the base case and the option to reduce the target storage to 85% of FSL storage levels based on climate signals that indicate 'wet' conditions (i.e. plotted on the primary y-axis (left) in the top box).
- Lake Eildon inflows, outflows for the base case and the option to reduce the target storage to 85% of FSL and downstream flow constraints after accounting for tributary inflows (i.e. plotted on the secondary y-axis (right) in the top box).
- HRWS and LRWS allocations for the base case and the option to reduce the target storage to 85% of FSL storage levels based on climate signals that indicate 'wet' conditions (plotted in the second box)
- The climate signal tested, with a dashed line showing the threshold adopted to represent 'wet' conditions (plotted in the third box).

The three boxes are repeated for three periods: the early 1900s, the early 1990s and the early 2020s.

Figure 58 demonstrates that:

- The climate signals during the early-1900s showed moderate to strong La Niña conditions which resulted in minor lowering of the storage level (downward shift of the curve between 1907 and 1908). In subsequent years however, the inflows were below-average and the released water was not able to be recovered thus resulting in minor impacts to HRWS and LRWS allocations between mid-1907 and mid-1908. This case study is an example of how the decision to reduce the target storage in one year can reduce allocations in the next.
- The climate signals during 1993, which led to the flood of record at Lake Eildon, showed neutral / weak El Niño conditions (i.e. below-average rainfall conditions) in the lead up to the event. Therefore, using climate signals to manage storage levels would not have changed the 1993 flood impacts. This demonstrates that using climate signals is an unreliable method of increasing the flood mitigation provided by Lake Eildon.
- The climate signals during 2022, which led to the flood of record at Seymour, showed strong La Niña conditions during May, June and July. However, the storage levels (modelled and actual) during this time were less than 85% and hence not affected by the simulated rule to reduce the target storage. In addition, the climate signal in October 2022 was just below the threshold used to implement the reduced target storage rule. This case study again illustrates why using climate signals to reduce the target storage at Lake Eildon will not be a robust option to increase the flood mitigation provided by the storage.

Figure 59 is a repeat of Figure 58 but showing the TPI climate index. In this case, using the TPI index would have resulted in an attempted lowering of the target storage at Lake Eildon during the spring of 2022, but the downstream flow constraint limited the extent to which additional airspace could be made without flooding downstream landholders.

These case studies are not intended to imply that using climate signals to reduce the target storage at Lake Eildon would never work. For example, in the 1970s (Figure 60) using climate signals would have lowered the target storage to provide up to 5.7% of additional airspace prior to the May 1974 event. Rather, the case studies are provided to demonstrate that this option is not a reliable way to increase the flood mitigation provided by Lake Eildon.

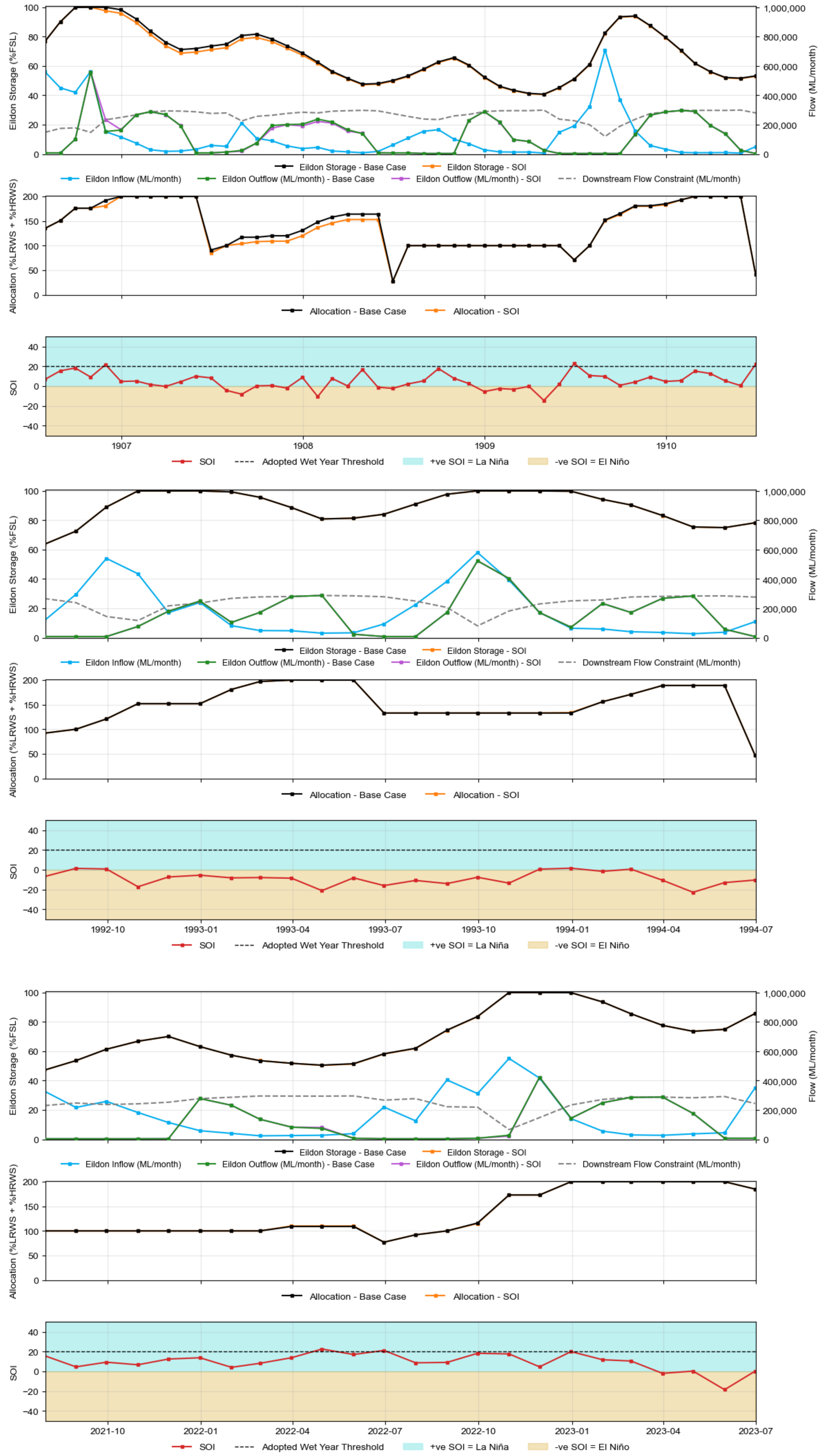


Figure 58: Case studies of early-1900s (top), 1993 (middle) and 2022 (bottom) using the ENSO index to reduce target storage to 85% of FSL based on 'wet' conditions.

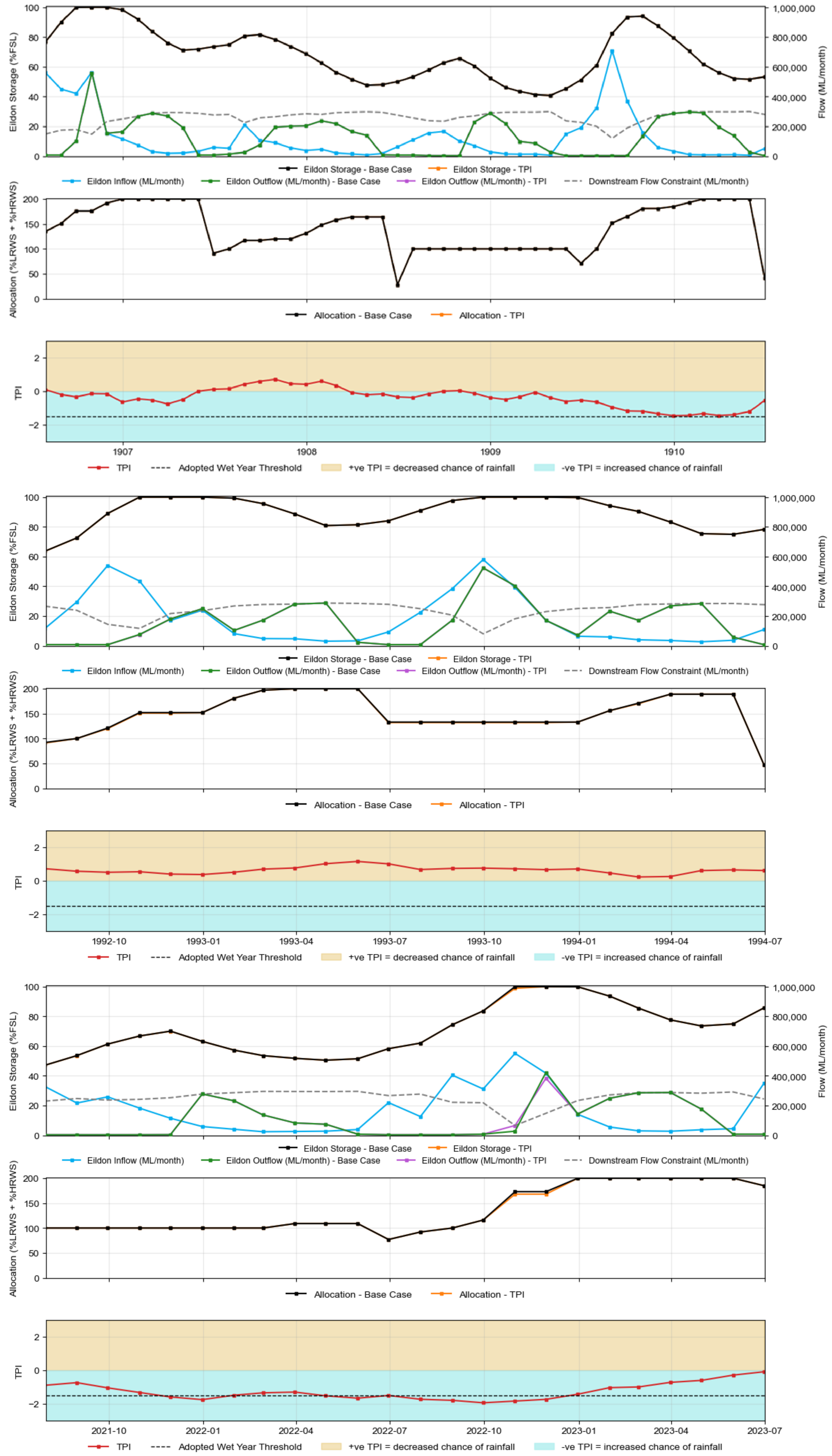


Figure 59: Case studies of early-1900s (top), 1993 (middle) and 2022 (bottom) using the TPI index to reduce target storage to 85% of FSL based on 'wet' conditions.

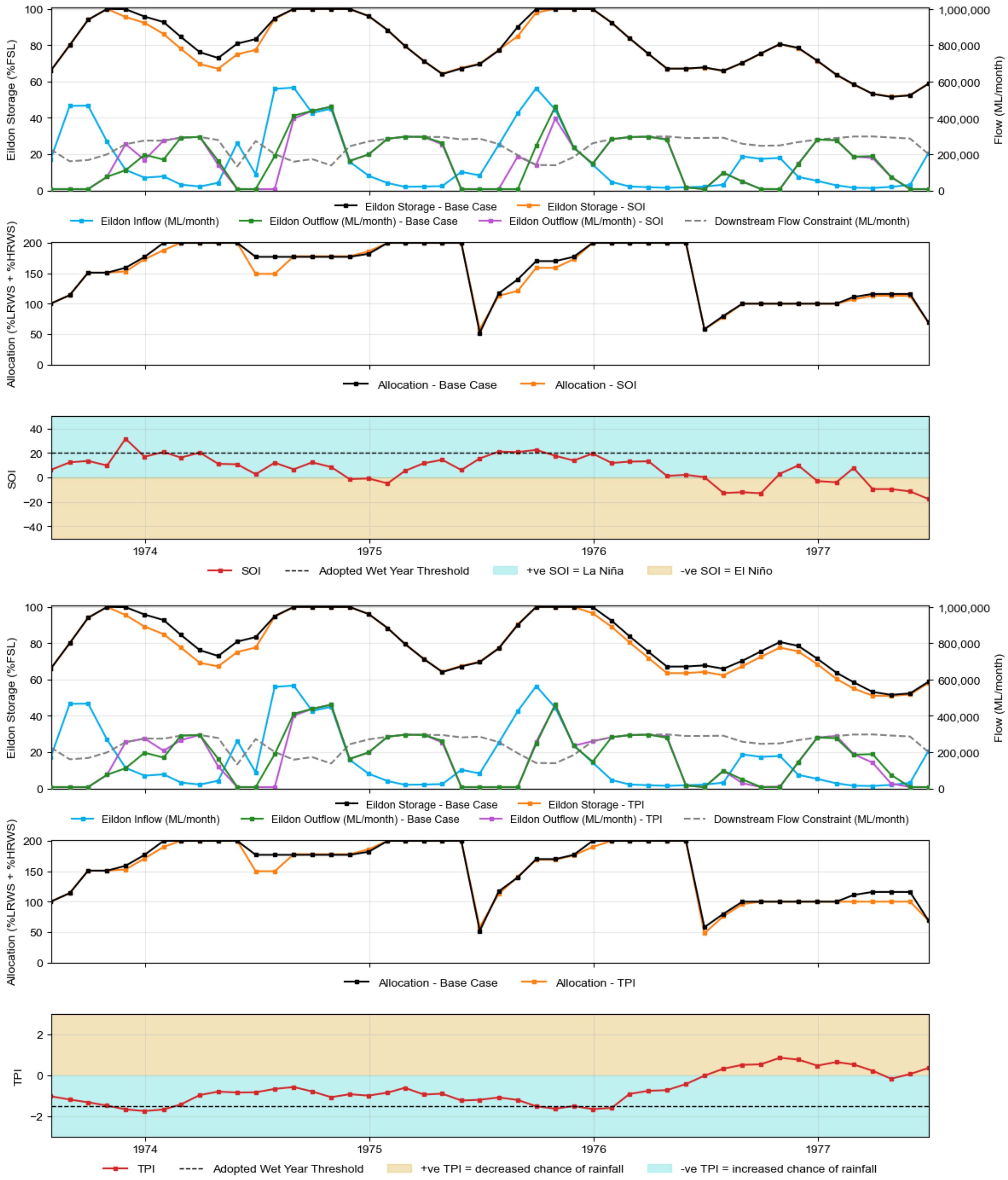


Figure 60: Case study of 1970s using the ENSO (top) and TPI (bottom) index to reduce target storage to 85% of FSL based on 'wet' conditions.

To present the data in an alternative way, a scatter plot is presented in Figure 61 showing the relationship between the TPI climate index and the modelled volume held in storage. TPI has been selected for this example because it summarises the tropical influences of both ENSO (SOI) and IOD on rainfall across Australia (Timbal and Hendon, 2011).

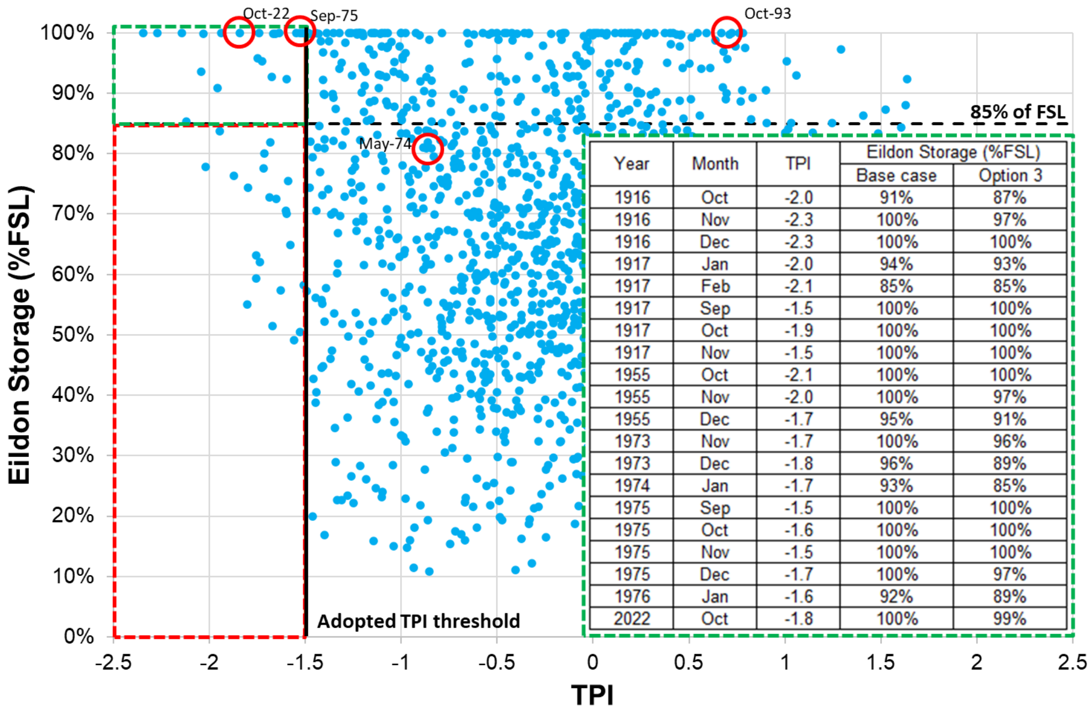
In Figure 61, the solid vertical black line denotes the TPI threshold that was modelled in the GSM to indicate ‘wet’ conditions. Figure 61 also shows the reduced target storage as a percentage of FSL as the dashed horizontal line, and the green dashed box summarises months in which the target storage was reduced – to the degree possible – to 85% capacity.

The adopted TPI threshold to denote ‘wet’ conditions was values less than -1.5 as it tended to correspond with the highest simulated Lake Eildon storage levels. TPI thresholds that were greater than -1.5 began to introduce variability into the monthly inflows and storage levels. That is, shifting the solid black vertical line to the right would begin to include points where modelled storage levels were less than 40% of FSL and inflows are below average (Figure 24). The May 1974, September 1975, October 1993 and October 2022 have also been highlighted in Figure 61 to denote the TPI value during four significant flood events in the Lake Eildon and mid-Goulburn catchment.

The number of points in the green region in Figure 61 – which are those that met the dual criteria of ‘wet’ conditions (TPI less than -1.5) and a storage level high enough to be reduced to 85% of FSL – were only 1.3% of the months simulated in the GSM. Changing the target storage to 95%, 90% or 78% of FSL is also unlikely to change the storage exceedance curves over a long-term period (1891 to 2022) because of the poor correlation the climate signals have with storage level and monthly inflows (Section 4.4).

In addition, Figure 62 shows that the degree to which the target storage reduction could be implemented during ‘wet’ conditions was limited. That is, the change in stored volume in the modelled option compared with the base case as a percentage of FSL was always less than the intended 15% reduction in storage capacity. For example, little to no additional airspace would be available at Lake Eildon prior to the September 1975 and October 1993 floods and approximately 5.7% and 1.2% of FSL of additional airspace would be available for the May 1974 and October 2022 flood events, respectively. In both the May 1974 and October 2022 flood events, the flood peak at Seymour was more influenced by rainfall that fell downstream of the storage (see Section 2.7). This is likely to be because of the influence of downstream flow constraints, as discussed in Section 5.3.

In summary, the results of this assessment suggests that the climate signals tested are a generally poor predictor of monthly inflows (Section 4.4) and Lake Eildon storage volumes in the base case (Figure 61). This means that – when combined with the influence of downstream flow constraints during wet periods (Section 5.3) – the option to reduce target storage based on climate signals is unlikely to be a robust option to increase the flood mitigation provided by Lake Eildon.



Year	Month	TPI	Eildon Storage (%FSL)	
			Base case	Option 3
1916	Oct	-2.0	91%	87%
1916	Nov	-2.3	100%	97%
1916	Dec	-2.3	100%	100%
1917	Jan	-2.0	94%	93%
1917	Feb	-2.1	85%	85%
1917	Sep	-1.5	100%	100%
1917	Oct	-1.9	100%	100%
1917	Nov	-1.5	100%	100%
1955	Oct	-2.1	100%	100%
1955	Nov	-2.0	100%	97%
1955	Dec	-1.7	95%	91%
1973	Nov	-1.7	100%	96%
1973	Dec	-1.8	96%	89%
1974	Jan	-1.7	93%	85%
1975	Sep	-1.5	100%	100%
1975	Oct	-1.6	100%	100%
1975	Nov	-1.5	100%	100%
1975	Dec	-1.7	100%	97%
1976	Jan	-1.6	92%	89%
2022	Oct	-1.8	100%	99%

Figure 61: Scatter plot of TPI and Lake Eildon storage capacity with the TPI threshold set to -1.5

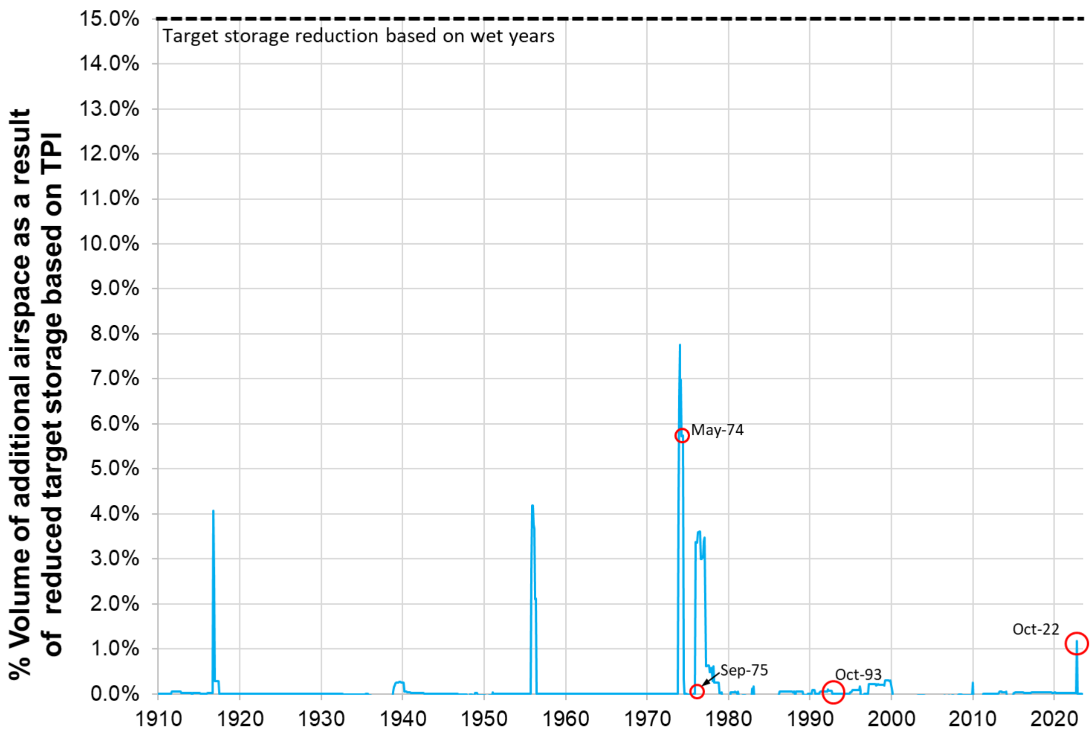


Figure 62: Percentage of FSL of additional airspace as a result of reduced target storage based on TPI and base case storage trace.

6. Flood frequency changes – Lake Eildon

6.1 Method

RORB (Laurenson and Mein, 1995) is a runoff and streamflow routing program that calculates flood hydrographs from spatially-distributed rainfall and stream network inputs. RORB subtracts losses from sub-daily rainfall time-series of a given annual exceedance probability (AEP) to determine rainfall excess, and then routes the rainfall excess through the catchment to produce streamflow hydrographs at points of interest.

RORB also has the capacity to use a Monte-Carlo approach to produce flood frequency estimates that incorporate the joint probability of flood causing factors (e.g. rainfall depth, rainfall temporal pattern, seasonal probabilities, losses and reservoir airspace).

The existing flood hydrology (RORB) models of the Goulburn River catchment was applied to simulate with the Monte-Carlo approach how the options described in Section 4 would change flood frequencies immediately downstream of the storage and at Molesworth and Seymour. Details of the RORB models are described in Section 1.4.

The flood frequency estimates at Lake Eildon have been simulated in RORB by sampling rainfall depths, temporal patterns and losses during storms centred on the Lake Eildon catchment (left flow chart in Figure 63). In turn, the flood frequency curves estimated for Molesworth and Seymour have been simulated by sampling space-time rainfall patterns, which are centred on the catchment areas to Trawool and Seymour respectively (right flow chart in Figure 63).

Figures of the adopted space-time patterns for events along the Goulburn River are provided in Appendix B.

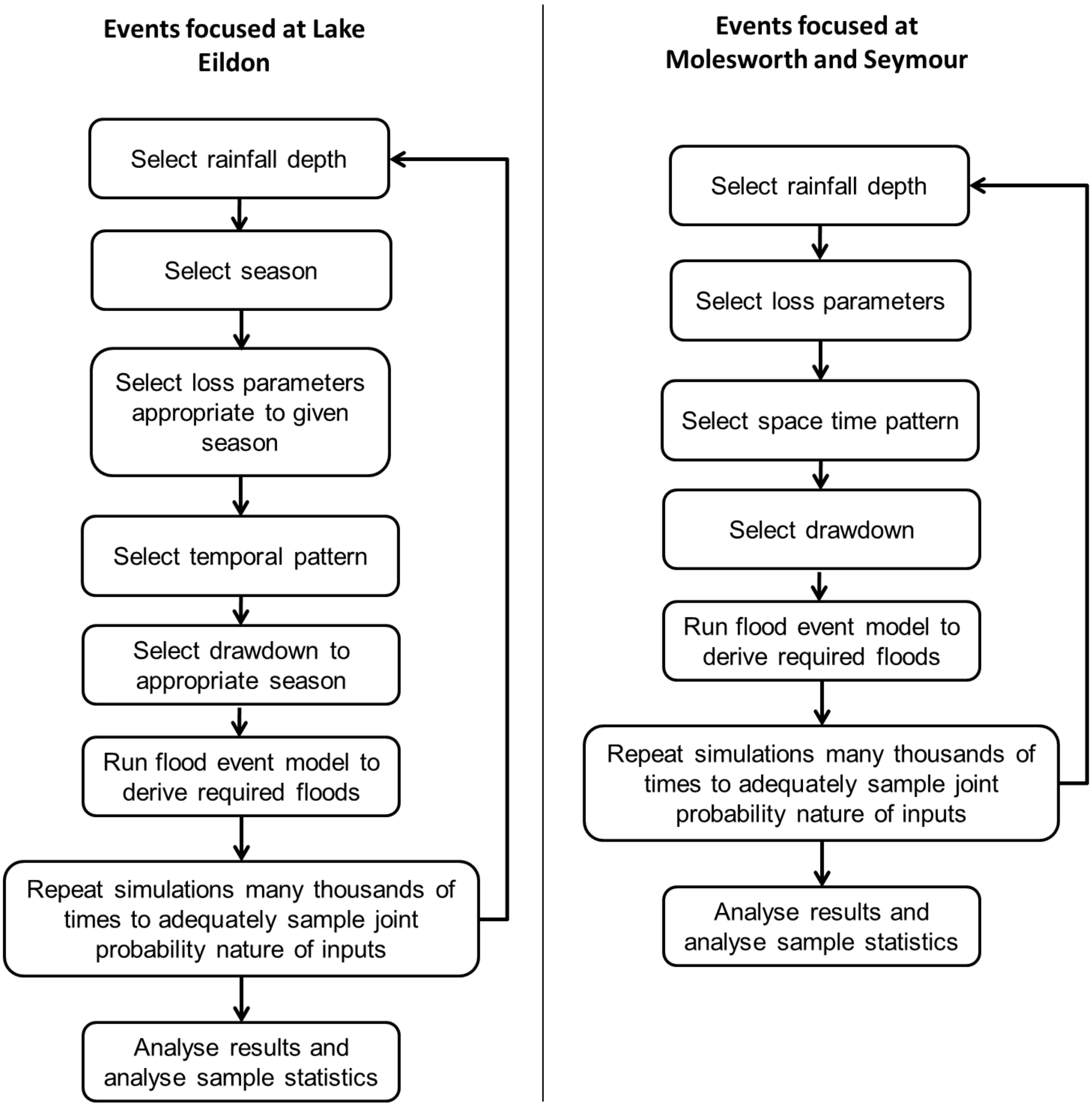


Figure 63: Joint probability framework used to simulate how the options in Section 4 would change flood frequencies immediately downstream of Lake Eildon, based on the drawdown distributions modelled in Section 5

Figure 64 shows the HARC (2017) Lake Eildon RORB modelling results – which are based on the left-hand side of Figure 63 – as compared with observed flood frequencies downstream of the dam. The RORB model results are shown as orange dots, and the expected flood quantiles for a given AEP are shown using the blue solid line which is based on a probability distribution (generalised extreme value (GEV) with LH2 shift) fitted to the annual maxima of historic spills. However, it should be noted that the estimates of historic flood frequencies have not been updated to incorporate the 2022 flood event. This work is currently being undertaken for downstream locations as part of the Goulburn and Broken Rivers Flood Study, but has not yet been completed for the dam catchment.

It should also be noted that the sampled drawdown distributions that have been used for this investigation are based on the exceedance curves presented in Section 5.2.1, which are different to the drawdown distributions modelled in HARC (2017). As discussed in Section 5.1

and Section 6.4, the GSM has a tendency to underestimate recently observed storage levels at Lake Eildon, and this will mean that drawdown is overestimated and outflow flood frequencies are underestimated. Appendix C demonstrates this in more detail. However, although the *absolute* magnitudes for the drawdown distributions and outflow flood frequency curves used in this technical assessment are different to the HARC (2017) study, the *relative* differences between the base case and options modelled are still informative.

In this report section, peak outflows from Lake Eildon as modelled using RORB are reported in m³/s. These values can be converted to ML/d by multiplying them by 86.4. For example, the peak outflow from Lake Eildon in 2022 was approximately 400 m³/s or 38,000 ML/d.

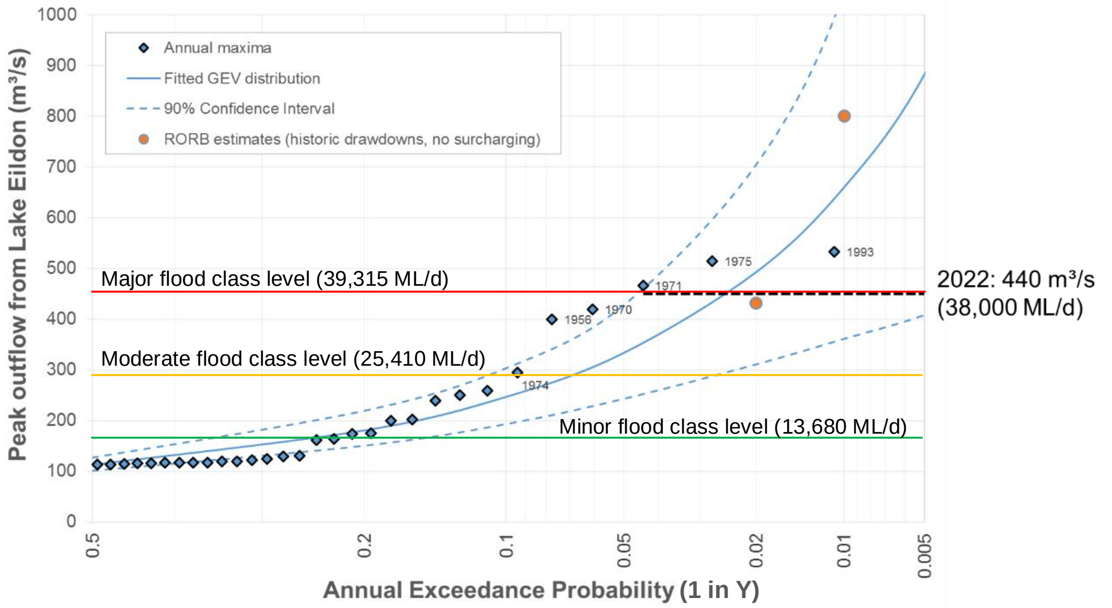


Figure 64: RORB model design results compared with flood frequency analyses of peak outflows from Lake Eildon between 1956 and 2015. In 1993, the reservoir was surcharged 590 mm to reduce the peak outflow.

6.2 Results

6.2.1 Option 1 – Change target filling curves

The following target filling curves were modelled in RORB:

- Base case (95PoE to Oct 1 (post-1891 data))
- 95PoE to Dec 1 (post-1891 data)
- 95PoE to Jan 1 (post-1891 data)
- 95PoE to Jan 1 (post-1975 data)
- 85PoE to Oct 1 (post-1891 data)
- 85PoE to Dec 1 (post-1891 data)
- 85PoE to Jan 1 (post-1891 data)
- 85PoE to Jan 1 (post-1975 data)
- 75PoE to Oct 1 (post-1891 data)
- 75PoE to Dec 1 (post-1891 data)
- 75PoE to Jan 1 (post-1891 data)
- 75PoE to Jan 1 (post-1975 data)

In order to represent the various options above, the GSM results presented in Figure 36 to Figure 38 (Section 5.2) were Monte Carlo sampled in RORB to produce the flood frequency curves.

Target filling curves based on 95PoE inflows

The following information was extracted from the RORB results for the 95PoE target filling curve options:

- The estimated change in the outflow flood frequency at Lake Eildon compared with the base case (Figure 65).
- The estimated change in the flood frequency curves at Molesworth and Seymour (Figure 66 and Figure 67).
- The relative change in peak flow for the 1% AEP event at each location (Table 22).
- The estimated AEP of the Lake Eildon peak outflow exceeding the minor, moderate and major flood class level flow thresholds for the Goulburn River at Eildon (Table 23).

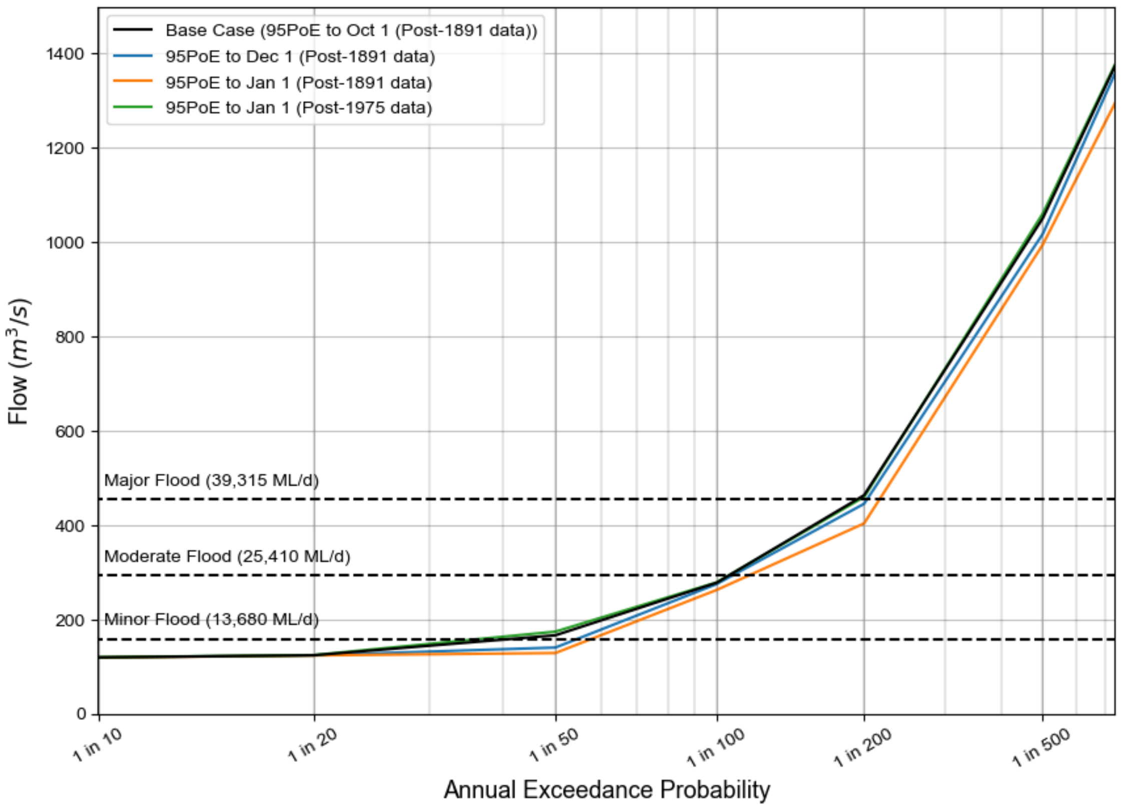


Figure 65: RORB model estimates of Lake Eildon peak outflow AEPs for the options that involve a target filling curve based on 95PoE inflow conditions.

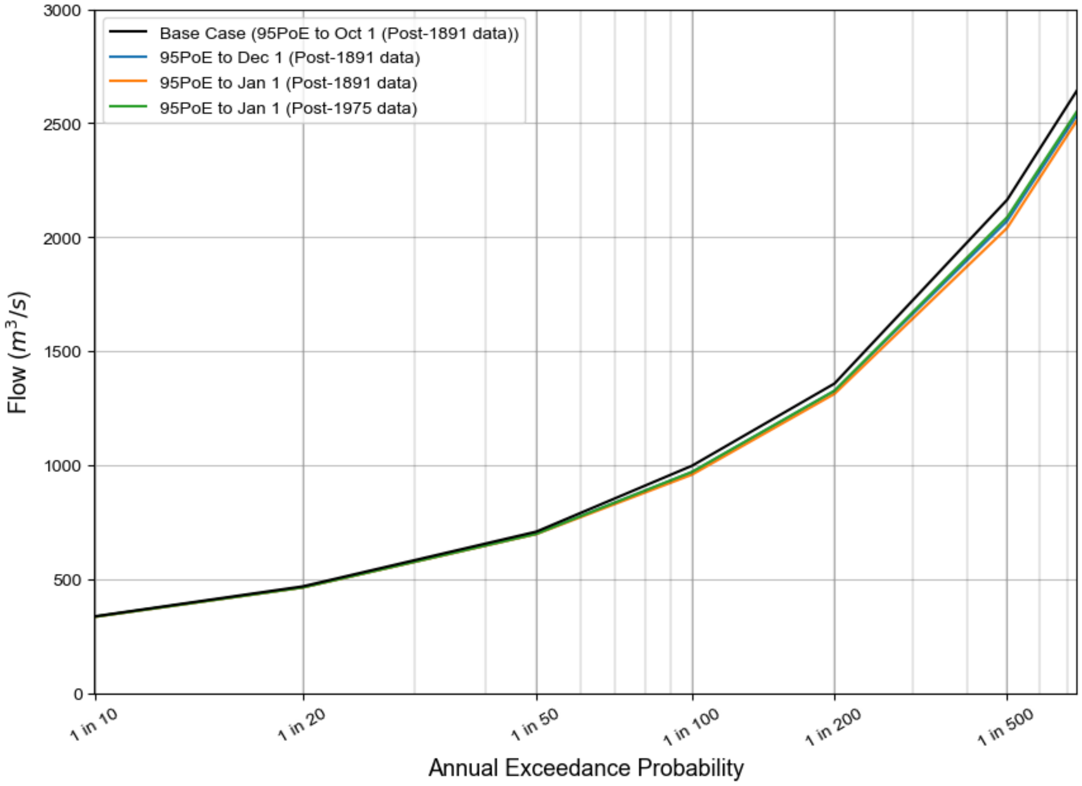


Figure 66: RORB model estimates of peak flow at Molesworth for the options that involve a target filling curve based on 95PoE inflow conditions.

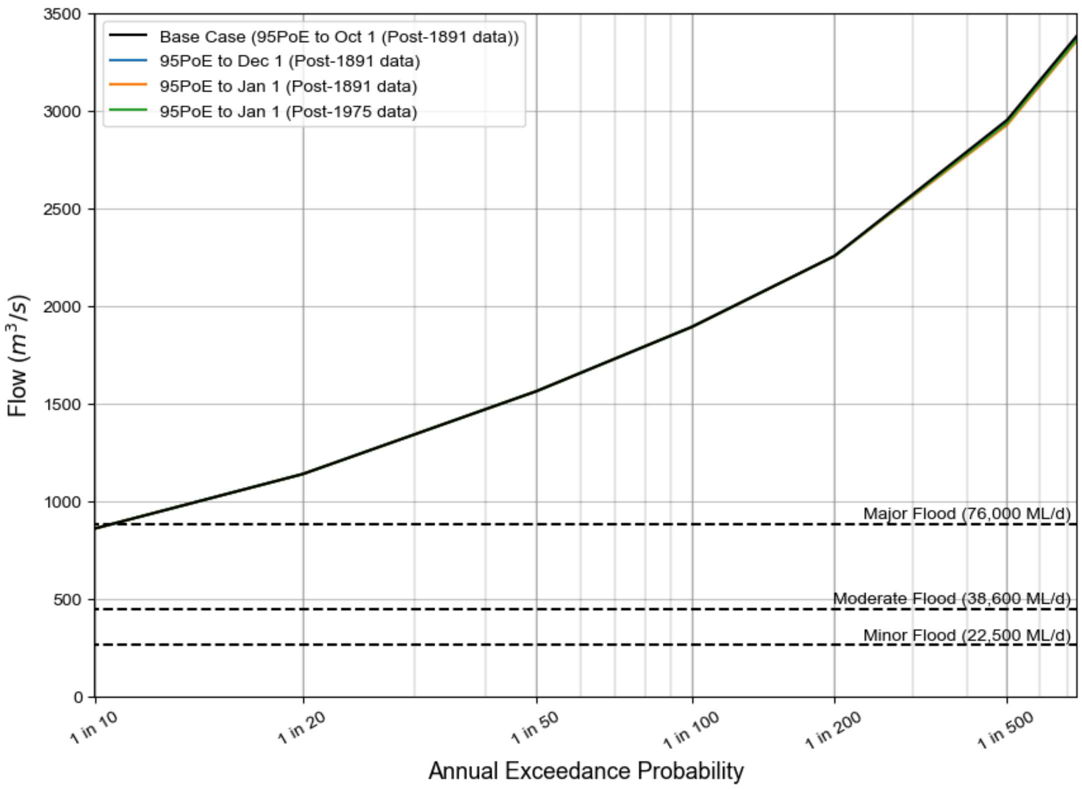


Figure 67: RORB model estimates of peak flow at Seymour for the options that involve a target filling curve based on 95PoE inflow conditions.

Table 22: Estimated 1% (1 in 100) AEP peak outflows from Lake Eildon for the options that involve a target filling curve based on 95PoE inflow conditions. These numbers are indicative, and should be used only for comparison between options rather than as best estimates of absolute peak outflows.

Option	Eildon outflow			Molesworth			Seymour		
	Peak flow (m³/s)	Peak flow (ML/d)	% change from base case	Peak flow (m³/s)	Peak flow (ML/d)	% change from base case	Peak flow (m³/s)	Peak flow (ML/d)	% change from base case
Base case (95PoE to Oct 1 (post-1891))*	277	23,970		997	86,120		1,890	163,350	
95PoE to Dec 1 (post-1891 data)	275	23,730	-1%	969	83,700	-3%	1,890	163,350	0%
95PoE to Jan 1 (post-1891 data)	262	22,650	-6%	958	82,760	-4%	1,890	163,350	0%
95PoE to Jan 1 (post-1975 data)	266	22,980	-4%	970	83,770	-3%	1,890	163,350	0%

*These values are lower than quoted by HARC (2017), because the base case Lake Eildon drawdown distribution provided by DEECA for this study differs to the drawdown distribution used by HARC (2017). Refer to Appendix C for a comparison between the two estimates.

Table 23: Estimated AEPs for peak outflows from Lake Eildon that reach the minor, moderate and major flood class level flow thresholds for the Goulburn River at Eildon (405203). These numbers are indicative, and should be used only for comparison between options rather than as best estimates.

Option	Approximate AEP (1 in Y) of Eildon outflow at flood class		
	Minor	Moderate	Major
Base case (95PoE to Oct 1 (post-1891))*	40	110	190
95PoE to Dec 1 (post-1891 data)	50	110	200
95PoE to Jan 1 (post-1891 data)	60	120	220
95PoE to Jan 1 (post-1975 data)	40	110	200

*These values are different than quoted by HARC (2017), because the base case Lake Eildon drawdown distribution provided by DEECA for this study differs to the drawdown distribution used by HARC (2017). Refer to Appendix C for a comparison between the two estimates.

Target filling curves based on 85PoE inflows

The following information was extracted from the RORB results for the 85PoE target filling curves options:

- The estimated change in the outflow flood frequency at Lake Eildon compared with the base case (Figure 68).
- The estimated change in the flood frequency curves at Molesworth and Seymour (Figure 69 and Figure 70).
- The relative change in peak flow for the 1% AEP event at each location (Table 24).
- The estimated AEP of the Lake Eildon peak outflow exceeding the minor, moderate and major flood class level flow thresholds for the Goulburn River at Eildon (Table 25).

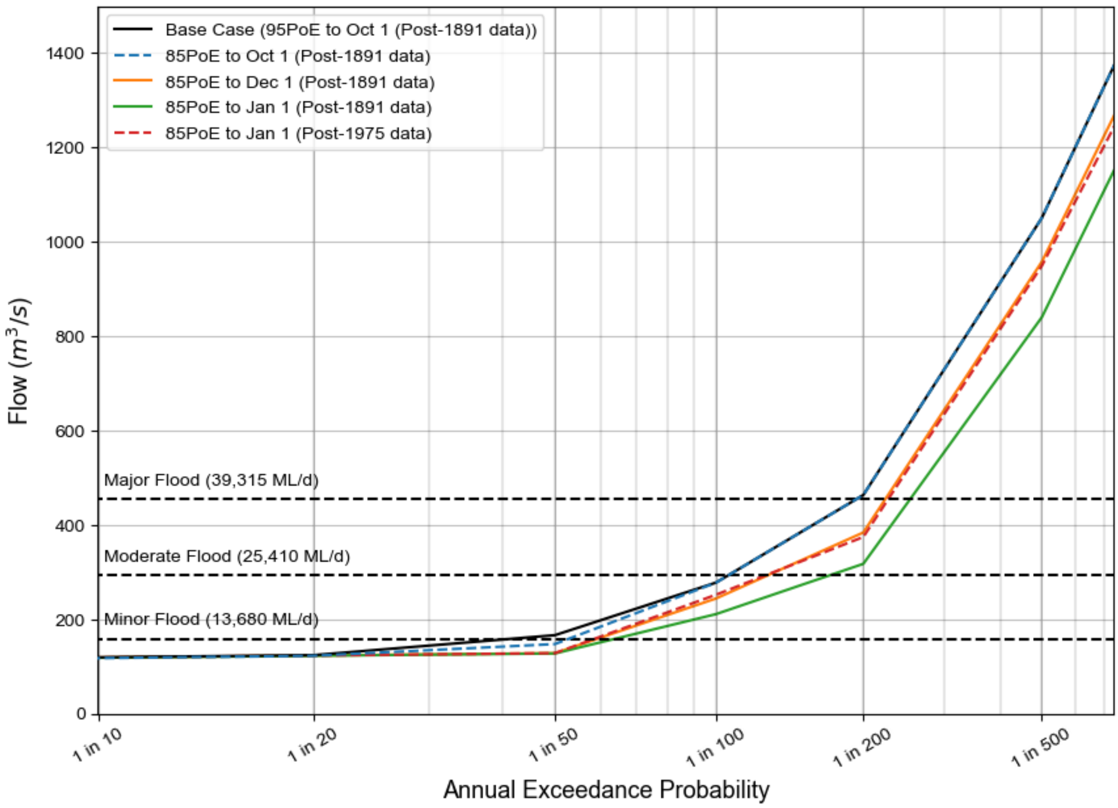


Figure 68: RORB model estimates of Lake Eildon peak outflow AEPs for the options that involve a target filling curve of 85PoE inflow conditions.

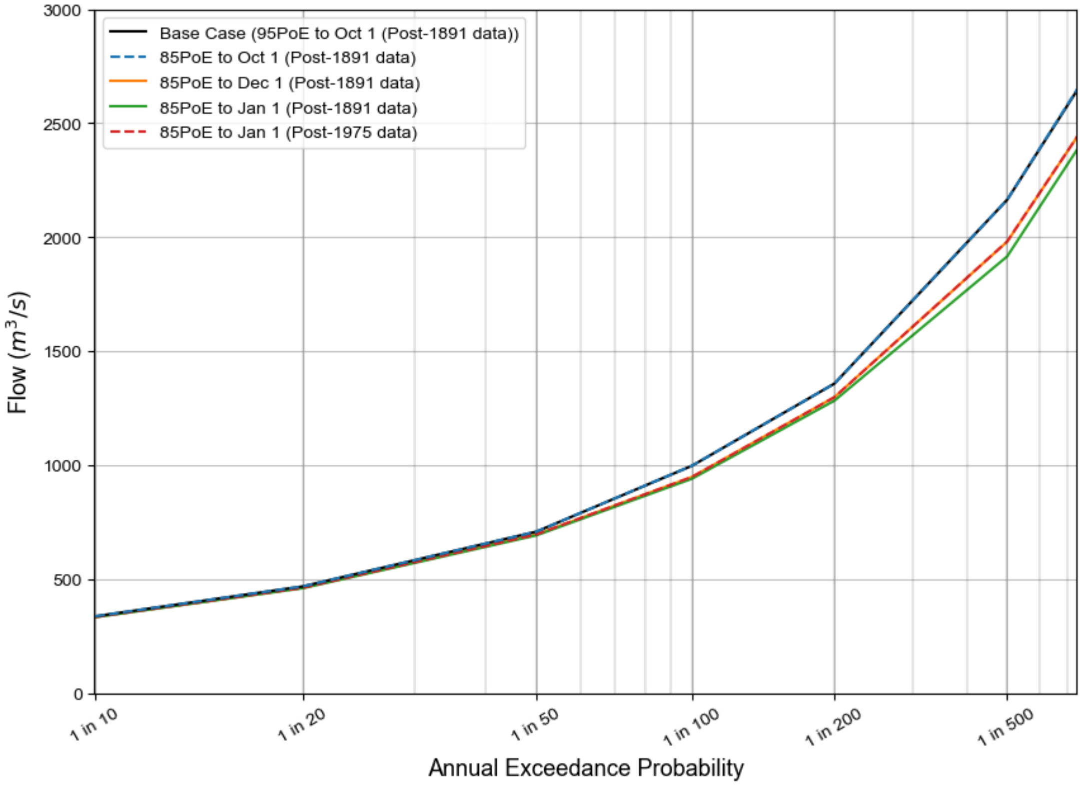


Figure 69: RORB model estimates of peak flow at Molesworth for the options that involve a target filling curve based on 85PoE inflow conditions.

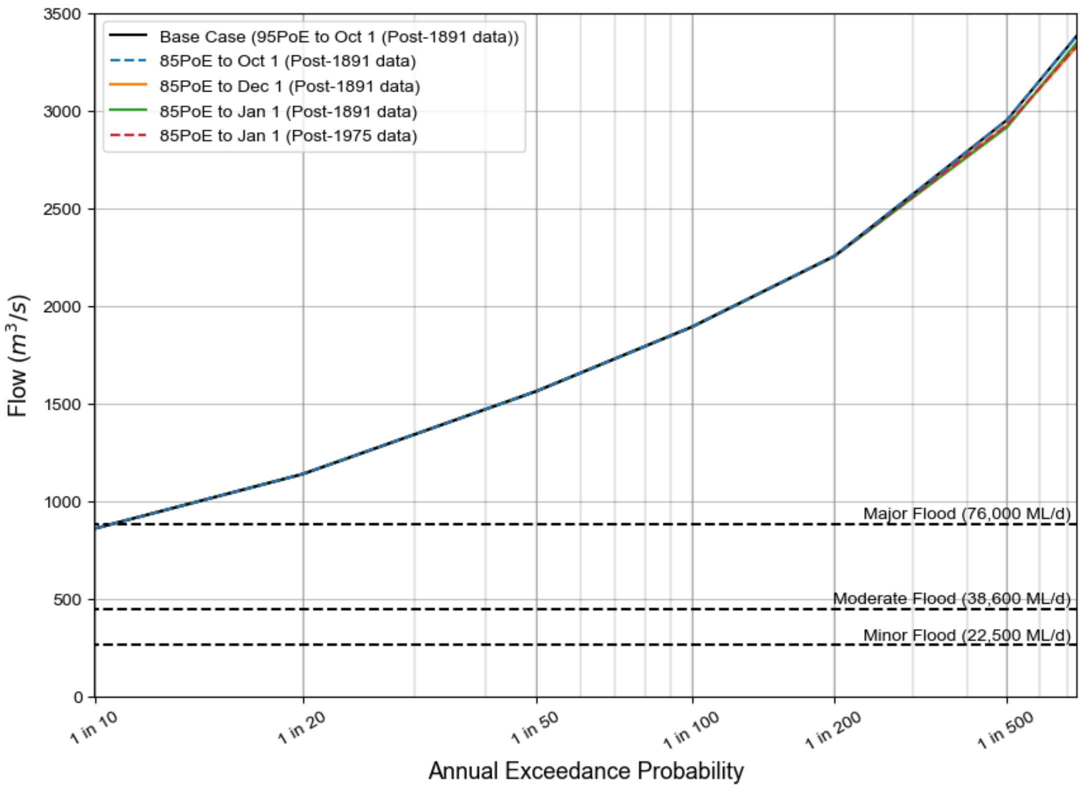


Figure 70: RORB model estimates of peak flow at Seymour for the options that involve a target filling curve based on 85PoE inflow conditions.

Table 24: Estimated 1% (1 in 100) AEP peak outflows from Lake Eildon for the options that involve a target filling curve of 85PoE inflow conditions. These numbers are indicative, and should be used only for comparison between options rather than as best estimates of absolute peak outflows.

Option	Eildon outflow			Molesworth			Seymour		
	Peak flow (m³/s)	Peak flow (ML/d)	% change from base case	Peak flow (m³/s)	Peak flow (ML/d)	% change from base case	Peak flow (m³/s)	Peak flow (ML/d)	% change from base case
Base case (95PoE to Oct 1 (post-1891))*	277	23,970		997	86,120		1,890	163,350	
85PoE to Oct 1 (post-1891 data)	277	23,970	0%	997	86,120	0%	1,890	163,350	0%
85PoE to Dec 1 (post-1891 data)	244	21,060	-12%	948	81,890	-5%	1,890	163,350	0%
85PoE to Jan 1 (post-1891 data)	211	18,200	-24%	940	81,210	-6%	1,890	163,350	0%
85PoE to Jan 1 (post-1975 data)	252	21,750	-9%	948	81,880	-5%	1,890	163,350	0%

*These values are lower than quoted by HARC (2017), because the base case Lake Eildon drawdown distribution provided by DEECA for this study differs to the drawdown distribution used by HARC (2017). Refer to Appendix C for a comparison between the two estimates.

Table 25: Estimated AEPs for peak outflows from Lake Eildon that reach the minor, moderate and major flood class level flow thresholds for the Goulburn River at Eildon (405203). These numbers are indicative, and should be used only for comparison between options rather than as best estimates.

Option	Approximate AEP (1 in Y) of Eildon outflow at flood class		
	Minor	Moderate	Major
Base case (95PoE to Oct 1 (post-1891))*	40	110	190
85PoE to Oct 1 (post-1891 data)	50	110	190
85PoE to Dec 1 (post-1891 data)	60	130	220
85PoE to Jan 1 (post-1891 data)	60	170	250
85PoE to Jan 1 (post-1975 data)	60	130	230

*These values are different than quoted by HARC (2017), because the base case Lake Eildon drawdown distribution provided by DEECA for this study differs to the drawdown distribution used by HARC (2017). Refer to Appendix C for a comparison between the two estimates.

Target filling curves based on 75PoE inflows

The following information was extracted from the RORB results for the 75PoE target filling options:

- The estimated change in the outflow flood frequency at Lake Eildon compared with the base case (Figure 71).
- The estimated change in the flood frequency curves at Molesworth and Seymour (Figure 72 and Figure 73).
- The relative change in peak flow for the 1% AEP event at each location (Table 26).
- The estimated AEP of the Lake Eildon peak outflow exceeding the minor, moderate and major flood class level flow thresholds for the Goulburn River at Eildon (Table 27).

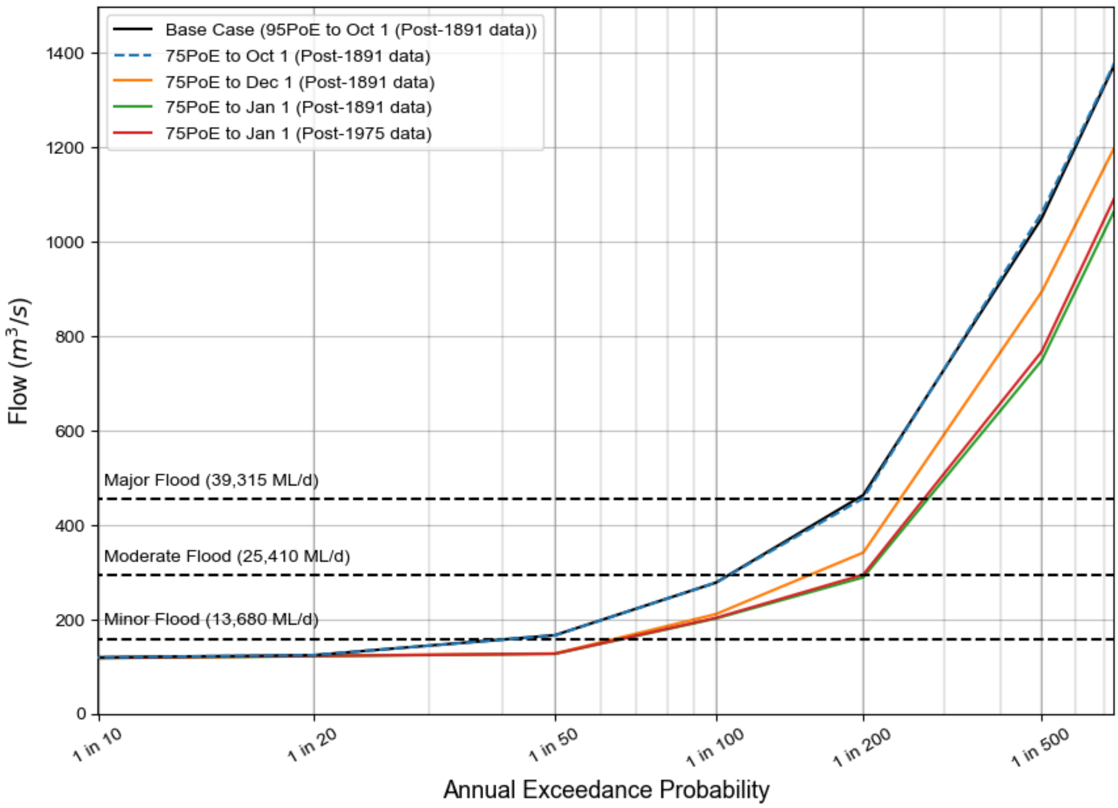


Figure 71: RORB model estimates of Lake Eildon peak outflow AEPs for the options that involve a target filling curve based on 75PoE inflow conditions.

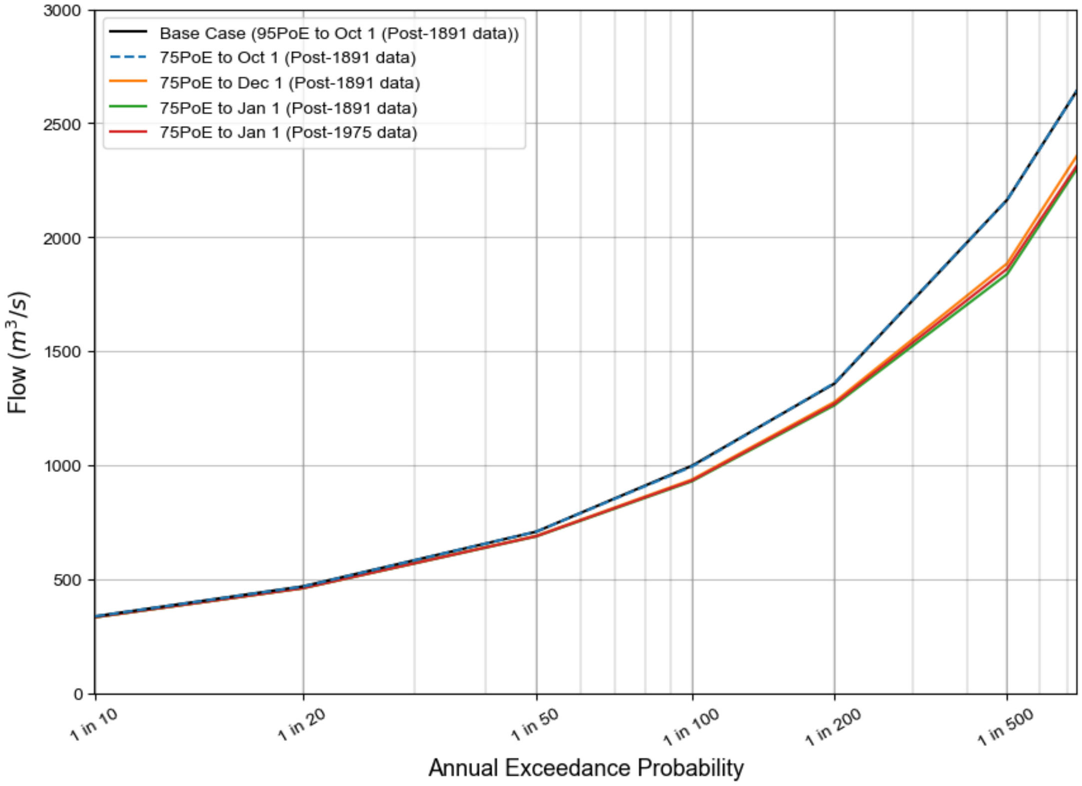


Figure 72: RORB model estimates of peak flow at Molesworth for the options that involve a target filling curve based on 75PoE inflow conditions.

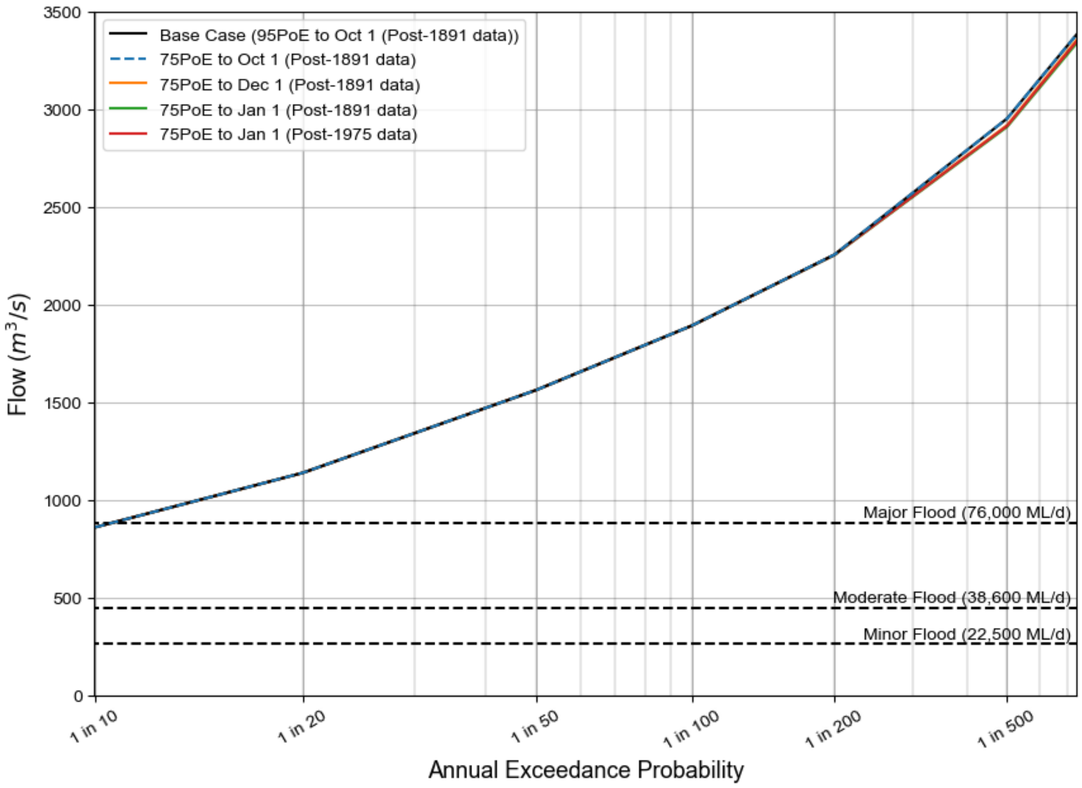


Figure 73: RORB model estimates of peak flow at Seymour for the options that involve a target filling curve based on 75PoE inflow conditions.

Table 26: Estimated 1% (1 in 100) AEP peak outflows from Lake Eildon for the options that involve a target filling curve of 75PoE inflow conditions. These numbers are indicative, and should be used only for comparison between options rather than as best estimates of absolute peak outflows.

Option	Eildon outflow			Molesworth			Seymour		
	Peak flow (m³/s)	Peak flow (ML/d)	% change from base case	Peak flow (m³/s)	Peak flow (ML/d)	% change from base case	Peak flow (m³/s)	Peak flow (ML/d)	% change from base case
Base case (95PoE to Oct 1 (post-1891))*	277	23,970		997	86,120		1,890	163,350	
75PoE to Oct 1 (post-1891 data)	277	23,970	0%	993	85,810	0%	1,890	163,350	0%
75PoE to Dec 1 (post-1891 data)	211	18,210	-24%	936	80,900	-6%	1,890	163,350	0%
75PoE to Jan 1 (post-1891 data)	201	17,400	-27%	929	80,240	-7%	1,890	163,350	0%
75PoE to Jan 1 (post-1975 data)	203	17,520	-27%	932	80,530	-6%	1,890	163,350	0%

*These values are lower than quoted by HARC (2017), because the base case Lake Eildon drawdown distribution provided by DEECA for this study differs to the drawdown distribution used by HARC (2017). Refer to Appendix C for a comparison between the two estimates.

Table 27: Estimated AEPs for peak outflows from Lake Eildon that reach the minor, moderate and major flood class level flow thresholds for the Goulburn River at Eildon (405203). These numbers are indicative, and should be used only for comparison between options rather than as best estimates.

Option	Approximate AEP (1 in Y) of Eildon outflow at flood class		
	Minor	Moderate	Major
Base case (95PoE to Oct 1 (post-1891))*	40	110	190
75PoE to Oct 1 (post-1891 data)	40	110	200
75PoE to Dec 1 (post-1891 data)	60	150	240
75PoE to Jan 1 (post-1891 data)	70	200	280
75PoE to Jan 1 (post-1975 data)	70	200	270

*These values are different than quoted by HARC (2017), because the base case Lake Eildon drawdown distribution provided by DEECA for this study differs to the drawdown distribution used by HARC (2017). Refer to Appendix C for a comparison between the two estimates.

Based on these figures and tables, the following observations can be made:

- Changes to the 95PoE target filling curves, by delaying the fill date or basing them on inflows post-1975 rather than post-1891, are unlikely to have flood mitigation benefits downstream of Lake Eildon. For example, the peak flows for the 1% AEP event at Molesworth were simulated to reduce by up to 4%, and the peak flows at Seymour were similar to the base case estimates.
- Using a 85PoE target filling curve and delaying the fill date provides some flood mitigation benefits from Eildon to Molesworth. For example, the peak flows for the 1% AEP event at Eildon and Molesworth were simulated to reduce by up to 24% and 6% respectively.
- Using a 75PoE target filling curve and delaying the fill date provides some additional flood mitigation benefits from Lake Eildon to Molesworth. For example, the peak flows for the 1% AEP event at Eildon and Molesworth were simulated to reduce by up to 27% and 7% respectively.
- The flood mitigation benefits diminished with increasing distance downstream of Lake Eildon, because of tributary inflows along the Goulburn River. This meant that peak flows simulated for the 1% AEP event at Seymour were similar to the base case scenario in each target filling curve option tested. Further discussion on these findings is presented in Section 6.3.
- The combination of the 75PoE and the later fill date was estimated to provide the biggest flood mitigation benefits amongst the target filling curve options assessed. Therefore, the 75PoE target filling curve options were progressed to the detailed technical assessment of the costs to offset supply reliability changes (Section 8), changes to downstream flow regime (Section 10) and flood damages (Section 11).

It needs to be stressed however, that these results are based on the joint probability framework shown in Figure 63, which involves many thousands of simulations. The relative performance of each option in terms of providing additional flood mitigation at Lake Eildon will vary for each individual event. Section 7 therefore assesses what differences each option may have made to outflows from Lake Eildon during the October 1993 and 2022 floods.

Again, it is also important to note that the base case estimates of the Lake Eildon outflow flood frequencies sit below prior estimates by HARC (2017). This is because the Lake Eildon drawdown distribution in the base case version of the GSM available for this technical assessment of operating options is greater than the modelled drawdown distribution used in 2017 (Appendix C). To account for the likelihood that the base case outflow flood frequencies are underestimated, the base case and selected options were also modelled using drawdown distributions available from the Melbourne University SGEFM model (Section 6.4).

6.2.2 Option 2 – Reduce target storage

The 95%, 90%, 85% and 78% of FSL target storage options were modelled in RORB and compared to the base case.

A limitation to target storage option is the constraints of regulated flows in the mid-Goulburn of 10,000 ML/d. This means that holding the lake at levels at a lower FSL may not always be possible if the preceding inflows into Lake Eildon are greater than 10,000 ML/d for a prolonged period. The impact of the downstream flow constraints on the modelled exceedance curves is discussed in greater detail in Section 5.3.

The following information was extracted from the RORB results:

- The estimated change in the outflow flood frequency at Lake Eildon compared with the base case (Figure 74).
- The estimated change in the flood frequency curves at Molesworth and Seymour (Figure 75 and Figure 76).
- The relative change in peak flow for the 1% AEP event at each location (Table 28).
- The estimated AEP of the Lake Eildon peak outflow exceeding the minor, moderate and major flood class level flow thresholds for the Goulburn River at Eildon (Table 29).

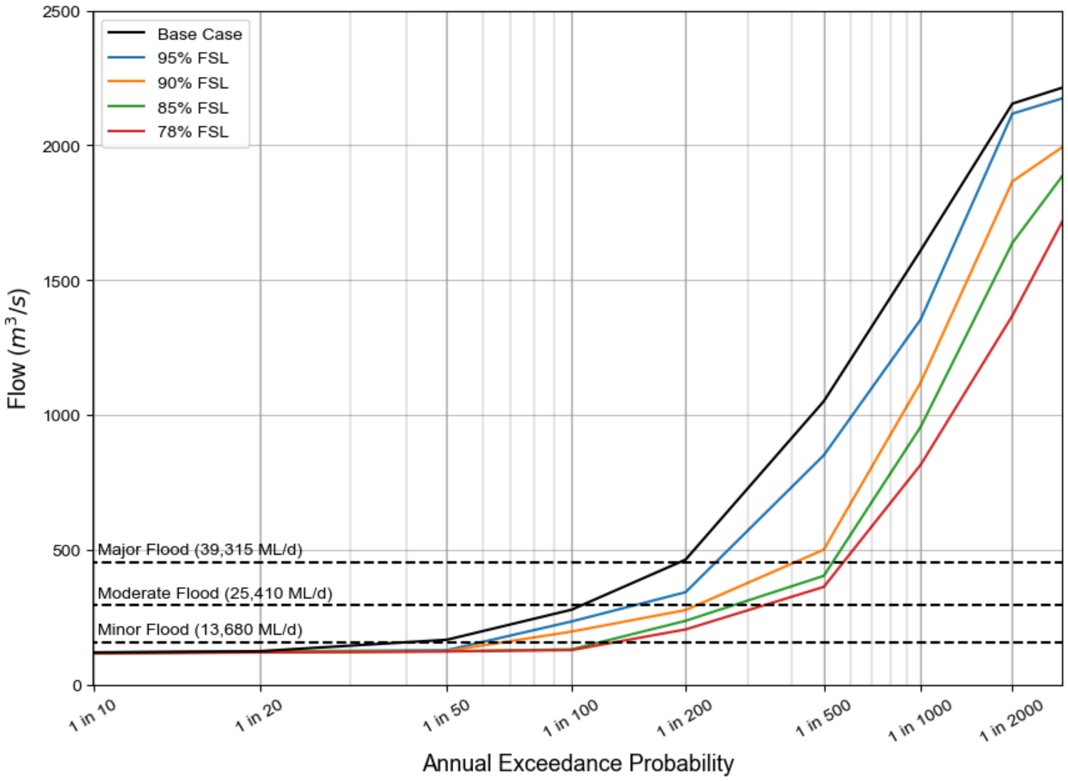


Figure 74: RORB model estimates of peak outflows for Lake Eildon for selected options that involve a target storage of 78%, 85%, 90% and 95% of FSL.

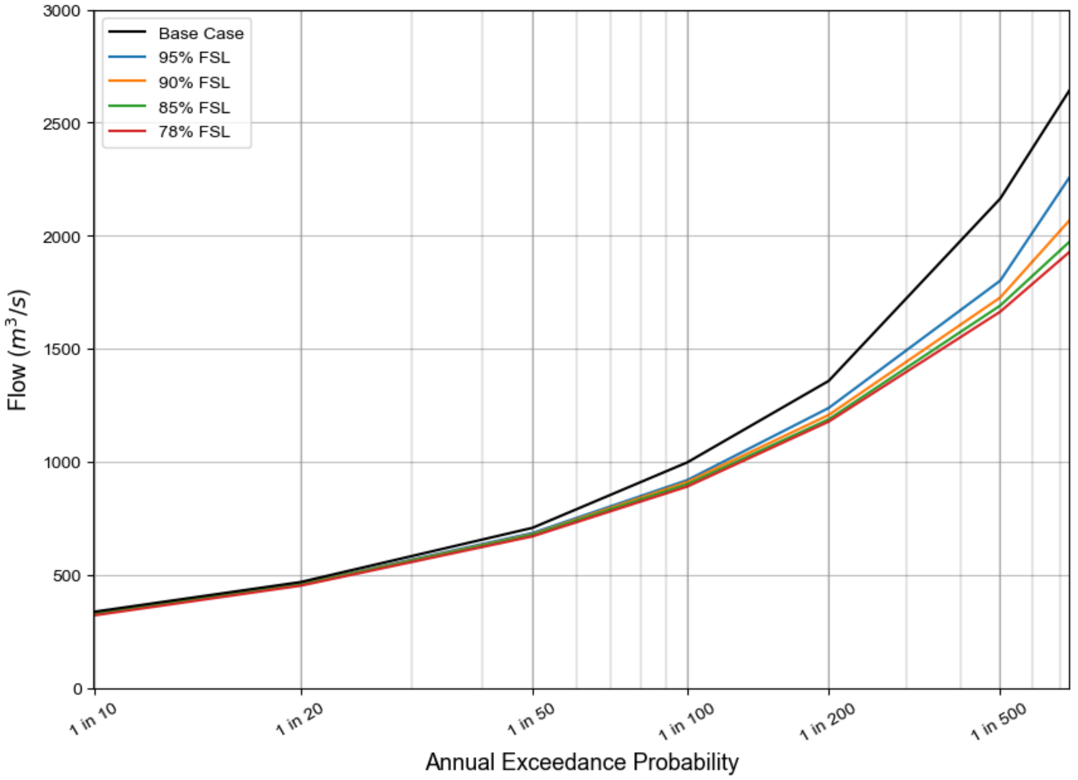


Figure 75: RORB model estimates of peak flow at Molesworth for selected options that involve a target storage of 78%, 85%, 90% and 95% of FSL.

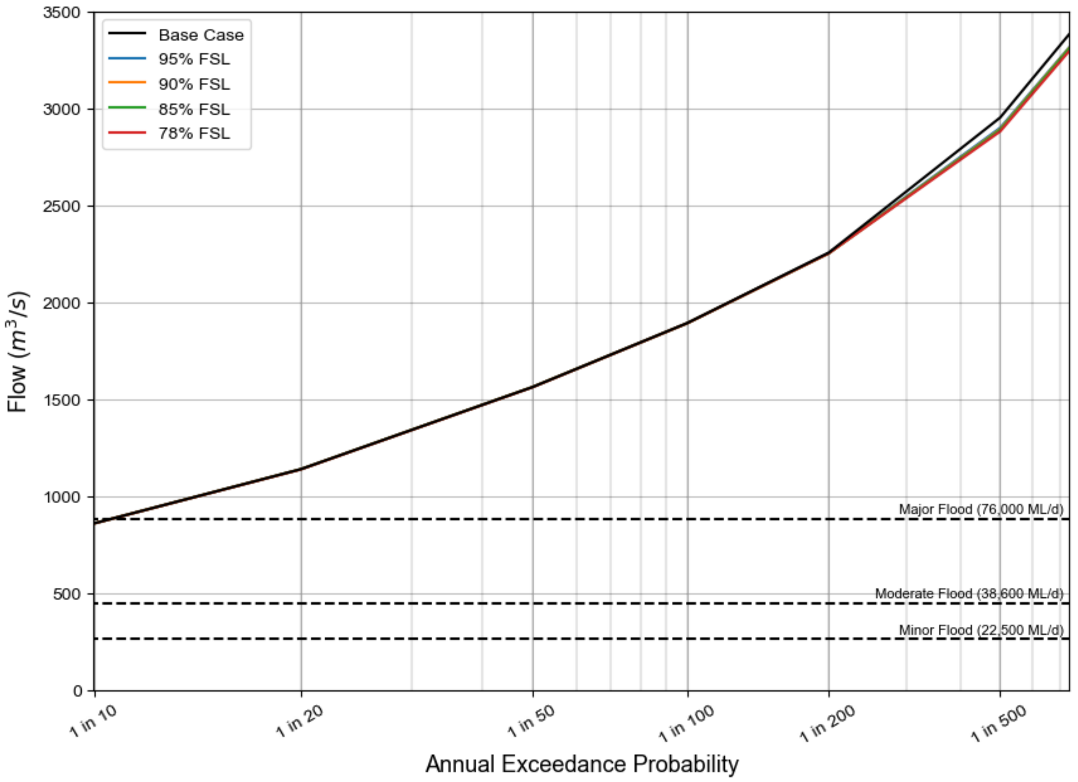


Figure 76: RORB model estimates of peak flow at Seymour for selected options that involve a target storage of 78%, 85%, 90% and 95% of FSL.

Table 28: Estimated 1% (1 in 100) AEP peak outflows from Lake Eildon. These numbers are indicative, and should be used only for comparison between options rather than as best estimates of absolute peak outflows.

Option	Eildon outflow			Molesworth			Seymour		
	Peak flow (m^3/s)	Peak flow (ML/d)	% change from base case	Peak flow (m^3/s)	Peak flow (ML/d)	% change from base case	Peak flow (m^3/s)	Peak flow (ML/d)	% change from base case
Base case* (100% of target storage)	277	23,970		997	86,120		1,890	163,350	
95% target storage	234	20,200	-16%	918	79,340	-8%	1,890	163,350	0%
90% target storage	196	16,960	-29%	910	78,630	-9%	1,890	163,350	0%
85% target storage	130	11,270	-53%	900	77,760	-10%	1,890	163,350	0%
78% target storage	128	11,030	-54%	890	76,870	-11%	1,890	163,350	0%

*These values are lower than quoted by HARC (2017), because the base case Lake Eildon drawdown distribution provided by DEECA for this study differs to the drawdown distribution used by HARC (2017). Refer to Appendix C for a comparison between the two estimates.

Table 29: Estimated AEPs for peak outflows from Lake Eildon that reach the minor, moderate and major flood class level flow thresholds for the Goulburn River at Eildon (405203). These numbers are indicative, and should be used only for comparison between options rather than as best estimates.

Option	Approximate AEP (1 in Y) of outflow at flood class		
	Minor	Moderate	Major
Base case* (100% of target storage)	40	110	190
95% target storage	60	150	240
90% target storage	70	210	410
85% target storage	120	270	530
78% target storage	130	330	570

*These values are different than quoted by HARC (2017), because the base case Lake Eildon drawdown distribution provided by DEECA for this study differs to the drawdown distribution used by HARC (2017). Refer to Appendix C for a comparison between the two estimates.

Based on these figures and tables, the following observations can be made:

- The chosen threshold for the target storage below FSL makes an appreciable difference to the modelled peak outflow frequencies for Lake Eildon. For example, the 1% AEP peak outflow is approximately 16% lower than the base case if the target storage is 95% of FSL, and >50% lower if the target storage is 78% of FSL.
- The flood mitigation benefits reduce with increasing distance downstream from Lake Eildon. For instance, the 1% AEP peak flow at Molesworth is approximately 8% to 11%

lower across the options considered, but at Seymour the estimated 1% AEP peak flow does not change.

It needs to be stressed however, that these results are based on the joint probability framework shown in Figure 63, which involves many thousands of simulations. The relative performance of each option in terms of providing additional flood mitigation at Lake Eildon will vary for each individual event. Section 7 therefore assesses what differences each option may have made to outflows from Lake Eildon during the October 1993 and 2022 floods.

Again, it is also important to note that the base case estimates of the Lake Eildon outflow flood frequencies sit below prior estimates by HARC (2017). This is because the Lake Eildon drawdown distribution in the base case version of the GSM available for this technical assessment of operating options is greater than the modelled drawdown distribution used in 2017 (Appendix C). To account for the likelihood that the base case outflow flood frequencies are underestimated, the base case and selected options were also modelled using drawdown distributions available from the Melbourne University SGEFM model (Section 6.4).

6.2.3 Option 3 – Reduce target storage based on climate signals

The flood frequency changes caused by reducing the Lake Eildon target storage based on climate signals was not modelled in RORB because there was little to no differences across the exceedance curves shown in Figure 35. Further discussion is provided in Section 5.4.

6.2.4 Option 4 – Pre-release based on forecast rainfall

Additional flood routing modelling was undertaken to better understand how higher pre-releases from Lake Eildon before the October 1993 and October 2022 floods may have changed peak flows at Seymour. However, this work did not involve flood frequency assessments, and is therefore included in Section 7.2.4.

6.2.5 Option 5 – Change maximum surcharge

Additional analysis was undertaken to investigate the trade-off between potential flood mitigation benefits and dam safety risks if the maximum surcharge at Lake Eildon was increased. The previous modelling undertaken by SKM (2006 & 2010) demonstrated some flood mitigation benefits with higher surcharge depths, but also highlighted the trade-off with increased durations of flooding above certain thresholds and increased likelihoods of overtopping the dam crest.

On the basis of current dam safety industry practice, increasing the maximum surcharge at Lake Eildon is unlikely to be a feasible option; however, further modelling was warranted to better demonstrate the dam safety implications of increasing the maximum surcharge. This involved updating the gate operating rules in the RORB model (HARC, 2017) to allow for a greater maximum surcharge. The RORB model was used to produce a design flood outflow and level frequency curve at Lake Eildon for the following options:

- Base case, which represents a maximum surcharge of 600 mm
- Maximum surcharge of 900 mm

- Maximum surcharge of 1200 mm

The RORB model results at Lake Eildon are shown in Figure 77 and Figure 78, and the AEPs of exceeding a flow threshold of 1,000 m³/s (86,400 ML/d) are summarised in Table 30. The estimated peak flow flood frequency curves at Molesworth and Seymour are shown in Figure 79 and Figure 80 respectively.

Based on these figures and tables, the following observations can be made:

- The probability of Lake Eildon outflows exceeding 1,000 m³/s (86,400 ML/d) decreases as the maximum surcharge is increased (refer to Figure 77 and Table 30), but the probability of outflows exceeding approximately 2,300 m³/s – 3,000 m³/s increases.
- The probability of a flood overtopping or reaching the dam crest level is essentially unchanged (refer to Figure 78 and Table 30).
- The flood mitigation benefits reduce with increasing distance downstream from Lake Eildon. For instance, the 1% AEP peak flow at Molesworth is approximately 9% to 10% lower across the surcharge options considered, but at Seymour the estimated 1% AEP peak flow does not change.

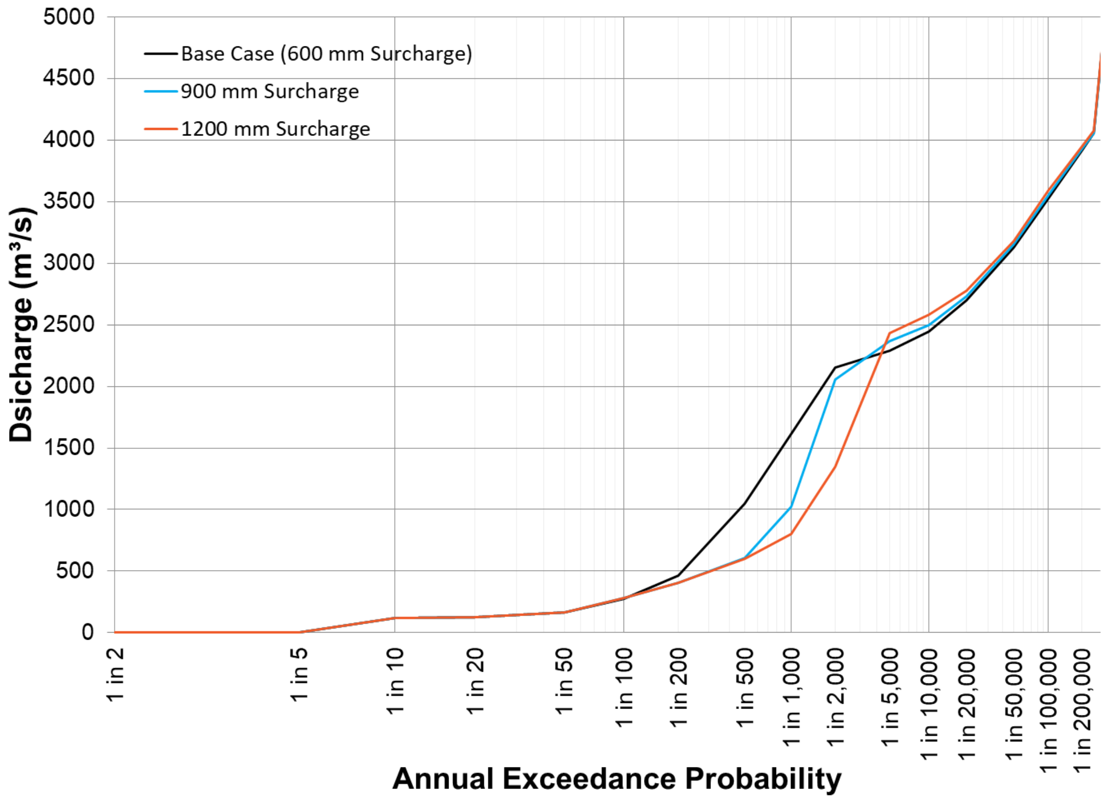


Figure 77: RORB model estimates of Lake Eildon peak outflow for the options that involve a maximum surcharge level of 600 mm, 900 mm and 1200 mm above FSL

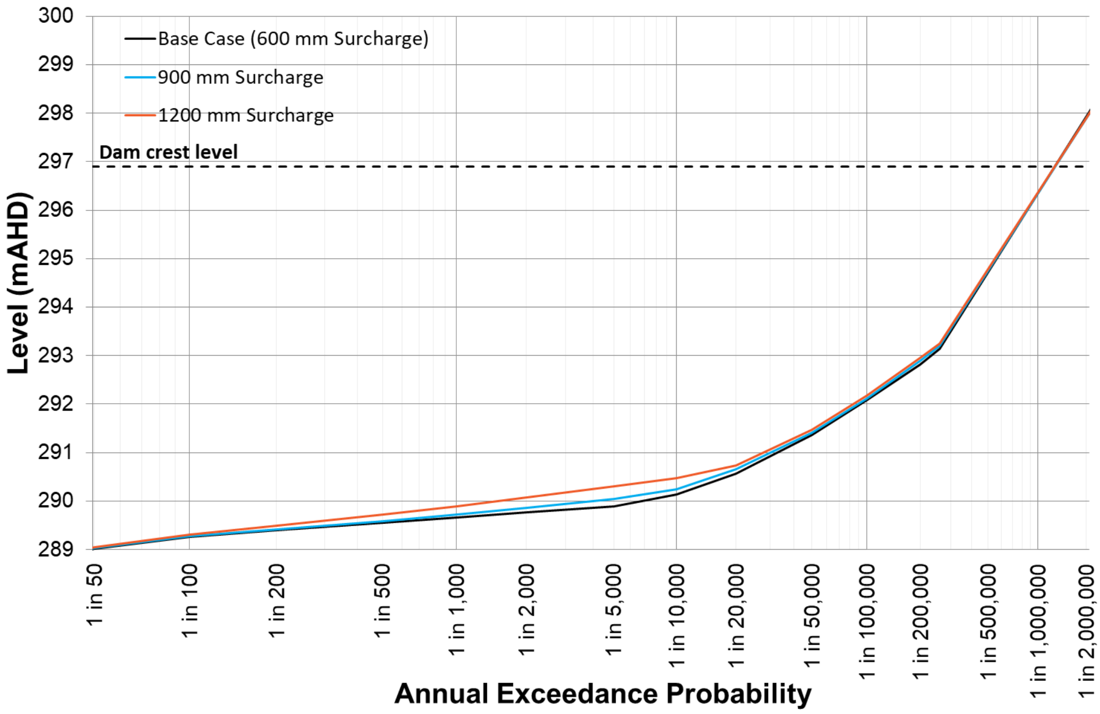


Figure 78: RORB model estimates of Lake Eildon levels for the options that involve a maximum surcharge level of 600 mm, 900 mm and 1200 mm above FSL

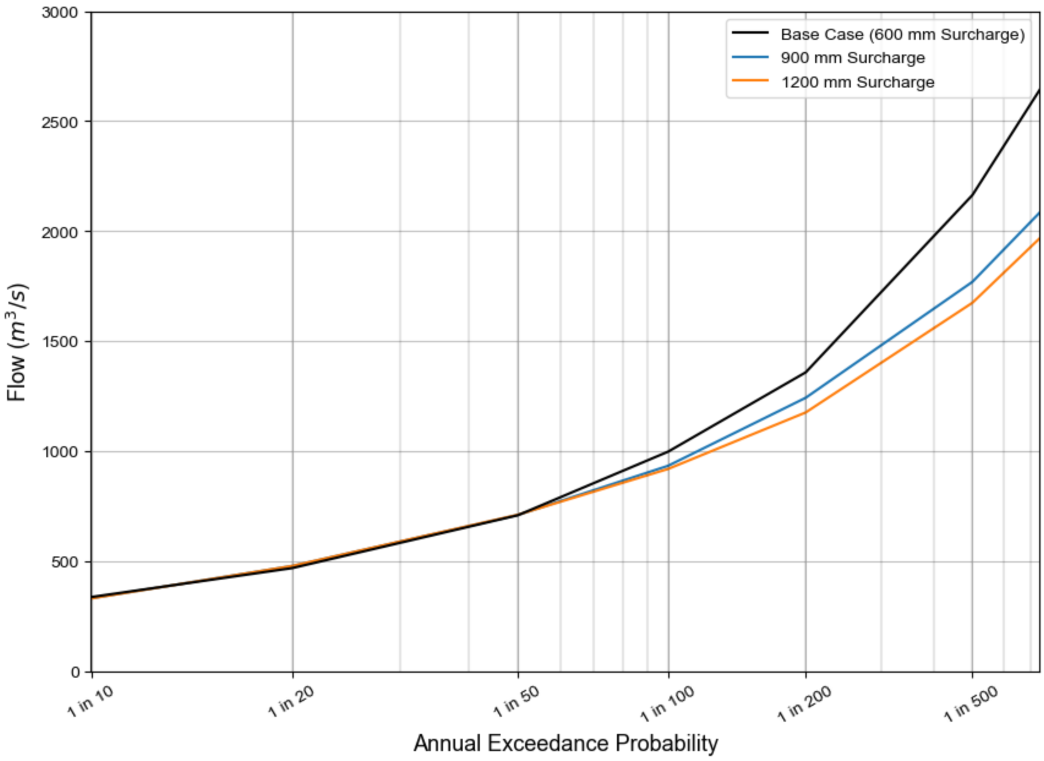


Figure 79: RORB model estimates of peak flow at Molesworth for the options that involve a maximum surcharge level of 600 mm, 900 mm and 1200 mm above FSL

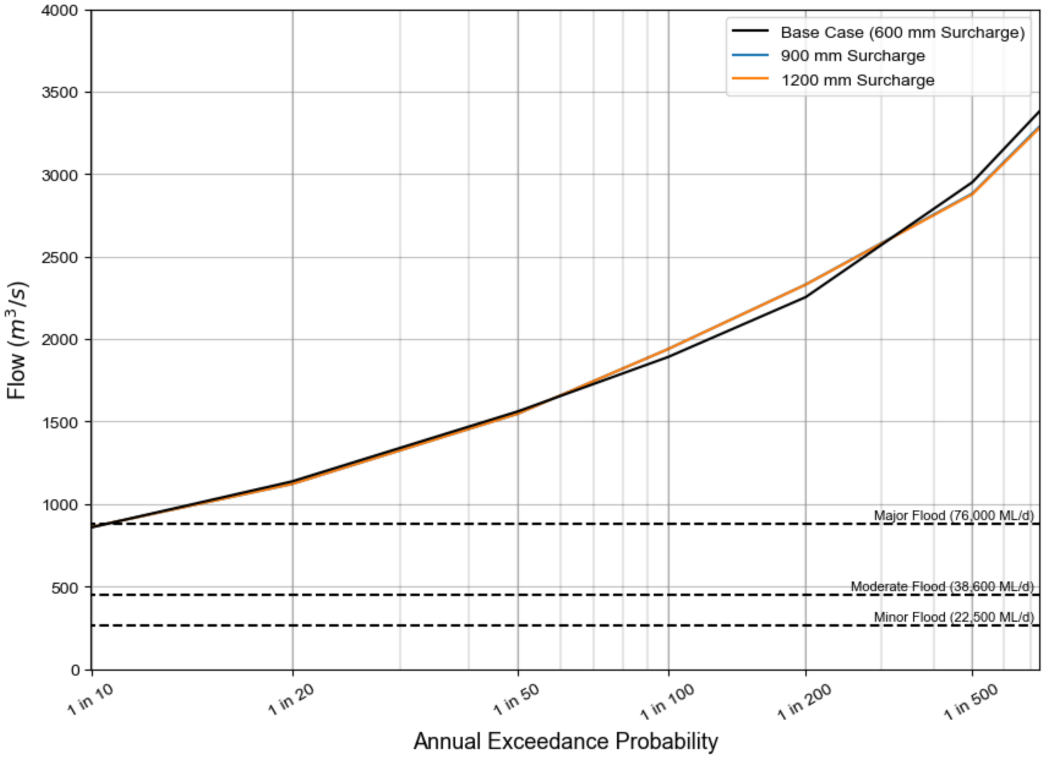


Figure 80: RORB model estimates of peak flow at Seymour for the options that involve a maximum surcharge level of 600 mm, 900 mm and 1200 mm above FSL

Table 30: Approximate AEPs of Eildon outflows for different surcharge levels

Target surcharge	AEP (1 in Y)	
	1000 m³/s (86,400 ML/d)	Dam crest flood (DCF)
Base case (600 mm)	460	1,270,000
900 mm	960	1,270,000
1200 mm	1,280	1,270,000

The duration of outflows above key thresholds was also assessed for the three surcharge options. The thresholds selected were:

- Minor flood class level flow threshold at Eildon (13,680 ML/d)
- Moderate flood class level flow threshold at Eildon (25,410 ML/d)
- Major flood class level flow threshold at Eildon threshold (39,315 ML/d)

The results are plotted in Figure 81 to Figure 83, and summarised in Table 31.

Based on these figures and table, the following observations can be made:

- The modelled duration of Lake Eildon outflows above the minor flood class level flow threshold at Lake Eildon (Figure 81 and Table 31) did not change from the base case.
- The modelled duration of Lake Eildon outflows above the moderate flood class level flow threshold at Lake Eildon (Figure 82 and Table 31) increased by 8% - 11% as a result of changing the maximum surcharge to 900 mm or 1200 mm.
- The modelled duration of Lake Eildon outflows above the major flood class level flow threshold at Lake Eildon (Figure 83 and Table 31) increased by up to 40% if the maximum

surcharge was increased to 900 mm or 1200 mm. Increasing the surcharge potentially reduces the peak outflow for the AEPs of interest, but horizontally stretches the outflow hydrograph because of the additional volumes held in the reservoir, thus increasing the duration of outflows above key flood class levels as the storage is returned to FSL following the event.

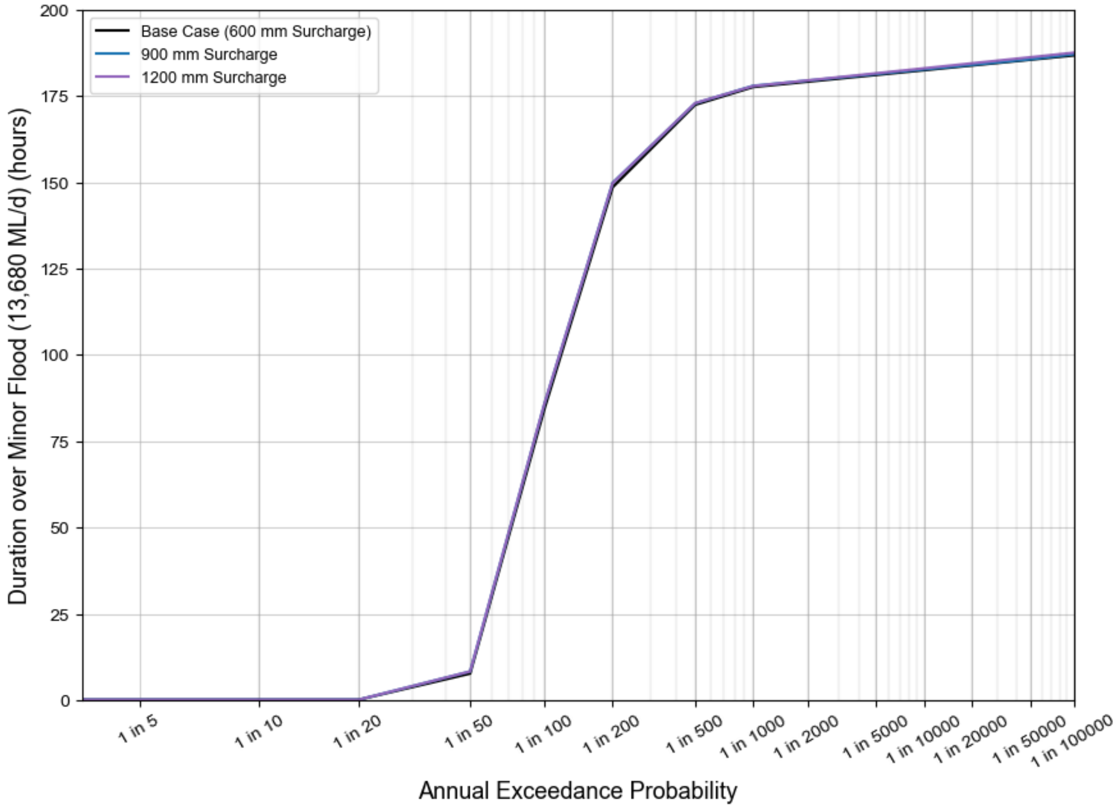


Figure 81: RORB model estimates of duration over minor flood class level flow threshold at Lake Eildon for the options that involve a maximum surcharge level of 600 mm, 900 mm and 1200 mm above FSL

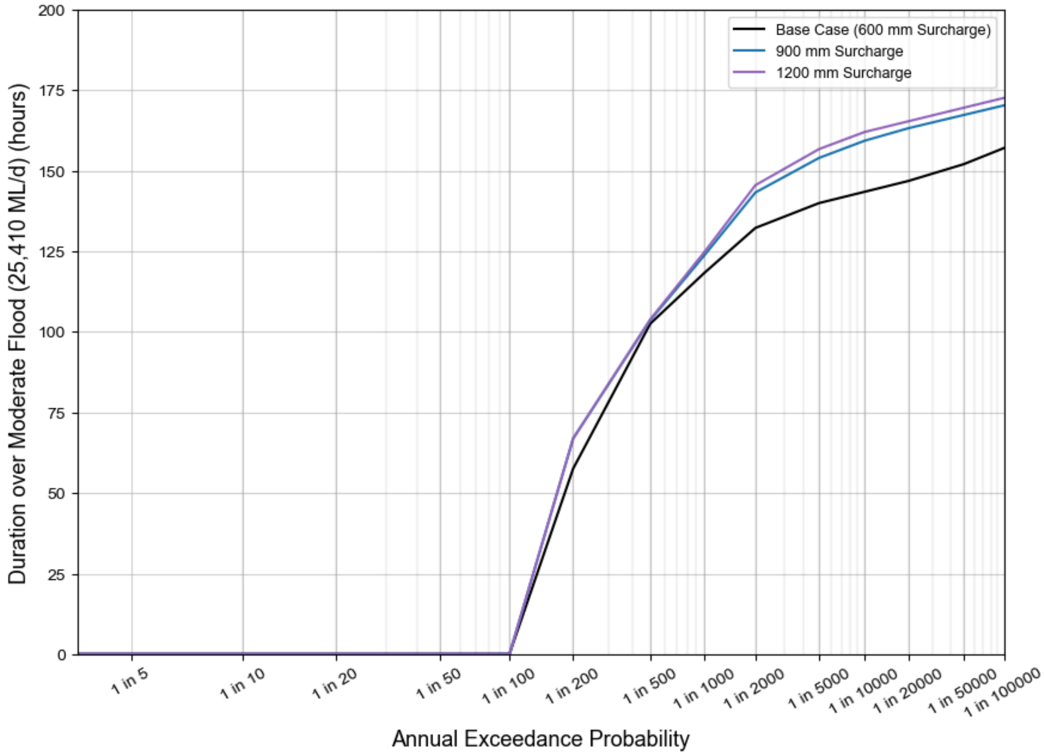


Figure 82: RORB model estimates of duration over moderate flood class level flow threshold at Lake Eildon for the options that involve a maximum surcharge level of 600 mm, 900 mm and 1200 mm above FSL

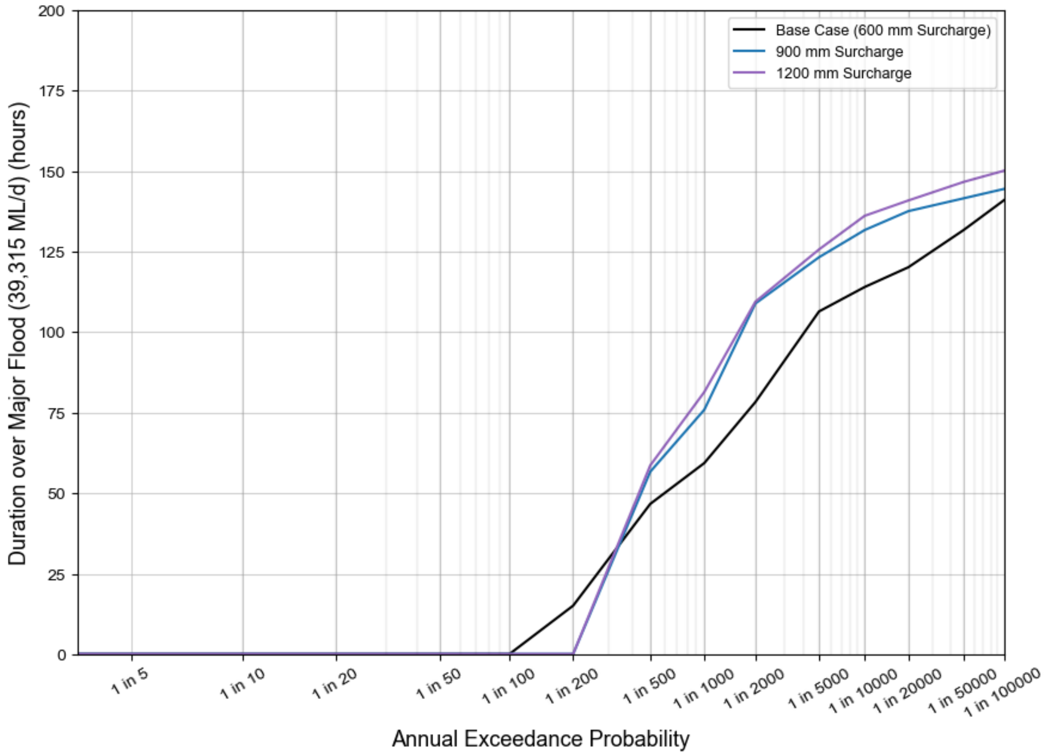


Figure 83: RORB model estimates of duration over major flood class level flow threshold at Lake Eildon for the options that involve a maximum surcharge level of 600 mm, 900 mm and 1200 mm above FSL

Table 31: RORB model estimates of duration above minor, moderate and major flood class level flow thresholds at Lake Eildon for the options that involve a maximum surcharge level of 600 mm, 900 mm and 1200 mm above FSL

Target surcharge	Duration over threshold (hrs)		
	Minor Flood Class Level Outflow (13,680 ML/d)	Moderate Flood Class Level Flow (25,410 ML/d)	Major Flood Class Level Flow (39,315 ML/d)
Base case (600 mm surcharge)	179	132	78
Surcharge 900 mm	180	143	109
Surcharge 1200 mm	180	146	110

Additional modelling was also undertaken to assess the impact on dam safety if the reservoir was assumed to be initially surcharged before an extreme rainfall event. The results are presented in Figure 84 and Table 32.

This modelling reflects a scenario where an extreme flood occurs while the storage has been surcharged to provide downstream flood mitigation during an earlier event. Such a scenario is unlikely, but possible, and should be considered to ensure that the operating objectives (Section 2.2) of the dam are not compromised.

Figure 84 and Table 32 show that the initial storage level at Lake Eildon has a significant impact on the AEP of peak outflows and reservoir levels that may compromise dam safety. For example, if the reservoir is assumed to be surcharged by 1200 mm before an extreme flood, the AEP of the dam crest flood (DCF) becomes >3 times more likely.

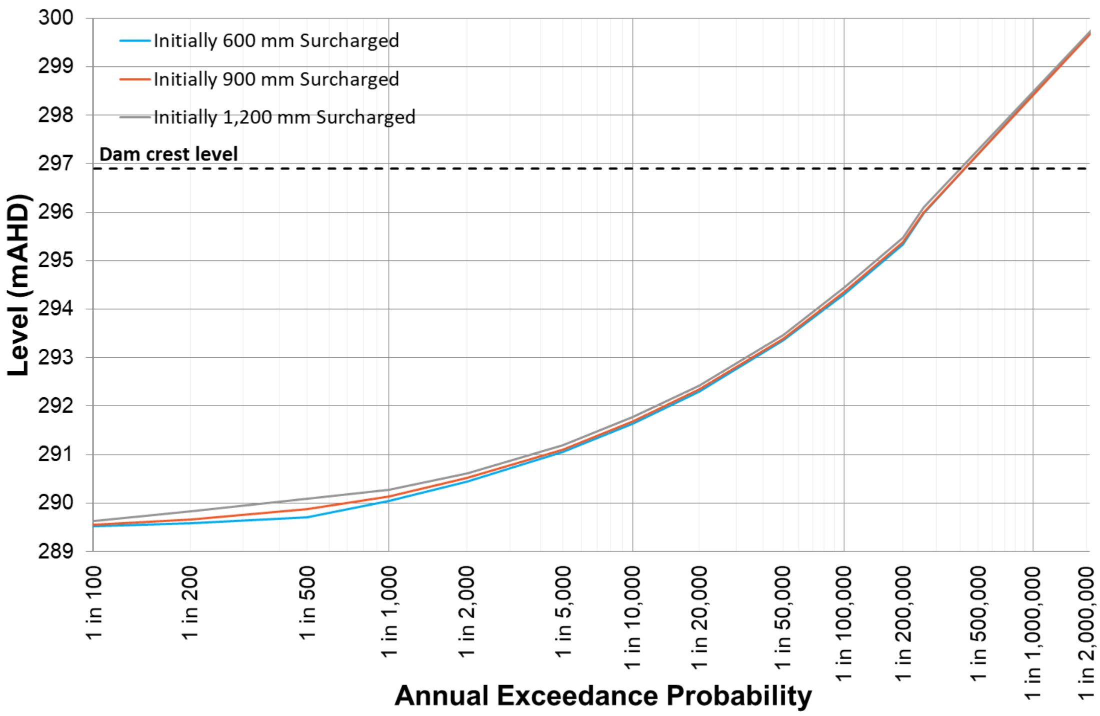


Figure 84: RORB model estimates of Lake Eildon levels for the options where the reservoir is initially surcharged at 600 mm, 900 mm and 1200 mm above FSL

Table 32: Approximate AEPs of Eildon dam crest flood (DCF) where the reservoir is initially surcharged

Initial surcharge level above FSL prior to flood event modelled in RORB	AEP of DCF (1 in Y)
600 mm initial surcharge	427,000
900 mm initial surcharge	425,000
1200 mm initial surcharge	403,000

To illustrate the potential of risk of concurrent flood events occurring while the reservoir is surcharged, a peaks over threshold (PoT) analysis was undertaken at the Tonga Bridge gauge along the Delatite River in the Lake Eildon catchment (Figure 85). This gauge was selected because of the period of record (1947 to current) of streamflow data and covers a reasonable portion of the Lake Eildon catchment (368 km^2) and has Bureau of Meteorology flood class levels assigned. The analysis looked at the frequency of peak flows exceeding the minor flood class level at the gauge (7,650 ML/d) and calculated the duration between each of the occurrences above minor flood class level.

The analysis showed that:

- The minimum interval between peaks above 7,650 ML/d with a two-to-three-day independence criteria was 5 days which occurred during September 1975. There were another two instances (1993 and 1996) where the peaks above 7,650 ML/d occurred within one week of the other peak. The hydrographs for the three events have been plotted in Figure 86 to Figure 88.
- During the September 1975 flood event (Figure 86) along the Delatite River, the first peak of 12,000 ML/d occurred 5 days before the higher peak of 40,000 ML/d on the 18/09/1975.
- Multiple peaks were recorded in September 1993 along the Delatite River (Figure 87). The highest peak occurred approximately 6 days after the initial peak which was slightly below the minor flood class level. Additionally, it was approximately 6 days before the third peak which slightly exceeded the minor flood class level at Tonga Bridge.
- During August 1996 (Figure 88) the first peak occurred approximately 5 days before the second peak which exceeded the minor flood class level at Tonga Bridge.

The PoT analysis shows that historically there have been back-to-back events in the Lake Eildon catchment that, if repeated, could exacerbate the dam safety risks associated with increasing the maximum surcharge at Lake Eildon.

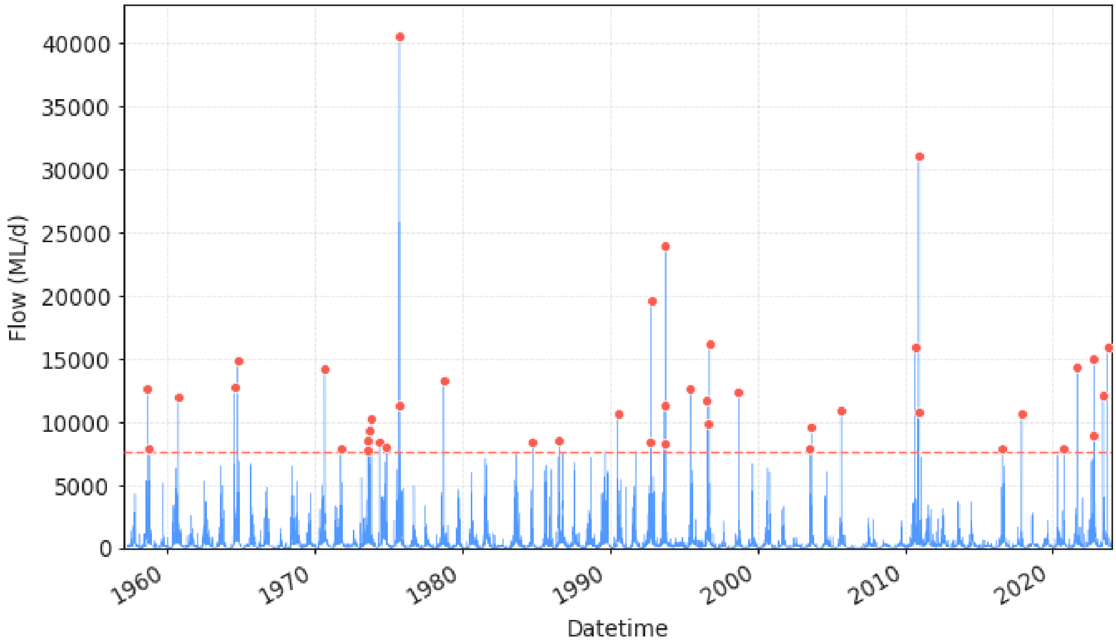


Figure 85: Peaks over threshold (PoT) analysis at Tonga Bridge along the Delatite River for threshold above minor flood class level (7,650 ML/d)

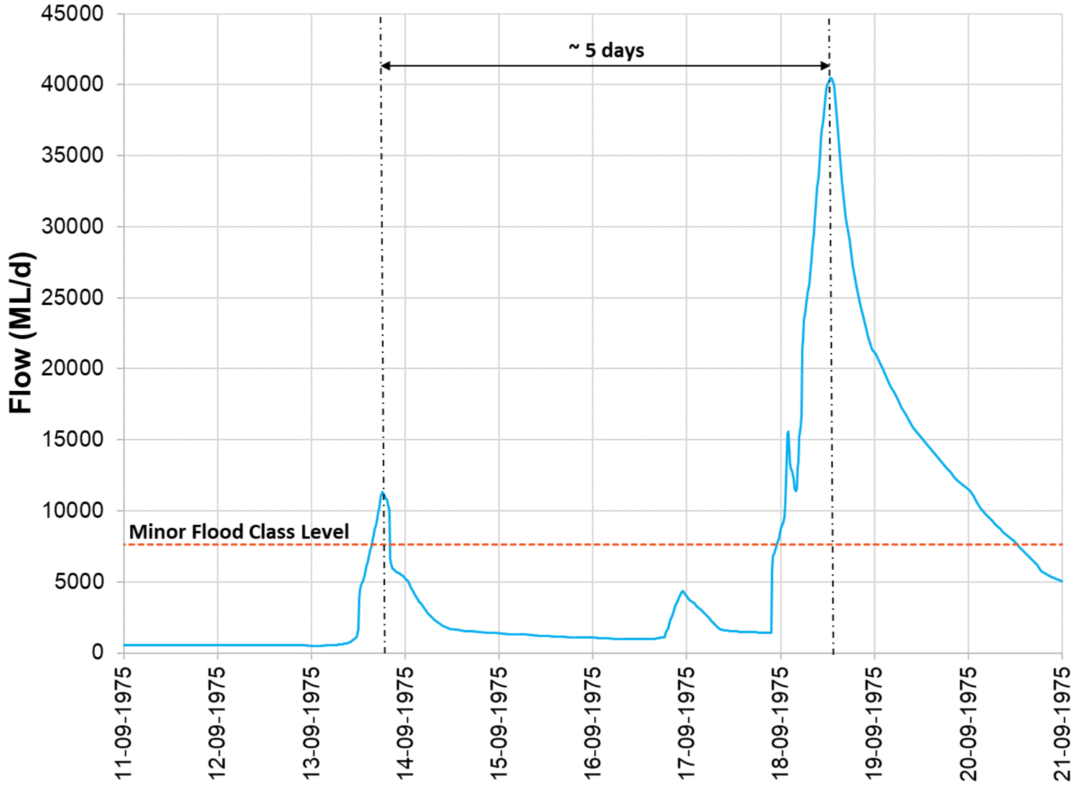


Figure 86: September 1975 event at Tonga Bridge along the Delatite River

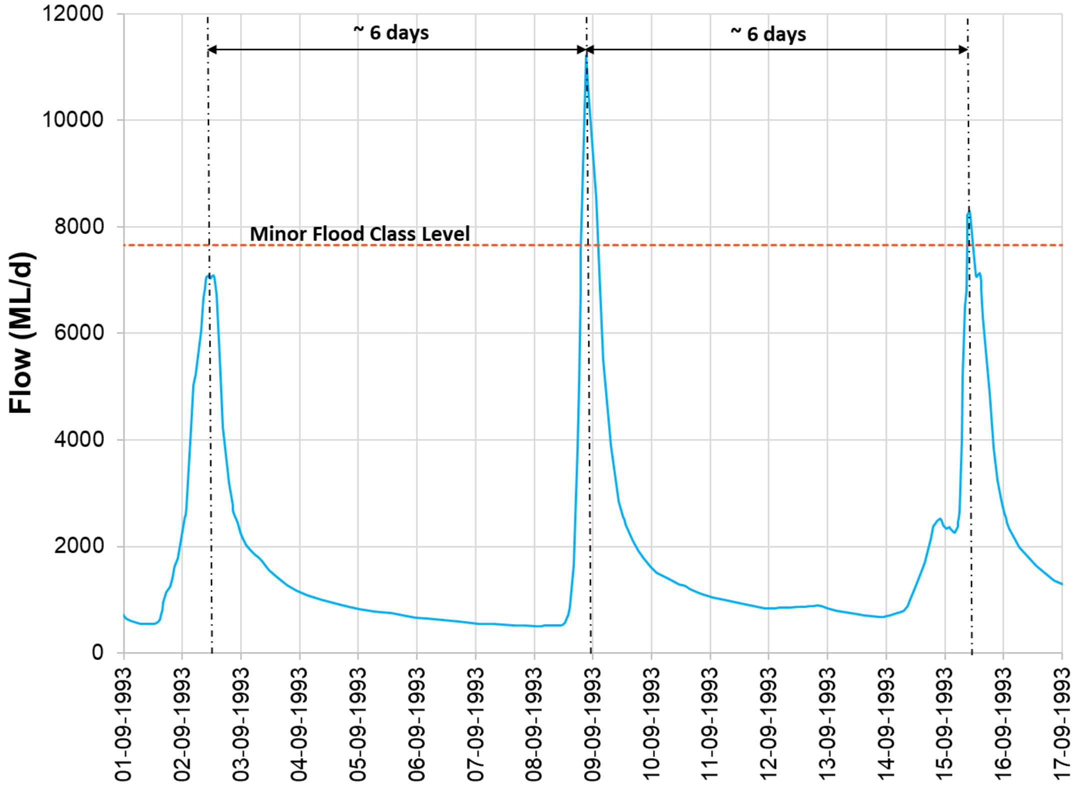


Figure 87: September 1993 event at Tonga Bridge along the Delatite River

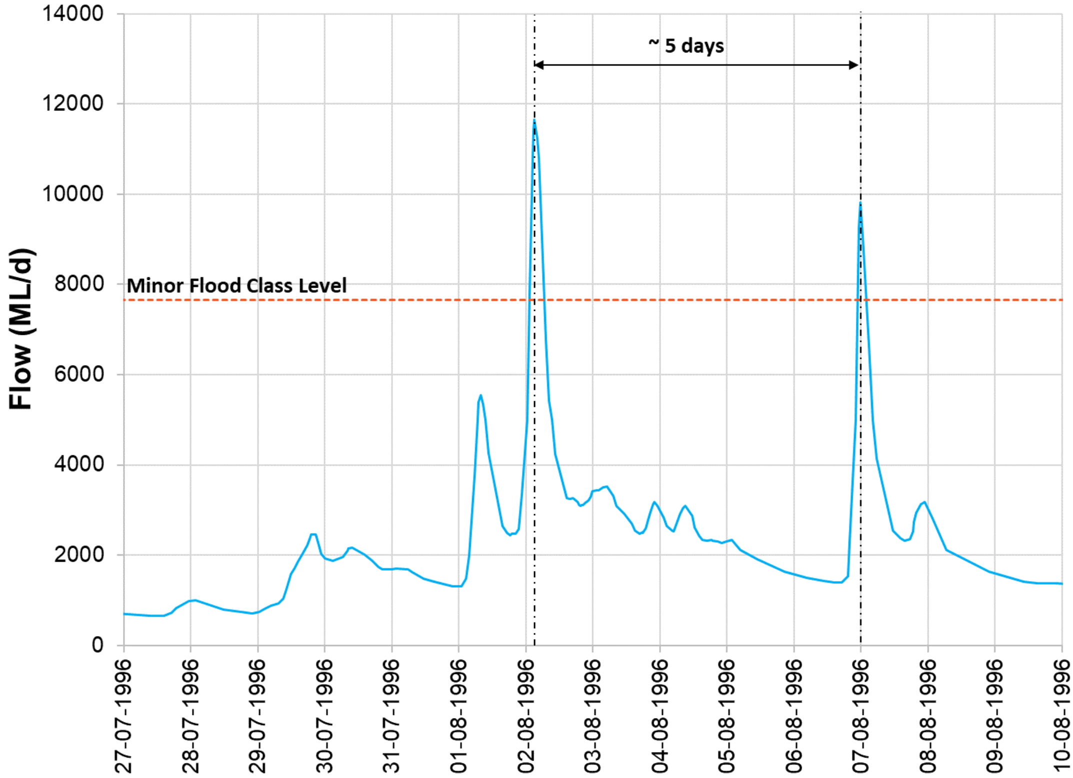


Figure 88: August 1996 event at Tonga Bridge along the Delatite River

Based on these analyses, the option to increase the maximum surcharge in Lake Eildon to provide additional flood mitigation benefit was not progressed further. Whilst increasing the maximum surcharge to 900 mm or 1200 mm would offer a limited amount of additional flood mitigation benefit immediately downstream of Lake Eildon, this benefit diminishes significantly at Seymour due to the influence of tributary inflows downstream of the dam (see Section 6.3). Additionally:

- Increasing the maximum surcharge to 900 or 1200 mm will increase the duration at which flows in the Goulburn River downstream of Lake Eildon remains above key flood class level flow thresholds. Increasing the surcharge potentially reduces the peak outflow for the AEPs of interest, but horizontally stretches the outflow hydrograph because of the additional volumes held in the reservoir, thus increasing the duration of outflows above key flood class levels as the storage is returned to FSL following the event.
- Increasing the maximum surcharge increases the risk of Lake Eildon dam failure due to overtopping.

The latter point occurs because back-to-back flood events can occur in the dam catchment, and have occurred in the period of historic record at the Delatite River at Tonga Bridge gauge. In a hypothetical scenario where Lake Eildon has been surcharged to provide flood mitigation, a second flood event could occur in rapid succession before sufficient time is available to drain the reservoir level back to FSL. This means that the second flood event will cause a greater increase in reservoir level and hence a sufficiently large event could cause the dam to overtop when it otherwise would not have. The greater the maximum surcharge level, the longer the duration that the dam will be in surcharge and hence the greater the risk of overtopping due to back-to-back flood events. Current dam industry practice would require a detailed dam safety risk assessment to be completed for Lake Eildon to fully assess the impacts of increasing the maximum surcharge level. Such an assessment would need to consider a range of other potential dam failure scenarios associated with increasing the maximum surcharge, such as internal erosion or instability of the dam embankment given the significant increase in sustained higher reservoir levels as well as the potential for damage or failure to the spillway structure and gate mechanisms. Given the catastrophic consequences associated with a dam failure at Lake Eildon, it appears unlikely that such an assessment would conclude that the increase in dam safety risks resulting from increasing the maximum surcharge at Lake Eildon would be acceptable.

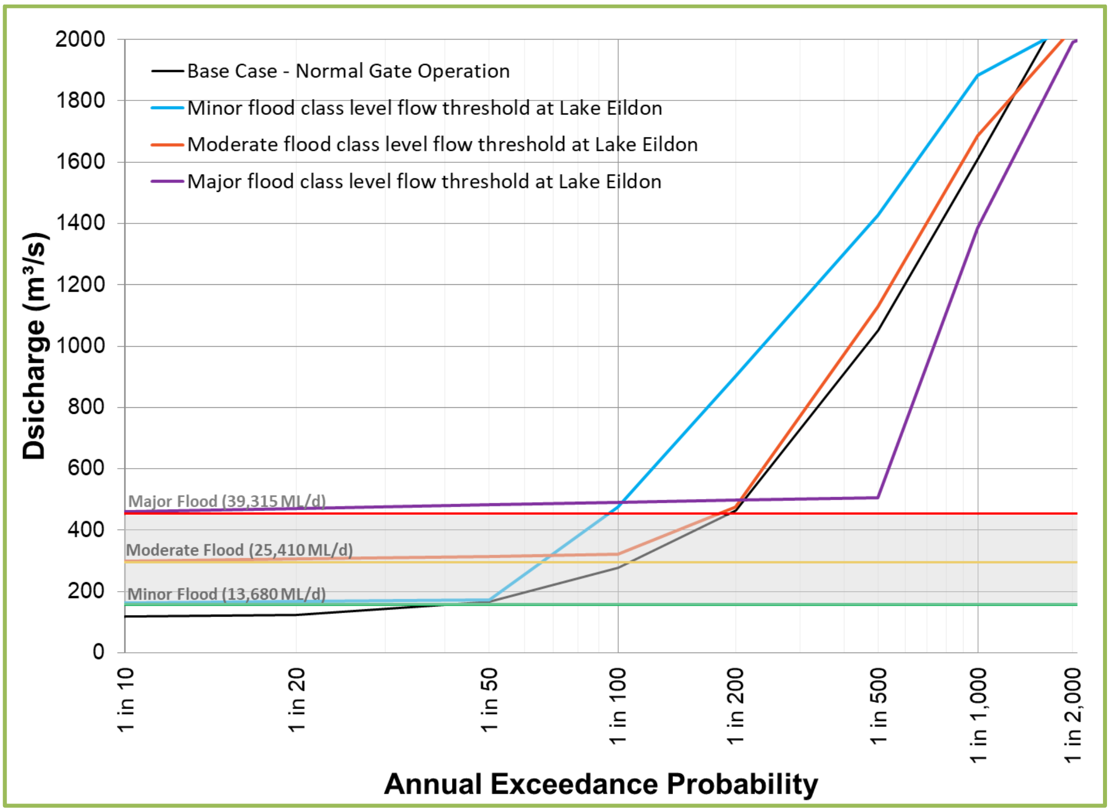
6.2.6 Option 6 – Restrict maximum outflows

Additional analysis was also undertaken to investigate the option of restricting the maximum outflows – to the degree possible while maintaining appropriate freeboard to the top of the spillway gates – at the minor (13,680 ML/d), moderate (25,410 ML/d) and major (39,315 ML/d) flood class level flow thresholds at Eildon. The previous modelling undertaken by SKM (2007) demonstrated that limiting the outflow from Lake Eildon (therefore surcharging the storage) only increased flood mitigation for events with AEP more common than the 10% AEP. This was because the ability to restrict outflows is constrained by the need to maintain reservoir levels below the top of the spillway gates. However, as per Section 6.2.5, further modelling was warranted to better demonstrate the dam safety implications. Therefore, the following options were assessed using the Lake Eildon RORB model:

- Restrict maximum outflow, to the degree possible to maintain freeboard to top of gates, to minor flood (13,680 ML/d)
- Restrict maximum outflow, to the degree possible to maintain freeboard to top of gates, to moderate flood (25,410 ML/d)
- Restrict maximum outflow, to the degree possible to maintain freeboard to top of gates, to major flood (39,315 ML/d)

The outflow frequency curves are shown in Figure 89. Based on this figure, the following observations can be made:

- For the scenarios which restrict the outflows to minor, moderate or major flood class level flow thresholds at Eildon, the outflow flood frequencies plot above the base case for events up to the 1 in 200 AEP (Figure 89).
- The flood mitigation benefits for this option are not realised until events rarer than the 1 in 2,000 AEP. However, the benefits come at the expense of prolonging the duration of floods. This is demonstrated in more detail below.



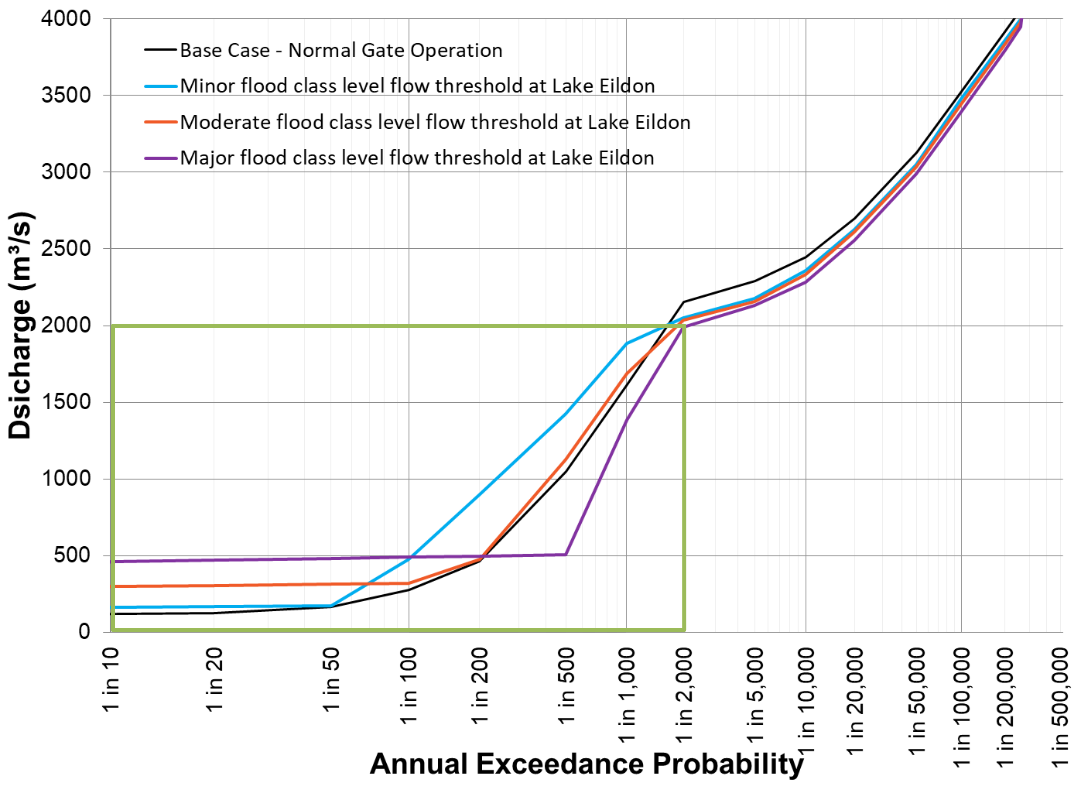


Figure 89: RORB model estimates of Lake Eildon peak outflow AEPs for the options that involve restricting maximum outflow to minor, moderate and major flood class level flow thresholds at Eildon. The figure on the top is a zoomed in version of the figure on the bottom to focus on the frequent events.

The duration of outflows above key thresholds was also assessed for the three options to restrict maximum outflow from Lake Eildon. The thresholds selected were:

- Minor flood class level flow threshold at Eildon (13,680 ML/d)
- Moderate flood class level flow threshold at Eildon (25,410 ML/d)
- Major flood class level flow threshold at Eildon (39,315 ML/d)

The results are plotted in Figure 90 to Figure 92, and summarised in Table 33.

Based on these figures and table, the following observations can be made:

- The duration of outflows at or above the minor flood class level flow threshold (Figure 90 and Table 33) significantly increase if maximum outflows are restricted to minor, moderate or major flood class level flow threshold at Eildon.
- The duration of outflows at or above the moderate flood class level flow threshold (Figure 91 and Table 33) was also simulated to significantly increase (by a factor of ~5) if maximum outflows were restricted to the major flood class level flow threshold.
- The duration of outflows at or above the major flood class level flow threshold (Figure 92 and Table 33) also increases (by a factor of ~2.5) if maximum outflows are restricted to the major flood class level flow threshold.

The flood frequency results re-emphasise the potential disadvantages of restricting maximum outflows from Lake Eildon, in that it will extend the duration of outflows above key thresholds downstream of the storage. Therefore, as per the option to increase the maximum surcharge at Lake Eildon, this option was not progressed further into the technical assessment.

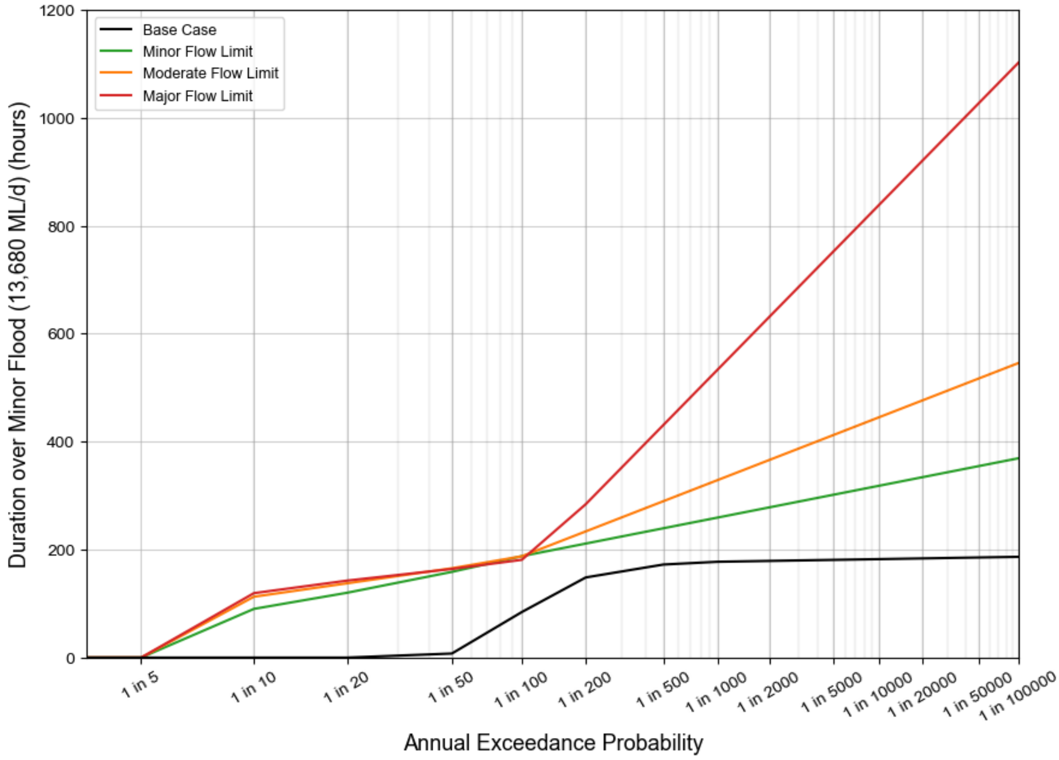


Figure 90: RORB model estimates of outflow durations above the minor flood class level flow threshold at Eildon for the options that involve restricting outflows to the minor, moderate or major flood class level flow thresholds

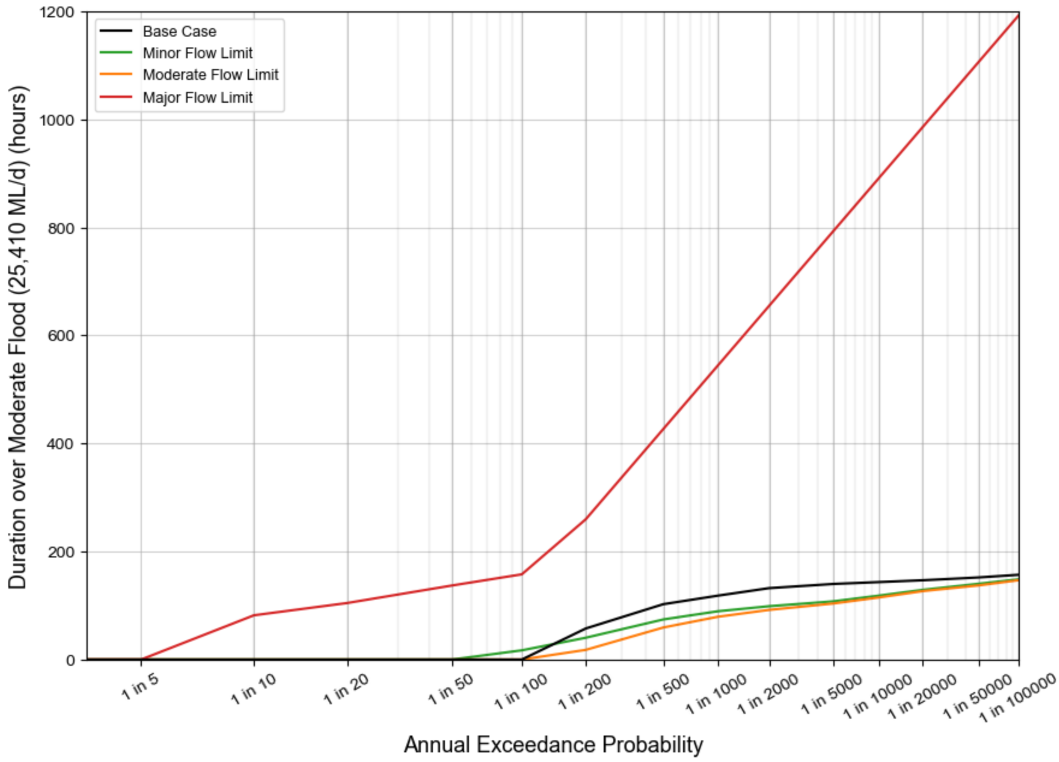


Figure 91: RORB model estimates of outflow durations above the moderate flood class level flow threshold at Eildon for the options that involve restricting outflows to the minor, moderate or major flood class level flow thresholds

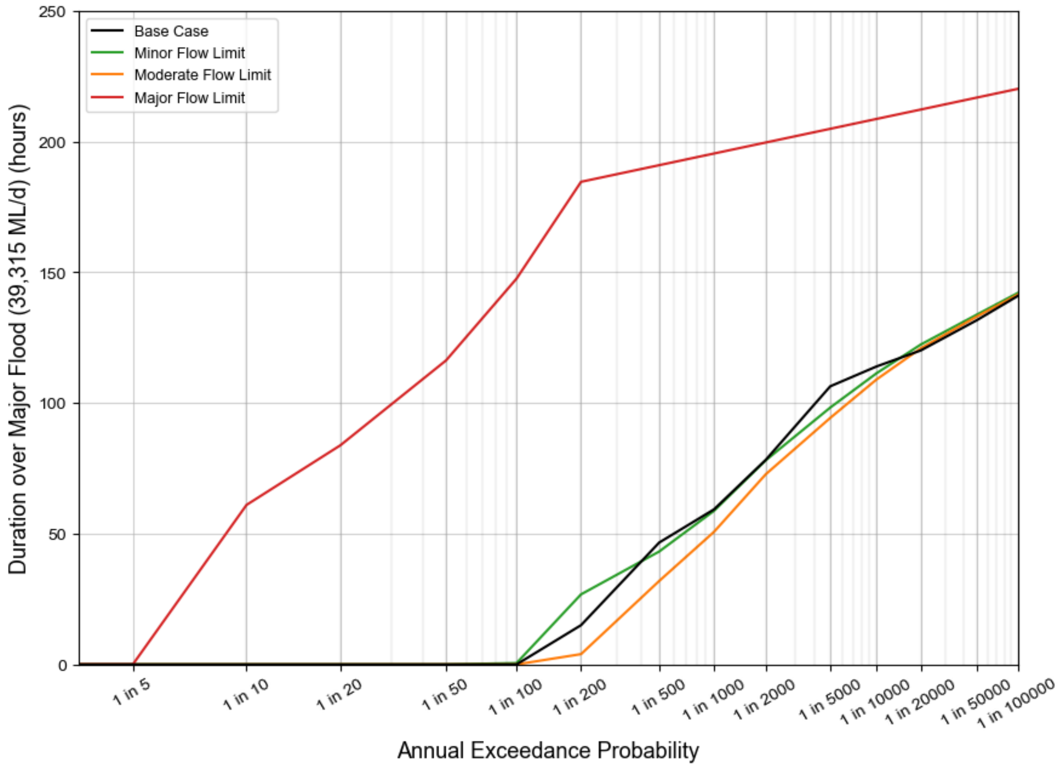


Figure 92: RORB model estimates of duration over major flood class level flow threshold at Eildon for the options that involve restricting outflows to minor, moderate and major flood class level flow thresholds

Table 33: RORB model estimates of outflow durations above the minor, moderate and major flood class level flow thresholds at Eildon for the options that involve restricting maximum outflow to the minor, moderate and major flood class level flows

Option	Duration over threshold (hrs)		
	Minor flood at Eildon (13,680 ML/d)	Moderate flood at Eildon (25,410 ML/d)	Major flood at Eildon (39,315 ML/d)
Base case	179	132	78
Minor flow limit	278	99	78
Moderate flow limit	366	92	73
Major flow limit	631	655	200

6.3 Influence of downstream tributary inflows

The results provided in Section 6.2 show that the flood mitigation benefits diminish the further downstream the flood frequencies are assessed i.e. the degree of difference between the frequency estimates reduce by Molesworth and the difference is minor at Seymour. This is because tributary flows from the Rubicon River, Acheron River, Yea River, King Parrot Creek, Sugarloaf Creek and, Sunday Creek influence the peak flows downstream of Lake Eildon. To better illustrate this, several simulations have been extracted from the RORB model results and plotted below.

Commentary on the January 2024 flood event in the Goulburn River catchment has been provided in Appendix D to illustrate a recent flood event with a significant contribution from tributary inflows downstream of Lake Eildon.

In Figure 93, each dot is representative of a single simulation of a 24-hour rainfall event centred on the catchment to Seymour, and the blue line is the fitted total probability theorem (TPT) curve. Four of these simulations – i.e. the circled dots in Figure 93 – have been extracted and results plotted in Figure 94 to Figure 97.

Based on these figures, the following observations can be made:

- There is a significant amount of variability in the timing, shape and peak of the Lake Eildon outflows and tributary inflows. For example, in simulation 4 (Figure 97), the Eildon outflows are controlling the peak flows at Molesworth and Seymour, with some contribution from the downstream tributaries. In contrast, in simulations 2 and 3 (Figure 95 and Figure 96) the flows at Seymour and Molesworth are primarily controlled by the tributary inflows. Simulation 1 (Figure 94) shows a moderate level of contribution from Eildon; however, the peak flow at Seymour is caused by the contribution from the tributaries.
- The simulations below explain why – as shown in Section 6.2 – the flood mitigation benefits of a reduced target storage or changed filling curve diminish with distance downstream. That is, increasing the airspace in Lake Eildon will reduce peak outflows from the storage, but in many cases, this will not reduce the peak flow at Seymour.

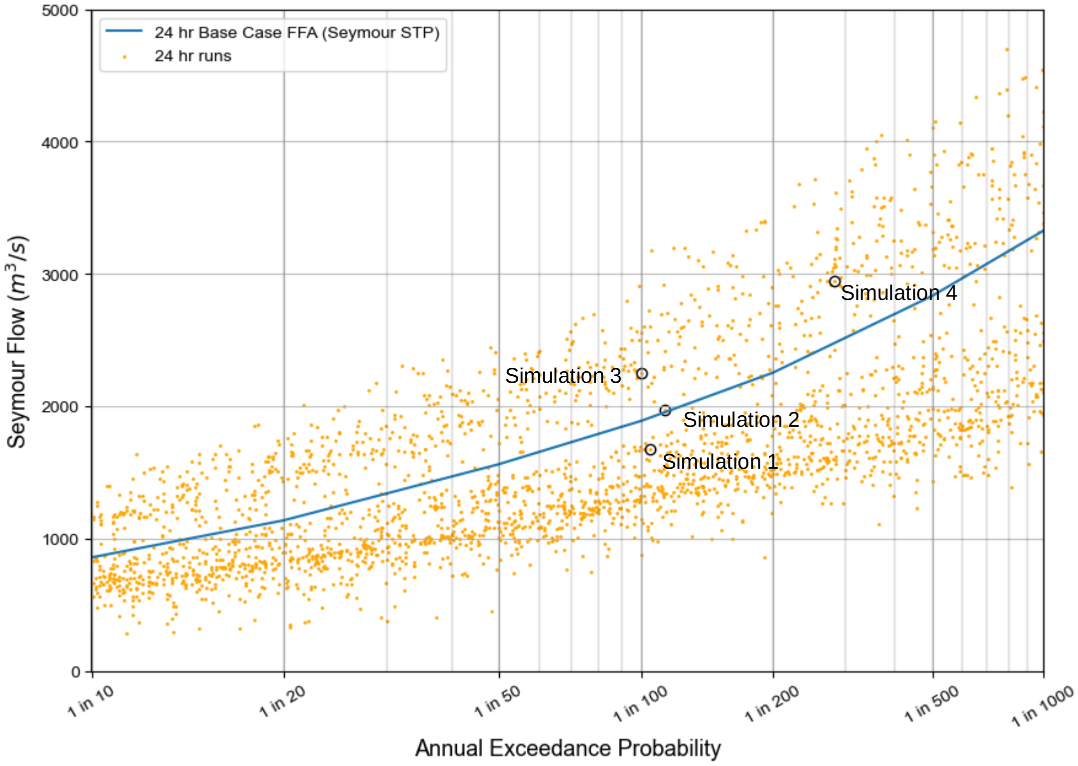


Figure 93: Example of 24-hour duration flows at Seymour with Monte Carlo simulation scatter plotted along with the TPT curve for outflows up to the 1 in 1,000 AEP.

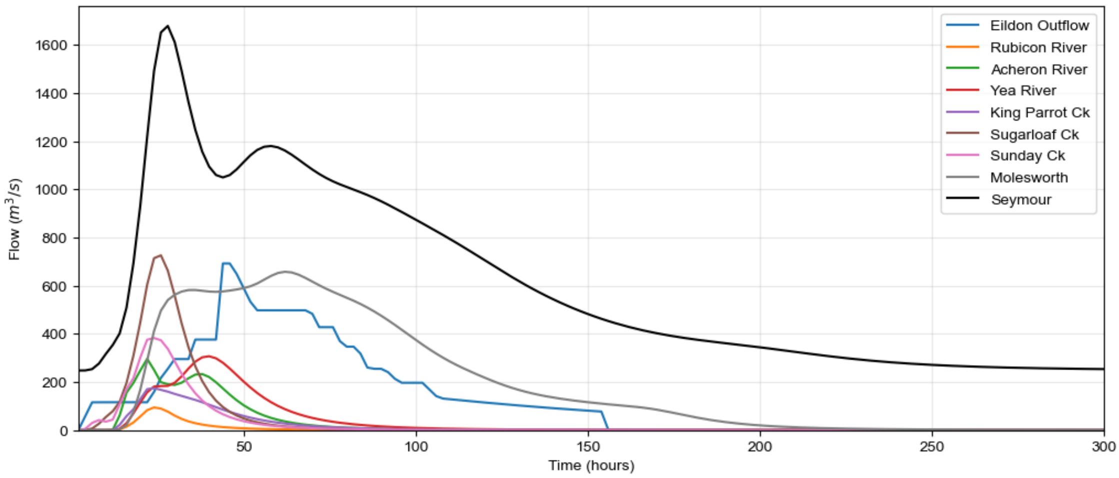


Figure 94: Simulation 1 hydrographs from the 24-hour Monte Carlo results from RORB

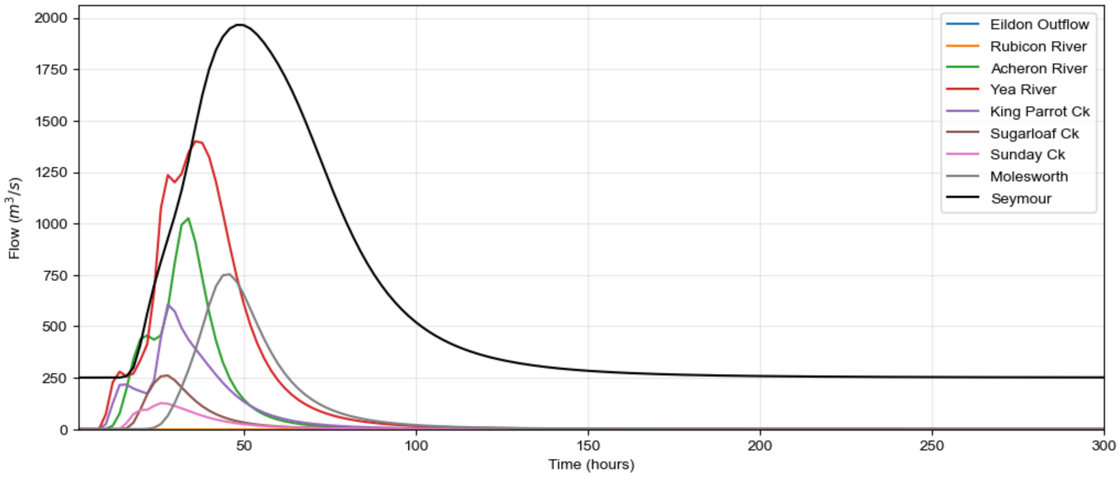


Figure 95: Simulation 2 hydrographs from the 24-hour Monte Carlo results from RORB

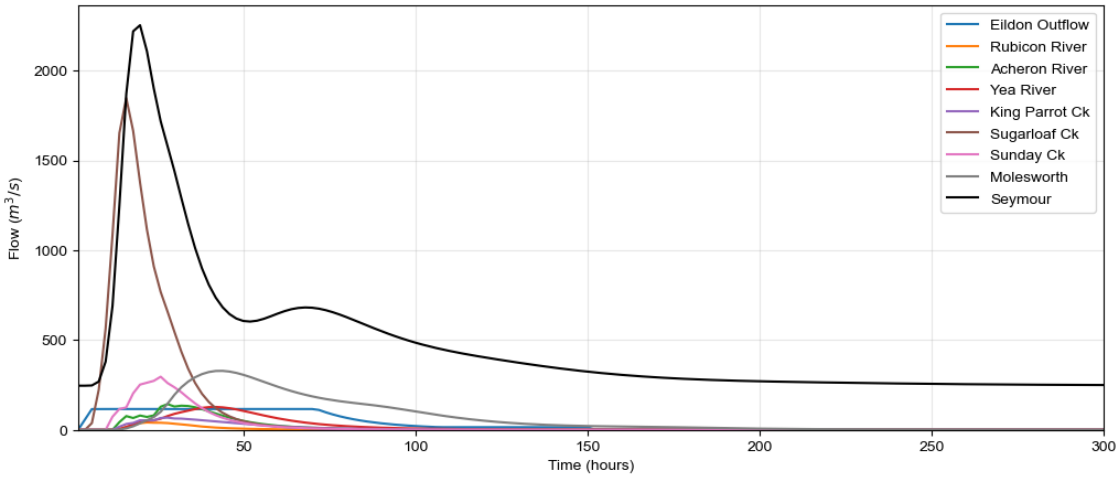


Figure 96: Simulation 3 hydrographs from the 24-hour Monte Carlo results from RORB

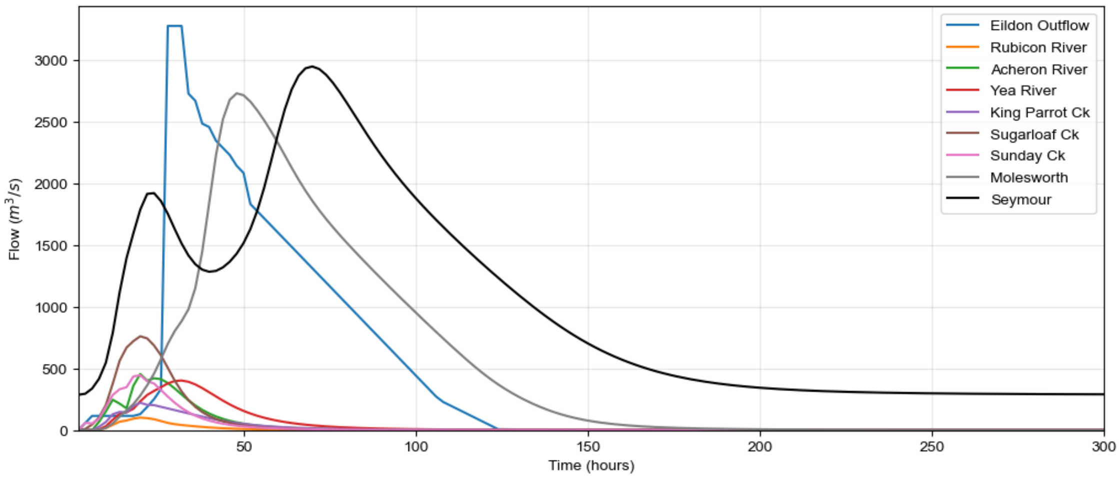


Figure 97: Simulation 4 hydrographs from the 24-hour Monte Carlo results from RORB

6.4 Sensitivity testing using the SGEFM in place of the GSM

Given the influence of the Lake Eildon drawdown distribution on modelled flood frequencies, and the observation that the GSM predictions sit below recent historical records (Figure 25), a subset of the options described in Section 4 were also modelled in RORB but with Stochastic Goulburn Environmental Flow Model (SGEFM) instead of GSM estimates of the Lake Eildon storage traces. The SGEFM, developed by the University of Melbourne (John, 2021), was used primarily to assess expected changes to the daily flow regime downstream of Lake Eildon (Section 10.2), but it can produce time-series of modelled storage volumes under historic climate conditions for the period 1941 – 2021 (Figure 98), and this provided an opportunity to sensitivity test the results included in Section 6.2.1 and Section 6.2.2.

The results are summarised in Table 34 to Table 37 and Figure 99 to Figure 101. Comparing these with Section 6.2.1 and Section 6.2.2 demonstrates that:

- The RORB model estimates of peak outflow from Lake Eildon for a given AEP are higher when the drawdown distributions are taken from the SGEFM instead of the GSM. This is because the SGEFM estimates of the volume stored in Lake Eildon under long-term historic climate conditions generally sit above the GSM (Figure 98).
- Although the *absolute* magnitudes of peak flows for a given AEP are higher when estimated using SGEFM drawdown distributions, the *relative* differences between the base case and options modelled are similar (albeit higher). Therefore, the degree to which varying the target filling curve or target storage is anticipated to increase the flood mitigation provided by Lake Eildon is not particularly sensitive to whether the storage trace is modelled using the GSM or SGEFM.

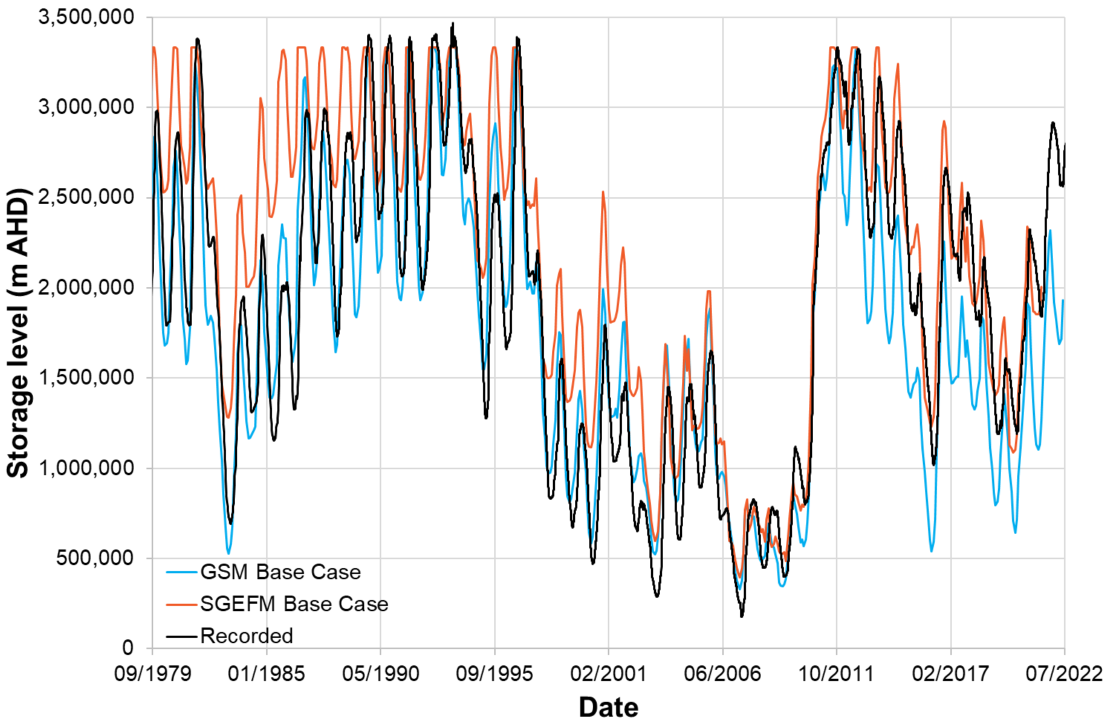


Figure 98: A comparison between the Lake Eildon storage trace as recorded over time, and modelled in the GSM base case and SGEFM base case

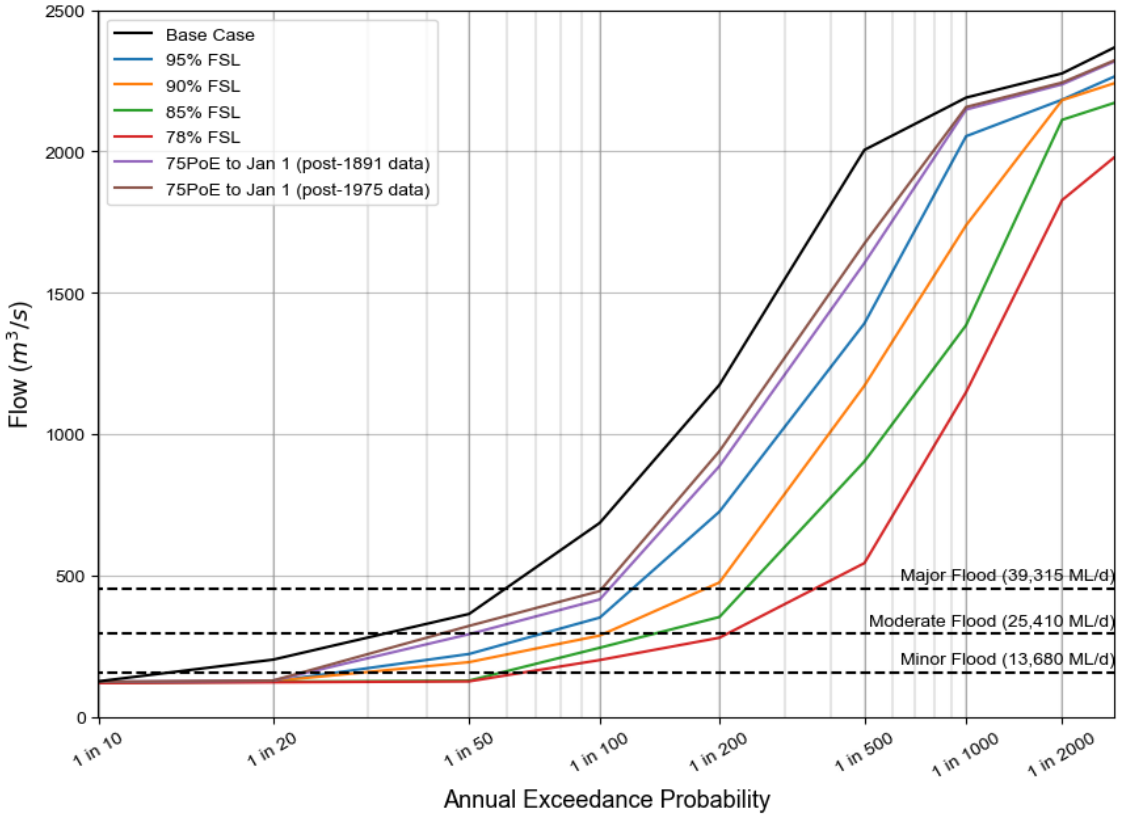


Figure 99: RORB model estimates of peak outflows for Lake Eildon for selected options, but with the Lake Eildon drawdown distribution modelled using the SGEFM instead of GSM. These frequency curves are indicative, and should be used only for comparison between options rather than as best estimates of absolute peak outflows.

Table 34: Estimated 5% (1 in 20), 1% (1 in 100) and 0.2% (1 in 500) AEP peak outflows from Lake Eildon, but with the Lake Eildon drawdown distribution modelled using the SGEFM instead of GSM. These numbers are indicative, and should be used only for comparison between options rather than as best estimates of absolute peak outflows.

Option	5% AEP peak outflow			1% AEP peak outflow			0.2% AEP peak outflow		
	m³/s	ML/d	Difference	m³/s	ML/d	Difference	m³/s	ML/d	Difference
Base case	200	17,300	-	690	59,600	-	2,000	173,000	-
Option 1 – Change target filling curves									
75PoE to Jan 1 (post-1891 data)	130	11,200	-35%	420	36,300	-39%	1,600	138,000	-20%
75PoE to Jan 1 (post-1975 data)	130	11,200	-35%	450	38,900	-35%	1,700	147,000	-15%
Option 2 – Reduce target storage									
95% target storage	125	10,800	-38%	350	30,200	-49%	1,400	121,000	-30%
90% target storage	125	10,800	-38%	290	25,100	-58%	1,200	104,000	-40%
85% target storage	125	10,800	-38%	240	20,700	-65%	900	77,800	-55%
78% target storage	120	10,400	-40%	200	17,300	-71%	540	46,700	-73%

Table 35: Estimated AEPs for peak outflows from Lake Eildon that reach the minor, moderate and major flood class level flow thresholds for the Goulburn River at Eildon (405203), but with the Lake Eildon drawdown distribution modelled using the SGEFM instead of GSM. These numbers are indicative, and should be used only for comparison between options rather than as best estimates.

Option	Approximate AEP (1 in X) of outflow at flood class		
	Minor	Moderate	Major
Base case	<20	35	60
Option 1 – Change target filling curves			
75PoE to Jan 1 (post-1891 data)	25	50	105
75PoE to Jan 1 (post-1975 data)	25	45	100
Option 2 – Reduce target storage			
95% target storage	30	75	120
90% target storage	30	100	185
85% target storage	60	135	235
78% target storage	65	210	365

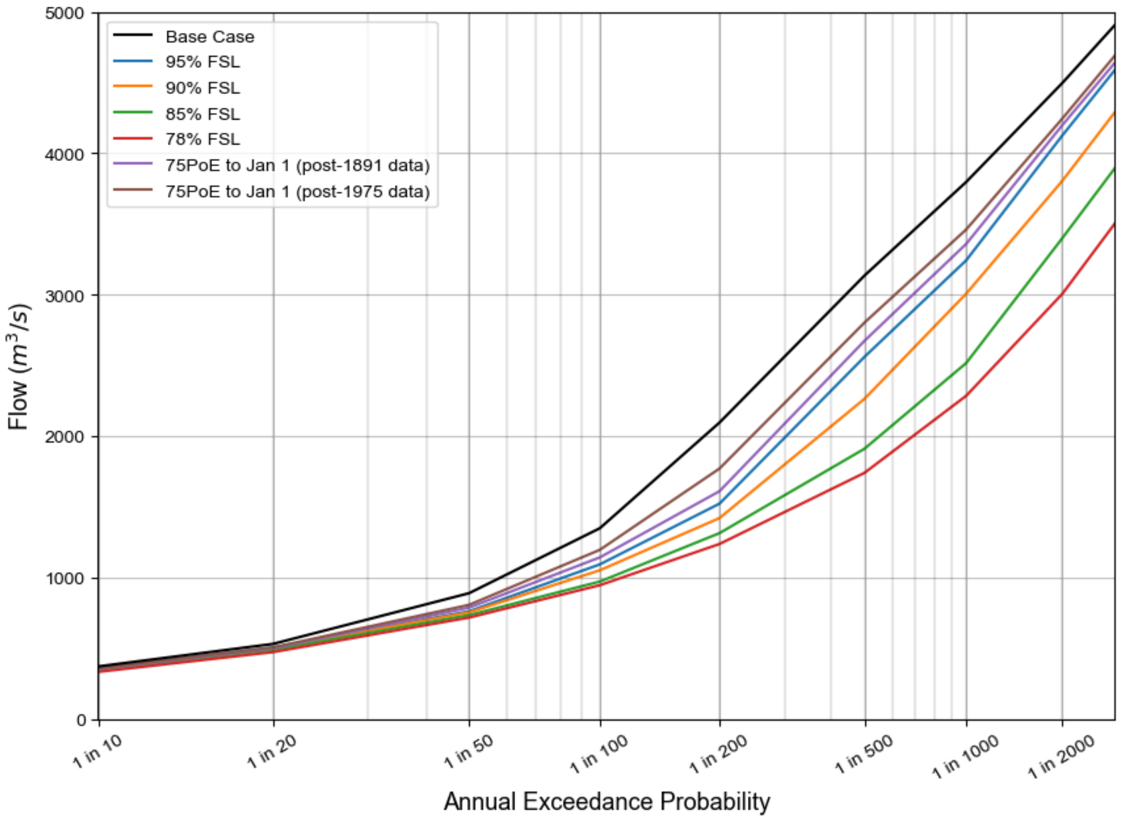


Figure 100: RORB model estimates of peak outflows at Molesworth for selected options, but with the Lake Eildon drawdown distribution modelled using the SGEFM instead of GSM. These frequency curves are indicative, and should be used only for comparison between options rather than as best estimates of absolute peak outflows.

Table 36: Estimated 5% (1 in 20), 1% (1 in 100) and 0.2% (1 in 500) AEP peak flows at Molesworth, but with the Lake Eildon drawdown distribution modelled using the SGEFM instead of GSM. These numbers are indicative, and should be used only for comparison between options rather than as best estimates of absolute peak outflows.

Option	5% AEP peak outflow			1% AEP peak outflow			0.2% AEP peak outflow		
	m³/s	ML/d	Difference	m³/s	ML/d	Difference	m³/s	ML/d	Difference
Base case	530	45,800	-	1,350	117,000	-	3,140	271,000	-
Option 1 – Change target filling curves									
75PoE to Jan 1 (post-1891 data)	500	43,200	-6%	1,140	98,000	-16%	2,670	231,000	-15%
75PoE to Jan 1 (post-1975 data)	505	43,600	-5%	1,200	104,000	-11%	2,800	242,000	-11%
Option 2 – Reduce target storage									
95% target storage	505	43,600	-5%	1,090	94,000	-20%	2,560	221,000	-18%
90% target storage	500	43,200	-6%	1,050	91,000	-22%	2,260	195,000	-28%
85% target storage	490	42,300	-8%	970	84,000	-28%	1,910	165,000	-39%
78% target storage	475	41,000	-10%	950	82,000	-30%	1,740	150,300	-45%

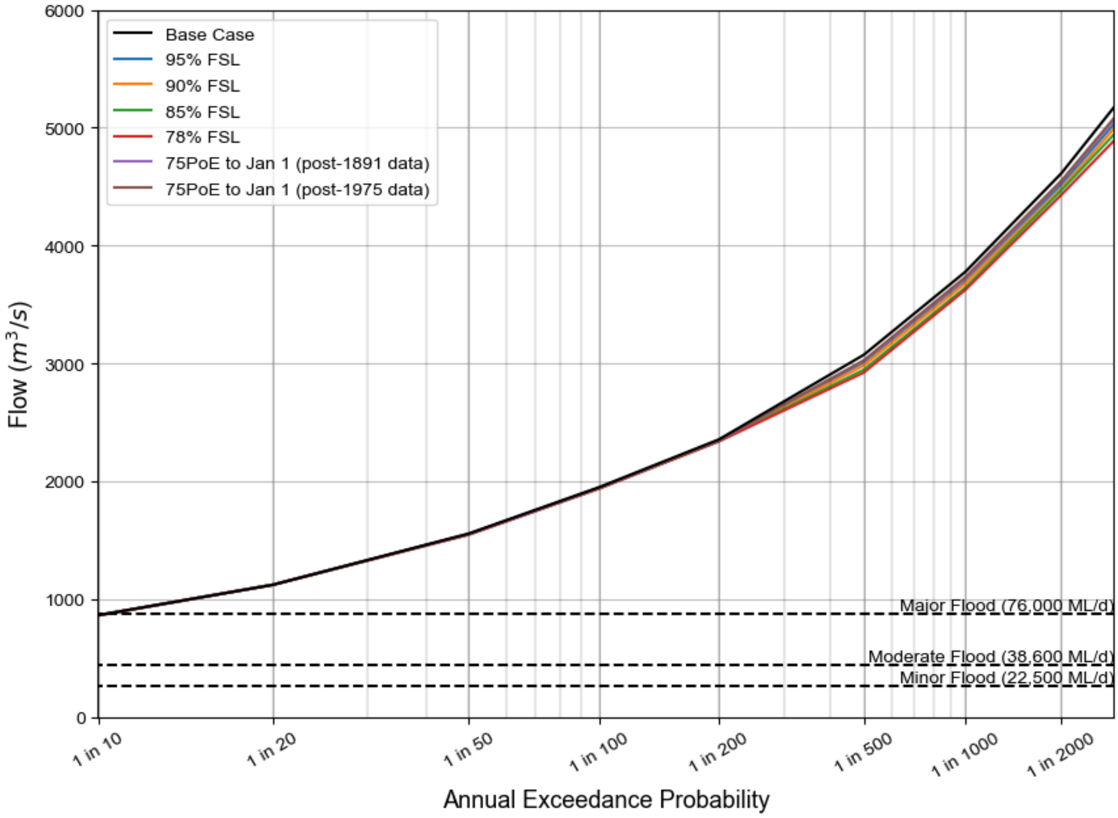


Figure 101: RORB model estimates of peak outflows at Seymour for selected options, but with the Lake Eildon drawdown distribution modelled using the SGEFM instead of GSM. These frequency curves are indicative, and should be used only for comparison between options rather than as best estimates of absolute peak outflows.

Table 37: Estimated 5% (1 in 20), 1% (1 in 100) and 0.2% (1 in 500) AEP peak flows at Seymour, but with the Lake Eildon drawdown distribution modelled using the SGEFM instead of GSM. These numbers are indicative, and should be used only for comparison between options rather than as best estimates of absolute peak outflows.

Option	5% AEP peak outflow			1% AEP peak outflow			0.2% AEP peak outflow		
	m³/s	ML/d	Difference	m³/s	ML/d	Difference	m³/s	ML/d	Difference
Base case	1120	96,800	-	1,950	168,000	-	3,070	265,000	-
Option 1 – Change target filling curves									
75PoE to Jan 1 (post-1891 data)	1120	96,800	0%	1,940	168,000	0%	3,020	261,000	-2%
75PoE to Jan 1 (post-1975 data)	1120	96,800	0%	1,940	168,000	0%	3,030	262,000	-1%
Option 2 – Reduce target storage									
95% target storage	1120	96,800	0%	1,940	168,000	0%	3,010	260,000	-2%
90% target storage	1120	96,800	0%	1,940	168,000	0%	2,980	257,000	-3%
85% target storage	1120	96,800	0%	1,940	168,000	0%	2,950	254,900	-4%
78% target storage	1120	96,800	0%	1,940	168,000	0%	2,920	252,300	-5%

The results presented in Section 6.2 and Section 6.4 are based on the joint probability framework shown in Figure 63, which involves many thousands of simulations. However, the relative performance of each option in terms of providing additional flood mitigation at Lake Eildon will vary by individual event. Section 7 therefore assesses what differences each option may have made to outflows from Lake Eildon if they were in place for the October 1993 and October 2022 floods.

7. The 1993 and 2022 floods

7.1 Historical information

In October 1993, significant depths of rain fell across a large portion of Victoria in the week ending 7 October, including in the Goulburn River catchment (Figure 102). Conditions preceding the event were relatively wet in terms of soil moisture (Figure 103), and the peak inflows to Lake Eildon of approximately 165,000 ML/d were the largest on record to that time (Figure 104).

Although Lake Eildon was close to capacity (FSL) at the time of the October 1993 flood, the storage still provided flood mitigation. This is because the reservoir was allowed to surcharge 590 mm above FSL. This temporarily stored volume of water was released at a rate of approximately 46,700 ML/d until the reservoir returned to FSL in 4.5 days.

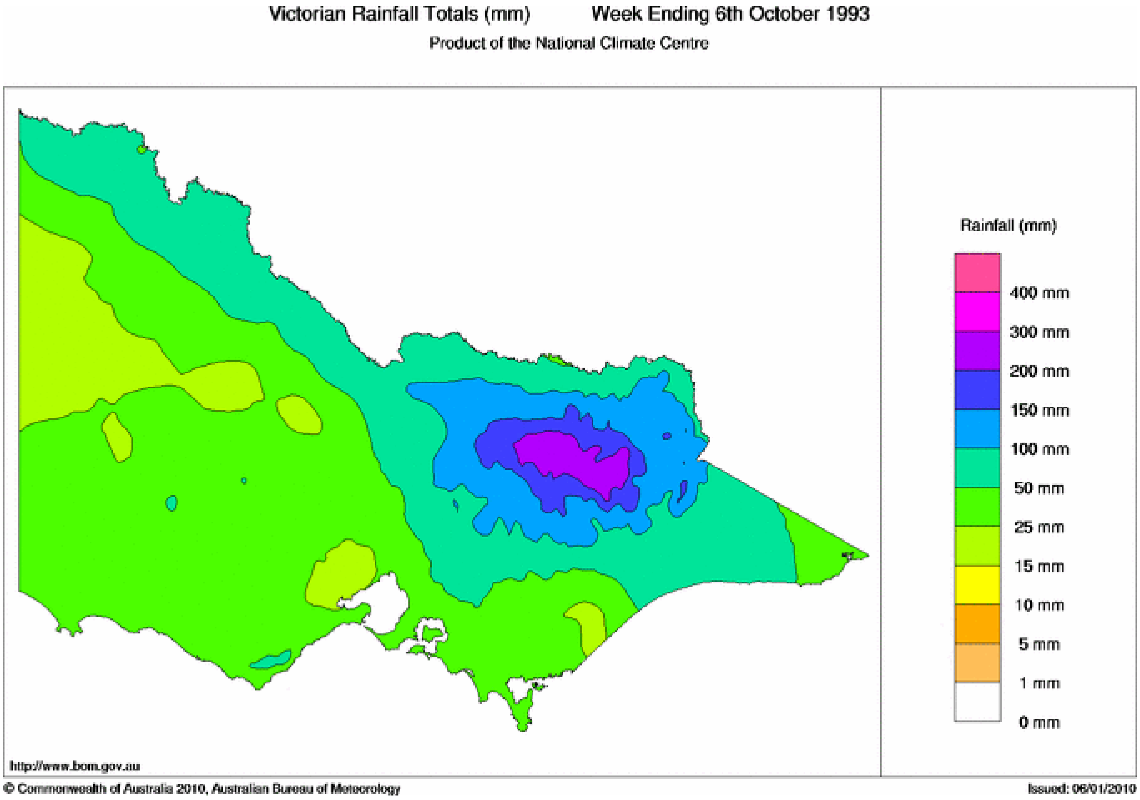


Figure 102: Victorian rainfall totals in the week ending 6/10/1993; www.bom.gov.au/

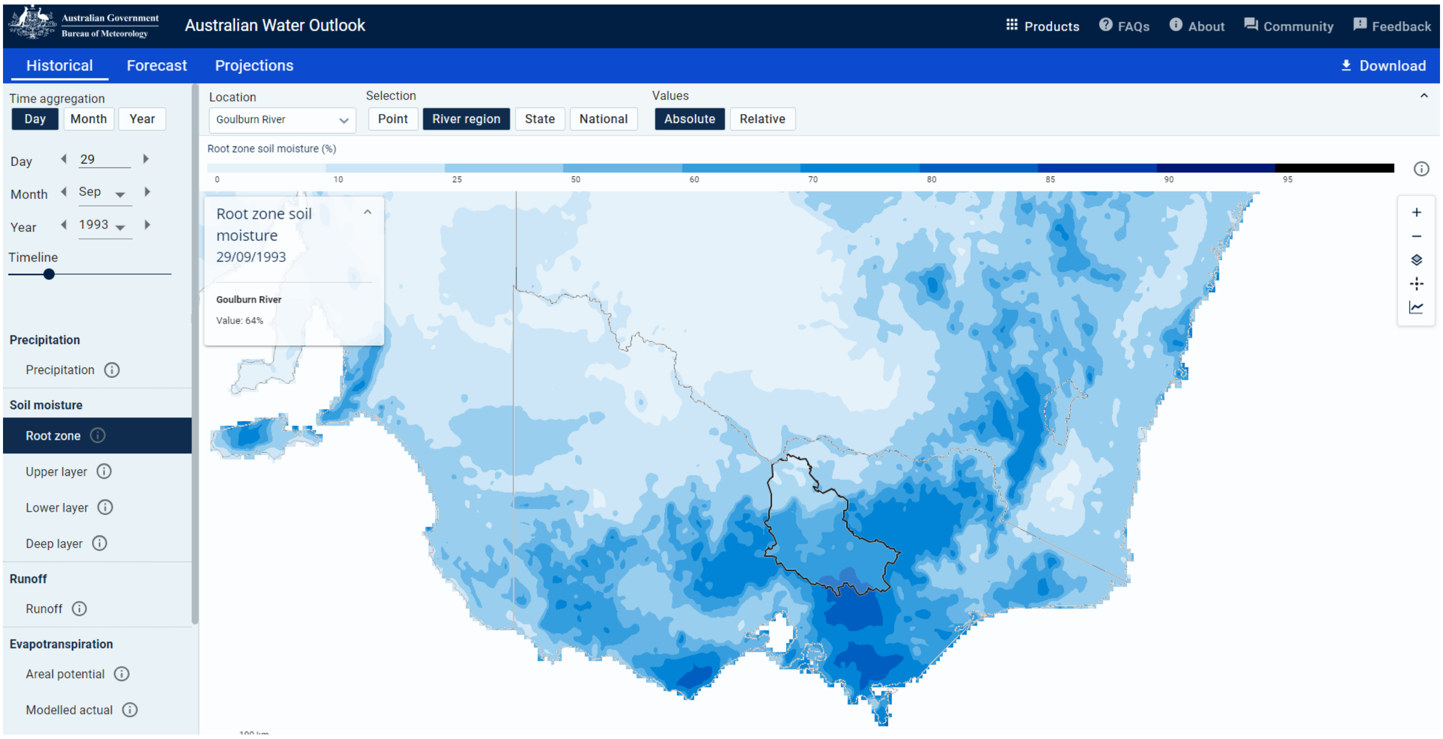


Figure 103: Root zone soil moisture estimates for Victoria on 29/09/1993; www.bom.gov.au/

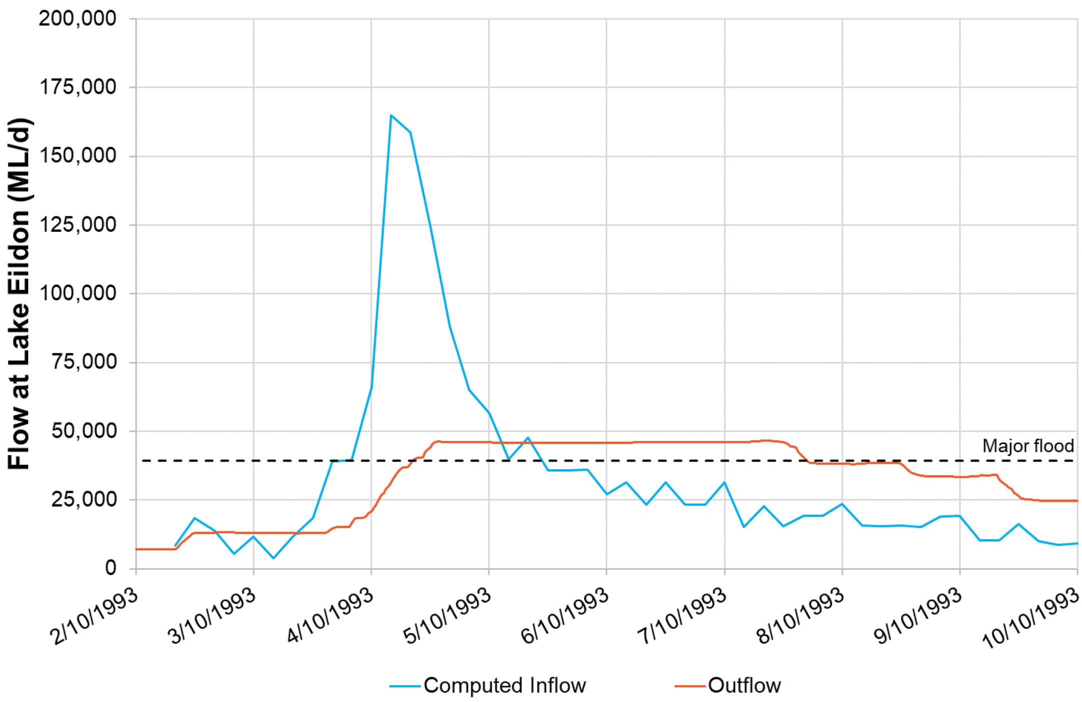


Figure 104: GMW estimates of Lake Eildon outflow and computed inflow for Lake Eildon during the October 1993 flood.

In the week preceding the October 2022 flood, rainfall depths in the Goulburn River catchment were less than during the October 1993 flood (Figure 105). However, the catchment was particularly wet at the time (Figure 106). The peak inflow to Lake Eildon was calculated as approximately 148,000 ML/d, while the peak outflow was approximately 38,000 ML/d (Figure 107) for 5 days.

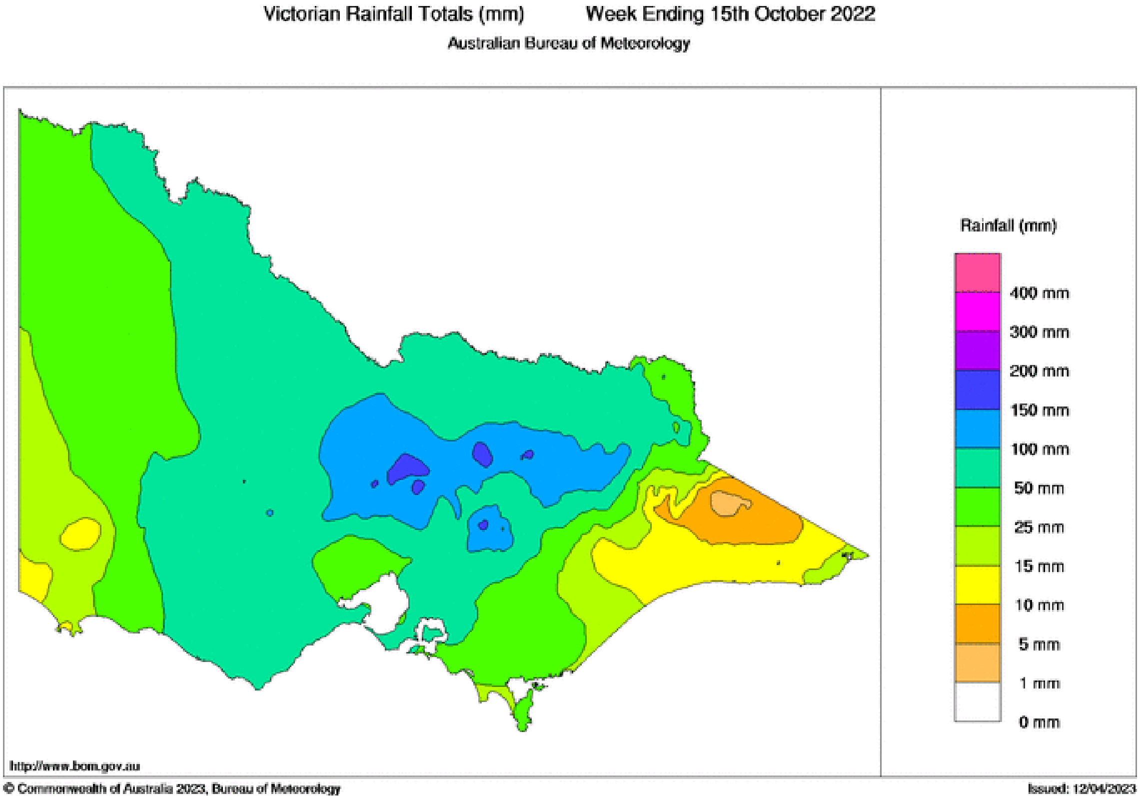


Figure 105: Victorian rainfall totals in the week ending 15/10/2022; www.bom.gov.au/

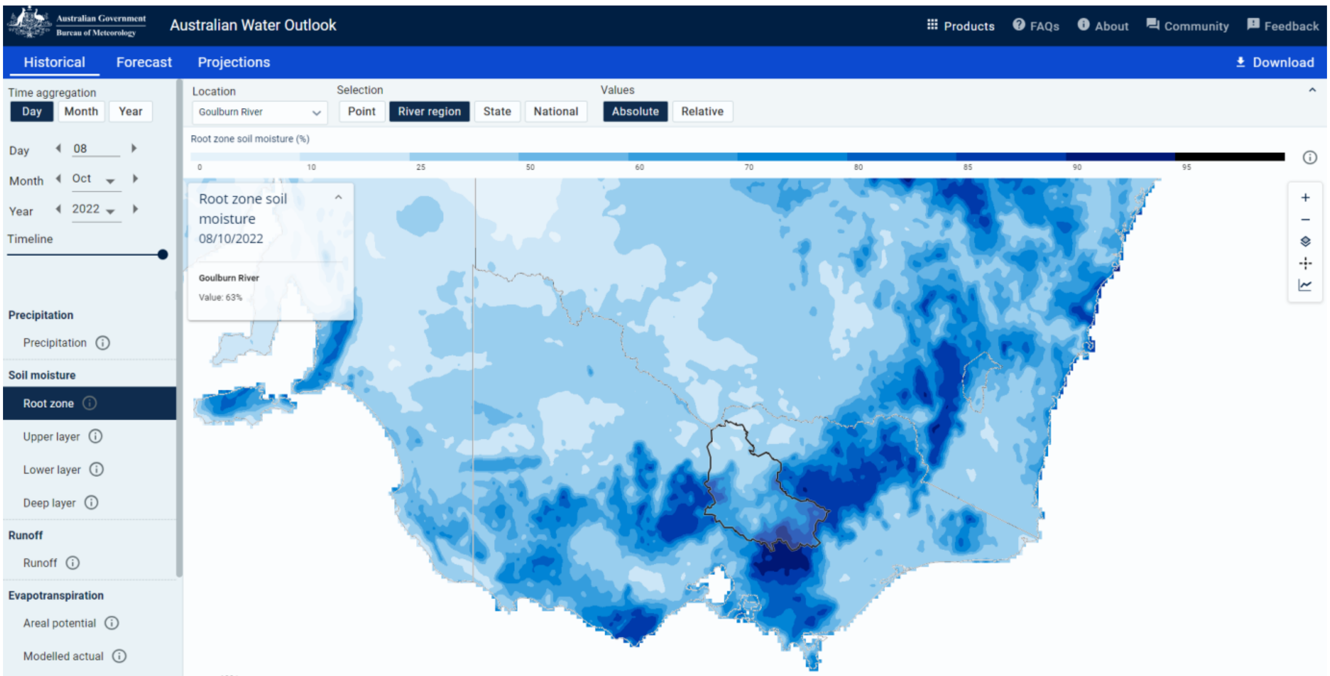


Figure 106: Root zone soil moisture estimates for Victoria on 08/10/2022; www.bom.gov.au/

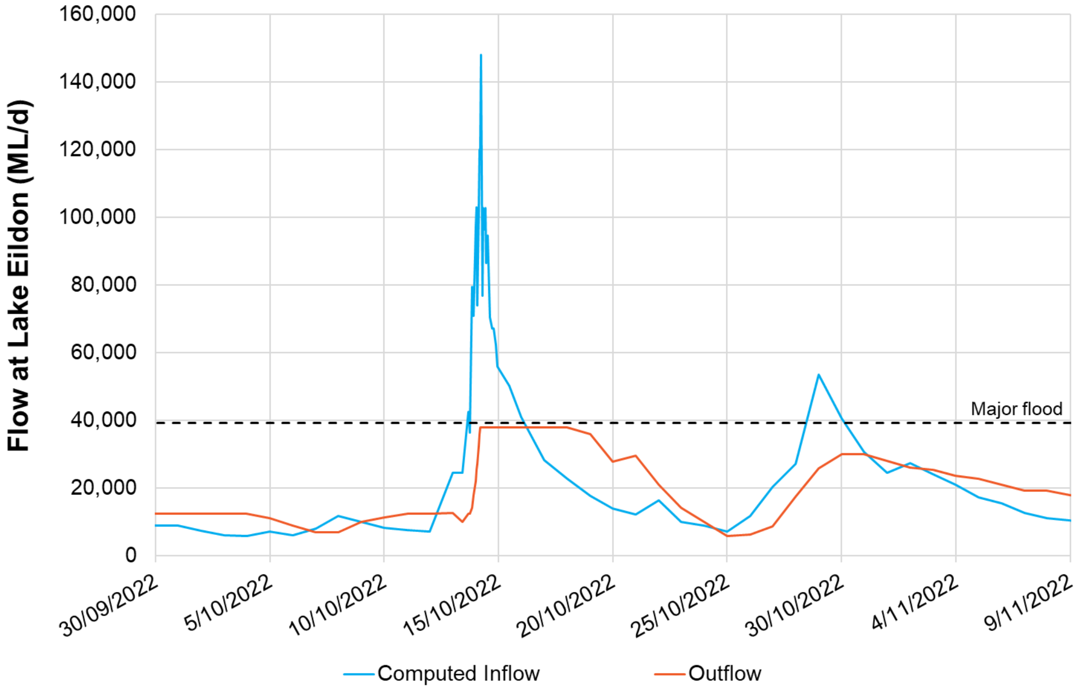


Figure 107: GMW estimates of Lake Eildon outflow and computed inflow for Lake Eildon during the October 2022 flood.

7.2 Potential changes to peak flows if options were implemented

7.2.1 Option 1 – Change target filling curves

A single-event version of the RORB model was used to assess what difference the options presented in Section 4 may have made to the peak Lake Eildon outflow had they been in place during the 1993 and 2022 floods based on a starting water level in Lake Eildon informed by the water resource modelling described in Section 5.

Loss and routing parameters in the single-event version of RORB that provided a reasonable representation of observed inflows to Lake Eildon were adopted for this assessment. These loss and routing parameters are not intended to represent a calibrated, best-estimate of inflows during the 1993 or 2022 floods, but are suitable for representing base case conditions and how they may have changed if the options assessed were in place.

The starting reservoir level for Lake Eildon in the base case and for the options assessed was estimated by interpolating the monthly GSM results described in Section 5.2 to actual dates for the 1993 and 2022 floods, therefore it is not an exact match to the observed data. It is recognised that the DEECA daily Goulburn-Broken-Campaspe-Coliban-Loddon Source model would provide a more accurate starting reservoir position and using observed starting reservoir levels instead of modelled values would only have been possible for the base case, and not the options assessed.

Regardless of the filling curve option modelled, in the GSM Lake Eildon was simulated to be full prior to the October 1993 flood and 89% full before the October 2022 flood. Even though the absolute values of the starting water level are different to the observed starting water level, the relative changes in outflows between the options are informative.

The hydrographs simulated in RORB at Eildon, Molesworth and Seymour are the same regardless of the option selected and therefore have not been plotted. The peak flows, however, are summarised in Table 38.

Table 38: Modelled peak flow at Eildon, Molesworth and Seymour if the October 1993 and October 2022 floods were repeated, for the options to change the Lake Eildon target filling curve

Event	Scenario	Starting storage	Modelled peak flow (m³/s)			Modelled peak flow (ML/d)		
			Lake Eildon	Molesworth	Seymour	Lake Eildon	Molesworth	Seymour
1993	Base case*	100%	460	470	480	39,500	40,300	41,700
	95PoE to Dec 1 (post-1891 data)	100%	460	470	480	39,500	40,300	41,700
	95PoE to Jan 1 (post-1891 data)	100%	460	470	480	39,500	40,300	41,700
	95PoE to Jan 1 (post-1975 data)	100%	460	470	480	39,500	40,300	41,700
	85PoE to Oct 1 (post-1891 data))	100%	460	470	480	39,500	40,300	41,700
	85PoE to Dec 1 (post-1891 data)	100%	460	470	480	39,500	40,300	41,700
	85PoE to Jan 1 (post-1891 data)	100%	460	470	480	39,500	40,300	41,700
	85PoE to Jan 1 (post-1975 data)	100%	460	470	480	39,500	40,300	41,700
	75PoE to Oct 1 (post-1891 data))	100%	460	470	480	39,500	40,300	41,700
	75PoE to Dec 1 (post-1891 data)	100%	460	470	480	39,500	40,300	41,700
	75PoE to Jan 1 (post-1891 data)	100%	460	470	480	39,500	40,300	41,700
	75PoE to Jan 1 (post-1975 data)	100%	460	470	480	39,500	40,300	41,700
2022	Base case*	89%	88	460	1,510	†7,600	39,600	130,600
	95PoE to Dec 1 (post-1891 data)	89%	88	460	1,510	7,600	39,600	130,600
	95PoE to Jan 1 (post-1891 data)	89%	88	460	1,510	7,600	39,600	130,600
	95PoE to Jan 1 (post-1975 data)	89%	88	460	1,510	7,600	39,600	130,600
	85PoE to Oct 1 (post-1891 data))	89%	88	460	1,510	7,600	39,600	130,600
	85PoE to Dec 1 (post-1891 data)	89%	88	460	1,510	7,600	39,600	130,600
	85PoE to Jan 1 (post-1891 data)	89%	88	460	1,510	7,600	39,600	130,600
	85PoE to Jan 1 (post-1975 data)	89%	88	460	1,510	7,600	39,600	130,600
	75PoE to Oct 1 (post-1891 data))	89%	88	460	1,510	7,600	39,600	130,600
	75PoE to Dec 1 (post-1891 data)	89%	88	460	1,510	7,600	39,600	130,600
	75PoE to Jan 1 (post-1891 data)	89%	88	460	1,510	7,600	39,600	130,600
	75PoE to Jan 1 (post-1975 data)	89%	88	460	1,510	7,600	39,600	130,600

*These values are different to the recorded values because a simplified calibration has been undertaken to approximate an inflow and outflow for this investigation.

†These values are lower than the recorded values because of lower starting water level informed by the monthly timestep water resources model. It is recognised that the DEECA daily Goulburn-Broken-Campaspe-Coliban-Loddon Source model would provide a more accurate starting reservoir position and using observed starting reservoir levels instead of modelled values would only have been possible for the base case, and not the options assessed.

7.2.2 Option 2 – Reduce target storage

A summary of the modelled start storage levels prior to the flood is provided in Table 39. The simulated hydrographs for the reduced target storage of 95%, 90%, 85% and 78% are shown for the October 1993 and October 2022 flood event in Figure 108 and Figure 109 respectively, and the peak flows at Eildon, Molesworth and Seymour are summarised in Table 40.

Based on these figures and table, the following observations can be made:

- Under the scenarios where the target storage was reduced to 95%, 90% and 85% of FSL, the starting storage level was similar to the base case, and hence no flood mitigation benefits were observed. The degree to which the storage levels can be reduced to the target storage are influenced by the downstream flow constraints as described in Section 5.3.
- Reducing the target storage to 78% of FSL resulted in lower starting levels in Lake Eildon and hence more airspace available prior to the October 1993 and October 2022 floods. This caused an appreciable reduction in peak outflows from Lake Eildon; however, the peak flows estimated at Molesworth and Seymour varied by event. For instance, if the October 1993 flood event was repeated, the peak flow at Seymour and Molesworth was simulated to reduce by 47% and 38% respectively, however, if the October 2022 flood event was repeated, the peak flow at Molesworth and Seymour was simulated to reduce by 2% and 0% respectively. The difference in the peak flow reduction was due to the downstream tributary inflows as described in Section 6.3.

Table 39: Summary of Lake Eildon starting storage levels as extracted from the GSM results presented in Section 5.2.

Event	Scenario	Starting storage %
1993	Base case	100% (FSL)
	95%	100% (FSL)
	90%	100% (FSL)
	85%	100% (FSL)
	78%	95%
2022	Base case	†89%
	95%	89%
	90%	89%
	85%	89%
	78%	83%

†These values are lower than the recorded values because of lower starting water level informed by the monthly timestep water resources model. It is recognised that the DEECA daily Goulburn-Broken-Campaspe-Coliban-Loddon Source model would provide a more accurate starting reservoir position and using observed starting reservoir levels instead of modelled values would only have been possible for the base case, and not the options assessed.

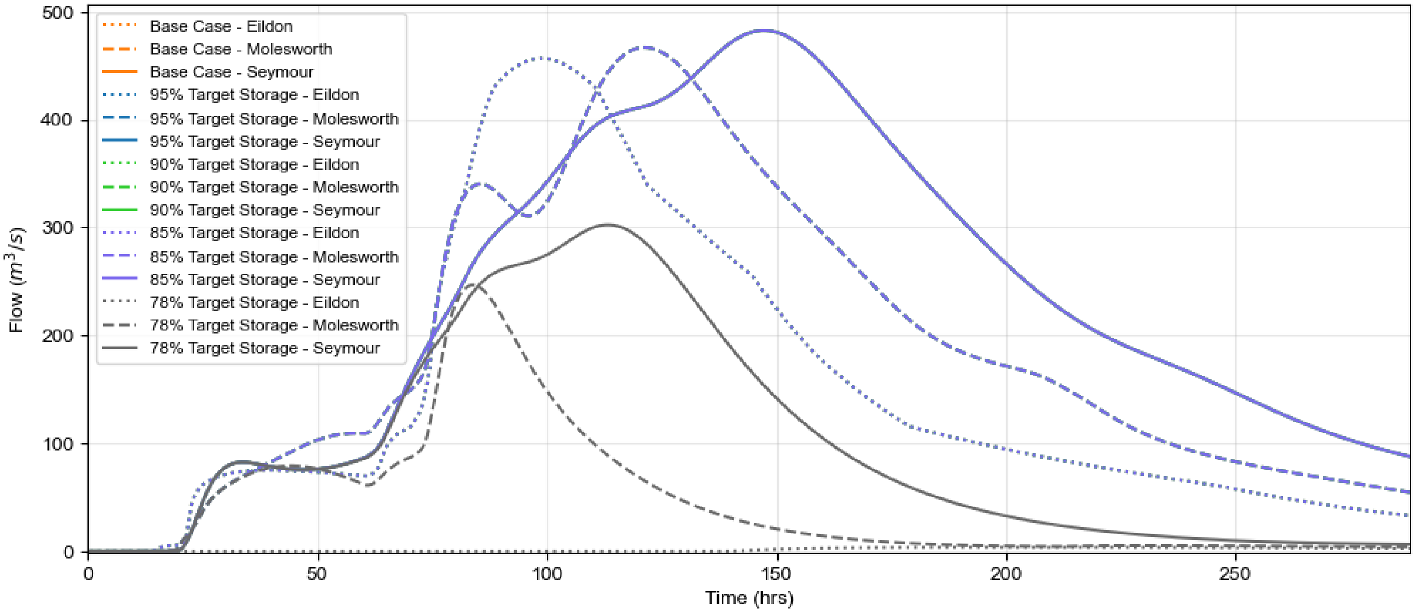


Figure 108: Modelled changes to flow at Eildon, Molesworth and Seymour if the October 1993 flood was repeated, for the options to reduce the Lake Eildon target storage

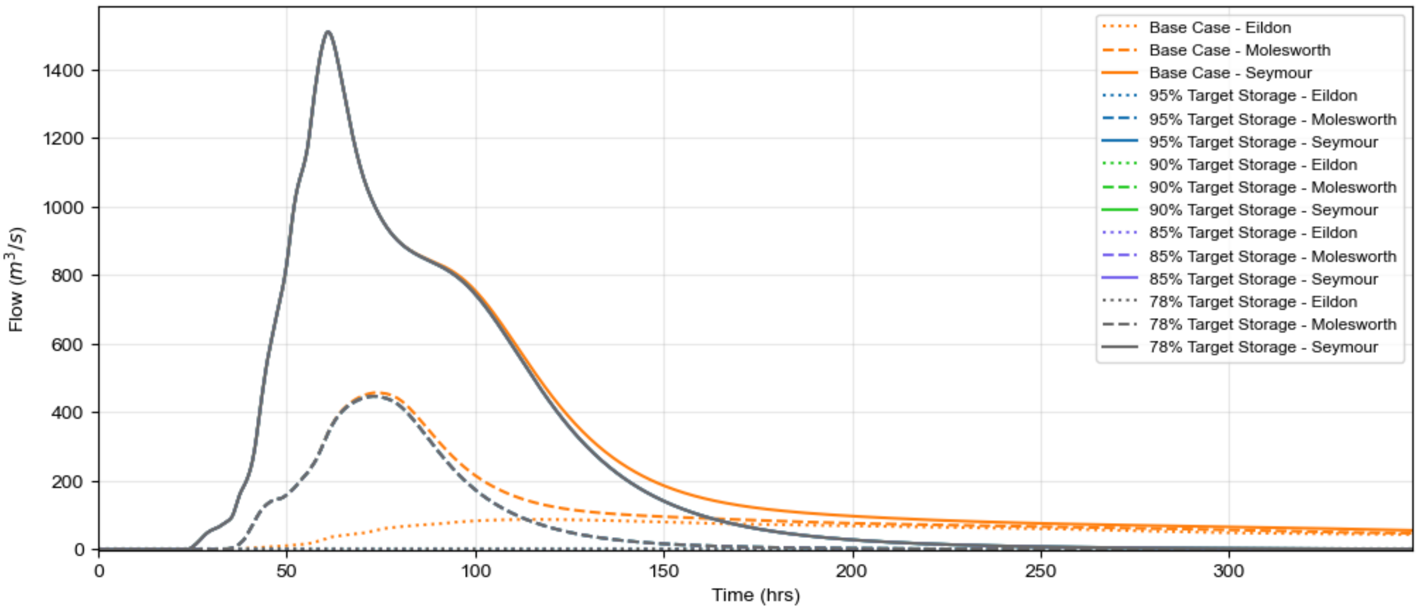


Figure 109: Modelled changes to flow at Eildon, Molesworth and Seymour if the October 2022 flood was repeated, for the options to reduce the Lake Eildon target storage

Table 40: Modelled peak flow at Eildon, Molesworth and Seymour if the October 1993 and October 2022 floods were repeated, for the options to reduce the Lake Eildon target storage

Flood event	Modelled peak flow (m³/s)			Modelled peak flow (ML/d)		
	Lake Eildon	Molesworth	Seymour	Lake Eildon	Molesworth	Seymour
1993 – base case*	460	470	480	39,500	40,300	41,700
1993 – 95% target storage	460	470	480	39,500	40,300	41,700
1993 – 90% target storage	460	470	480	39,500	40,300	41,700
1993 – 85% target storage	460	470	480	39,500	40,300	41,700
1993 – 78% target storage	4	250	300	300	21,300	26,100
2022 – base case*	88	460	1,510	†7,600	39,600	130,600
2022 – 95% target storage	88	460	1,510	7,600	39,600	130,600
2022 – 90% target storage	88	460	1,510	7,600	39,600	130,600
2022 – 85% target storage	88	460	1,510	7,600	39,600	130,600
2022 – 78% target storage	0	450	1,510	0	38,600	130,600

*These values are different to the recorded values because a simplified calibration has been undertaken to approximate an inflow and outflow for this investigation.

†These values are lower than the recorded values because of lower starting water level informed by the monthly timestep water resources model. It is recognised that the DEECA daily Goulburn-Broken-Campaspe-Coliban-Loddon Source model would provide a more accurate starting reservoir position and using observed starting reservoir levels instead of modelled values would only have been possible for the base case, and not the options assessed.

7.2.3 Option 3 – Reduce target storage based on climate signals

To represent the options that involve a reduced target storage based on the SOI, IOD and TPI climate signals discussed in Section 4.4, the REALM model results from Section 5.2 were extracted and simulated in RORB as a start storage level in Lake Eildon. This showed that reducing the target storage based on climate signals was unlikely to have increased flood mitigation downstream of Lake Eildon. For instance, the TPI value in the three months leading up to the October 1993 flood indicated a drier than average year, and therefore the target storage was not reduced. The TPI value in the three months before the October 2022 flood did signify ‘wet’ conditions; however, the downstream flow constraint limited the extent of drawdown possible in August and September (as discussed in Section 5.3).

7.2.4 Option 4 – Pre-release based on forecast rainfall

Before pre-releasing, GMW needs to be confident that a) water released from storage will be replenished by inflows resulting from the forecast rainfall and b) releases will not exacerbate downstream flooding. This means that the rainfall and streamflow quantities and locations need to be estimated or known with a high degree of certainty. If a maximum 10,000 ML/d of water can be released from Lake Eildon (e.g. assuming no tributary inflows), then at least 2 weeks of pre-releases are required to create 5% airspace. Rainfall and streamflow forecasts of this length, with the certainty needed for pre-release decisions are not available because:

- Forecasts of total rainfall are available for eight days at most[20], and the forecasts for days 5-8 are significantly less reliable than for days 1-4[21]
- Streamflow forecasts are available for periods of 7-days[22], 1 month, 2 months or 3 months[23] but not for durations in between these time-steps

Uncertainties in forecasts of inflows to Lake Eildon for lead times of multiple weeks will remain high unless there is a significant reduction in the uncertainty associated with rainfall forecasts. For example, Figure 110 shows the rainfall forecast on 10 October 2022 – 3 days before the October 2022 event began – from the two (of nine available) global deterministic models often given most weight in Bureau of Meteorology forecasts. Although the predicted rainfall totals are of a similar order of magnitude, the location of the heaviest rainfall is forecast to be in central Victoria in the Access (Australian) model and towards the north-east part of Victoria in the ECMWF (European) model. This variation in the predicted region of the heaviest rainfall makes it difficult to accurately predict streamflow at specific locations (e.g. inflows to Lake Eildon).

This type of variation in the predicted location of the heaviest rainfall is also apparent within a given model. For example, the ECMWF (European) model can provide 50 ensemble predictions by varying the initial model conditions. Figure 111 shows the rainfall forecasts from two of the ensemble predictions, again 3 days before the October 2022 flood. Similar to what is observed in Figure 110, the predicted location of the heaviest rainfall is uncertain at that lead time.

[20] http://www.bom.gov.au/jsp/watl/rainfall/pme.jsp

[21] http://www.bom.gov.au/watl/about/about-forecast-rainfall.shtml

[22] http://www.bom.gov.au/water/7daystreamflow/

[23] http://www.bom.gov.au/water/ssf/?ref=ftr

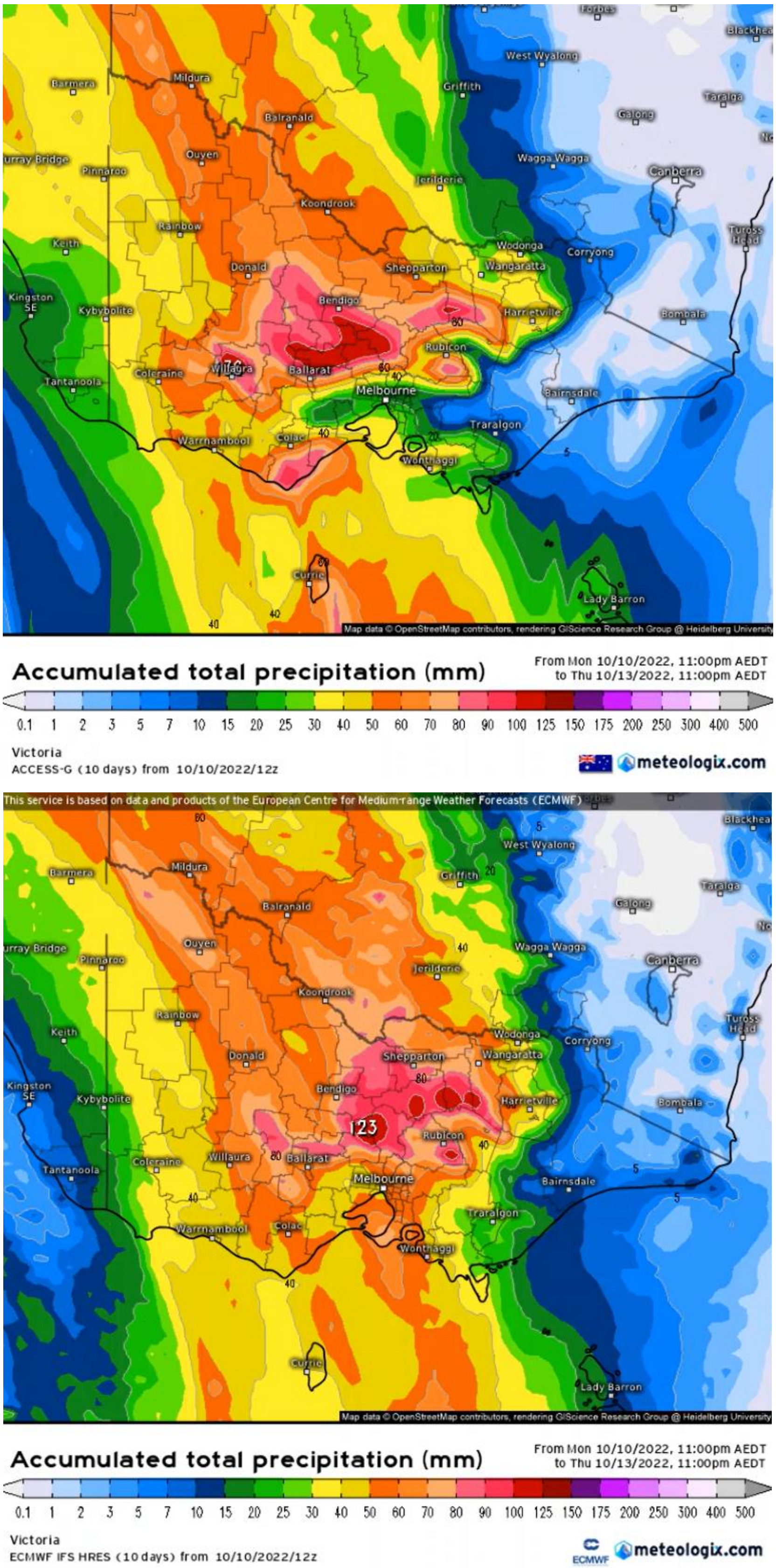


Figure 110: Rainfall forecasts prior to the October 2022 flood from two of the nine available global deterministic models (top: Access – Australia; bottom: ECMWF – Europe)

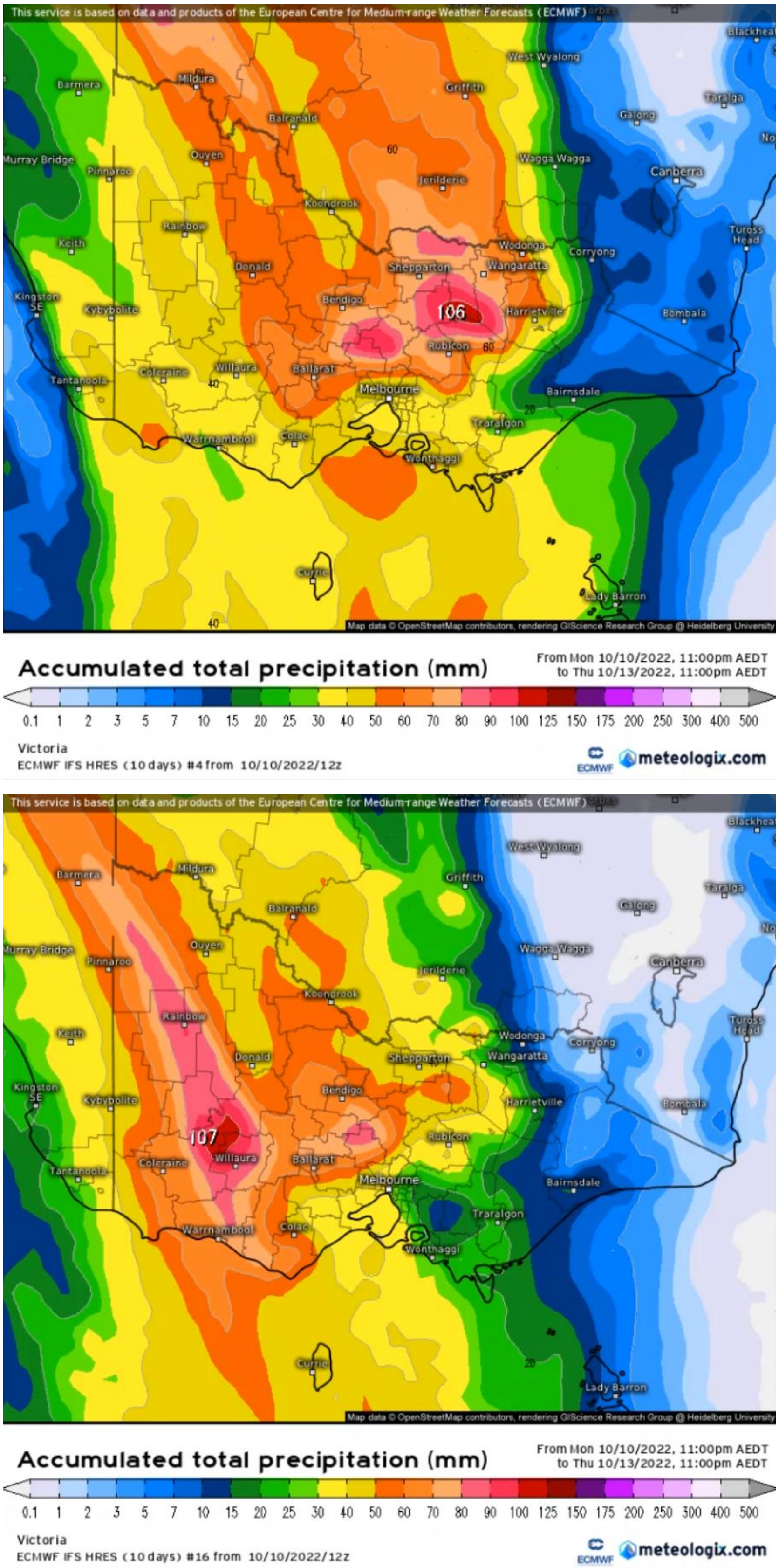


Figure 111: Rainfall forecasts prior to the October 2022 flood from two of the 50 ensemble predictions available from the ECMWF (European) model

This uncertainty in the predicted location of where rainfall will be heaviest will continue to constrain the degree to which storage operators can confidently make pre-releases in response to rainfall forecasts without either reducing the water available to entitlement holders or making downstream flooding worse.

To demonstrate this further, the event-based RORB model of the October 1993 and October 2022 floods was used to assess whether more significant pre-releases before these events would have changed downstream peak flows. That is, the releases from Eildon were modified to include:

- Pre-releasing at the minor flood class level flow threshold (13,680 ML/d) at least 48 hours (2 days) before gate releases were made during the flood events
- Pre-releasing at the moderate flood class level flow threshold (25,400 ML/d) at least 48 hours (2 days) before gate releases were made during the flood events

The modelled flows at Seymour were extracted from the RORB model, and are shown in Figure 112 and Figure 113 for the October 1993 and October 2022 floods respectively. The peak flows are summarised in Table 41 and Table 42. These figures and tables demonstrate that:

October 1993 flood event:

- If the October 1993 flood event was repeated, and pre-releases at the moderate flood class level flow threshold occurred for 3 days prior to gate releases being elevated, the peak flow at Seymour would have been approximately 2% higher due to the coincidence of the pre-releases and the downstream tributary inflows. The rising limb at Seymour would have also increased above the moderate flood class flow threshold in a shorter span of time compared with the base case scenario.
- Pre-releasing at the minor flood class level flow threshold was simulated to have little to no impact on the peak flows at Seymour; however, the rising limb at Seymour increased above the minor flood class flow threshold in a shorter span of time compared with the base case scenario.

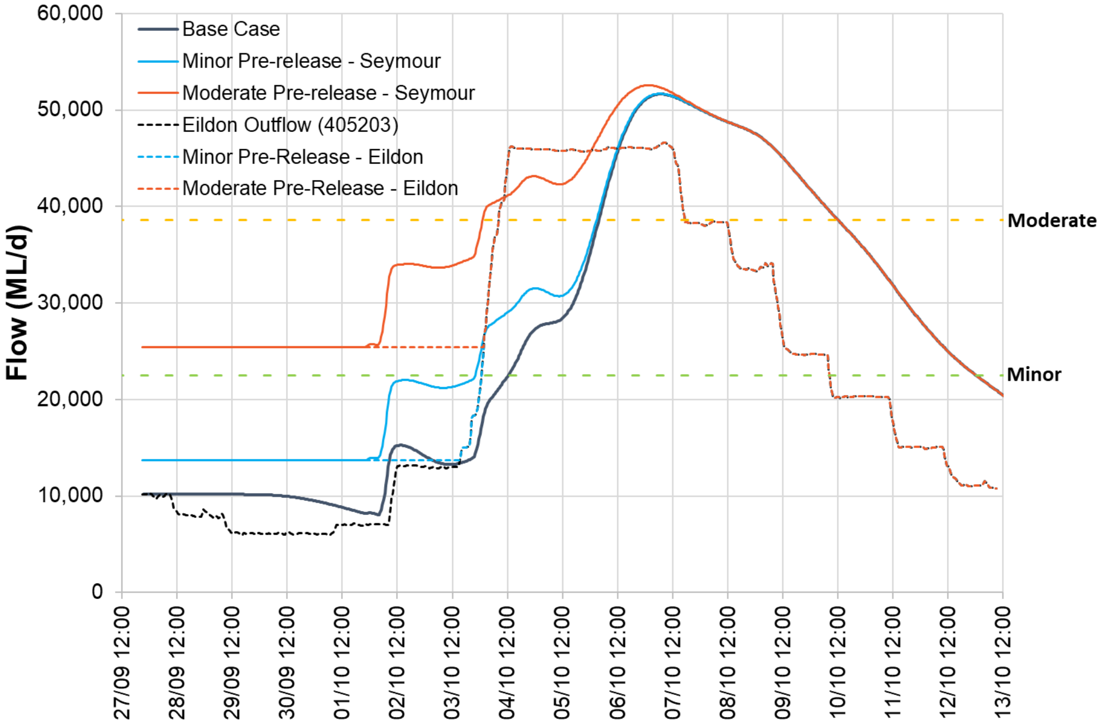


Figure 112: Modelled hydrographs at Eildon and Seymour if the October 1993 flood was repeated, for the option to increase pre-releases from Lake Eildon

Table 41: Modelled peak flow at Seymour if the October 1993 flood was repeated, for the option to increase pre-releases from Lake Eildon

Flood event	Peak flow	
	m³/s	ML/d
Base case	600	51,800
Minor flood pre-release	600	51,800
Moderate flood pre-release	610	52,700

October 2022 flood event:

- Pre-releasing at the minor flood class level flow threshold made little difference to the peak flow at Seymour. This is because actual pre-releases (i.e. the base case) were already close to the minor flood class level flow threshold.
- Higher peak flows at Seymour were observed when the pre-releases were increased to the moderate flood class level flow threshold (25,400 ML/d). This is because the higher pre-releases would have coincided with the downstream tributary inflows.

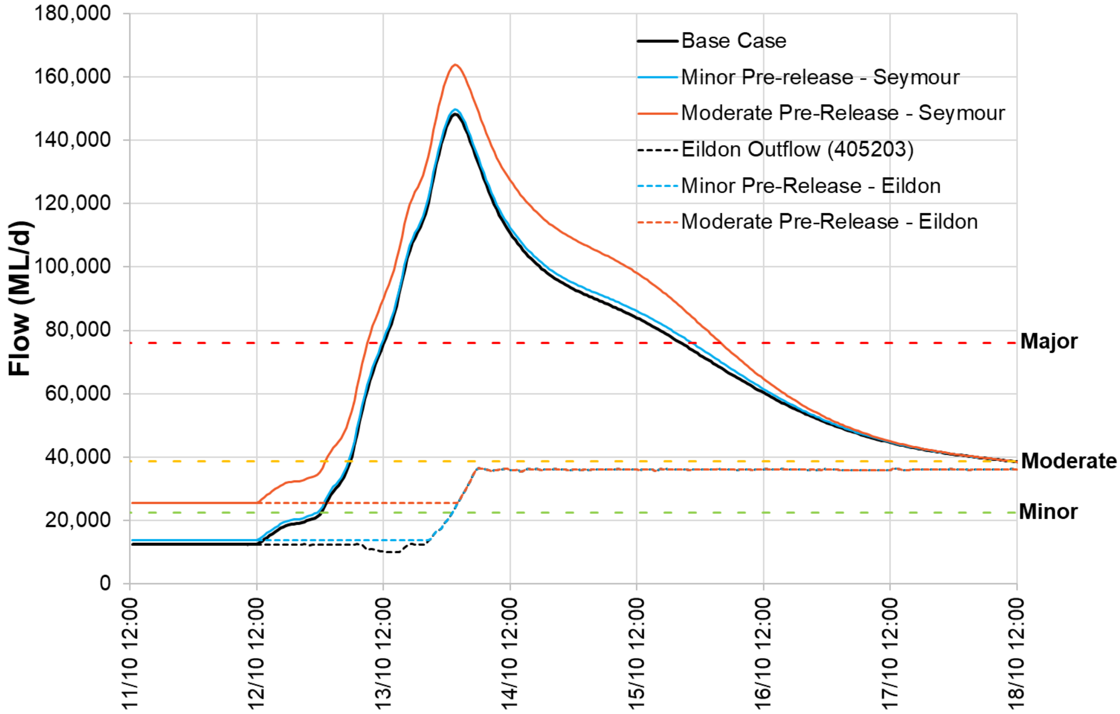


Figure 113: Modelled hydrographs at Eildon and Seymour if the October 2022 flood was repeated, for the option to increase pre-releases from Lake Eildon

Table 42: Modelled peak flow at Seymour if the October 2022 flood was repeated, for the option to increase pre-releases from Lake Eildon

Flood event	Peak flow	
	m³/s	ML/d
Base case	1,710	148,000
Minor flood pre-release	1,730	150,000
Moderate flood pre-release	1,900	164,000

7.2.5 Option 5 – Change maximum surcharge

This option has not been assessed for the event-based analysis. Refer to the discussion provided in Section 6.2.5.

7.2.6 Option 6 – Restrict maximum outflows

This option has not been assessed for the event-based analysis. Refer to the discussion provided in Section 6.2.6.

8. Costs to offset supply reliability changes

8.1 Estimated using the GSM

For the options that change the percentage of exceedance for target filling curves from 95% to 75% PoE and delay the fill date, or reduce the target storage at Lake Eildon, there will be water resource implications (Section 5). This report section therefore considers the costs that may be associated with offsetting the reduced reliability of supply for entitlement holders. The assessment is preliminary in nature, and the cost estimates could be refined through more detailed investigations of potential ways to address the supply reliability impacts.

The volume of water that may need to be recovered to offset the reduced reliability of supply to entitlement holders was estimated using the same version of the GSM described in Section 5. However, prior to completing this assessment, the climate and inflow inputs to the GSM for the period pre-1975 were transformed to represent post-1975 conditions, using seasonally-based decile scaling in accordance with the *Guidelines for Assessing the Impact of Climate Change on Water Availability in Victoria* (DELWP, 2020). This is because the post-1975 reference period is more representative of recent water availability compared with long-term historic climate conditions (DELWP, 2020).

The limit curves describe the maximum volume supplied in a water year for a given allocation. To estimate the water recovery volumes, the limit curves for simulated non-urban demands in the GSM downstream of Lake Eildon were reduced until the modelled seasonal determinations (i.e. allocations) for each option was similar to the base case under post-1975 conditions. It is outside the scope of this study to explore mechanisms for water recovery. However, the bulk of the water use in the Goulburn system downstream of Lake Eildon is for irrigation and the environment. Therefore, for practical reasons, only non-urban demands were considered in the following analysis.

Figure 114 to Figure 116 shows the combined limit curves in the GSM for the non-urban demands downstream of Lake Eildon, for the base case, and the options that change the PoE in the target filling curves to 75% and delay the fill date, or reduce the Lake Eildon target storage to 95%, 90%, 85% and 78% of FSL. The difference the limit curves shown in Figure 114 to Figure 116 make to simulated February allocations in the Goulburn system is demonstrated in Figure 117 to Figure 122.

Figure 117 to Figure 122 shows the modelled distribution of February allocations under post-1975 climate conditions prior to altering the limit curves (blue series), and the other colours show the February allocations after the changes. Although the allocation distributions for the base case and options assessed are not a perfect match, they are reasonably similar with the exception of the options to reduce the target storage to 78% or 85% of FSL. For these options, it was not possible to match the base case distribution of modelled allocations from 100% to 200% of HRWS plus LRWS, and therefore a range of limit curves were modelled in order to match different parts of the base case allocation curve.

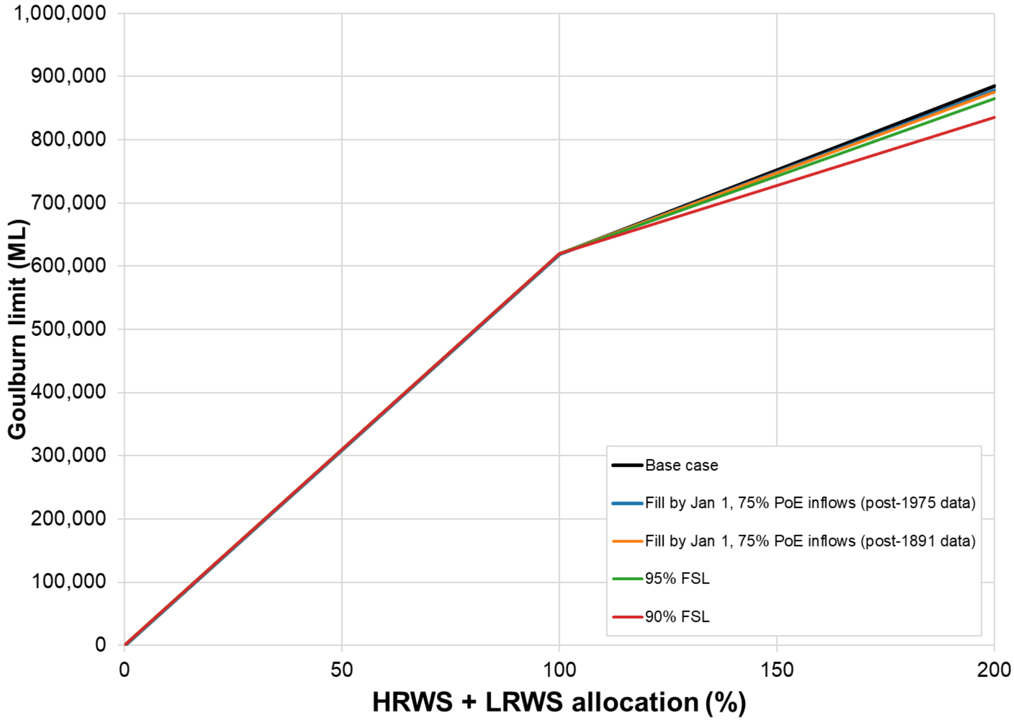


Figure 114: Simulated changes to the limit curves in the GSM for the target filling curve options and the reduced target storage of 95% and 90% of FSL

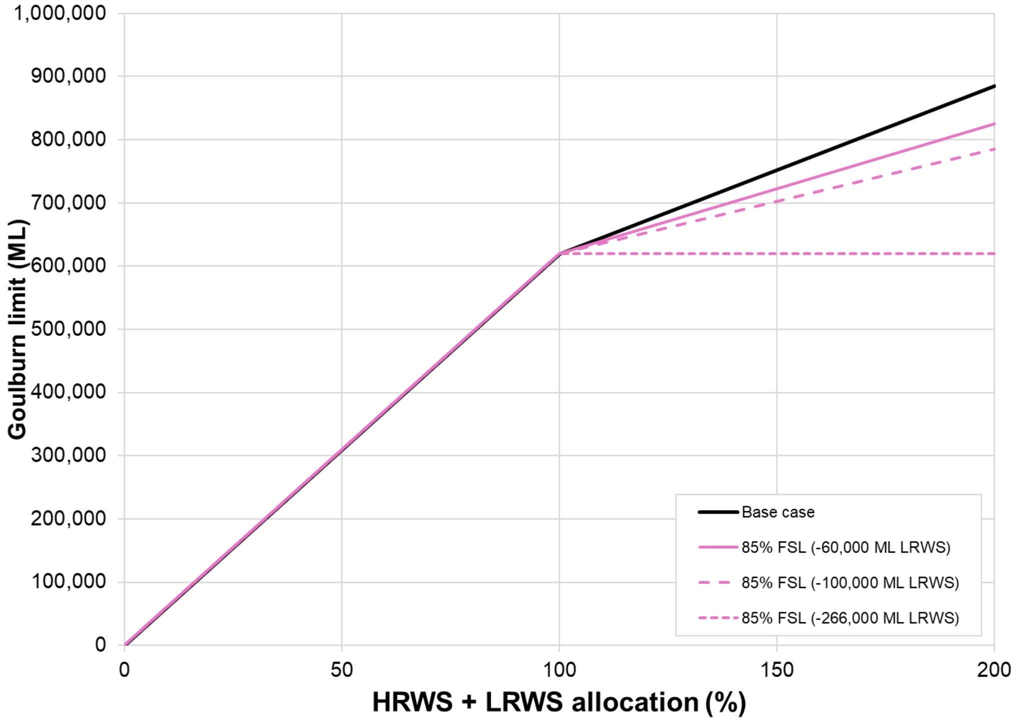


Figure 115: Simulated changes to the limit curves in the GSM for the reduced target storage of 85% of FSL

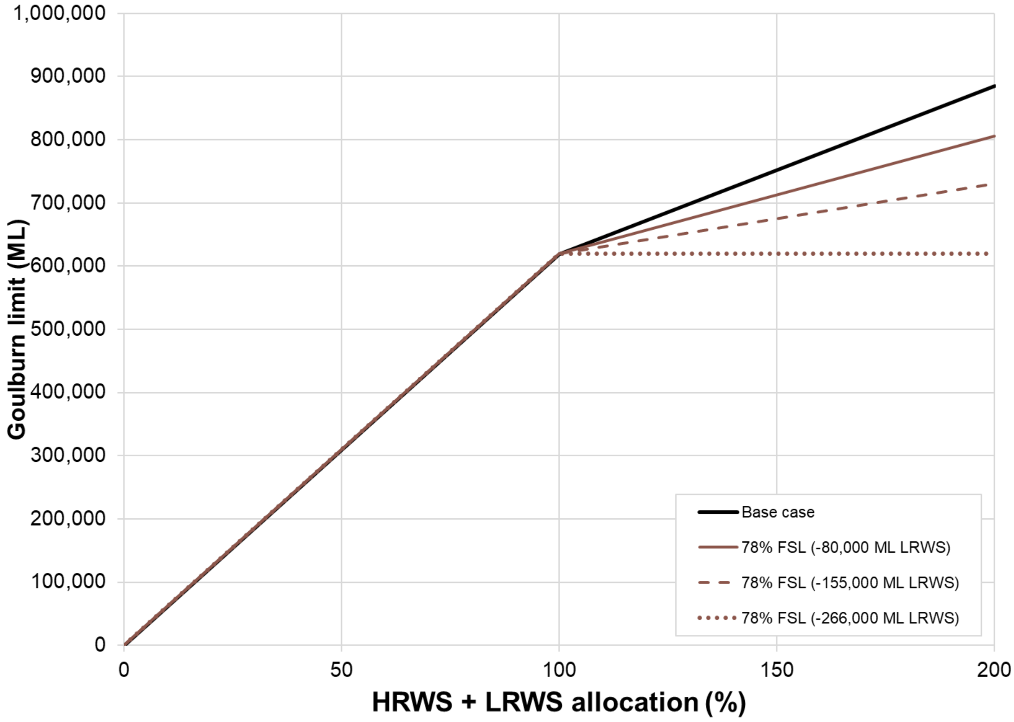


Figure 116: Simulated changes to the limit curves in the GSM for the reduced target storage of 78% of FSL

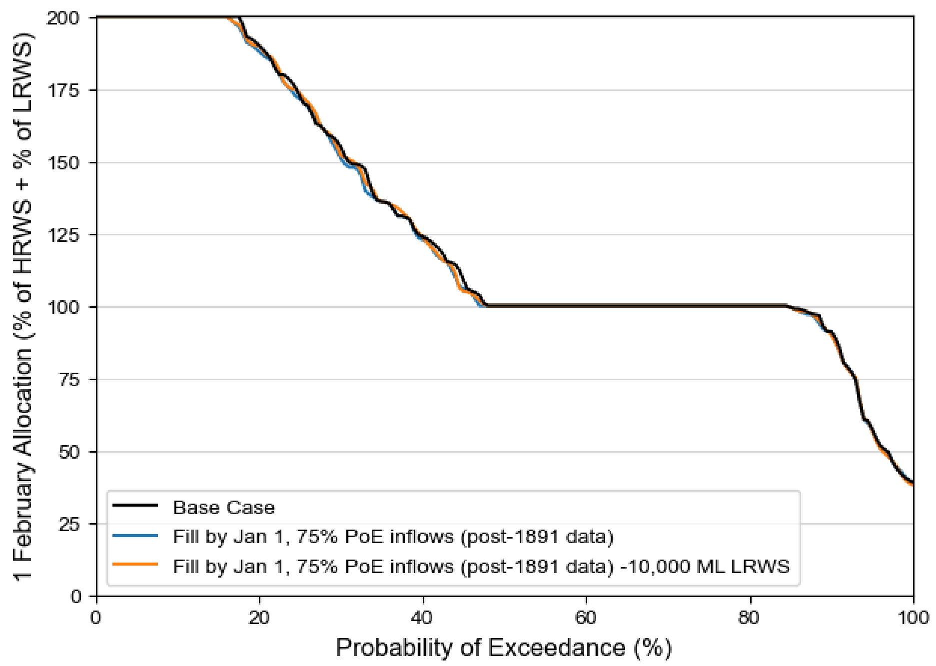


Figure 117: Simulated proportion of years when seasonal determinations (allocations) of varying percentages to HRWS and LRWS in the Goulburn system are exceeded in February under post-1975 conditions for delayed target filling curves based on post-1891 climate data, before and after changes to the limit curves in the GSM

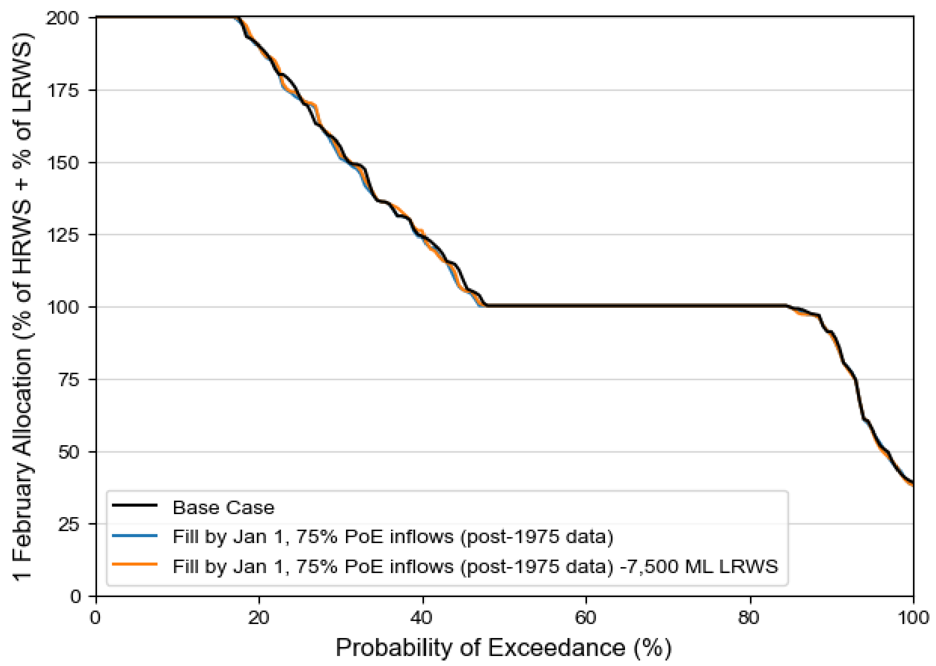


Figure 118: Simulated proportion of years when seasonal determinations (allocations) of varying percentages to HRWS and LRWS in the Goulburn system are exceeded in February under post-1975 conditions for delayed target filling curves based on post-1975 climate data, before and after changes to the limit curves in the GSM

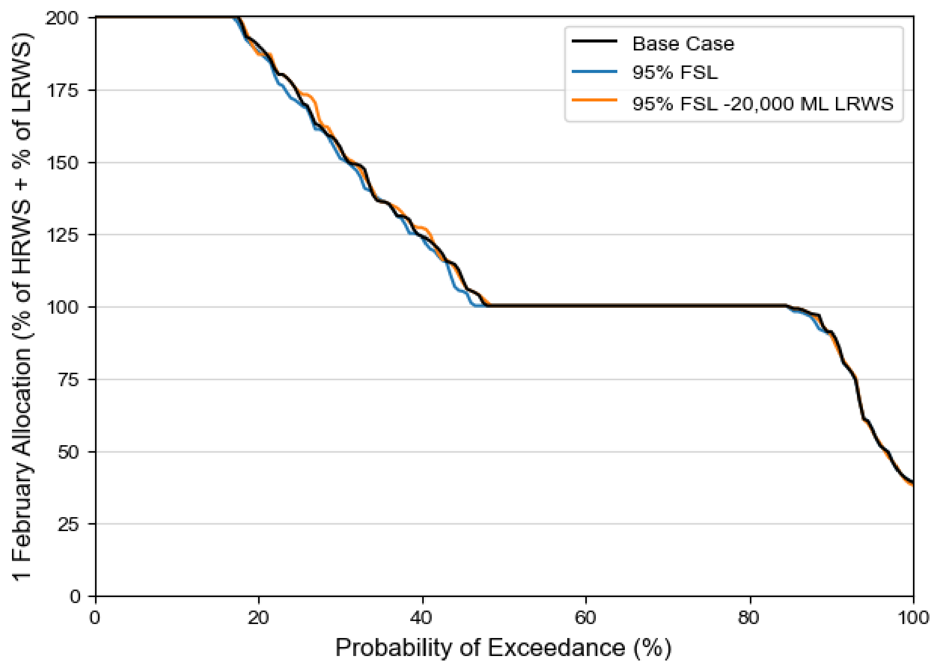


Figure 119: Simulated proportion of years when seasonal determinations (allocations) of varying percentages to HRWS and LRWS in the Goulburn system are exceeded in February under post-1975 conditions for 95% of FSL target storage option, before and after changes to the limit curves in the GSM

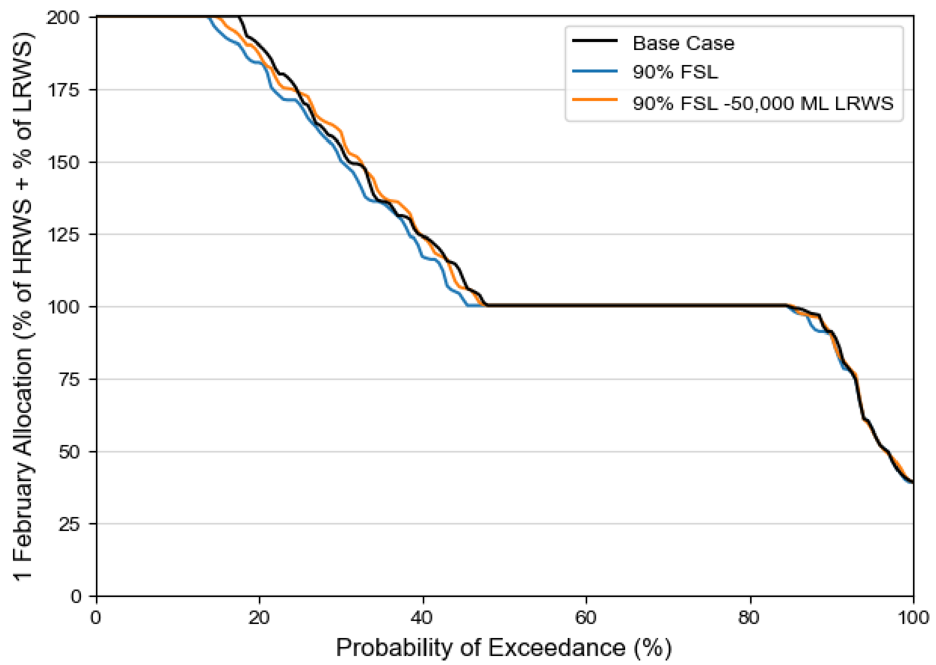


Figure 120: Simulated proportion of years when seasonal determinations (allocations) of varying percentages to HRWS and LRWS in the Goulburn system are exceeded in February under post-1975 conditions for the 90% of FSL target storage option, before and after changes to the limit curves in the GSM

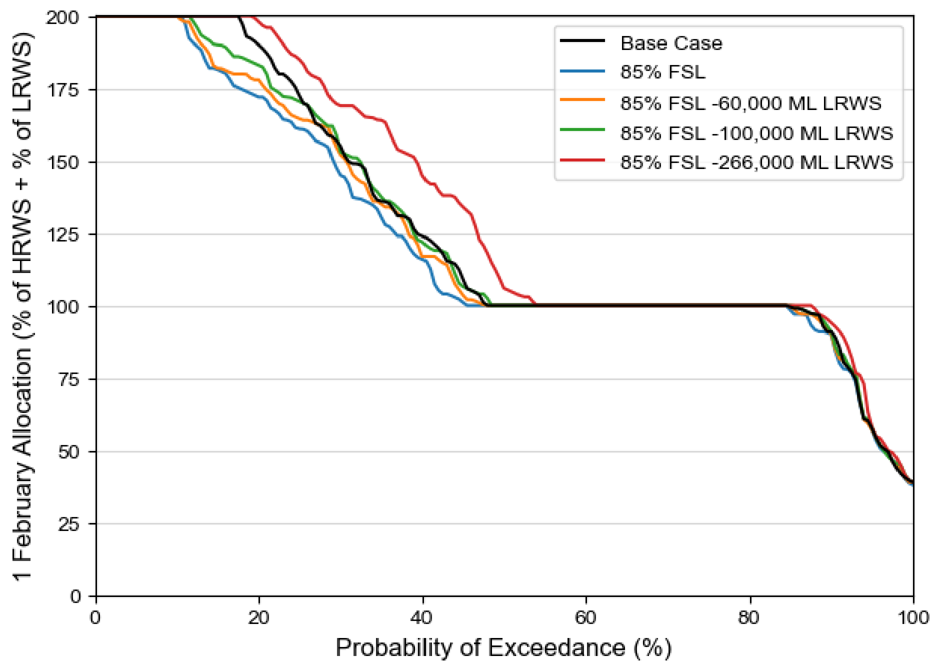


Figure 121: Simulated proportion of years when seasonal determinations (allocations) of varying percentages to HRWS and LRWS in the Goulburn system are exceeded in February under post-1975 conditions for the 85% of FSL target storage option, before and after changes to the limit curves in the GSM

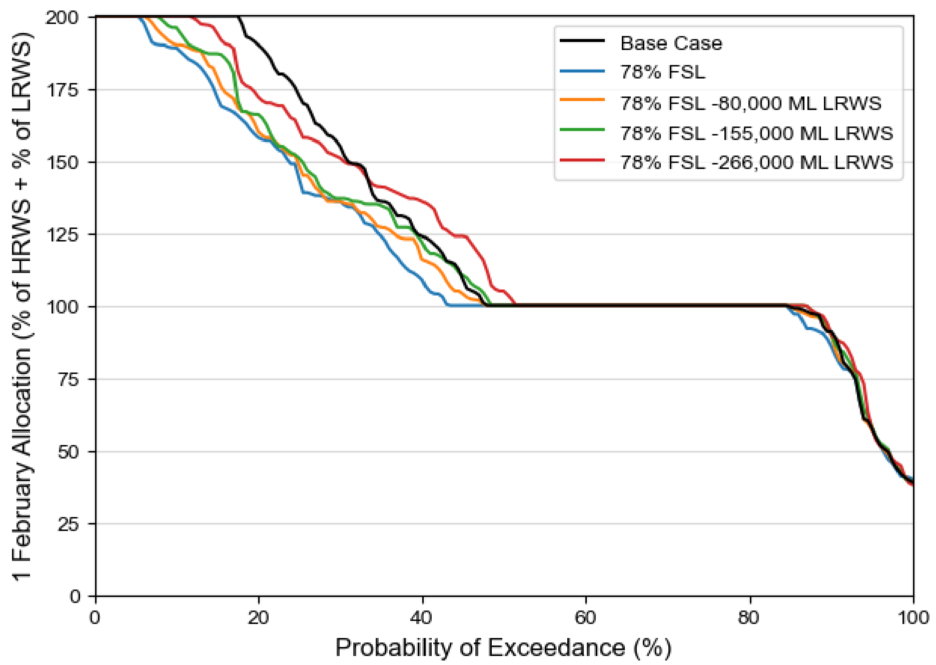


Figure 122: Simulated proportion of years when seasonal determinations (allocations) of varying percentages to HRWS and LRWS in the Goulburn system are exceeded in February under post-1975 conditions for the 78% of FSL target storage option, before and after changes to the limit curves in the GSM

The differences at the 100% and 200% allocation points between the base case and the various options in Figure 114 to Figure 116 can be used to estimate the volume of HRWS and LRWS that may need to be recovered to offset the reduced reliability of supply to entitlement holders in the Goulburn system. These volumes are summarised in Table 43, and indicate that only LRWS would need to be recovered.

Table 43: Approximate volumes that would be required to offset changes to reliability of supply

Option	Limit curve for given allocation (ML)		Difference to base case (ML)	
	At 100%	At 200%	At 100%	At 200%
Base case	619,200	885,150	-	-
Option 1 – Change target filling curves				
75PoE to Jan 1 (post-1891 data)	619,200	875,150	0	10,000
75PoE to Jan 1 (post-1975 data)	619,200	877,650	0	7,500
Option 2 – Reduce target storage				
95% target storage	619,200	865,150	0	20,000
90% target storage	619,200	835,150	0	50,000
85% target storage (-60,000 ML LRWS) †	619,200	825,150	0	60,000
85% target storage (-100,000 ML LRWS) †	619,200	785,150	0	100,000
85% target storage (-266,000 ML LRWS) †	619,200	619,200	0	266,000
78% target storage (-80,000 ML LRWS) †	619,200	805,150	0	80,000
78% target storage (-155,000 ML LRWS) †	619,200	730,150	0	155,000
78% target storage (-266,000 ML LRWS) †	619,200	619,200	0	266,000

†A range of values have been provided to match different parts of the base case allocation curve from 100% to 200% of HRWS plus LRWS.

Within the Goulburn system (1A Greater Goulburn trading zone, 1B Boort and 3 Lower Goulburn) there is approximately 670,000 ML of LRWS water shares and environmental entitlements that can be supplied from Lake Eildon (https://waterregister.vic.gov.au/). Therefore, if 266,000 ML of LRWS needs to be recovered to offset the supply reliability impacts of reducing the Lake Eildon target storage to 78% of the current FSL, this is equivalent to approximately 40% of the existing entitlements and water shares. At present, irrigators and water corporations hold approximately 65% of the low-reliability entitlements and water shares in the Goulburn system, and the environment – via the Victorian and Commonwealth environmental water holders – has the other 35%.

The cost associated with purchasing the water shares shown in Table 43 were estimated by multiplying the volumes by $1,000 / ML. This is the price that LRWS have most recently traded for in the Goulburn system, according to the Victorian Water Register (https://waterregister.vic.gov.au/). This analysis simply tries to quantify the possible initial capital costs of implementing these options and does not explore the mechanisms that could be used to recover the water (e.g. purchases via the water market, changes to water sharing arrangements), or whether the approach is the same for all entitlement holders or varies by end-use (e.g. consumptive vs environmental).

Table 44: Best estimates initial capital costs for the operating options considered in this study for increasing flood mitigation at Lake Eildon

Option	Approximate initial capital costs of water shares (in millions)
Option 1 – Change target filling curves	
75PoE to Jan 1 (post-1891 data)	$10
75PoE to Jan 1 (post-1975 data)	$7.5
Option 2 – Reduce target storage	
95% target storage	$20
90% target storage	$50
85% target storage (-60,000 ML LRWS)†	$60
85% target storage (-100,000 ML LRWS)†	$100
85% target storage (-266,000 ML LRWS)†	$266
78% target storage (-80,000 ML LRWS)†	$80
78% target storage (-155,000 ML LRWS)†	$155
78% target storage (-266,000 ML LRWS)†	$266

†A range of values have been provided to match different parts of the base case allocation curve from 100% to 200% of HRWS plus LRWS.

The costs in Table 44 do not include:

- Foregone production if the volume of water available for consumptive use in the Goulburn system is reduced.
- The costs of modifying community assets around Lake Eildon (e.g. boat ramps) so they have the same utility if the target storage is reduced.
- Reduced income to GMW from fees associated with storing water if entitlements are retired from the Goulburn system. The annual entitlement storage fees are currently $4.84 for LRWS[24], and therefore the fees foregone may up to $2,820,000 each year, based on the options and volumes included in Table 44.
- Potential other ongoing socio-economic consequences of reducing the volume of water stored in the Goulburn system, and the recreational impacts of holding Lake Eildon below FSL.
- Impacts to water markets and foregone productivity as a result of increased write-offs of allocation in spillable water accounts.

8.2 Sensitivity testing using the SGEFM

Similar to the sensitivity testing done in Section 6.4, the volume of HRWS and LRWS that would need to be recovered from the Goulburn system to offset the reduced reliability of supply to entitlement holders was re-estimated using the SGEFM. The SGEFM, developed by the University of Melbourne (John, 2021), was used primarily to assess expected changes to the daily flow regime downstream of Lake Eildon (Section 10.2), but it can also produce time-series

[24] www.g-mwater.com.au/downloads/gmw/Pricing_List/20230530_GMW_Pricing_Table_2023_24.pdf

of modelled allocations and this provided an opportunity to sensitivity test the results included in Section 8.1.

Given this was a sensitivity test, the assessment was based on returning the average annual end-of-season allocation to base case conditions, rather than matching the distribution of February allocations as per Section 8.1. Table 45 shows the results, and how they compare to estimates from the GSM. In each case, the cost estimates based on the SGEFM are more than double those based on the GSM.

The water recovery costs estimated using the SGEFM are higher compared with the GSM-based estimates because LRWS are modelled as having a lower reliability of supply in the SGEFM. Therefore, more LRWS needs to be recovered to offset the modelled reliability of supply changes that occur when the target filling curve is changed or the target storage reduced. This demonstrates that estimates of the water recovery required to offset changes to entitlement holders' supply reliability if the operation of Lake Eildon is changed may be noticeably different if other climate conditions are modelled, the assessment is done in more detail (e.g. by changing both the limit curves and demand nodes in the GSM), or the assessment is repeated using the DEECA daily Goulburn-Broken-Campaspe-Coliban-Loddon Source model (which is intended to replace the GSM in the near future).

Table 45: Approximate volumes that would be required to offset changes to reliability of supply – sensitivity testing

Option	Cost (in millions)	
	GSM estimates	SGEFM estimates
Base case	-	-
Option 1 – Change target filling curves		
75PoE to Jan 1 (post-1891 data)	10	50
75PoE to Jan 1 (post-1975 data)	7.5	60
Option 2 – Reduce target storage		
95% target storage	20	80
90% target storage	50	170
85% target storage	^100	270
78% target storage	^155	460

^ A range of initial capital costs is provided in Table 44 however for demonstrative purposes the middle initial capital cost has been adopted.

9. Upstream impacts

9.1 Reduced target storage or full supply level

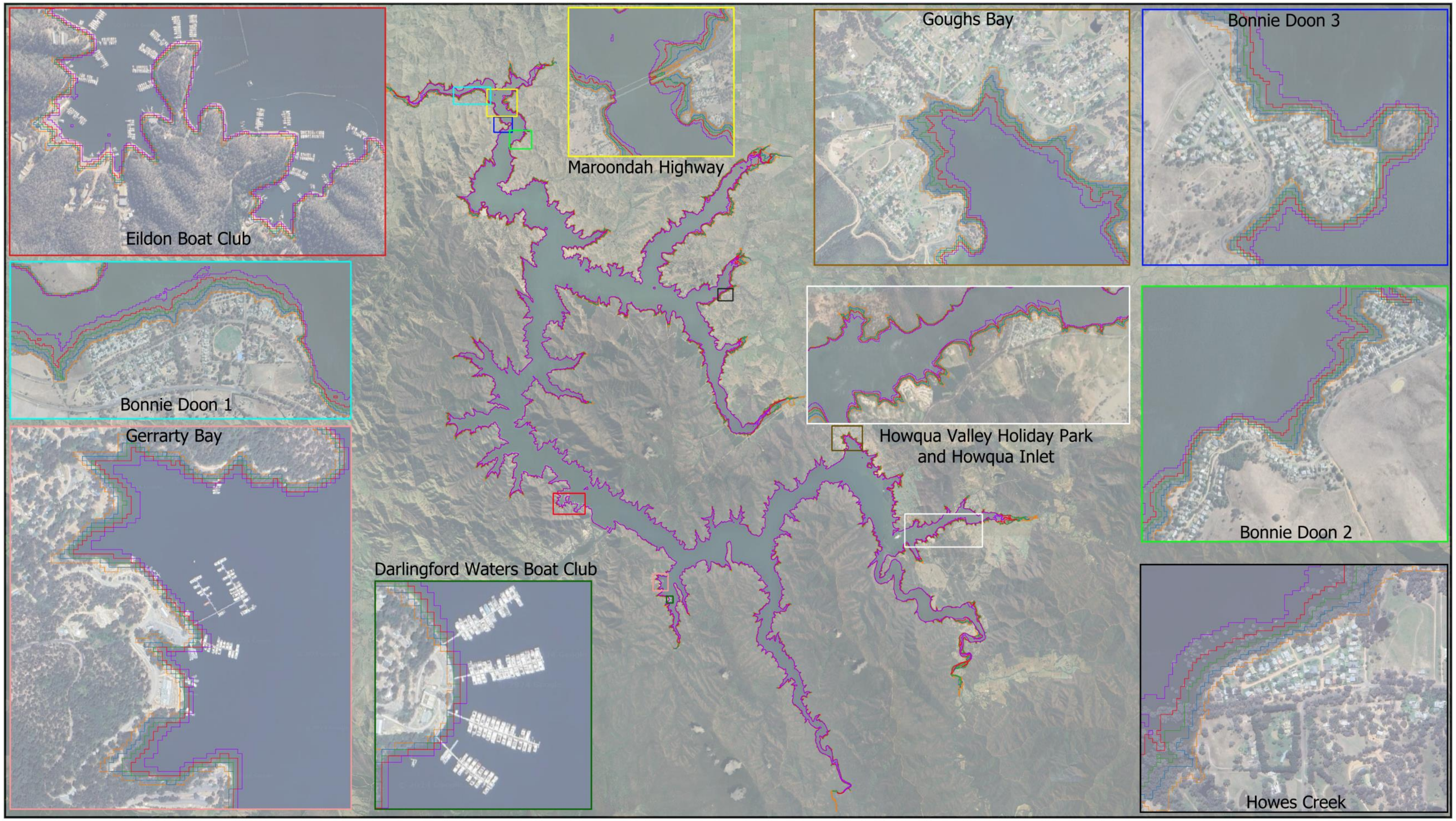
The options that include a reduced target storage at Lake Eildon will reduce the extent of the waterbody. Map M1 below shows the difference in footprint between the current FSL at Lake Eildon, and the footprint at 78%, 85%, 90% and 95% of FSL, both for the reservoir as a whole and focused on seven different locations around the lake.

Map M1 demonstrates that if the target storage is reduced at Lake Eildon:

- The waterbody will cover a smaller area, with the differences most noticeable in the shallow regions of Lake Eildon (for example the outer corners of the reservoir).
- The distance between community and recreational facilities (e.g. holiday accommodation) and the water's edge will increase under the reduced target storage scenarios.

The consequences of these changes are likely to include:

- Having to extend existing boat ramps so they are useable with the reduced target storage at Lake Eildon.
- Reducing the areas where houseboats and watercraft can be used, or used without speed limits.



Legend

- Current FSL (full supply level)
- 95% reduced target storage
- 90% reduced target storage
- 85% reduced target storage
- 78% reduced target storage

0 4 8 km Map Projection: Transverse Mercator Horizontal Datum: GDA 2020 Grid: GDA 2020 MGA Zone 55	N	Study Name - Lake Eildon flood mitigation options assessment

Job Number	VIC00120
Revision	A
Date	13 Feb 2024
Reviewed By	S. Lang
Created By	H. Wang
Map Number	VIC00120-M1

10. Changes to downstream flow regime

10.1 Monthly time-step assessment

The same water resource plan version of the GSM described in Section 5 was used to simulate the monthly flow in the Goulburn River at Seymour and McCoys Bridge under long-term historic (post-1891) climate conditions. Only the results for the long-term historic climate conditions assessment are presented here; how the options compare with the base case is similar in the post-1975 case.

Figure 123 shows the modelled flow duration curves for Seymour (top) and McCoys Bridge (bottom) under the base case and the options to change the target filling curve, or reduce the target storage at Lake Eildon to 95%, 90%, 85% or 78% of the current FSL. A flow duration curve describes the proportion of time a flow of a given magnitude is expected to be met or exceeded.

From Figure 123, the following observations can be made:

- The proportion of time flows are between 300,000 ML/month and 400,000 ML/month at Seymour will increase, and the degree of increase is greater as the target storage is reduced. Conversely, the frequency of flows >400,000 ML/month at Seymour will decrease as per the second dot point.
- Further downstream at McCoys Bridge, which is near where the Goulburn River meets the River Murray, the differences are less noticeable. This is because of the lag and attenuation of flows between Seymour and McCoys Bridge, and tributary inflows from waterways such as the Broken River.
- If the target storage at Lake Eildon is reduced to 78%, 85%, 90% or 95% of the current FSL, flows in the Goulburn River at Seymour will be ≥ ~430,000 ML/month less often. This is because Lake Eildon will spill less often if the target storage is below FSL.

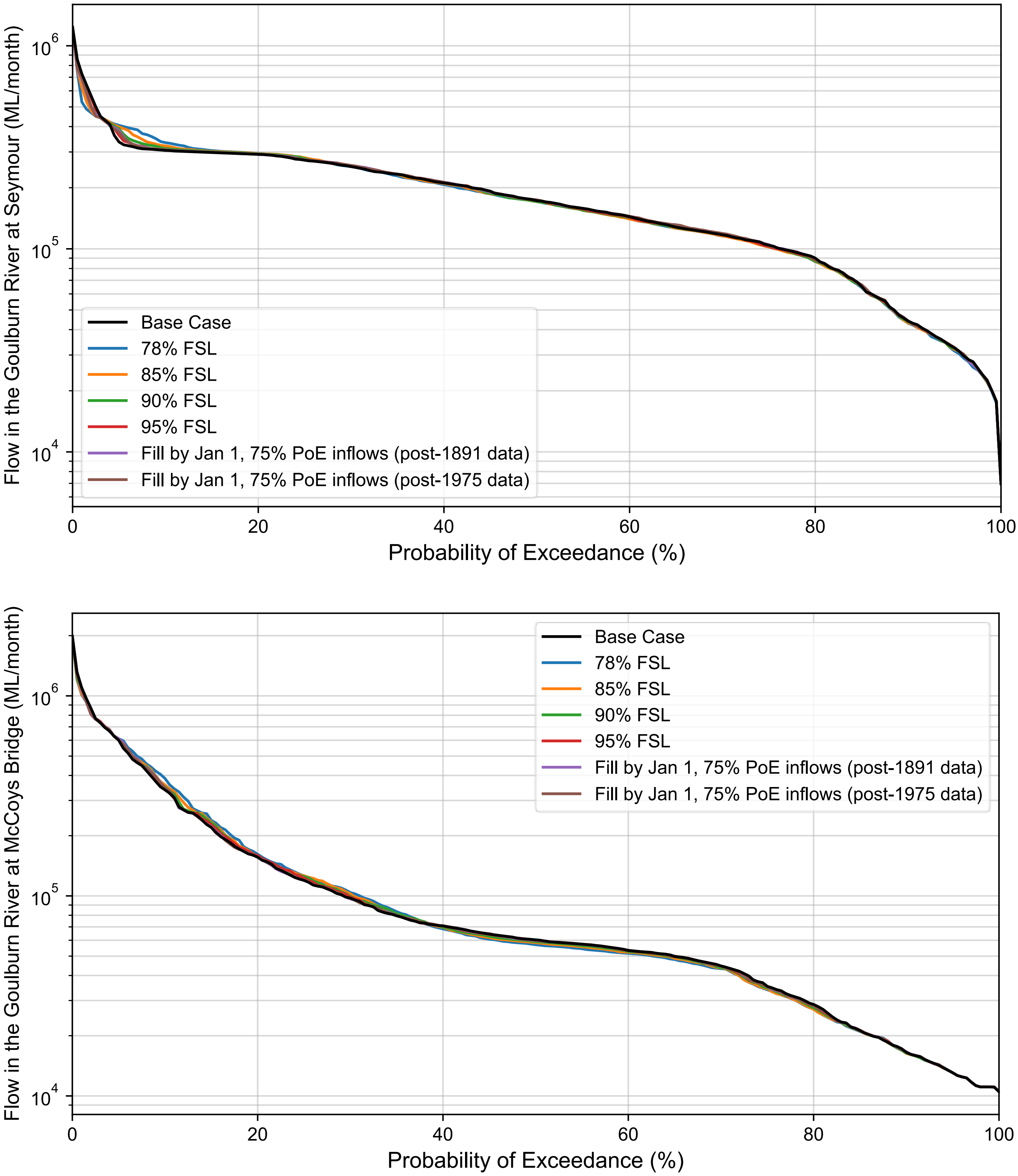


Figure 123: Simulated monthly flows in the Goulburn River at Seymour (top) and McCoys Bridge (bottom) – under long-term historic climate conditions – for the base case, select target filling curve options and options to reduce the target storage at Lake Eildon to 95%, 90%, 85% or 78% of FSL.

10.2 Daily time-step assessment

The use of monthly data to assess potential changes to flow regimes can mask important differences at a daily time-step. Therefore, the Stochastic Goulburn Environmental Flow Model (SGEFM) developed by the University of Melbourne (John, 2021) was also used to investigate expected changes to the flow regime downstream of Lake Eildon.

The SGEFM was originally developed to support the Australian Research Council Linkage Project *Vulnerabilities for Environmental Water Outcomes in a Changing Climate*. The model covers the Goulburn, Broken, Campaspe and Loddon systems, and was developed in consultation with DEECA, GMW, and the Goulburn Broken Catchment Management Authority.

The SGEFM represents the current water allocation frameworks and system operations in northern Victoria's river systems, including the management of environmental water and inter-valley transfers to the River Murray. It uses a monthly timestep to calculate water allocations and environmental and irrigation demands, and a custom disaggregation algorithm to model daily river flows (John et al., 2021b).

The SGEFM was previously used to support the update of environmental flow recommendations in the lower Goulburn (Kaiela) River (Horne et al., 2020), to understand interacting stressors to freshwater ecosystem outcomes (John et al., 2022), and to assess the effectiveness of different climate adaptation (John et al., 2021a) and constraint relaxation options in the Goulburn River. It has also recently been used to assess operating and infrastructure options for increasing flood mitigation at Lake Eppalock (HARC, 2023c).

The options described in Section 4 to change the target filling curve or reduce the target storage at Lake Eildon were simulated in the SGEFM for the period 1941 – 2021, assuming either long-term historic or post-1975 climate conditions. Figure 124 summarises the results for the base case and the options to change the target filling curve or reduce the target storage at Lake Eildon to 95%, 90%, 85% or 78% of the current FSL. This is done by plotting for each month of the year (starting in winter) the 10th, 25th, 50th (median), 75th and 90th percentile of daily flows at McCoys Bridge, as simulated over 1941 – 2021 for the base case and the various options.

Figure 124 demonstrates that:

- If the target filling curves are changed by delaying the target fill date to January 1 based on 75% exceedance inflows, there will be a reduction of flows in winter and an increase in autumn (Figure 28). This is because the May target filling point for Lake Eildon will be lower than currently the case, and therefore more flows will be passed in the lead-up, and there will be fewer spills in the subsequent months.
- If the target storage at Lake Eildon is reduced, there will be generally lower flows from August to October, and higher flows in the months either side. This is because there will be fewer spills from Lake Eildon in the generally wet months, but higher flows in the shoulder months because higher releases will be required to maintain the target storage below FSL.
- The degree of difference between the base case and option modelled increases as the target storage is reduced (i.e. 78% of current FSL vs 95% of current FSL).

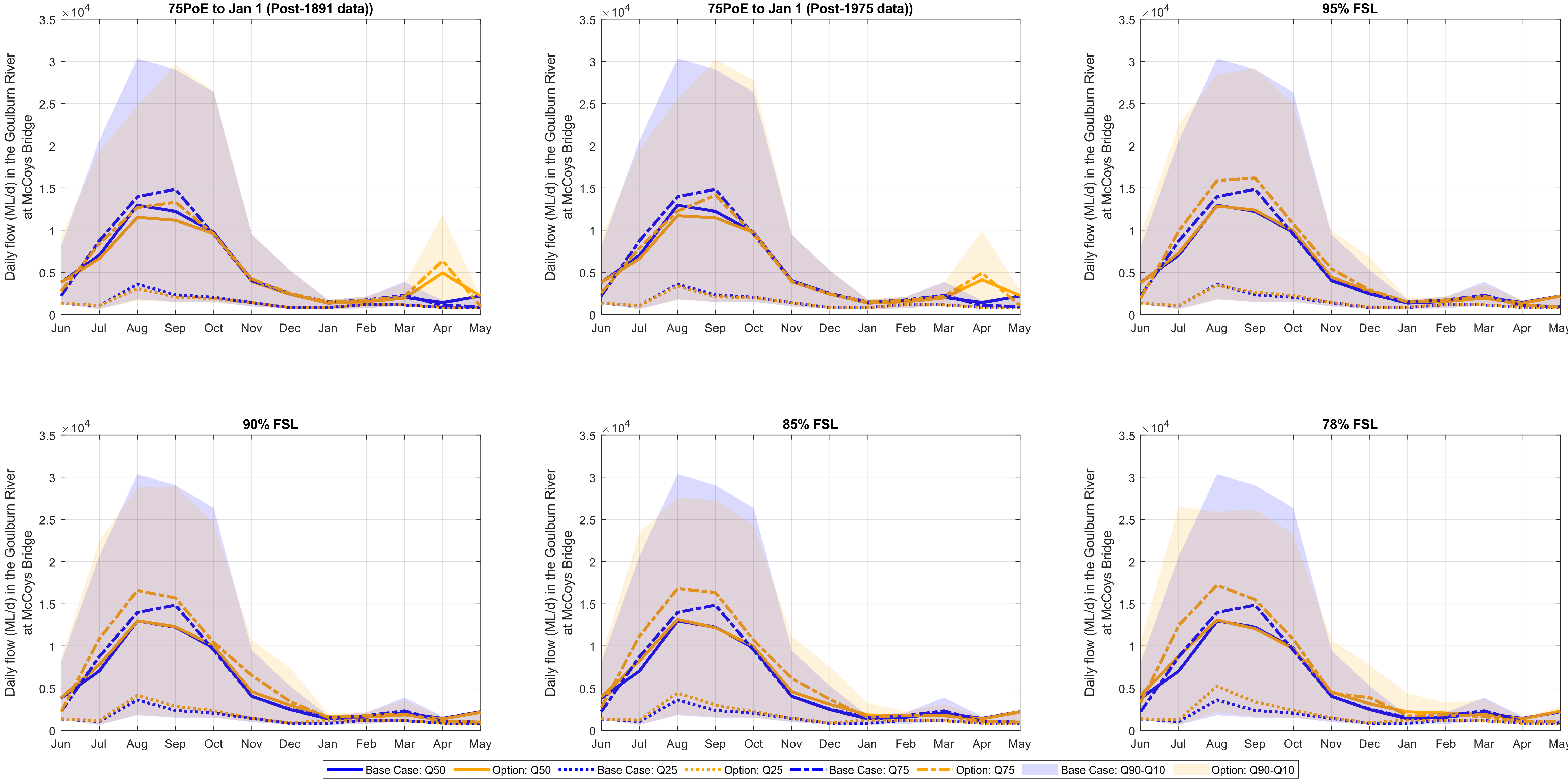


Figure 124: Simulated daily flows in the Goulburn River at McCoys Bridge – under long-term historic climate conditions – for the base case, select target filling options and options to reduce the target storage at Lake Eildon to 95%, 90%, 85% or 78% of FSL

Based on these results, it can be surmised that the options to change the target filling curve or reduce the target storage at Lake Eildon may have some negative environmental impacts, resulting from reduced flows in generally wetter months and increased flow in drier months. However, further investigations would be required to confirm this.

Figure 125 is a repeat of Figure 124 but for post-1975 rather than long-term historic climate conditions. The differences between the daily flow regime for the base case and options considered are generally similar to Figure 124. The main exception is that for the post-1975 simulations, there is less difference between the 90th percentile flows for the base case, and the options that involve reducing the target storage to 95%, 90%, 85% and 78% of FSL.

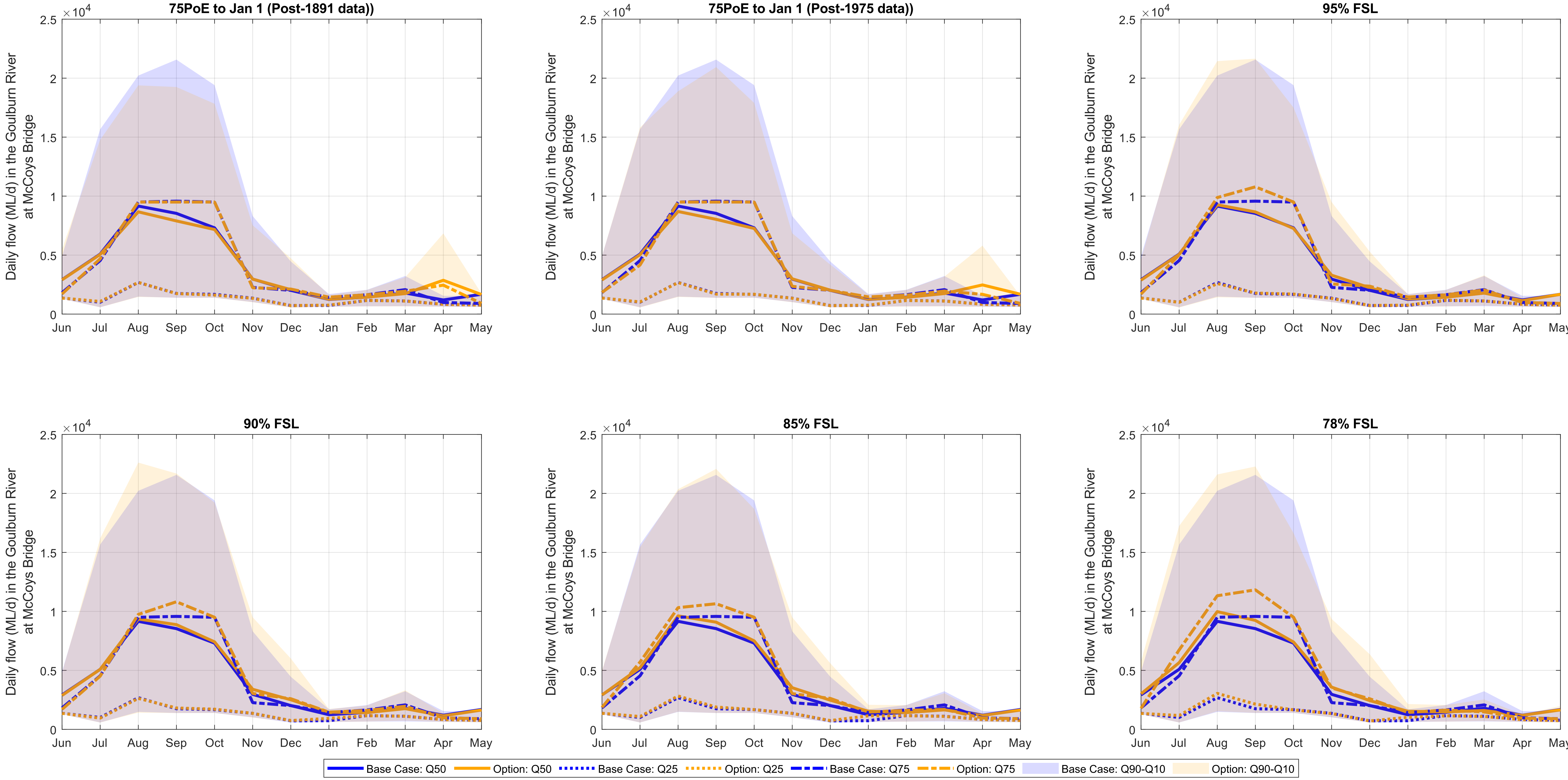


Figure 125: Simulated daily flows in the Goulburn River at McCoys Bridge – under post-1975 climate conditions – for the base case, select target filling options and options to reduce the target storage at Lake Eildon to 95%, 90%, 85% or 78% of FSL

11. Changes to downstream flooding

11.1 Flood class extents in Seymour

Figure 126 qualitatively describes the impacts of the minor, moderate and major flood class level at Seymour, and Figure 127 shows the extent of the 1% AEP flood (8.37 m on the Goulburn River gauge). The 1% AEP level at the Seymour gauge was previously estimated to be above the 1993 (6.65 m) and 2022 (8.25 m) flood levels, however, is below the flood of record which occurred in 1916 (estimated level of 8.9 m).

Furthermore, it is noted from the VICSES (2018) local flood guide that:

- Below minor flood class level, the Goulburn River breaks its banks causing flooding of low-lying farmland, parkland, low-lying roads and river crossings
- At minor flood class level, three of the local caravan parks and farmland along the Old Hume Highway begin to flood
- At moderate flood class level, some roads in Seymour begin to flood and the Goulburn River Caravan Park activates its evacuation plan
- At major flood class level Kings Park is flooded and the Goulburn Valley Highway is closed between Seymour Toyota and Redbank Road.

Figure 126: Goulburn River flood class levels at the Seymour gauge (VICSES, 2018)

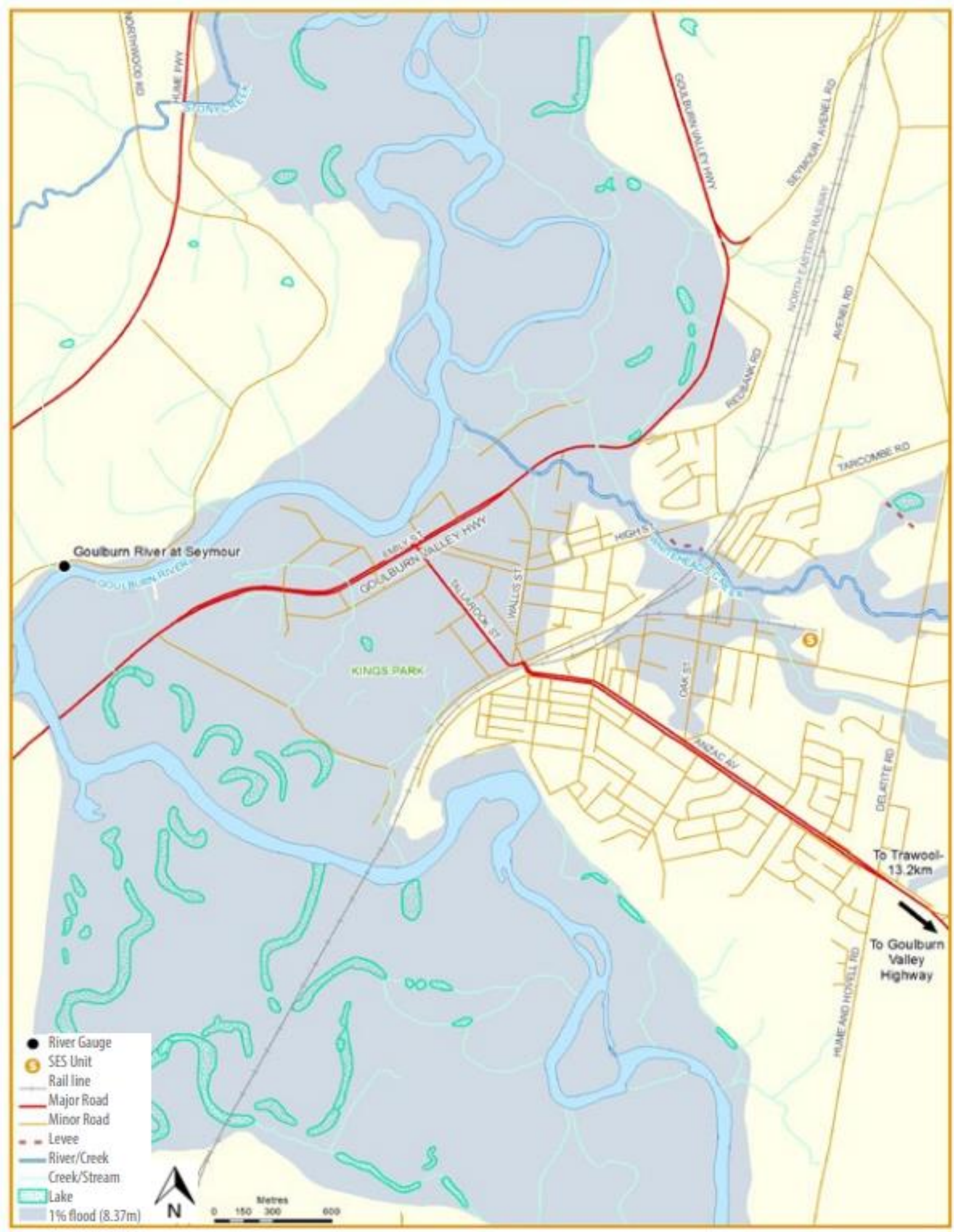


Figure 127: Flood extent map from VICSES (2018) local flood guide for Seymour

The options discussed in Section 4 may change the peak outflow frequencies (Section 6), and the general patterns of flow in the Goulburn River downstream of the dam. This report section describes how the changes to the downstream flow regime were modelled, and summarises the outcomes.

11.2 Potential changes if options were implemented

11.2.1 Flood peaks in Seymour

Figure 128 combines the RORB model results in Figure 108, Figure 109, Figure 112 and Figure 113 with the historic data previously introduced in Section 2.7.

Figure 128 shows that – as discussed in Section 7 – if the October 1993 and October 2022 floods were repeated and Lake Eildon was operated with a target storage of 95%, 90%, 85% and 78% of FSL then:

- The peak flow at Seymour for the October 1993 flood event would have likely reduced quite substantially if the target storage was 78% of FSL. In contrast, the options with a reduced target storage between 85% and 95% of FSL produced similar peak flows.
- The peak flow at Seymour for the October 2022 flood event would not change significantly, and would still have been above the major flood class level flow threshold even if Lake Eildon was operated with a reduced target storage of 78% of FSL.

Likewise, Figure 129 shows that – as discussed in Section 7 – if the October 1993 and October 2022 flood event were to be repeated and there were different pre-releases from Lake Eildon in the 2-days before the event then:

- The peak flow at Seymour would not have significantly changed. For example, the peak flow at Seymour was simulated to increase by up to 2% for the scenario which pre-released from Lake Eildon at moderate flood class level flow threshold.
- The peak flow at Seymour for the October 2022 flood event was simulated to increase by up to 11% if pre-releases from Lake Eildon were raised to the moderate flood class level flow threshold at Eildon.

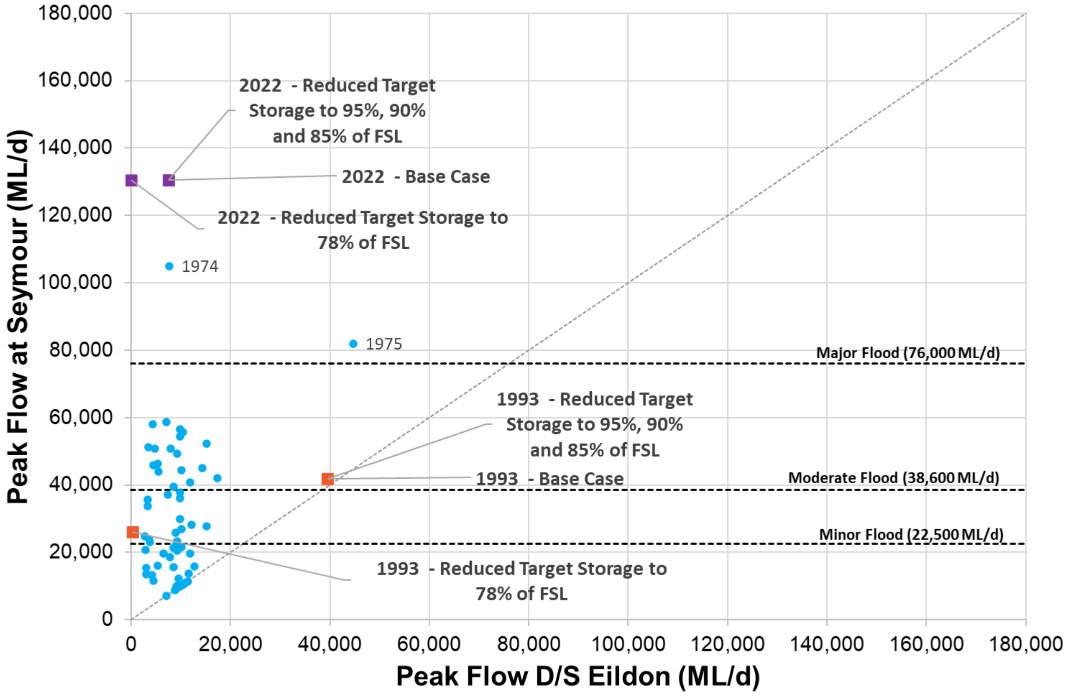


Figure 128: An indicative assessment of how the October 1993 and October 2022[25] flood at Seymour may have differed if Lake Eildon had a reduced target storage

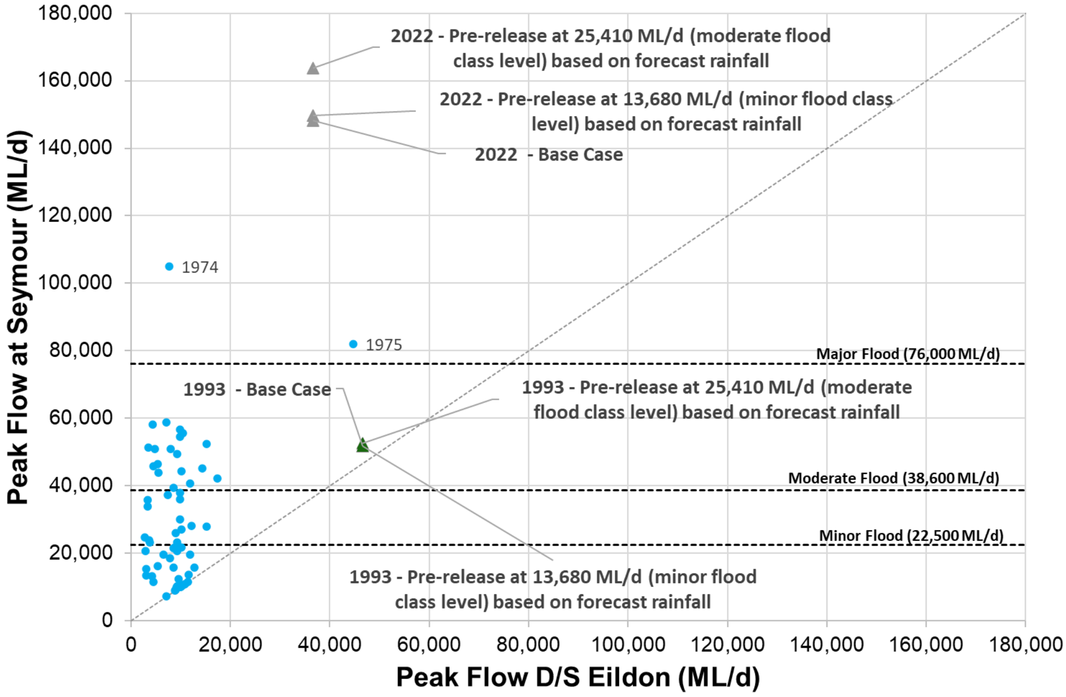


Figure 129: An indicative assessment of how the October 1993 and October 2022 flood at Seymour may have differed if pre-releases were increased or decreased

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[25] These values are lower than the recorded values because of lower starting water level informed by the monthly timestep water resources model. It is recognised that the DEECA daily Goulburn-Broken-Campaspe-Coliban-Loddon Source model would provide a more accurate starting reservoir position and using observed starting reservoir levels instead of modelled values would only have been possible for the base case, and not the options assessed.

11.2.2 Flood damages

The method described in Appendix C was used to approximate how tangible flood damages from Lake Eildon to Seymour vary according to the peak flow from storage[26]. The purpose of the analysis described in Appendix C is to undertake an assessment of the average annual damages (AAD) for the options to change the target filling curve and reduce the target storage. The results are shown in Figure 130, and demonstrate that most of the costs are incurred in Seymour. Table 46 shows the components that comprise the total values. Damages to residential and non-residential structures in Seymour become a larger component of total costs as the peak outflow from Lake Eildon increases.

The Goulburn and Broken Rivers Flood Study hydraulic model (TUFLOW) was used to estimate the relationship between the tangible flood damages downstream of Lake Eildon and steady-state flows along the Goulburn River (Figure 130).

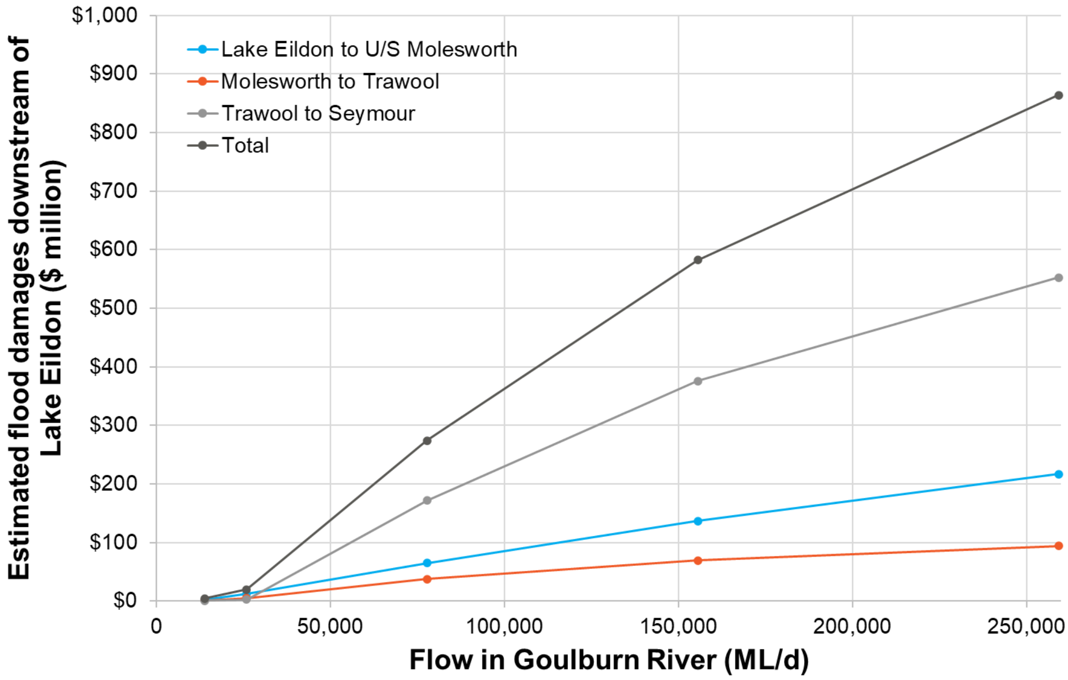

Figure 130: An indicative assessment of how tangible flood damages downstream of Lake Eildon vary with peak flow from storage

[26] This analysis does not account for the intangible damages caused by flooding, such as mental health impacts for individuals, or unwanted changes to community dynamics as well as the duration of inundation flood damages to agricultural land uses.

Table 46: Elements of the estimated total flood damages shown in Figure 130

Peak flow along Goulburn River		Approximate flood damages ($ million)																	
		Lake Eildon to U/S Molesworth						Molesworth to Seymour						Seymour					
m^3/s	ML/d	Residential structures	Non-residential structures	Roads	Agriculture*	Indirect costs	Total	Residential structures	Non-residential structures	Roads	Agriculture*	Indirect costs	Total	Residential structures	Non-residential structures	Roads	Agriculture*	Indirect costs	Total
160	14,000	0	0	1.3	0.2	0.5	0	0	0	1.1	0.2	0.4	1.7	0	0	0.7	0	0.2	1.0
300	25,920	1.9	1.4	5.4	0.9	2.9	10	0	0	3.1	0.6	1.2	10	0	0.6	1.3	0.1	0.6	2.6
900	77,760	10	10	30	2.6	10	60	1	2.6	20	2.7	8.7	40	20	80	20	0.6	40	170
1,800	155,520	20	20	60	3.8	30	140	10	10	30	3.5	20	70	30	220	30	1.1	90	380
3,000	259,200	40	30	90	4.4	50	220	10	20	40	3.7	20	90	50	340	30	1.2	130	550
4,000	345,600	50	40	90	4.6	60	250	10	20	50	3.7	30	110	50	420	40	1.2	150	660
7,500	648,000	80	60	110	4.8	80	330	20	30	70	3.9	40	170	100	690	50	1.4	250	1100
20,000	1,728,000	160	120	160	5	140	590	90	90	150	4.4	100	430	420	1190	100	1.8	520	2230

*Agricultural flood damages have been assessed on a peak flow basis. The duration of inundation has not been considered as part of this investigation because a daily water resources model was not provided for this investigation.

The tangible flood damages along the Goulburn River for the 2022 base case scenario was estimated to be $410 million (Figure 131 and Table 47). The tangible flood damages in Seymour contributed to approximately 80% of the estimated total cost and the other 20% was between Lake Eildon to upstream of Seymour. For context, Deloitte (2023)[27] estimated the tangible cost of the October 2022 flood to be $432 million for the local government areas (LGAs) of Mitchell, Moira, Murrundindi and Strathbogie. Only the Mitchell and Murrundindi LGAs are within the study area for this assessment of potential options for increasing the flood mitigation provided by Lake Eildon, however, it is reassuring that the estimated tangible flood damages for the October 2022 flood are the same order of magnitude as the Deloitte (2023) estimate.

The flood damages were estimated for the reduced target storage of 78% of FSL option, and Figure 131 shows how tangible flood damages from Lake Eildon to Seymour would differ if the 1993 or 2022 floods were repeated. The values are summarised in Table 47 and Table 48, and show for example that the estimated difference in 1993 and 2022 flood damages between the base case 78% target storage option is approximately $100 million and $14 million, respectively. The flood damage assessments for the changed target filling curve and other target storage options (95%, 90% and 85% of FSL) have not been plotted because they would have made minimal difference to the flood damages in 1993 or 2022 (see Section 7.2).

[27] https://www.parliament.vic.gov.au/floodinquiry

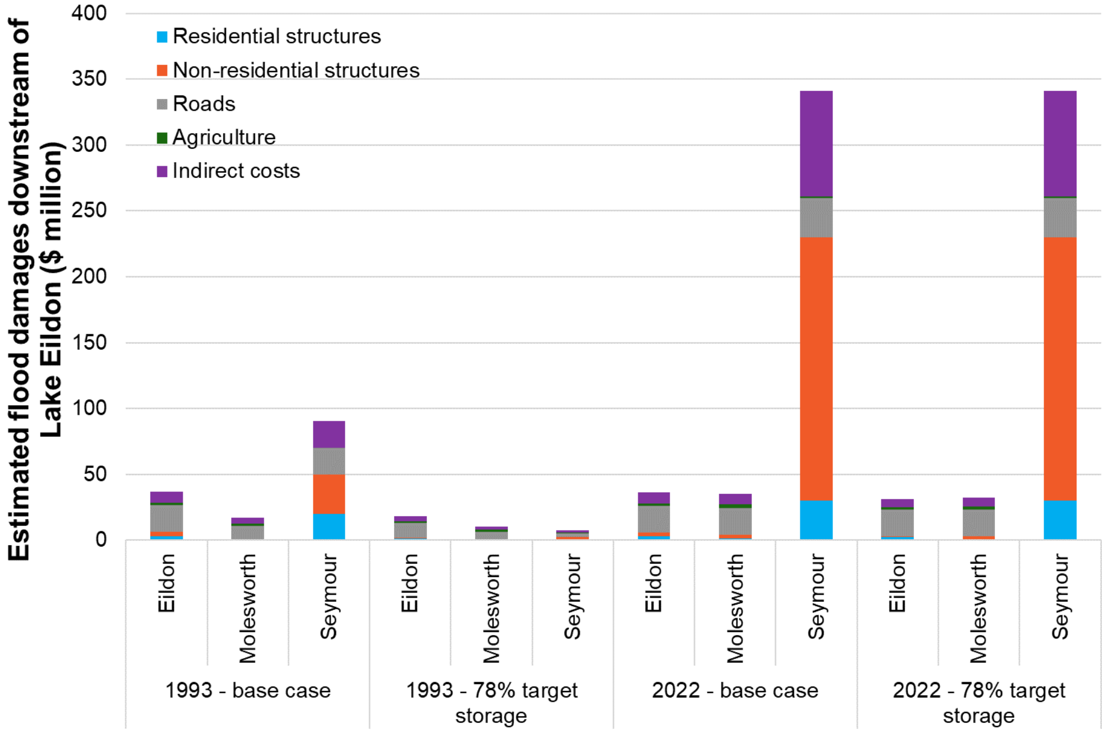

Figure 131: An indicative assessment of how tangible flood damages from Lake Eildon to Seymour would differ if the 1993 or 2022 floods were repeated but with the reduced target storage of 78% of FSL in place. The other target filling curve and reduced target storage options (95%, 90% and 85% of FSL) have not been plotted due to the similar reservoir stating water levels as summarised in Section 7.2.1 and Section 7.2.2.

Table 47: Elements of the estimated total flood damages shown in Figure 131

Event – Option	Approximate flood damages ($ million)																	
	Lake Eildon to U/S Molesworth						Molesworth to Seymour						Seymour					
	Residential structures	Non-residential structures	Roads	Agriculture*	Indirect costs	Total	Residential structures	Non-residential structures	Roads	Agriculture*	Indirect costs	Total	Residential structures	Non-residential structures	Roads	Agriculture*	Indirect costs	Total
1993 – base case	3.1	3.5	20	1.8	8.6	40	0	0.9	10	1.9	4.6	20	20	30	20	0.4	20	80
1993 – 78% target storage	1.6	0.6	11	1	4.3	20	0	0	6.7	1.2	2.5	10	0	2.4	3	0.3	1.7	10
2022 – base case	3.2	2.9	20	1.9	8.3	40	1.2	3.2	20	2.7	8.1	30	30	200	30	1.0	80	340
2022 – 78% target storage	2.3	1	20	1.6	6.2	30	0.6	2.6	20	2.5	7	30	30	200	30	0.9	80	340

*Agricultural flood damages have been assessed on a peak flow basis. The duration of inundation has not been considered as part of this investigation because a daily water resources model was not provided for this investigation.

Table 48: Tangible flood damage summary at Lake Eildon, Molesworth and Seymour to reduced target storage options for 95%, 90%, 85% and 78% of FSL capacity if the October 1993 and October 2022 flood was repeated. The target filling curve options have not been tabulated because of the same results as the base case scenario.

Event – Option	Approximate flood damages (in millions)				
	Lake Eildon to U/S Molesworth (rounded)	Molesworth to Seymour (rounded)	Seymour (rounded)	Total (rounded)	Difference v base case
1993 – base case	$40	$20	$80	$140	-
1993 – 95% target storage	$40	$20	$80	$140	$0
1993 – 90% target storage	$40	$20	$80	$140	$0
1993 – 85% target storage	$40	$20	$80	$140	$0
1993 – 78% target storage	$20	$10	$10	$40	$100
2022 – base case	$40	$30	$340	$410	-
2022 – 95% target storage	$40	$30	$340	$410	$0
2022 – 90% target storage	$40	$30	$340	$410	$0
2022 – 85% target storage	$40	$30	$340	$410	$0
2022 – 78% target storage	$30	$30	$340	$400	$14

Table 49 and Table 50 combines the information in Section 8.1 with the flood damage assessment results described above, to show the approximate initial capital costs versus approximate reduction in tangible flood damages for peak outflows with an estimated AEP of 10%, 1% and 0.2% (Table 49) and those experienced in 1993 and 2022 (Table 50). This comparison shows that:

- The extent of avoided damages varies by both the flood magnitude and option. This means that if any of the options considered were to be implemented, the time to recoup the costs in the form of avoided damages will depend on the timing and magnitude of future flooding along the Goulburn River.
- The options to change the target filling curves – to be based on the 75PoE inflow conditions and a later fill date – begin to have a minor impact on flood damages for larger magnitude floods; however, they would not have changed the flood damages during the 1993 and 2022 floods.
- The options to reduce the target storage generally have relatively low ratios of avoided damages to initial capital cost for the scenarios modelled. However, the agricultural loss component of the estimated flood damages is likely to be underestimated because the assessment is based on changes in peak flows rather than the timing or duration of flooding. On the other hand, the costs of implementing the option do not include the ongoing socio-economic consequences of reducing the volume of water stored in the Goulburn system, lost revenue for GMW, environmental impacts and the recreational impacts of holding the Lake Eildon water level below the current FSL.
- The avoided flood damages and initial capital cost ratios for the rarer AEP events tend to be higher compared with the frequent events (e.g. 10% AEP). This is because the initial capital cost to offset the supply reliability impacts is fixed, but the avoided flood damages vary by flood magnitude. Section 11.3 therefore considers how estimates of average annual flood damages avoided compare with the initial capital cost of implementing the options.

Table 49: Summary of approximate initial capital costs versus approximate reduction in tangible flood damages resulting from peak outflows from Lake Eildon that have an estimated AEP of 10%, 1% and 0.2%

Peak outflow from Lake Eildon – option	Approximate peak flow (ML/d)		Approximate value (in millions)		Ratio
	Eildon outflow	Seymour	Reduction in flood damage between Lake Eildon and Seymour	Initial capital cost*	
10% AEP peak outflow					
Base case	^10,300	74,400	-	-	-
Change target filling curves (75PoE to Jan 1 (post-1891 data))	10,100	74,400	0.3	10	< 0.1 : 1
Change target filling curves (75PoE to Jan 1 (post-1975 data))	10,200	74,400	0.2	7.5	< 0.1 : 1
95% target storage	10,200	74,400	0.3	20	< 0.1 : 1
90% target storage	10,100	74,400	0.5	50	< 0.1 : 1
85% target storage	10,100	74,400	0.6	†100	< 0.1 : 1
78% target storage	10,000	74,400	0.8	†155	< 0.1 : 1
1% AEP peak outflow					
Base case	^24,000	170,000	-	-	-
Change target filling curves (75PoE to Jan 1 (post-1891 data))	17,400	170,000	8.8	10	0.9 : 1
Change target filling curves (75PoE to Jan 1 (post-1975 data))	17,500	170,000	8.3	7.5	1.1 : 1
95% target storage	20,200	170,000	6.6	20	0.3 : 1
90% target storage	17,000	170,000	9.9	50	0.2 : 1
85% target storage	11,300	170,000	13.2	†100	0.1 : 1
78% target storage	11,000	170,000	13.7	†155	< 0.1 : 1
0.2% AEP peak outflow					
Base case	^90,800	250,000	-	-	-
Change target filling curves (75PoE to Jan 1 (post-1891 data))	64,700	250,000	38	10	4 : 1
Change target filling curves (75PoE to Jan 1 (post-1975 data))	66,300	250,000	36	7.5	5 : 1
95% target storage	73,500	250,000	31	20	2 : 1
90% target storage	43,200	250,000	65	50	1.3 : 1
85% target storage	34,800	250,000	78	†100	0.8 : 1
78% target storage	31,300	250,000	83	†155	0.5 : 1

^ These values are lower than quoted by HARC (2017) for the associated AEP, because the base case Lake Eildon drawdown distribution provided by DEECA for this study differs to the drawdown distribution used by HARC (2017)

* For the estimates of costs:

- The costs associated with offsetting the supply reliability impacts are approximate, as discussed in Section 8.
- The ongoing socio-economic costs associated with reducing the volume of water stored in the Goulburn system (if the target storage at Lake Eildon is reduced) are not included.

† A range of initial capital costs is provided in Table 44, however, the benefit-cost ratio is a similar order of magnitude if the high or low estimates of initial capital costs are used instead.

Table 50: Summary of approximate initial capital costs versus approximate reduction in tangible flood damages resulting from peak outflows from Lake Eildon experienced in 1993 and 2022.

Event – Option	Approximate value (in millions)		Ratio
	Reduction in flood damage between Lake Eildon and Seymour	Initial capital cost*	
1993 – base case	-	-	-
1993 – Change target filling curves (75PoE to Jan 1 (post-1891 data))	0	10	< 0.1 : 1
1993 – Change target filling curves (75PoE to Jan 1 (post-1975 data))	0	7.5	< 0.1 : 1
1993 – 95% target storage	0	20	< 0.1 : 1
1993 – 90% target storage	0	50	< 0.1 : 1
1993 – 85% target storage	0	†100	< 0.1 : 1
1993 – 78% target storage	100	†155	0.6 : 1
2022 – base case	-	-	-
2022 – Change target filling curves (75PoE to Jan 1 (post-1891 data))	0	10	< 0.1 : 1
2022 – Change target filling curves (75PoE to Jan 1 (post-1975 data))	0	7.5	< 0.1 : 1
2022 – 95% target storage	0	20	< 0.1 : 1
2022 – 90% target storage	0	50	< 0.1 : 1
2022 – 85% target storage	0	†100	< 0.1 : 1
2022 – 78% target storage	14	†155	0.1 : 1

* For the estimates of costs:

- The costs associated with offsetting the supply reliability impacts are approximate, as discussed in Section 8.
- The ongoing socio-economic costs associated with reducing the volume of water stored in the Goulburn system (if the target storage at Lake Eildon is reduced) are not included.

† A range of initial capital costs is provided in Table 44, however, the benefit-cost ratio is a similar order of magnitude if the high or low estimates of initial capital costs are used instead.

11.2.3 Inundation maps

Inundation maps for the scenarios modelled in Figure 130 and Figure 131 and tabulated in Table 46 to Table 48 are provided in Appendix G.

11.3 Average annual damages

The outflow flood frequency curves from Section 6.2 and Section 6.4 were combined with the Lake Eildon peak outflow vs downstream damage curve (Figure 130) to estimate the average annual damages (AAD, or the average annual flood damages over a long period of time) for the base case and each option. The results are summarised in Table 51.

These values are approximate because:

- The assessment has been based on the peak flows estimated between Lake Eildon and Seymour, and does not consider the duration of inundation.
- The relationship between peak outflows from Lake Eildon and flood damages from Lake Eildon to Seymour is approximate (Figure 130).
- Flood damages downstream of Seymour have not been considered.
- Estimates of AAD may change once the hydraulic modelling is completed as part of the Goulburn and Broken Rivers Flood Study, which includes calibration of the hydraulic model to inundation extents observed during the October 1993 and October 2022 floods.

Table 51: Estimates of average annual flood damages under the base case and options assessed. The limitations of these estimates are listed above.

Option	Approximate average annual damages ($ millions)
Base case	23.2
Option 1 – Change target filling curves	
Change target filling curves (75PoE to Jan 1 (post-1891 data))	23.1
Change target filling curves (75PoE to Jan 1 (post-1975 data))	23.1
Option 2 – Reduce target storage	
95% target storage	23.1
90% target storage	23.0
85% target storage	22.9
78% target storage	22.9

Table 52 shows how the average annual damages avoided under each option (versus the base case) compares with the initial capital cost. For the reasons stated below Table 52, the actual ratios of avoided damages to initial capital costs need to be used with caution, but the values show the relative order of options in terms of benefit versus cost.

The table demonstrates:

- The options to change the target filling curve or reduce the target storage have low benefit-cost ratios. For example, the avoided flood damages were in the order of $270,000 per annum for the option to reduce the target storage to 95% of FSL, whereas the initial capital cost to offset the supply reliability changes to LRWS entitlement holders was $20 million dollars.

- The options to change the target filling curve by delaying the target fill date to Jan 1 with 75PoE inflows have a marginally higher benefit - cost ratio; however, the value is still < 1.
- For the options that reduce the target storage to 78% or 85% of FSL, the middle value of LRWS entitlement offsets have been used for the calculation of the benefit-cost ratio. Adopting the higher or lower estimates does not change the outcome of the ratio being less than 0.1 : 1.

Table 52: Estimates of avoided damages vs initial capital costs.

Option	Approximate benefit-cost ratio (50 years, 6% discount)		
	Avoided damages ($ m)^	Initial capital cost ($ m)*	Ratio
Option 1 – Change target filling curves			
Change target filling curves (75PoE to Jan 1 (post-1891 data))	3.1	10	0.3 : 1
Change target filling curves (75PoE to Jan 1 (post-1975 data))	2.9	7.5	0.4 : 1
Option 2 – Reduce target storage			
95% target storage	2.6	20	0.1 : 1
90% target storage	4.7	50	< 0.1 : 1
85% target storage	5.9	†100	< 0.1 : 1
78% target storage	6.7	†155	< 0.1 : 1

^ The estimates of avoided damages are approximate, because:

- The relationship between peak flows along the Goulburn River and flood damages from Lake Eildon to Seymour is approximate, and has been interpolated (Figure 130).
- Flood damages downstream of Seymour have not been considered.
- Estimates of AAD may change once the hydraulic modelling is completed as part of the Goulburn and Broken Rivers Flood Study.

* For the estimates of costs:

- The costs associated with offsetting the supply reliability impacts are approximate, as discussed in Section 8.
- The ongoing socio-economic costs associated with reducing the volume of water stored in the Goulburn system (if the target storage at Lake Eildon is reduced) are not included.

† For the initial capital costs for 78% and 85% reduced target storage:

- A range of initial capital costs is provided in Table 44, however, the benefit-cost ratio is a similar order of magnitude if the high or low estimates of initial capital costs are used instead.

11.3.1 Sensitivity testing using the SGEFM

The results from Section 6.4, Section 8.2 and Section 11.2.2 were used to estimate how the ratios between avoided flood damages, and the costs of offsetting water supply reliability impacts, differ if the Lake Eildon drawdown distributions and Goulburn system allocations are simulated using the SGEFM instead of the GSM.

Table 53 shows that for each option the ratio was similar. This is because, even though the reduction of peak outflow frequencies (Section 6.4) is higher when the Lake Eildon drawdown distributions are modelled using the SGEFM, so are the costs to offset the supply reliability changes (Section 8.2). The ratio between the avoided flood damages and initial cost of water recovery is therefore similar. It would also be prudent to repeat this assessment using Lake Eildon drawdown distributions and Goulburn system allocations simulated by the DEECA daily Goulburn-Broken-Campaspe-Coliban-Loddon Source model (which is intended to replace the GSM in the near future).

Table 53: Estimates of avoided damages vs initial capital costs – sensitivity testing

Option	Approximate benefit-cost ratio (50 years, 6% discount)					
	GSM			SGEFM		
	Avoided damages ($ m)^	Initial capital cost ($ m)*	Ratio	Avoided damages ($ m)^	Initial capital cost ($ m)*	Ratio
Option 1 – Change target filling curves						
Change target filling curves (75PoE to Jan 1 (post-1891 data))	3.1	10	0.3 : 1	8.4	60	0.1 : 1
Change target filling curves (75PoE to Jan 1 (post-1975 data))	2.9	7.5	0.4 : 1	7.0	50	0.1 : 1
Option 2 – Reduce target storage						
95% target storage	2.6	20	0.1 : 1	10	80	0.1 : 1
90% target storage	4.7	50	< 0.1 : 1	12	170	< 0.1 : 1
85% target storage	5.9	†100	< 0.1 : 1	16	270	< 0.1 : 1
78% target storage	6.7	†155	< 0.1 : 1	20	460	< 0.1 : 1

^ The estimates of avoided damages are approximate, because:

- The relationship between peak flows along the Goulburn River and flood damages from Lake Eildon to Seymour is approximate, and has been interpolated (Figure 130).
- Flood damages downstream of Seymour have not been considered.
- Estimates of AAD may change once the hydraulic modelling is completed as part of the Goulburn and Broken Rivers Flood Study.

* For the estimates of costs:

- The costs associated with offsetting the supply reliability impacts are approximate, as discussed in Section 8.
- The ongoing socio-economic costs associated with reducing the volume of water stored in the Goulburn system (if the target storage at Lake Eildon is reduced) are not included.

† For the initial capital costs for 78% and 85% reduced target storage:

- A range of initial capital costs is provided in Table 44 however for demonstrative purposes the middle initial capital cost has been adopted.

12. Conclusion

This assessment of potential operating options for increasing the flood mitigation provided by Lake Eildon examined six options. The initial assessment (referred to as stage 1) included assessments of the water resource implications, flood frequency changes at Lake Eildon, and anticipated changes to 1993 and 2022 peak outflows from Lake Eildon (if the events were repeated) for the following options:

- Option 1 – Change the target filling curves at Lake Eildon
- Option 2 – Reduce the target storage at Lake Eildon
- Option 3 – Reduce the target storage at Lake Eildon based on climate signals that indicate 'wet' conditions
- Option 4 – More significant pre-releases at Lake Eildon based on forecast rainfall
- Option 5 – Increase the maximum allowable surcharge level at Lake Eildon
- Option 6 – Restrict the maximum outflows from Lake Eildon

After the initial assessment, four of the six options were found to be not robust ways to increase the flood mitigation provided by Lake Eildon. A brief justification for each option is presented below:

- The option to reduce the target storage based on climate signals that indicated 'wet' conditions (option 3) was not a robust option because the climate signals tested were generally poor predictors of monthly inflows and storage volumes at Lake Eildon. This meant that – when combined with the influence of downstream flow constraints during wet periods – the option to reduce target storage based on climate signals was unlikely to increase the flood mitigation provided by Lake Eildon. For example, the 1993 flood occurred during El Niño conditions and during spring 2022 downstream flow constraints limited the ability to provide additional airspace.
- Increasing pre-releases from Lake Eildon based on forecast rainfall (option 4) was not deemed to be a robust option, because the uncertainty in the predicted location of where rainfall will be heaviest will constrain the degree to which storage operators can confidently make pre-releases without either reducing the water available to entitlement holders or making downstream flooding worse. Furthermore, the event-based analysis of the October 1993 and October 2022 floods showed that higher pre-releases (i.e. at the moderate flood class level flow threshold downstream of Lake Eildon), the peak flows would have increased at Seymour by up to 11%.
- The option to change the maximum surcharge (option 5) was not deemed to be a robust option because it will increase the duration of Lake Eildon outflows above the minor, moderate and major flood class level flow thresholds at Eildon as well as materially increase the likelihood of dam overtopping during back-to-back floods.
- The option of restricting the maximum outflow from Lake Eildon (option 6) would extend the duration of outflows above the minor, moderate or major flood class level flow thresholds at Eildon, and increase dam safety risks.

The two options which were progressed to stage 2 of the assessment were changing the target filling curve (option 1) and reducing the target storage (option 2). These options did increase the flood mitigation provided by Lake Eildon; however, the cost of offsetting supply reliability impacts outweighed the avoided flood damages.

The main reason for the low benefit to cost ratio is that the flood mitigation benefits provided by the changes to target filling curve (option 1) and reduced target storage (option 2) diminish the further downstream the flood frequencies are assessed i.e. the degree of difference between the frequency estimates reduce by Molesworth and the difference is minor at Seymour.

This happens because the tributary flows downstream of Eildon from the Rubicon River and Acheron River influence the peak flows at towns such as Molesworth, and inflows from the Yea River, King Parrot Creek, Sugarloaf Creek and Sunday Creek influence the peak flows at towns such as Seymour. To explain this in an alternative way, the catchment area of the Goulburn River between Lake Eildon and Seymour (i.e. downstream of Lake Eildon) is approximately 4,500 km² while the Lake Eildon catchment area is approximately 3,900 km². This means that changes to operations at Eildon have less influence on reducing the overall avoided damages downstream. In contrast, the approximate initial capital cost of water shares to implement these options ranges from $7.5 million to $266 million.

When looking at the 1993 and 2022 floods, the only option that would have made a difference to what was actually observed during these floods, would have been holding the storage to a reduce level of 78% FSL. If option 1 or any other target storage within option 2 was implemented, there would have been no material difference to the flows observed downstream of Lake Eildon, Molesworth and Seymour.

The assessment also looked at other impacts from changing the filling curve (option 1) and reducing the volume of water stored in Lake Eildon (option 2). Both options would change the downstream flow regime in the Goulburn River, by reducing flows in generally wetter months and increasing them in drier months. This may have negative environmental impacts. however, further investigations would be required to confirm this.

For option 2, there would also be some recreational impacts, because the water body would be smaller and the distance between community and recreational facilities (e.g. holiday accommodation) and the water's edge would increase.

These conclusions also need to be read with the following caveats in mind:

Given the time available for this study, existing models were used, as made available by DEECA and the GBCMA. When these models are updated in future (for example by finalising the calibration of the RORB and TUFLOW model to October 2022 flood records), the results presented in this report may become superseded., However, the estimated ratios of avoided flood damages to the initial capital cost to implement the various options would need to shift by a substantial amount for this to have a material impact on the conclusions of this study.

The potential for operating options to increase the flood mitigation provided by Lake Eildon has been assessed in this study using both a joint-probability and event-based approach to simulating floods. This has demonstrated that the additional flood mitigation from each option varies depending on the specific nature of the flood (e.g. peak, volume, sequencing), and the relative differences between options will therefore vary by event.

The estimates of avoided flood damages included in this report are approximate. This is because a) the relationship between peak outflows from Lake Eildon and flood damages from Lake Eildon to Seymour is approximate, and has been interpolated from a steady-state assessment of flow along the Goulburn River; b) the assessment of agricultural damages was based on expected changes in peak flows, rather than the timing and duration of flooding, and c) flood damages downstream of Seymour were not considered. Estimates of average annual damages may also change once the Goulburn and Broken Rivers Flood Study is completed.

The modelling of how the Lake Eildon storage trace would behave with a reduced target storage, and hence affect downstream flood frequencies, was done prior to the assessment of the water recovery required to offset the reliability impacts. If the volume of water shares in the Goulburn system was reduced, this in turn would change the demand for water and hence the storage trace. Therefore, iterative modelling would be required to gain a more precise estimate of the increased flood mitigation vs water recovery applicable for a given target storage and to a lesser degree the different target filling curves. This type of iteration has not been completed as part of this technical assessment.

The costs estimated to offset the supply reliability impacts do not include the socio-economic consequences of reducing the volume of water stored for entitlement holders in the Goulburn system, or the lost revenue for GMW. The impact of the options on Traditional Owner values is also yet to be assessed.

Finally, this assessment has been informed by datasets and models that represent historic climate conditions, either over the full period of record or post-1975. Appendix F provides some commentary on how future climate change may influence the hydrological behaviour of the Goulburn system, and the effectiveness of the potential operating options for increasing the flood mitigation provided by Lake Eildon. In summary, the most recent research suggests that as the climate warms there will be reduced water availability in the Goulburn system, and worse flooding because of increased rainfall intensities. However, the range of potential changes to rainfall and runoff in response to a warmer climate is large, and therefore it will be important to also consider the future adaptability of the options if one or more is selected for further investigation.

Further work could be done to improve aspects of this technical assessment. This includes:

- Using long-term time series of modelled flows from the daily Goulburn-Broken-Campaspe-Coliban-Loddon-Source model to characterise the expected change in the timing and duration of flooding, and how this will impact agricultural losses.
- Assessing the costs and benefits of different potential ways for recovering water shares.
- Refining the initial assessments of the expected costs and benefits to existing recreational and environmental values around Lake Eildon and downstream.
- A more detailed assessment of how potential future climate change is likely to influence flood frequencies downstream of Lake Eildon.

However, doing additional work is not expected to change the conclusion that the cost of offsetting reliability of supply changes will be greater than the avoided flood damages for the Lake Eildon operating options considered in this study.

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Appendix A Sensitivity of post-1975 climate inputs for average February allocations for entitlement holders

Table A1: Modelled average February allocations (July 1891 – June 2022) for 95PoE inflow conditions to HRWS and LRWS in the Goulburn system, using post-1975 climate inputs.

Option	HRWS*	LRWS*
Base Case (95PoE to Oct 1 (Post-1891 data))	**95.7%**	**32.1%**
95PoE to Dec 1 (post-1891 data)	95.7%	32.1%
95PoE to Jan 1 (post-1891 data)	95.7%	32.0%
95PoE to Jan 1 (post-1975 data)	95.7%	32.0%

Table A2: Modelled average February allocations (July 1891 – June 2022) for 85PoE inflow conditions to HRWS and LRWS in the Goulburn system, using post-1975 climate inputs.

Option	HRWS	LRWS
Base Case (95PoE to Oct 1 (Post-1891 data))	**95.7%**	**32.1%**
85PoE to Oct 1 (post-1891 data))	95.7%	31.9%
85PoE to Dec 1 (post-1891 data)	95.7%	31.9%
85PoE to Jan 1 (post-1891 data)	95.6%	31.8%
85PoE to Jan 1 (post-1975 data)	95.6%	31.9%

Table A3: Modelled average February allocations (July 1891 – June 2022) for 75PoE inflow conditions to HRWS and LRWS in the Goulburn system, using post-1975 climate inputs.

Option	HRWS	LRWS
Base Case (95PoE to Oct 1 (Post-1891 data))	**95.7%**	**32.1%**
75PoE to Oct 1 (post-1891 data))	95.6%	32.1%
75PoE to Dec 1 (post-1891 data)	95.7%	31.8%
75PoE to Jan 1 (post-1891 data)	95.6%	31.6%
75PoE to Jan 1 (post-1975 data)	95.6%	31.7%

Table A4: Modelled average February allocations (July 1891 – June 2022) for reduced target storage options to HRWS and LRWS in the Goulburn system, using post-1975 climate inputs.

Option	HRWS	LRWS
Base Case	**95.7%**	**32.1%**
95% FSL	95.6%	31.4%
90% FSL	95.5%	30.3%
85% FSL	95.5%	27.9%
78% FSL	95.4%	24.2%

Table A5: Modelled average February allocations (July 1891 – June 2022) for 85% reduced target storage based on climate signals that predict 'wet' years to HRWS and LRWS in the Goulburn system, using post-1975 climate inputs.

Option	HRWS	LRWS
Base Case	**95.7%**	**32.1%**
Reducing target storage based on TPI	95.7%	32.0%
Reducing target storage based on IOD	95.7%	31.9%
Reducing target storage based on SOI	95.7%	32.0%

Appendix B Design rainfall space-time patterns

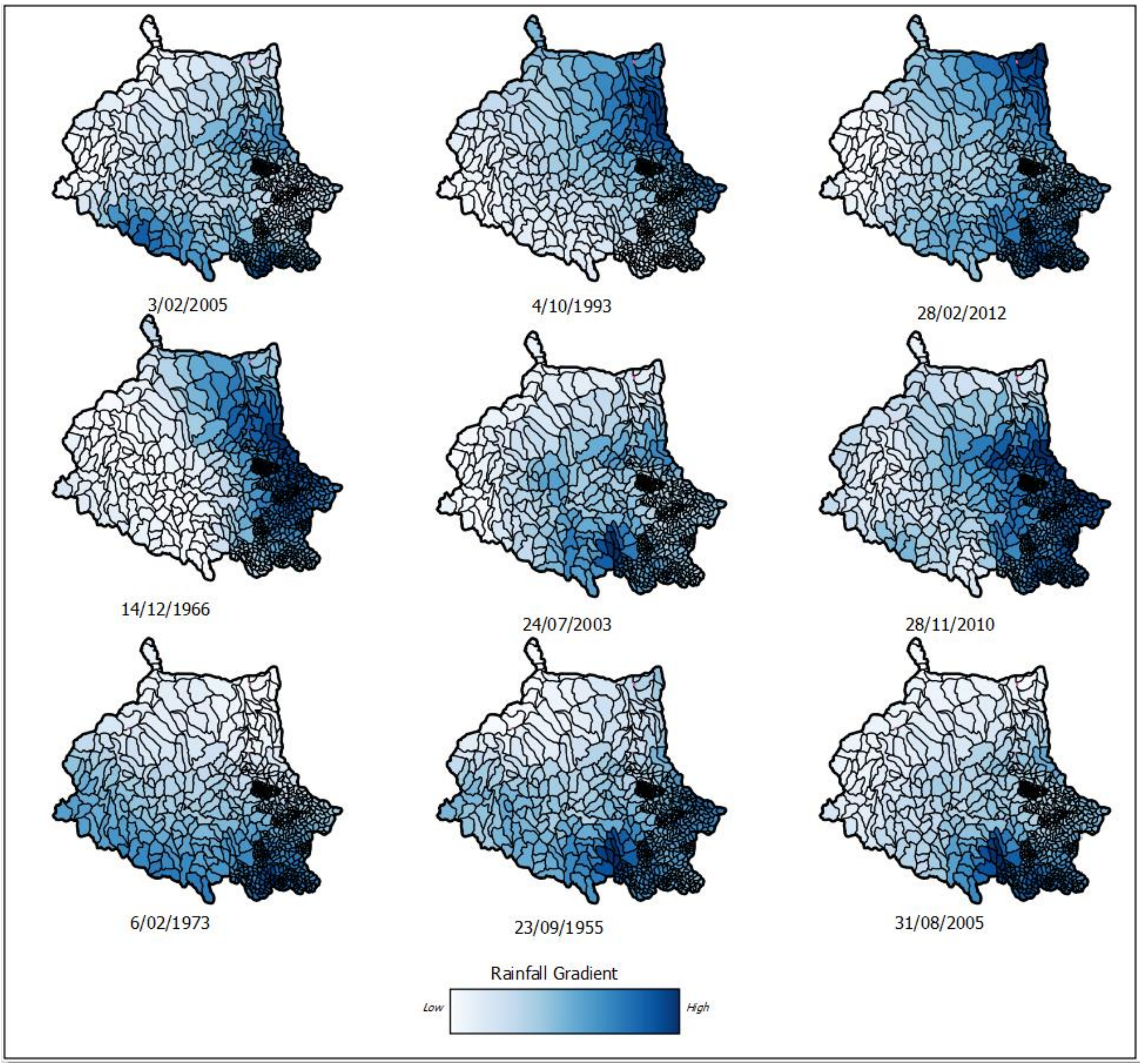


Figure B-1: Example set of 24-hour design rainfall space-time patterns

Appendix C Comparison with HARC (2017) results

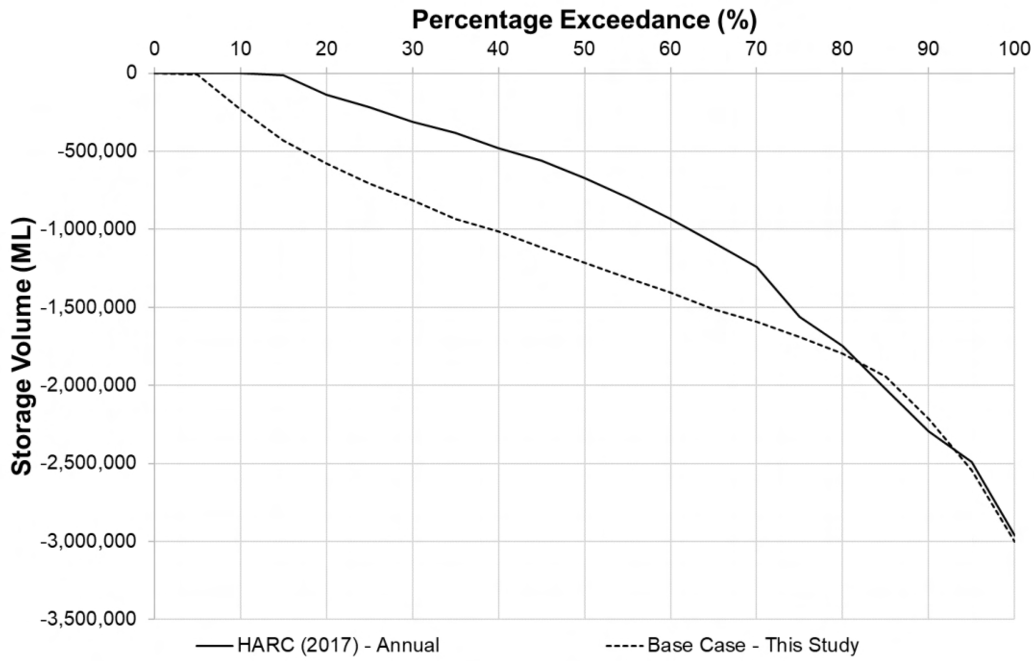


Figure C1: Lake Eildon drawdown curve used in RORB by HARC (2017), versus the base case drawdown curve available for this technical assessment. Both curves are based on the GSM results available at the time.

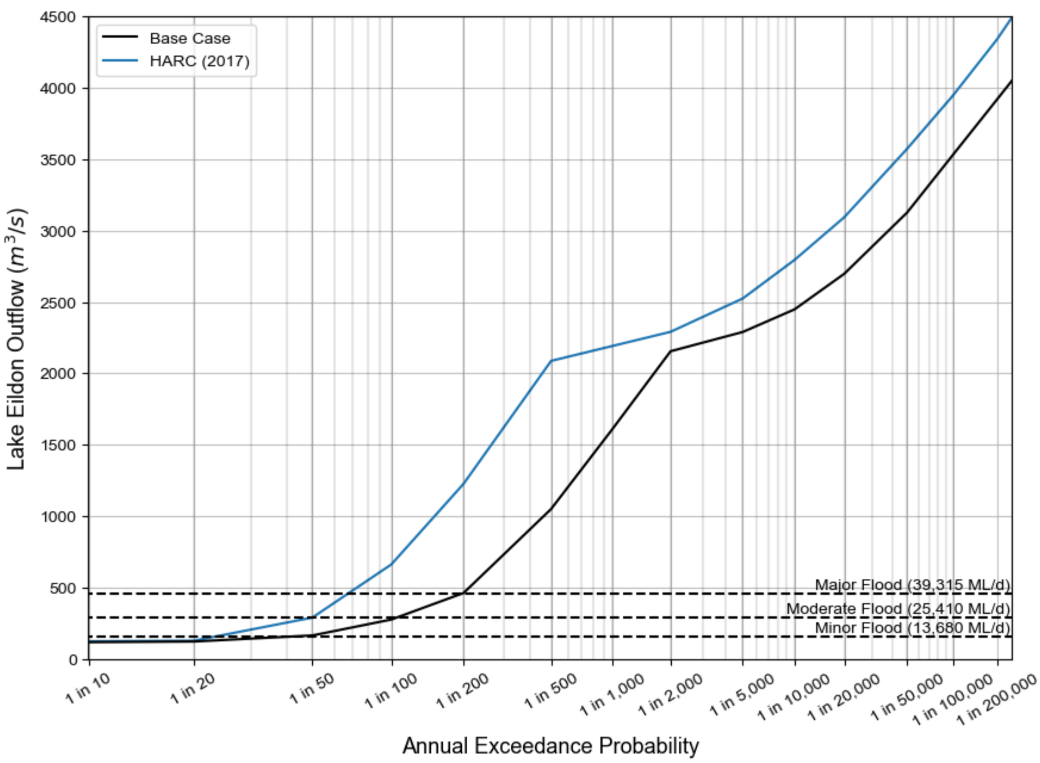


Figure C2: Comparison between the HARC (2017) estimates of Lake Eildon outflow flood frequency and the outflow flood frequency curve after the drawdown distribution was updated using the GSM base case results available for this technical assessment.

Appendix D January 2024 Goulburn River flood event

In January 2024, significant depths of rain fell across a large portion of Victoria between 7 and 9 January, including in the Goulburn River catchment (Figure D1). The majority of the most intense rainfall occurred in the Yea River, King Parrot Creek, Sunday Creek and Sugarloaf Creek catchments.

At the start of January 2024, Lake Eildon was close to FSL, and the releases from Lake Eildon were well below minor flood class level (Figure D2). Between 4 and 7 January, releases from Lake Eildon were reduced to less than 1,000 ML/d to decrease the impacts of flooding downstream.

The peak flows recorded at Trawool (44,000 ML/d) and Seymour (66,000 ML/d) were much higher than the Lake Eildon outflows (Figure D2) as a result of the significant rainfall occurring in the downstream tributaries. Releases from Lake Eildon were increased gradually from January 10 once the peak flows at Trawool and Seymour had passed and flood levels were beginning to fall. The maximum release from Lake Eildon was approximately 7,800 ML/d, well below the minor flood class level downstream of Lake Eildon.

The January 2024 flood event highlights the potential for tributary inflows downstream of Lake Eildon to cause significant flooding in Goulburn River. Even if the operating options that have been investigated as part of this study were implemented at Lake Eildon and the January 2024 flood event was repeated, the degree of flooding at Trawool and Seymour would be similar.

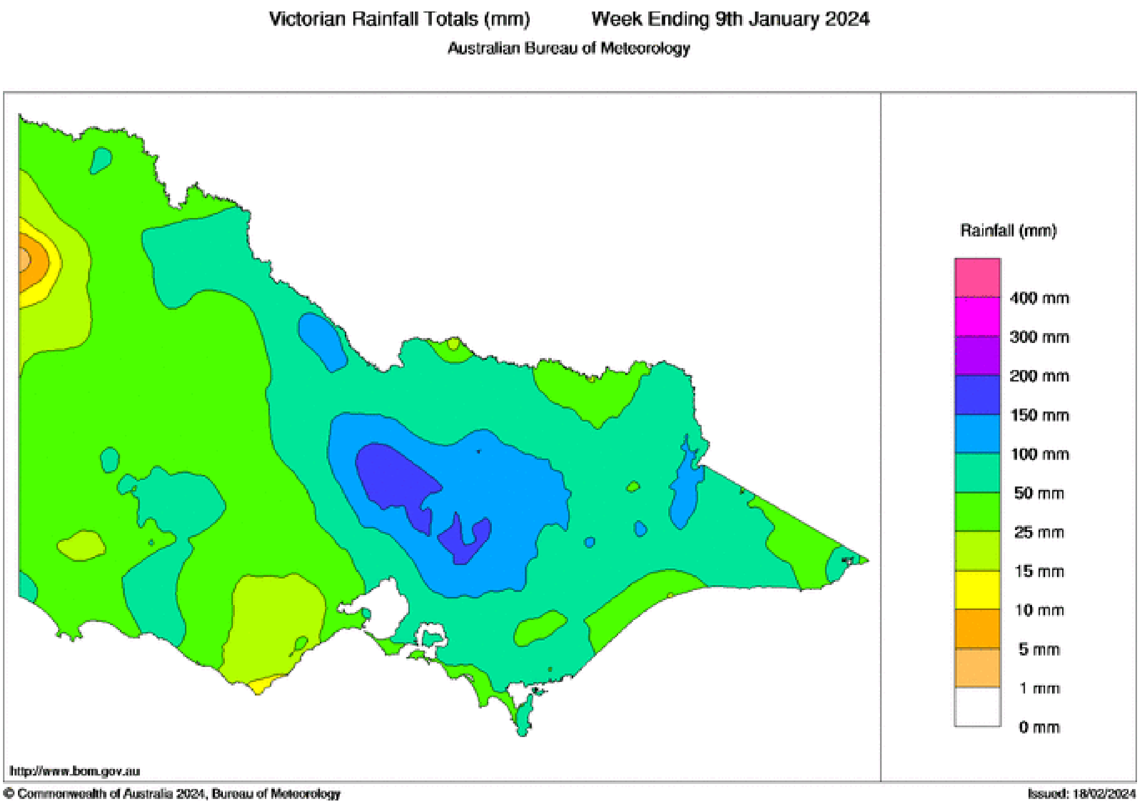


Figure D1: Victorian rainfall totals in the week ending 09/01/2024; www.bom.gov.au/

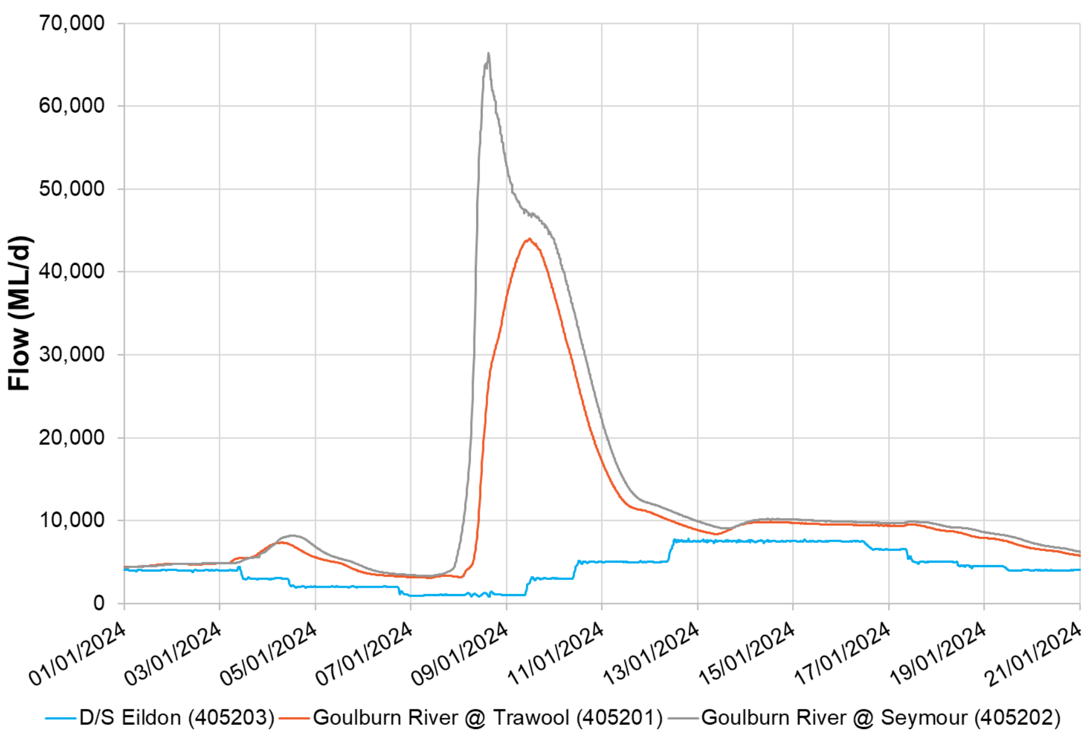


Figure D2: Recorded streamflow gauge information for the January 2024 flood event between Lake Eildon and Seymour.

Appendix E Method to estimate flood damages

Method outline

To assess the potential changes to the economic costs of flood damages if the options described in Section 4 were implemented, peak outflows from Lake Eildon were correlated with estimates of tangible direct damages (in dollars) to:

- Buildings and contents
- Vehicles
- Roads and rail
- Agriculture

The steps involved were:

- Develop a subset of steady-state simulation inflows using the frequency curve results presented in Section 6.2.1 and Section 6.2.2 for the 10% AEP, 1% AEP, 0.2% AEP, 1 in 2,000 AEP and the probable maximum precipitation (PMP) events.
- Use the Goulburn and Broken Rivers Flood Study two-dimensional hydraulic model (TUFLOW) (yet to be finalised) to simulate the steady-state inflows between Lake Eildon and downstream of Seymour.
- Assess the tangible direct costs for each steady-state scenario and construct flow-rate and tangible damage curves for interpolation based on the flood frequency results presented in Section 6.2.1 and Section 6.2.2 for the 10% AEP, 1% AEP, 0.2% AEP, 1 in 2,000 AEP.

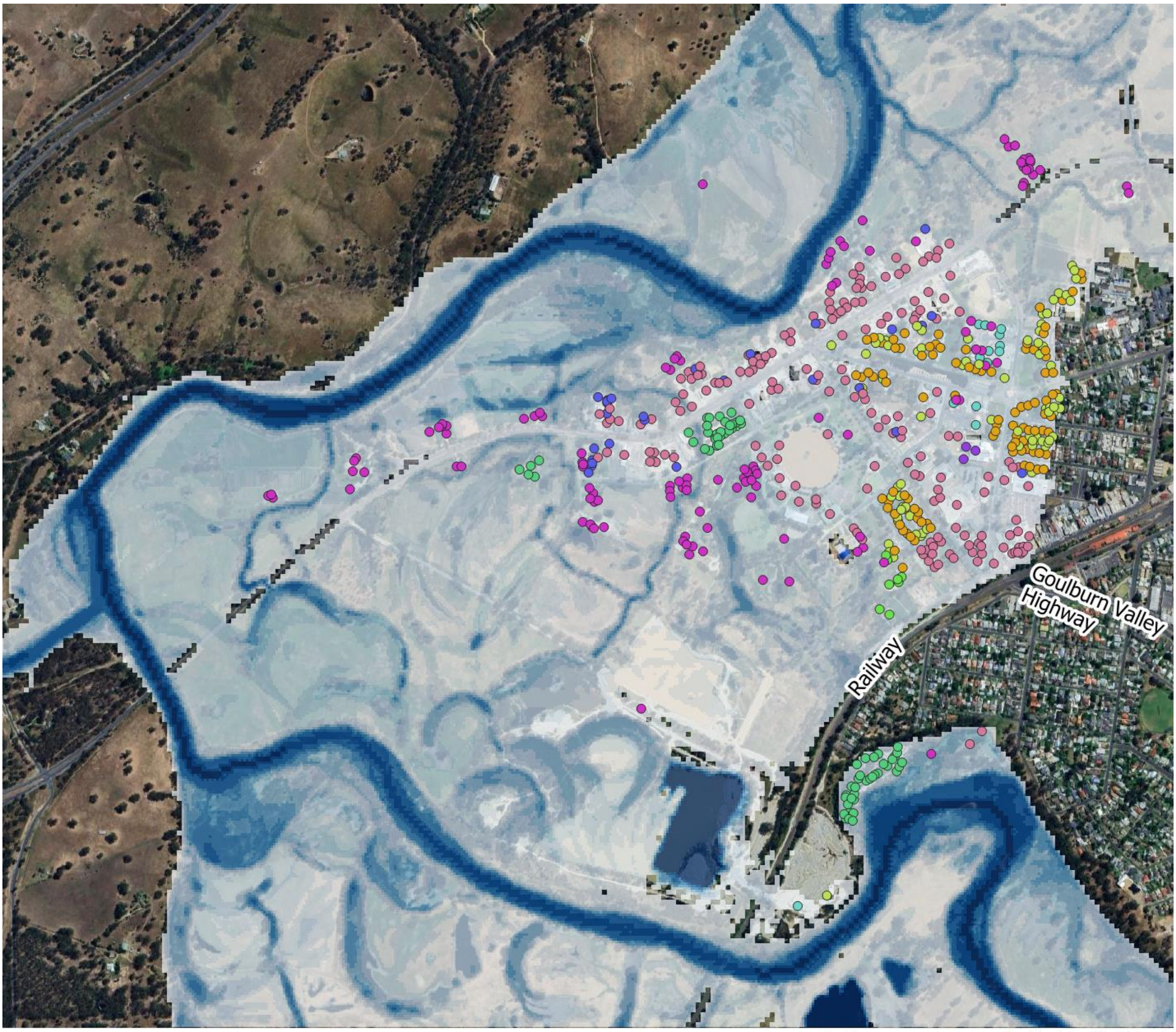
Tangible indirect costs (e.g. emergency response, clean-up costs, transport disruption) were estimated as a proportion of the direct costs.

Buildings and contents

Destruction costs

A building is 'destroyed' from an economic perspective once the cost of repairing it exceeds the cost of rebuilding. For this assessment, it was assumed that buildings are destroyed once the flood depth exceeded 3 m. The indicative reconstruction costs for destroyed non-residential buildings was based on unit rates in Blong (2003) adjusted for inflation, and estimates of building footprints available from Geoscape data and aerial photography. The value of stock and equipment lost in destroyed non-residential buildings depends on many factors and is therefore difficult to estimate without detailed ground surveys. To gain an indicative estimate, a content to structure ratio of 30% was applied. This is an average value for industrial and commercial buildings used by FEMA in their Benefit Cost Analysis Toolkit[28].

[28] https://www.fema.gov/grants/tools/benefit-cost-analysis#toolkit



Legend

Depth (m)
- <= 1.0
- 1.0 - 2.0
- 2.0 - 3.0
- 3.0 - 4.0
- 4.0 - 5.0
- 5.0 - 6.0
- 6.0 - 7.0
- 7.0 - 8.0
- > 8.0

Buillding Types
- Caravan Park
- Commercial
- Commercial Shed
- Farm
- Farm Shed
- Industrial
- Residential
- Residential Shed
- School
- Shed

0 0.2 0.4 0.6 km

Map Projection: Transverse Mercator
Horizontal Datum: GDA 2020
Grid: GDA 2020 MGA Zone 55

N

Buildings in Seymour inundated by 127,000 ML/day at Seymour

Job Number	VIC00120
Revision	A
Date	15 Feb 2024
Reviewed By	S. Lang
Created By	H. Wang
Map Number	VIC00120-M2

The indicative reconstruction cost and contents for destroyed residential buildings was based on 2021 data from NEXIS[29]. The residential contents value was calculated by applying the average value(s) of household contents, by dwelling structure, from the ABS Survey of Income and Housing (SIH)[30], rounded to the nearest million $AUD.

Damage costs

Depth-damage curves were used to estimate the economic cost associated with damage to buildings and contents that are not destroyed. (Figure 132). The curve for residential buildings was based on guidance provided by NSW Environment and Heritage[31], and the curve for non-residential buildings is from FEMA's Benefit Cost Analysis Tool (based on an average of individual curves for an office, school, light industrial property, retail clothing store and electronics store).

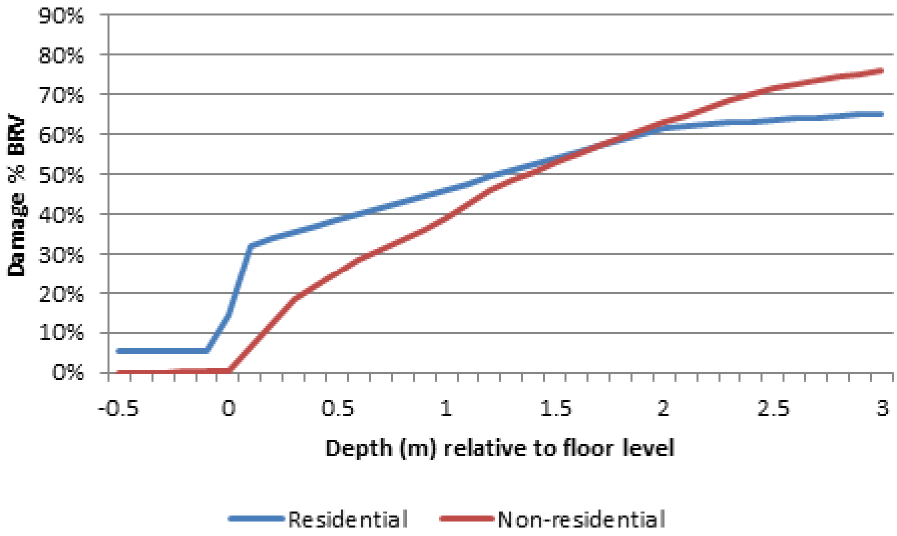


Figure 132: Estimated damage (building and contents) as a percent of building replacement value (BRV), for a given flood depth relative to floor level. Above ground but below floor-level flooding is represented by a negative depth.

Vehicles

To estimate the direct damages to vehicles, it was estimated that on average one vehicle per inundated residence is saved from flooding. The vehicles remaining on properties where the residence is destroyed were assumed to be written-off, and half the vehicles on all other inundated residences were also assumed to be destroyed. There are 1.8 vehicles per household in Australia[25]. This means the expected economic cost from writing-off vehicles was estimated to be 0.8 vehicles per destroyed residential building, and 0.4 per damaged residential building.

[29] https://researchdata.edu.au/national-exposure-information-1-sa1/1278205

[30] https://www.abs.gov.au/

[31] https://www.environment.nsw.gov.au/topics/water/floodplains/floodplain-guidelines

The average vehicle is 10 years old[32], and therefore the average depreciated value per vehicle was estimated to be $28,860, based on prices for a similarly aged Toyota Hilux (which has been the highest selling car for nearly a decade on www.carsguide.com.au).

Roads and rail

Direct damages to roads and rail are generally a function of flood depth (Habermann and Hedel, 2018; Huizinga et al., 2017). Habermann and Hedel (2018) have estimated that, as a function of replacement costs, damage to roads and rail is approximately 20% for every 1 m of flooding. For example, if flood depth is 2 m the damage is 40% of the replacement cost, and for depths of 5 m and greater the road is likely to need replacing (i.e. the damage cost equals the replacement cost). Estimated replacement costs are shown in Table 54.

Table 54: Replacement costs for roads and rail

Infrastructure Type	Replacement cost ($/m)
Walking track	50
Unsealed road	500
1 lane sealed road	1,500
2 lane sealed road	3,000
4 lane sealed road	5,000
Railway	5,000

Agriculture

The indicative unit costs used to estimate agricultural losses from flooding were taken from the Rapid Appraisal Method (DNRE, 2000) and adjusted for inflation (Table 55). These unit costs are based on the assumption that the flooding will be of sufficient force and/or duration to result in re-establishment costs, clean-up costs and lost production, but there is a large degree of uncertainty associated with the values.

Table 55: Indicative unit costs for damage to agriculture from flooding

Type	Damage ($/ha)
Dryland pastures	130
Dryland broadacre crops	200
Orchard	10,100
Grapes	4,300
Vegetables	10,000
Irrigated pastures	580
Irrigated broadacre crops	480

[32] https://www.abs.gov.au/

The Rapid Appraisal Method (DNRE, 2000) also provides a guide on indicative stock losses from flooding, in that expected losses can be estimated as 2 sheep and 0.5 cows per hectare inundated. The price of sheep ($90/head) and cattle ($850/head) was taken from the meat and livestock Australia web site[33].

The Rapid Appraisal Method also says that "when calculating the cost of livestock lost during floods, the cost of carcass disposal should be considered. It is reasonable to suggest that the costs of livestock disposal will be in the order of $6 to $10 per sheep and $40 to $80 for cattle". For this assessment, a disposal cost of $8 per sheep and $60 for cattle was adopted.

Indirect costs

Examples of the indirect costs associated with flooding include emergency services and volunteers responding to the flood, clean-up costs and disruption to transport and utility services. For this assessment, general indirect costs were estimated to be 30% of the total direct damage costs.

References

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Habermann, N. and Hedel, R. (2018). *Damage functions for transport infrastructure*. Fraunhofer Institute for Transportation and Infrastructure Systems, Germany.

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[33] https://www.mla.com.au/prices-markets/Trends-analysis/

Appendix F Future impacts of climate change

Climate change in the Goulburn River catchment

Although there is high uncertainty, climate projections over Victoria point to drying conditions, driven by decreases in seasonal rainfall and increases in temperature. These changes are expected to interact to reduce soil moisture, and therefore both increase the demand for water and reduce reservoir inflows. The projected changes in annual rainfall, potential evapotranspiration and runoff in the Goulburn River catchment (DELWP, 2020) are summarised in Table 56 (the year 2040 projection for the RCP8.5 emissions scenario is used as an illustrative example).

Table 56: Projected change in hydroclimate variables in the Goulburn River catchment by 2040, relative to 1995, for the RCP8.5 emissions scenario (DELWP, 2020)

Climate impact scenario	Projected change (%) by 2040 compared with 1995, for RCP8.5 emissions scenario		
	Rainfall	Potential evaporation	Runoff
Low (10th percentile)	3.9	3.2	9.9
Medium (50th percentile)	-2.5	4.9	-9.5
High (90th percentile)	-13.6	5.8	-29.1

At the same time, climate projections suggest there will be an increase in rainfall intensity, driven by an increase in atmospheric moisture as temperatures increase. The net effects of a drying climate but with higher rainfall intensities can lead to differences in trends depending on flood severity. For example, smaller floods which provide useful reservoir filling flows or ecologically-beneficial inundation are likely to be more sensitive to changes in soil moisture conditions compared with larger, more damaging floods, which are likely to be more sensitive to changes in rainfall intensities and volumes.

Historical trends in floods

Research across Victoria has found that extreme rainfall intensities have been increasing over time (Wasko and Nathan, 2019). However, floods have been either increasing or decreasing in magnitude depending on their rarity. The cross-over point between this increasing or decreasing trend appears to be around the 10% AEP event (Wasko and Nathan, 2019). That is, floods more frequent than the “1 in 10” event appear to be decreasing in magnitude, and rarer, more severe floods appear to be increasing in magnitude, although this can vary by catchment. These observations (Figure 133) match the expected trends caused by climate change.

Future climate projections for flooding

Continued climate change will have a progressively larger effect on floods, thus potentially accelerating historic trends. Increasing temperatures will increase rainfall intensities of long-duration events (≥ 24 hours) by about 6-8% per degree of warming (Wasko et al., 2021). Rainfall intensities during shorter duration events will increase at a faster rate of about 15% per degree of warming (Wasko et al., 2021).

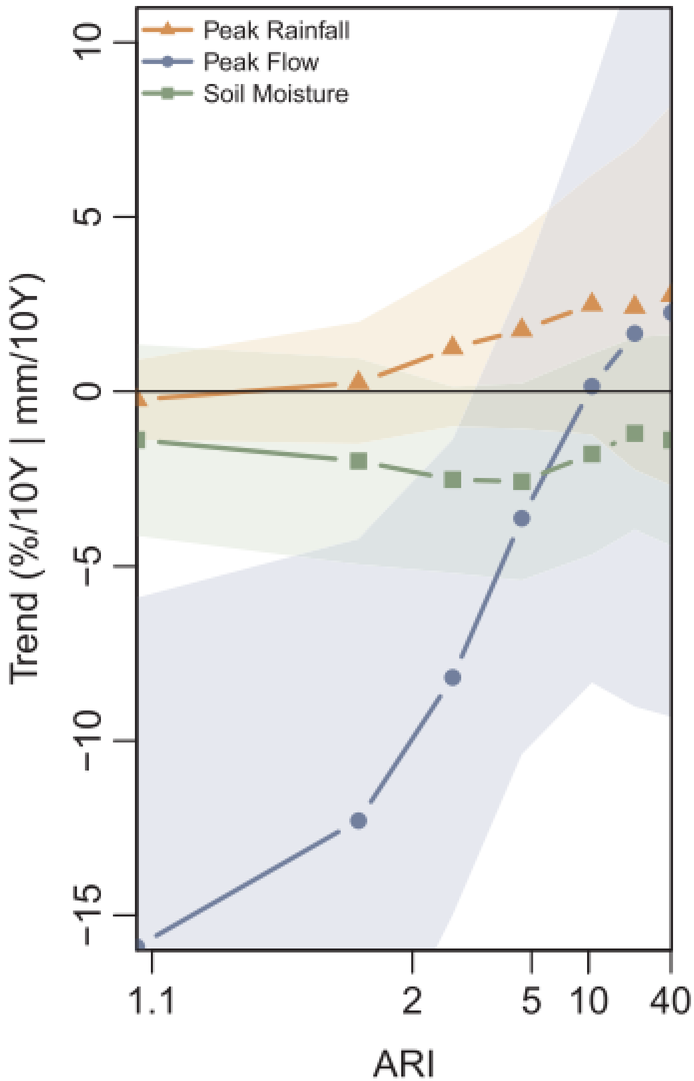

Figure 133: Average historic trend for peak rainfall, peak flow and soil moisture – across all sites assessed by Wasko and Nathan (2019) – versus the Average Recurrence Interval (ARI in years) of the peak rainfall. A 10-year ARI event is the same as a 10% or 1 in 10 annual exceedance probability (AEP) event. The thick lines show the mean trend, and the shaded interval represent one standard deviation. Source: Figure 7 of Wasko and Nathan (2019).

Implications for reservoir and flood management

In the shorter term, the natural variability of Australia's climate rather than climate change will be the dominate influence on Lake Eildon storage and peak outflow behaviour. However, natural variability can also mask or enhance longer-term climate change. For example, some recent research suggests that the influence of climate change may exceed the influence of natural variability on long-term water entitlement yield in the Goulburn River catchment by 2040 (John et al., 2023).

The options assessed in this report provide additional flood mitigation by reducing the target storage at Lake Eildon below the current FSL. Whilst the effect of these options on water supply reliability can be offset via the purchase or retirement of entitlements, reducing the volumes stored at Lake Eildon is likely to exacerbate for consumptive users the impacts of a drying climate.

In turn, there may also be some point in future when there is simultaneously reduced water availability in the Goulburn system because of a drying climate, and worse flooding because of increased rainfall intensities. In other words, it is likely that the flood mitigation benefits relative to current conditions of any change in reservoir operations at Lake Eildon will be eroded as the climate continues to change.

Unfortunately, how to best quantitatively assess the impacts of climate change in the context of operating reservoirs for water supply and/or flood mitigation is an open research question. This is due to difficulties in combining water resource and flood modelling (mostly due to the complexities of models, uncertainties in future climate and differences in simulation time step required).

However, future work on potential operating options for increasing the flood mitigation provided by Lake Eildon could be informed by using decision-making or similar processes recommended by Maier et al., (2016); Haasnoot et al. (2013) and John et al. (2021). These approaches can highlight potential adaptation options that deliver benefits despite climate change uncertainty. In any case, whatever operating options are implemented at Lake Eildon will need to be adaptable in future to adequately cope with the expected continued climate change.

References

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Maier, H. R., Guillaume, J. H., van Delden, H., Riddell, G. A., Haasnoot, M. and Kwakkel, J. H. (2016). *An uncertain future, deep uncertainty, scenarios, robustness and adaptation: How do they fit together?* Environmental modelling & software, 81, 154-164.

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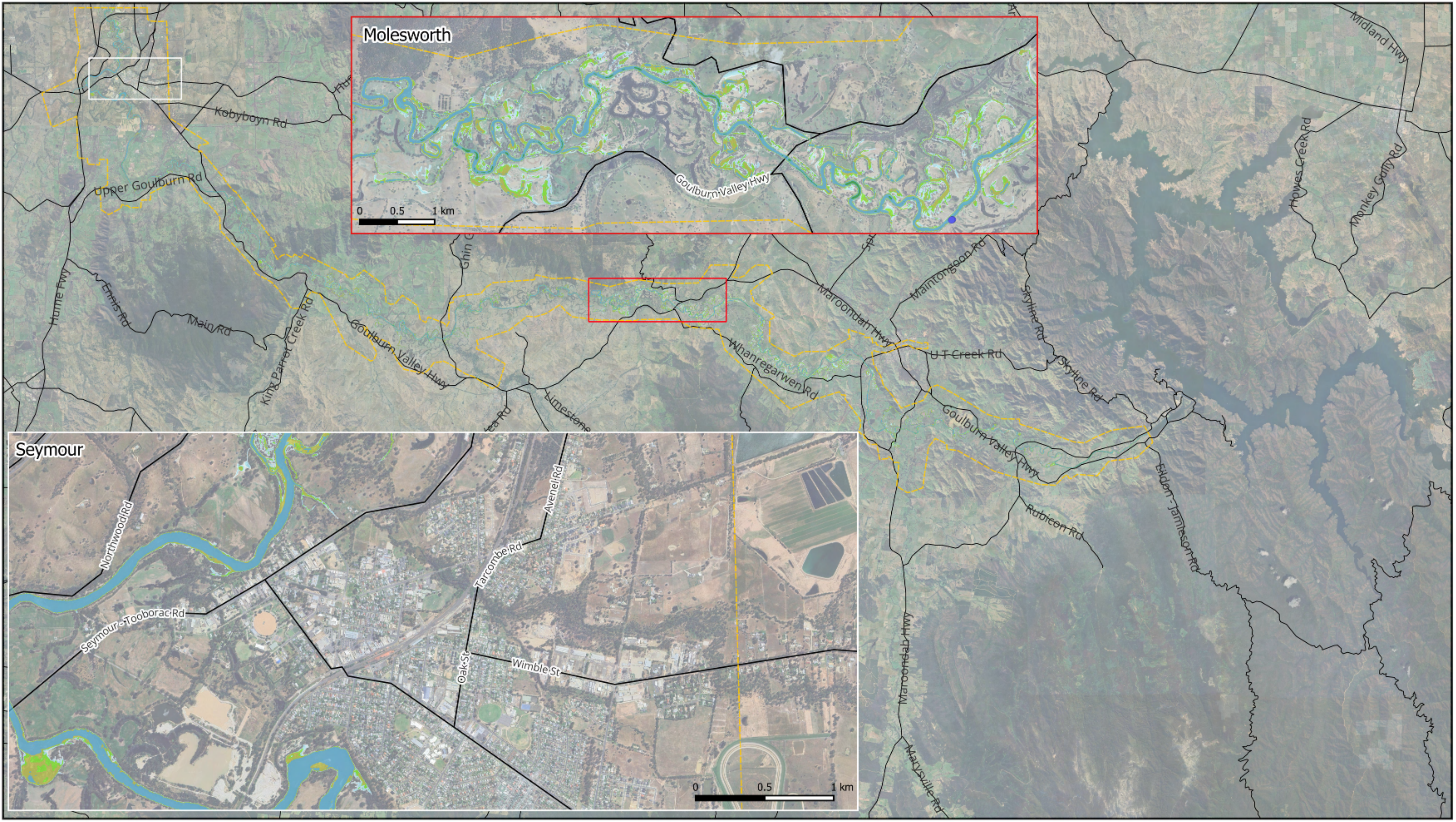
Appendix G Inundation flood maps



Legend

- Hydraulic Model Extent
- Main Roads

Inundated Structures

- Caravan Park
- Commercial
- Shed
- Farm
- Industrial
- Residential
- School
- Hospital

Max Depth (m)

- 0.00 - 0.15
- 0.15 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 5.00
- 5.00 - 10.00
- 10.00 - 15.00
- 15.00 - 20.00
- > 20.00

0 4 8 km

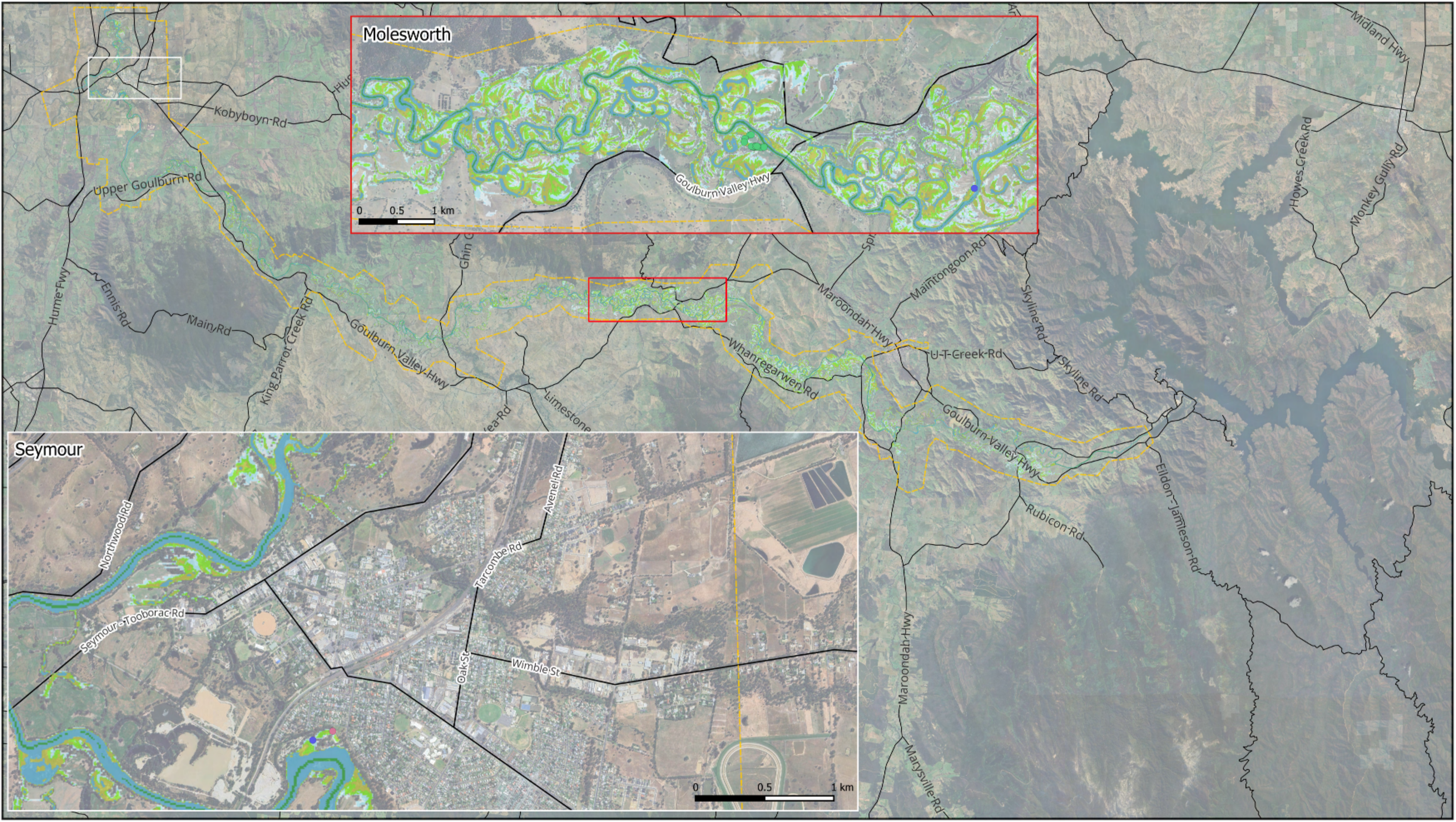
Map Projection: Transverse Mercator
Horizontal Datum: GDA 2020
Grid: GDA 2020 MGA Zone 55

N

Study Name - Lake Eildon flood mitigation options assessment
Flood Extent Map - steady state flow along the Goulburn River of 160 m³/s (14,000 ML/d)

Study Area

Job Number	VIC00120
Revision	A
Date	19 Feb 2024
Reviewed By	
Created By	
Map Number	VIC00120-M3



Legend

- Hydraulic Model Extent
- Main Roads

Inundated Structures

- Caravan Park
- Shed
- Industrial
- School
- Commercial
- Farm
- Residential
- Hospital

Max Depth (m)

- 0.00 - 0.15
- 0.15 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 5.00
- 5.00 - 10.00
- 10.00 - 15.00
- 15.00 - 20.00
- > 20.00

0 4 8 km

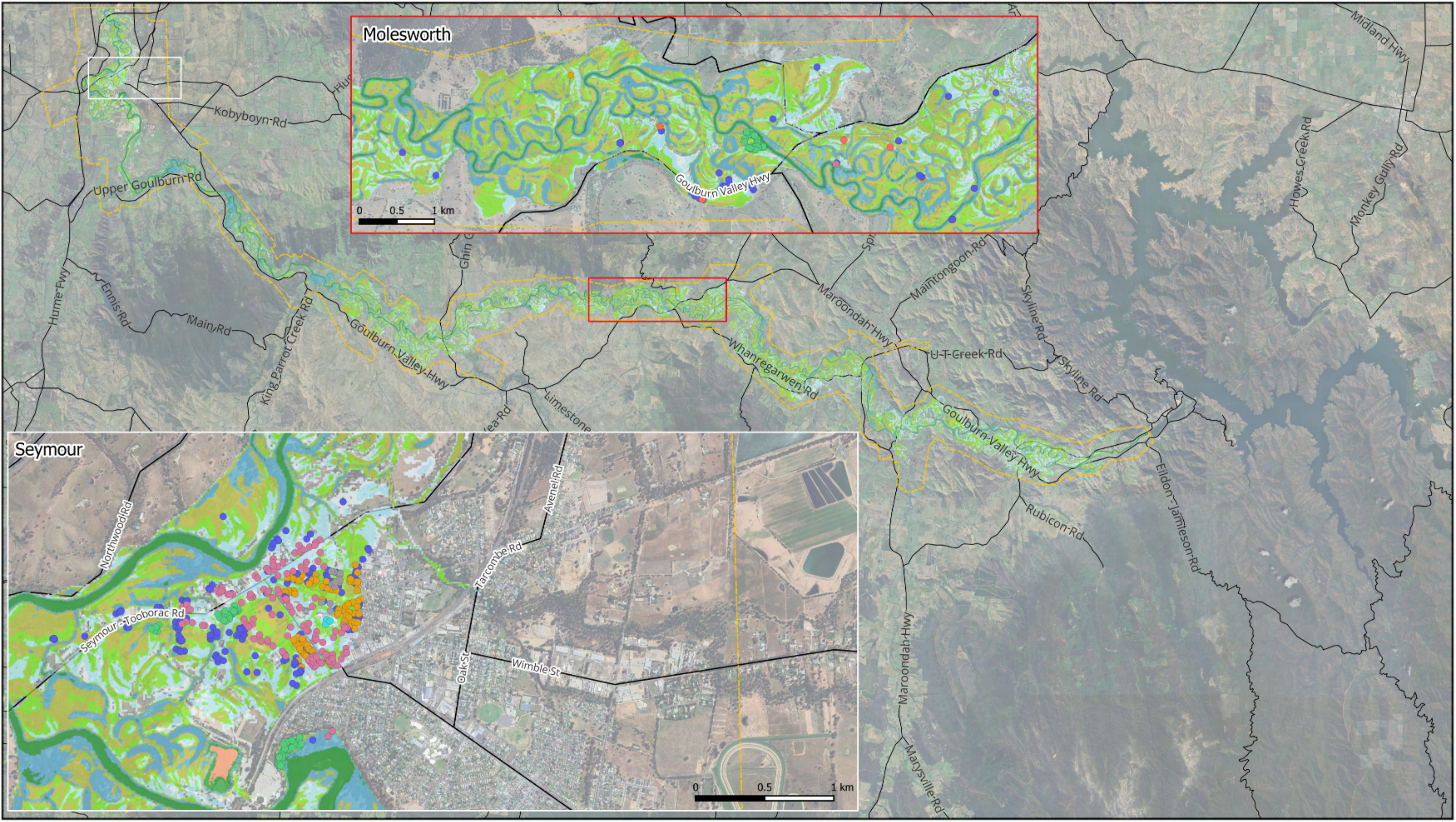
Map Projection: Transverse Mercator
Horizontal Datum: GDA 2020
Grid: GDA 2020 MGA Zone 55

N

Study Name - Lake Eildon flood mitigation options assessment
Flood Extent Map - steady state flow along the Goulburn River of 300 m³/s (25,920 ML/d)

Study Area

Job Number	VIC00120
Revision	A
Date	19 Feb 2024
Reviewed By	
Created By	
Map Number	VIC00120-M4



Legend

Hydraulic Model Extent

Main Roads

Inundated Structures

Caravan Park | Shed | Industrial | School

Commercial | Farm | Residential | Hospital

Max Depth (m)

0.00 - 0.15	0.50 - 1.00	2.00 - 5.00	10.00 - 15.00	> 20.00
0.15 - 0.50	1.00 - 2.00	5.00 - 10.00	15.00 - 20.00	

0 4 8 km

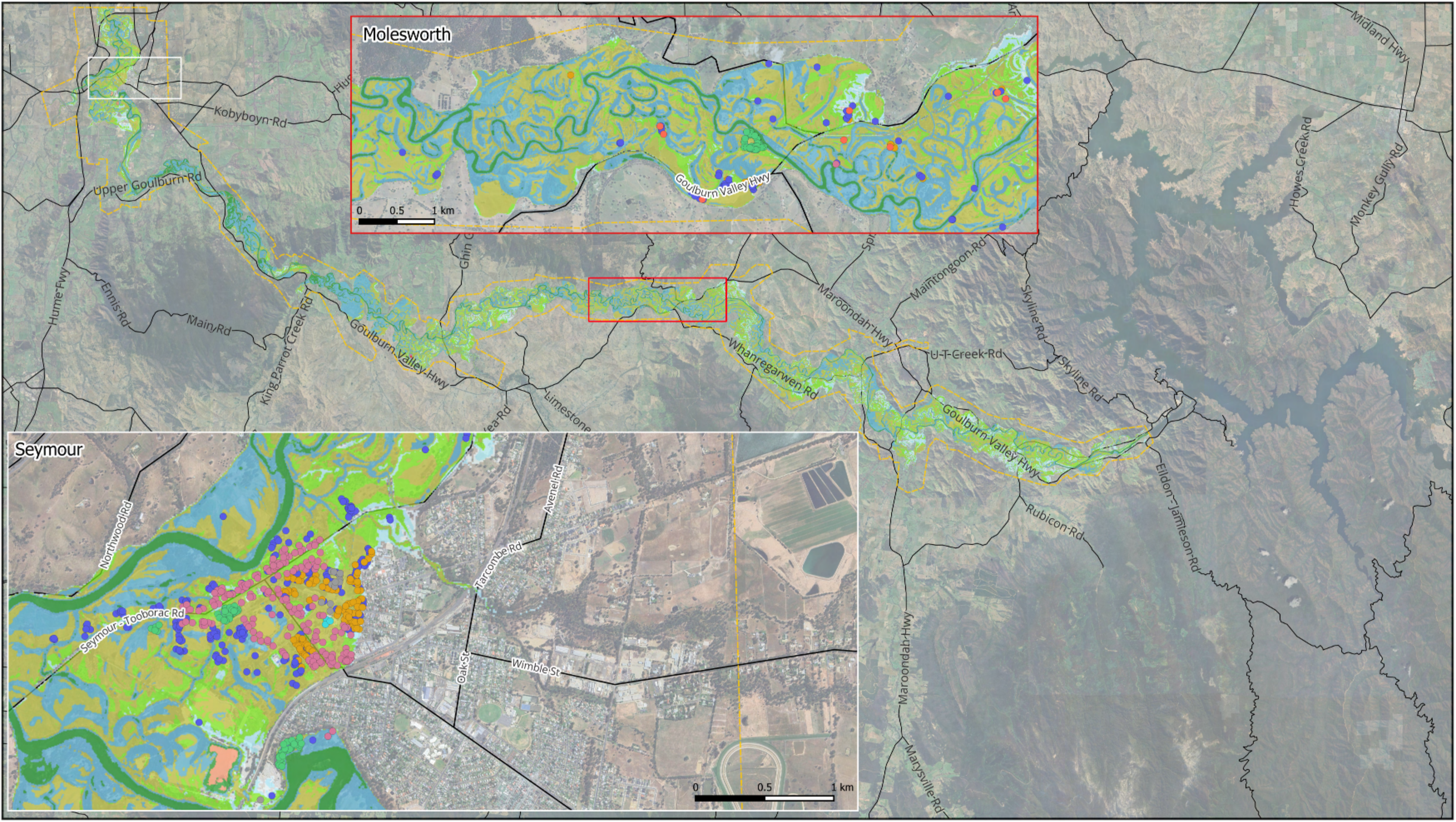
Map Projection: Transverse Mercator
Horizontal Datum: GDA 2020
Grid: GDA 2020 MGA Zone 55

N

Study Name - Lake Eildon flood mitigation options assessment
Flood Extent Map - steady state flow along the Goulburn River of 900 m³/s (77,760 ML/d)

Study Area

Job Number	VIC00120
Revision	A
Date	19 Feb 2024
Reviewed By	
Created By	
Map Number	VIC00120-M5



Legend

Hydraulic Model Extent

Main Roads

Inundated Structures

- Caravan Park
- Shed
- Industrial
- School
- Commercial
- Farm
- Residential
- Hospital

Max Depth (m)

- 0.00 - 0.15
- 0.15 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 5.00
- 5.00 - 10.00
- 10.00 - 15.00
- 15.00 - 20.00
- > 20.00

0 4 8 km

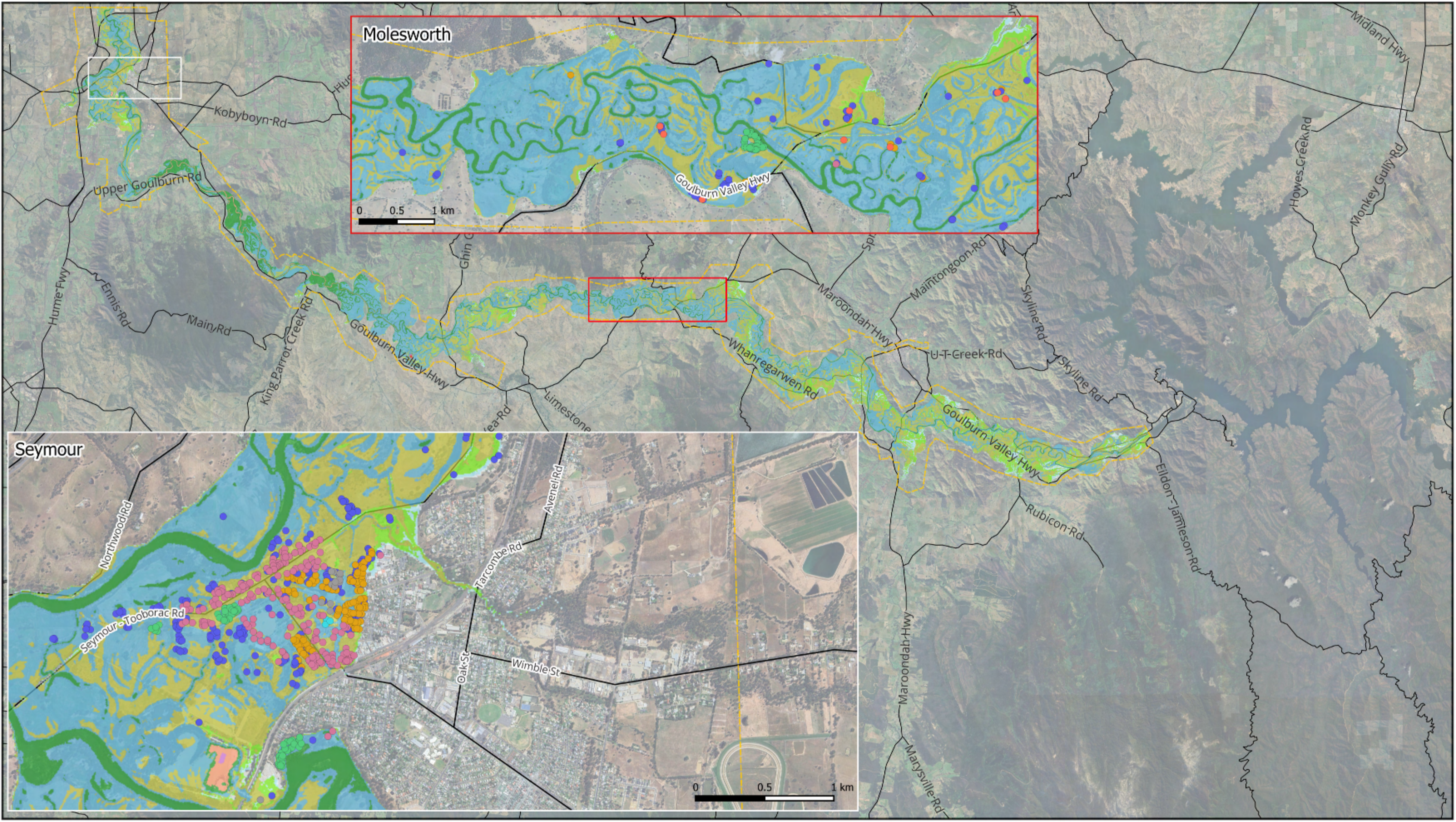
Map Projection: Transverse Mercator
Horizontal Datum: GDA 2020
Grid: GDA 2020 MGA Zone 55

N

Study Name - Lake Eildon flood mitigation options assessment
Flood Extent Map - steady state flow along the Goulburn River of 1,800 m³/s (155,520 ML/d)

Study Area

Job Number	VIC00120
Revision	A
Date	19 Feb 2024
Reviewed By	
Created By	
Map Number	VIC00120-M6



Legend

Hydraulic Model Extent

Main Roads

Inundated Structures

Caravan Park, Commercial, Shed, Farm, Industrial, Residential, School, Hospital

Max Depth (m)

0.00 - 0.15, 0.15 - 0.50, 0.50 - 1.00, 1.00 - 2.00, 2.00 - 5.00, 5.00 - 10.00, 10.00 - 15.00, 15.00 - 20.00, > 20.00

0 4 8 km

Map Projection: Transverse Mercator
Horizontal Datum: GDA 2020
Grid: GDA 2020 MGA Zone 55

N

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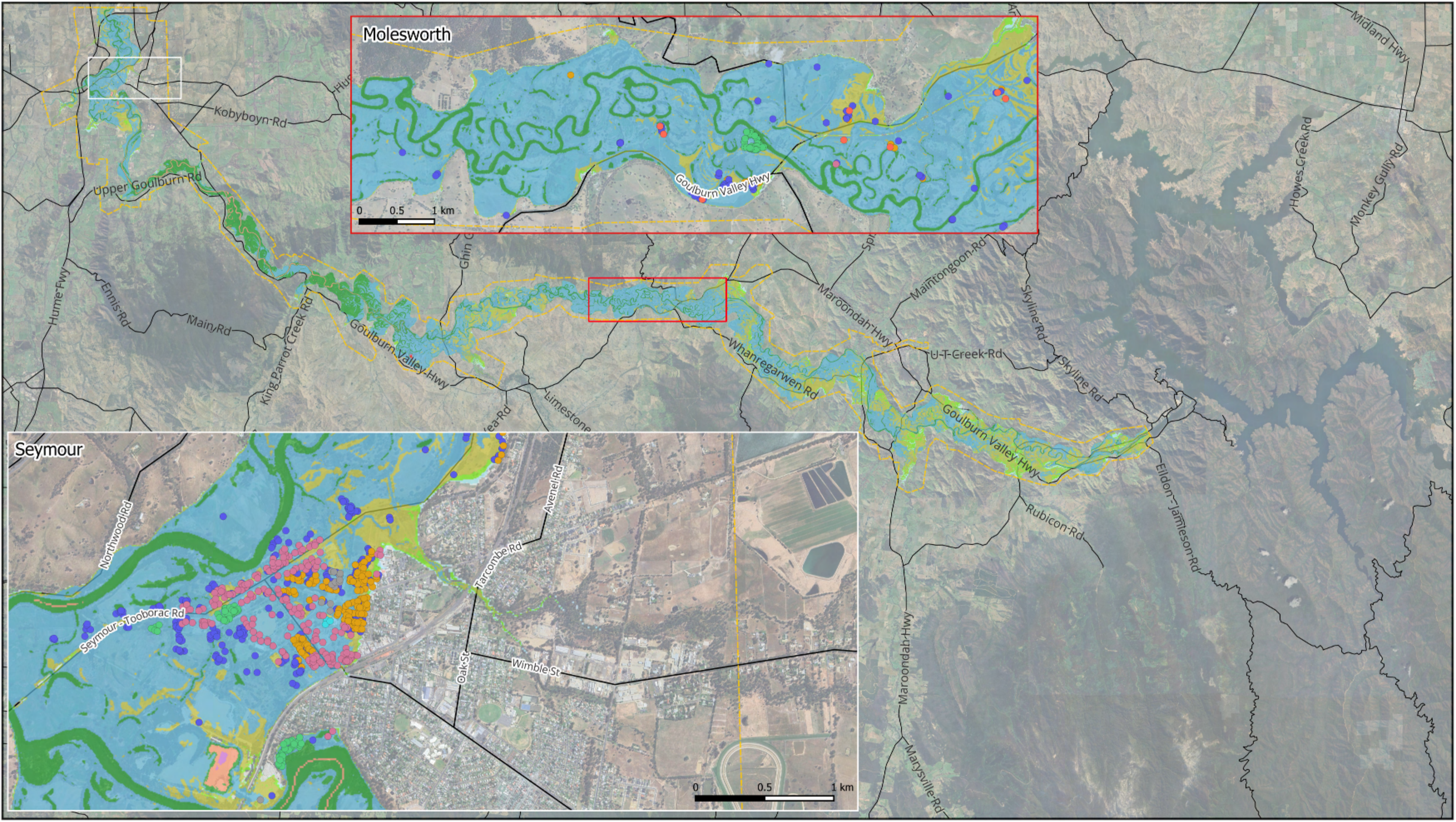
HARC

Study Name - Lake Eildon flood mitigation options assessment
Flood Extent Map - steady state flow along the Goulburn River of 3,000 m³/s (259,200 ML/d)

Study Area

Job Number	VIC00120
Revision	A
Date	19 Feb 2024
Reviewed By	
Created By	
Map Number	VIC00120-M7



Legend	Inundated Structures				Max Depth (m)				
Hydraulic Model Extent	Caravan Park	Shed	Industrial	School	0.00 - 0.15	0.50 - 1.00	2.00 - 5.00	10.00 - 15.00	> 20.00
Main Roads	Commercial	Farm	Residential	Hospital	0.15 - 0.50	1.00 - 2.00	5.00 - 10.00	15.00 - 20.00	

0 4 8 km

Map Projection: Transverse Mercator
Horizontal Datum: GDA 2020
Grid: GDA 2020 MGA Zone 55

N

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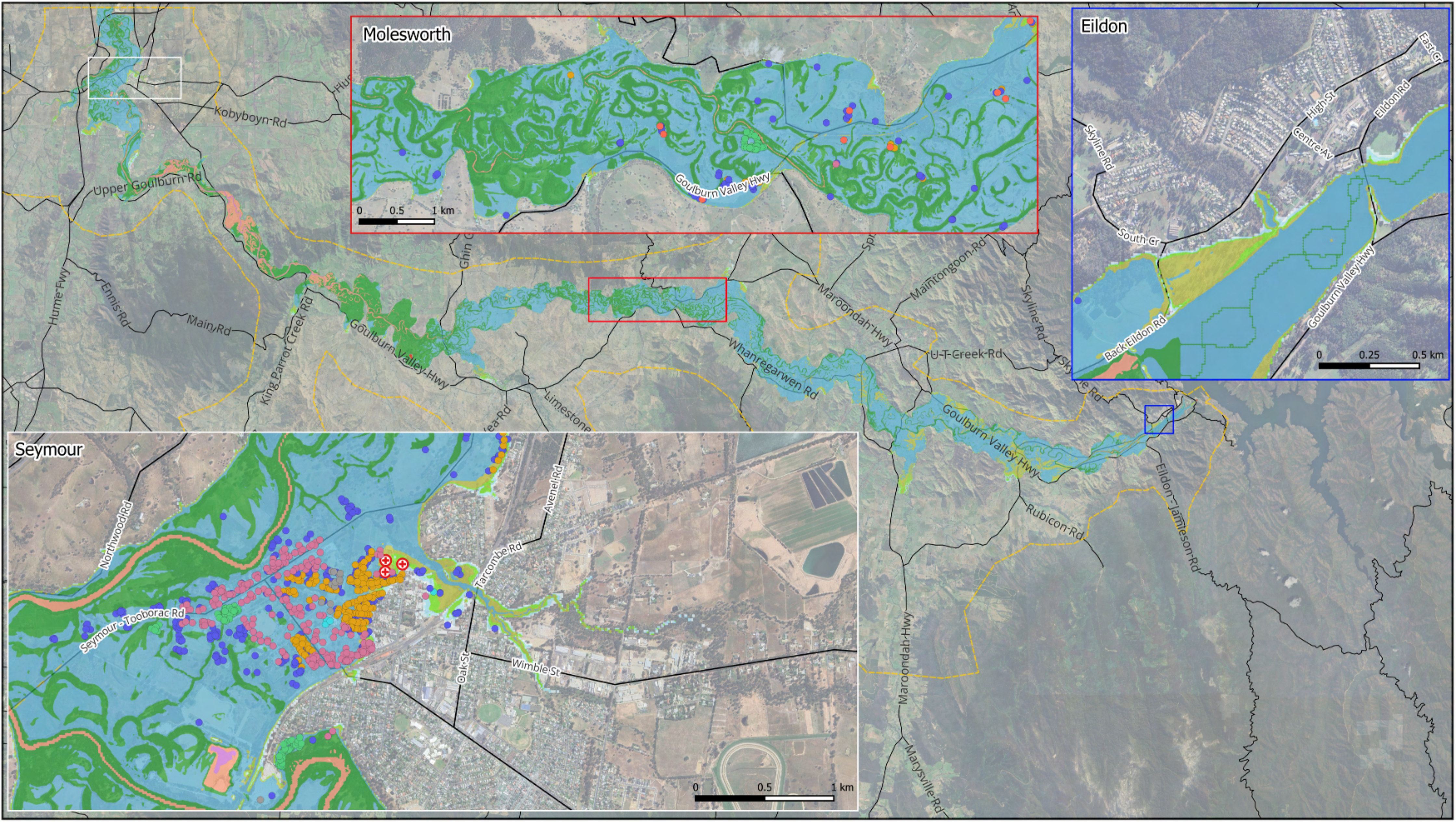
Study Name - Lake Eildon flood mitigation options assessment
Flood Extent Map - steady state flow along the Goulburn River of 4,000 m³/s (345,600 ML/d)

Study Area

Job Number	VIC00120
Revision	A
Date	19 Feb 2024
Reviewed By	
Created By	
Map Number	VIC00120-M8



Legend

Hydraulic Model Extent
Main Roads

Inundated Structures

- Caravan Park
- Shed
- Industrial
- School
- Commercial
- Farm
- Residential
- Hospital

Max Depth (m)

- 0.00 - 0.15
- 0.15 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 5.00
- 5.00 - 10.00
- 10.00 - 15.00
- 15.00 - 20.00
- > 20.00

0 4 8 km

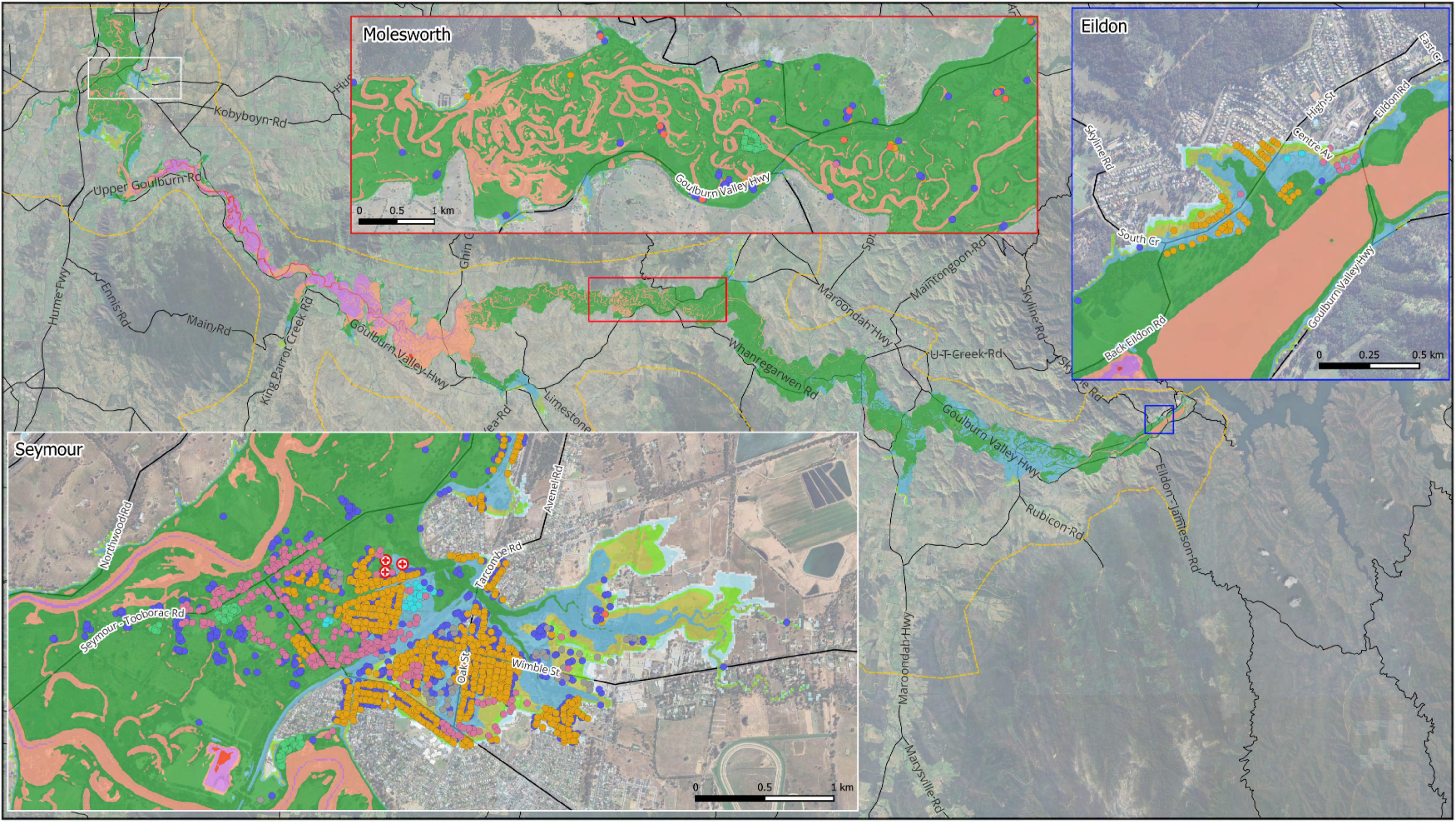
Map Projection: Transverse Mercator
Horizontal Datum: GDA 2020
Grid: GDA 2020 MGA Zone 55

N

Study Name - Lake Eildon flood mitigation options assessment
Flood Extent Map - steady state flow along the Goulburn River of 7,500 m³/s (648,000 ML/d)

Study Area

Job Number	VIC00120
Revision	A
Date	19 Feb 2024
Reviewed By	
Created By	
Map Number	VIC00120-M9



Legend

- Hydraulic Model Extent
- Main Roads

Inundated Structures

- Caravan Park
- Shed
- Industrial
- School
- Commercial
- Farm
- Residential
- Hospital

Max Depth (m)

- 0.00 - 0.15
- 0.15 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 5.00
- 5.00 - 10.00
- 10.00 - 15.00
- 15.00 - 20.00
- > 20.00

0 4 8 km

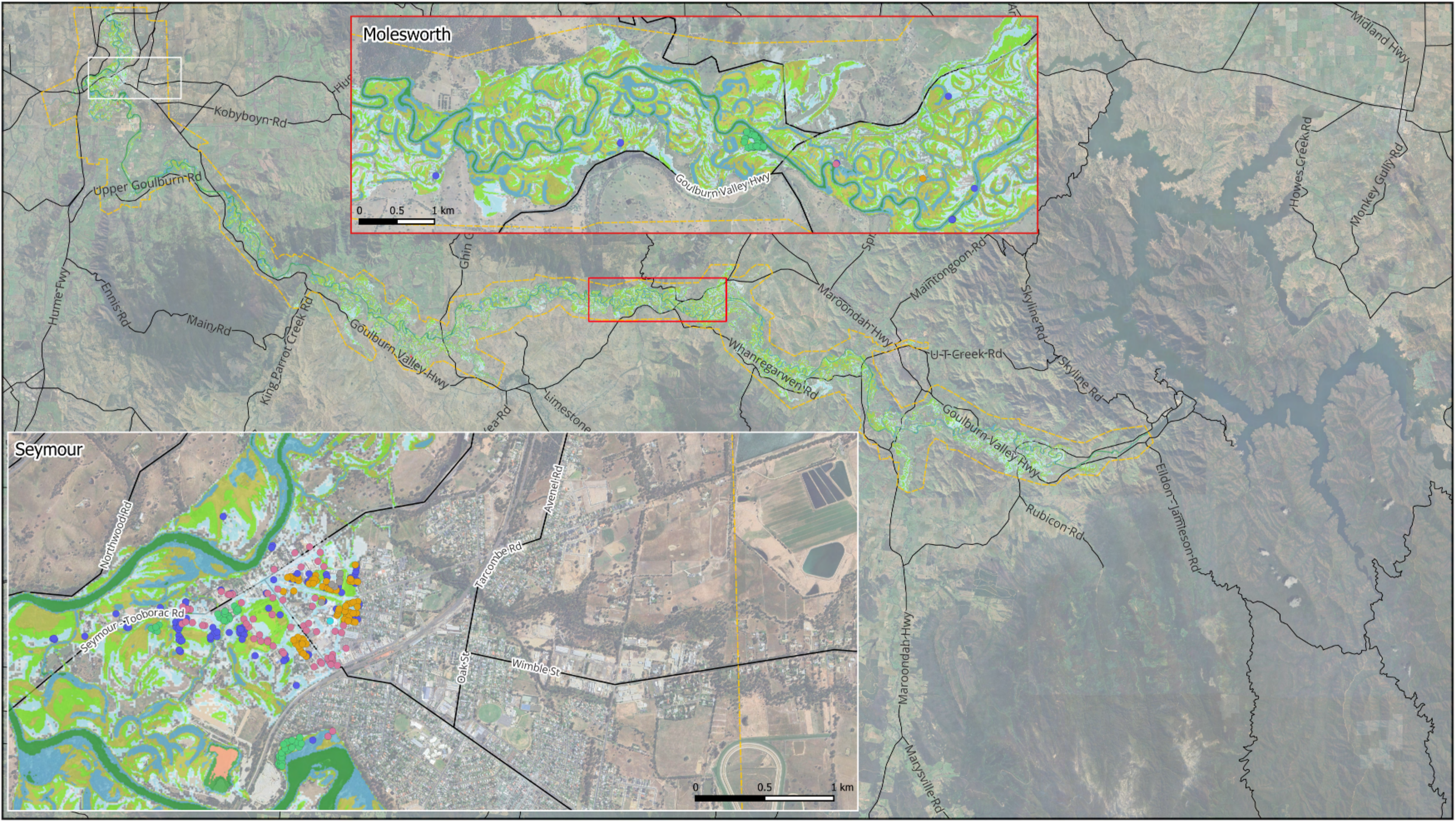
Map Projection: Transverse Mercator
Horizontal Datum: GDA 2020
Grid: GDA 2020 MGA Zone 55

N

Study Name - Lake Eildon flood mitigation options assessment
Flood Extent Map - steady state flow along the Goulburn River of 20,000 m³/s (1,728,000 ML/d)

Study Area

Job Number	VIC00120
Revision	A
Date	19 Feb 2024
Reviewed By	
Created By	
Map Number	VIC00120-M10



Legend

- Hydraulic Model Extent
- Main Roads

Inundated Structures

- Caravan Park
- Commercial
- Shed
- Farm
- Industrial
- Residential
- School
- Hospital

Max Depth (m)

- 0.00 - 0.15
- 0.15 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 5.00
- 5.00 - 10.00
- 10.00 - 15.00
- 15.00 - 20.00
- > 20.00

0 4 8 km

Map Projection: Transverse Mercator
Horizontal Datum: GDA 2020
Grid: GDA 2020 MGA Zone 55

N

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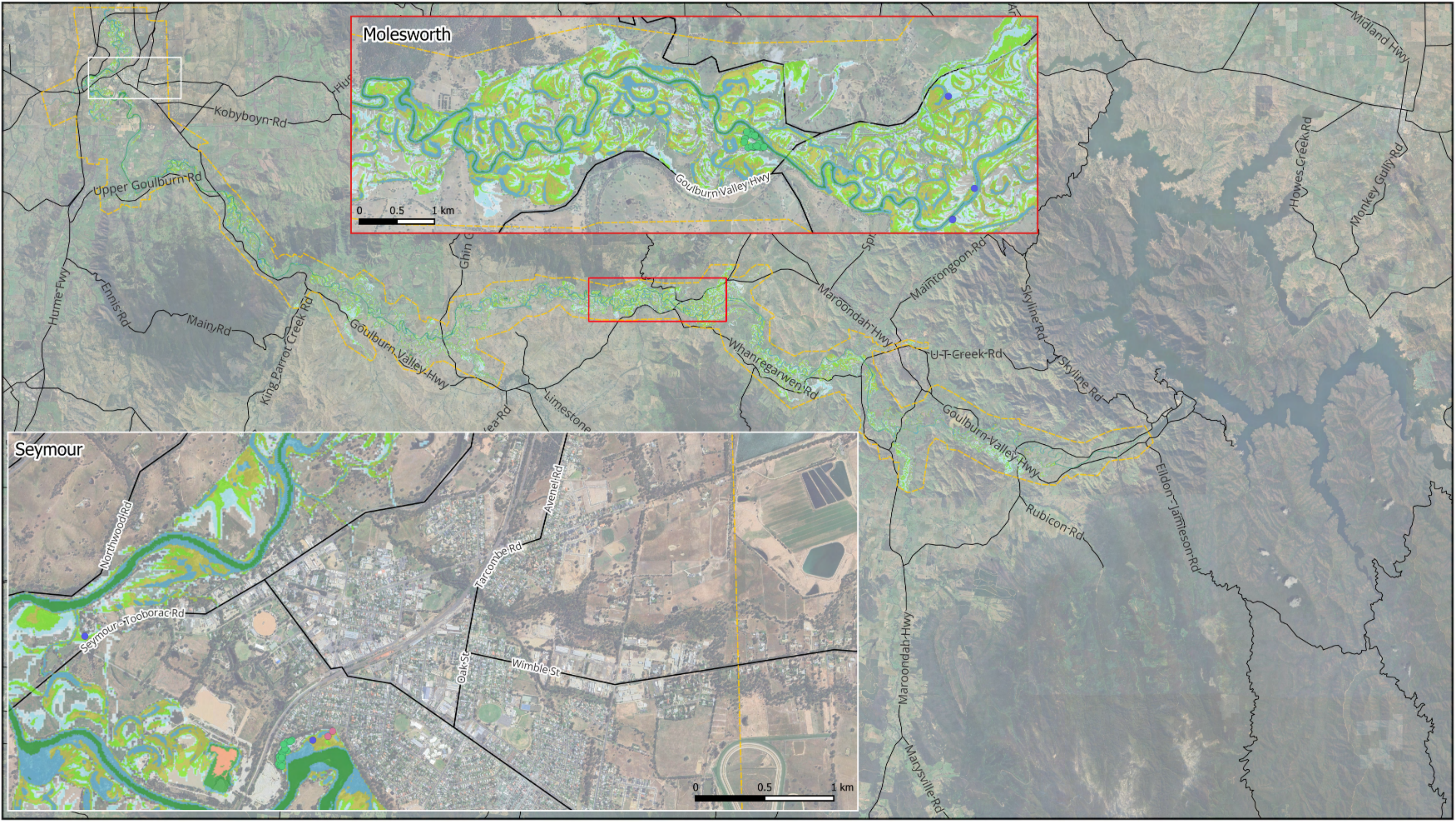
Study Name - Lake Eildon flood mitigation options assessment
Flood Extent Map - 1993 event

Study Area

Job Number	VIC00120
Revision	A
Date	19 Feb 2024
Reviewed By	
Created By	
Map Number	VIC00120-M11



Legend

- Hydraulic Model Extent
- Main Roads

Inundated Structures

- Caravan Park
- Commercial
- Shed
- Farm
- Industrial
- Residential
- School
- Hospital

Max Depth (m)

- 0.00 - 0.15
- 0.15 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 5.00
- 5.00 - 10.00
- 10.00 - 15.00
- 15.00 - 20.00
- > 20.00

0 4 8 km

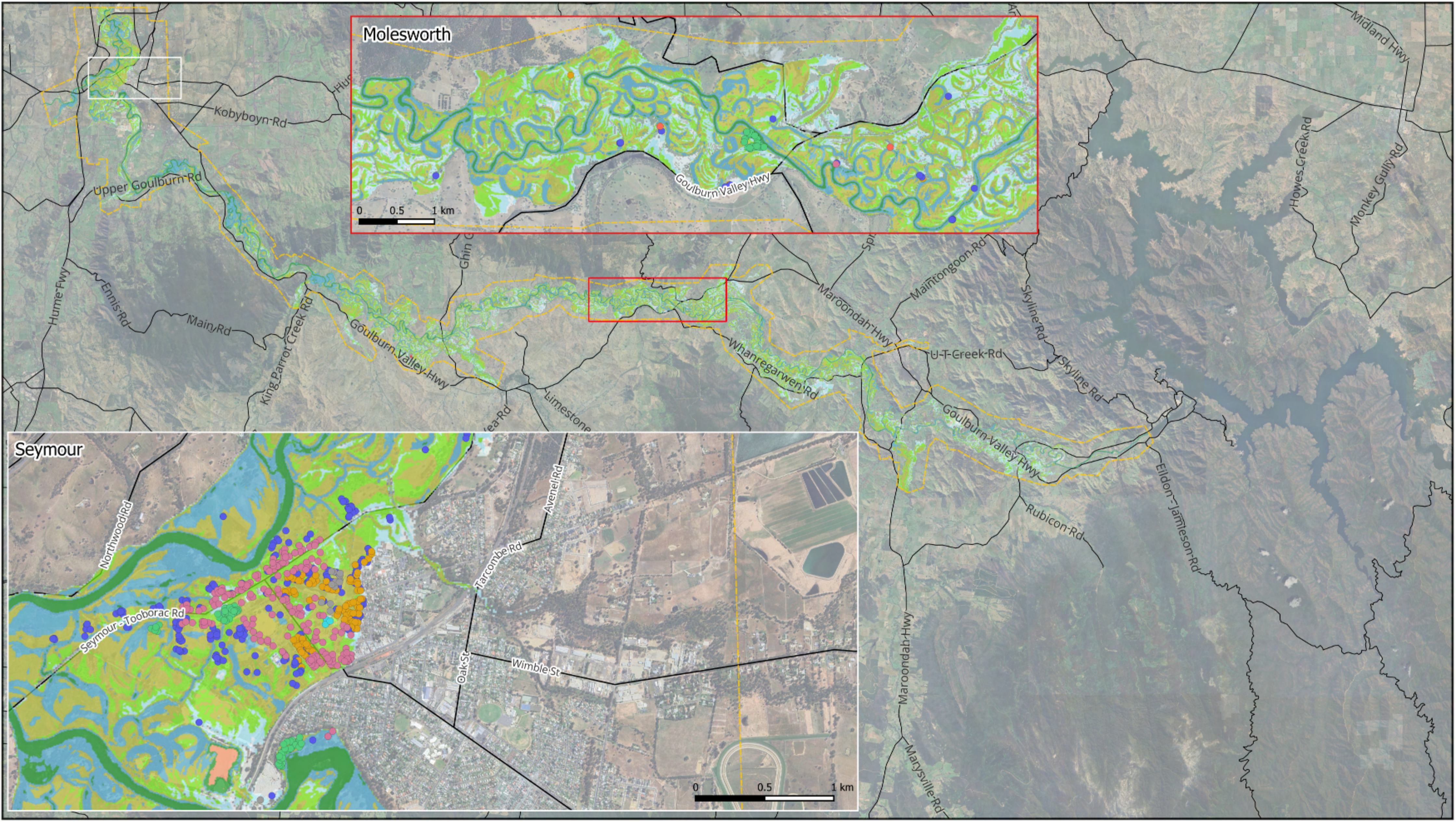
Map Projection: Transverse Mercator
Horizontal Datum: GDA 2020
Grid: GDA 2020 MGA Zone 55

N

Study Name - Lake Eildon flood mitigation options assessment
Flood Extent Map - 1993 event with a target storage of 78% of FSL

Study Area

Job Number	VIC00120
Revision	A
Date	19 Feb 2024
Reviewed By	
Created By	
Map Number	VIC00120-M12



Legend

Hydraulic Model Extent

Main Roads

Inundated Structures

Caravan Park, Commercial, Shed, Farm, Industrial, Residential, School, Hospital

Max Depth (m)

0.00 - 0.15, 0.15 - 0.50, 0.50 - 1.00, 1.00 - 2.00, 2.00 - 5.00, 5.00 - 10.00, 10.00 - 15.00, 15.00 - 20.00, > 20.00

0 4 8 km

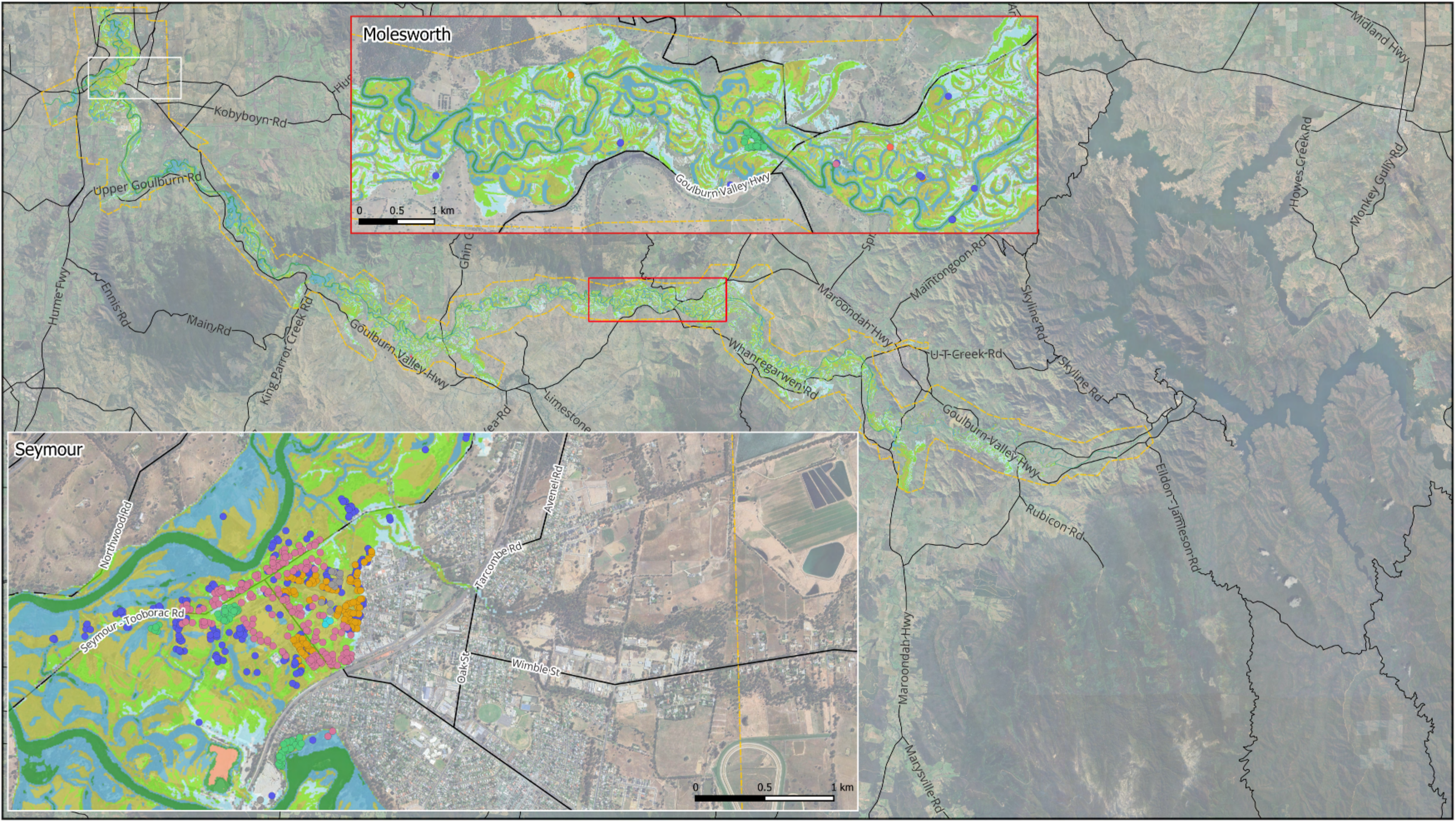
Map Projection: Transverse Mercator
Horizontal Datum: GDA 2020
Grid: GDA 2020 MGA Zone 55

N

Study Name - Lake Eildon flood mitigation options assessment
Flood Extent Map - 2022 event

Study Area

Job Number	VIC00120
Revision	A
Date	19 Feb 2024
Reviewed By	
Created By	
Map Number	VIC00120-M13



Legend

- Hydraulic Model Extent
- Main Roads

Inundated Structures

- Caravan Park
- Commercial
- Shed
- Farm
- Industrial
- Residential
- School
- Hospital

Max Depth (m)

- 0.00 - 0.15
- 0.15 - 0.50
- 0.50 - 1.00
- 1.00 - 2.00
- 2.00 - 5.00
- 5.00 - 10.00
- 10.00 - 15.00
- 15.00 - 20.00
- > 20.00

0 4 8 km

Map Projection: Transverse Mercator
Horizontal Datum: GDA 2020
Grid: GDA 2020 MGA Zone 55

N

VICTORIA State Government | Energy, Environment and Climate Action

HARC

Study Name - Lake Eildon flood mitigation options assessment
Flood Extent Map - 2022 event with a target storage of 78% of FSL

Study Area

Job Number	VIC00120
Revision	A
Date	19 Feb 2024
Reviewed By	
Created By	
Map Number	VIC00120-M14