Operating and infrastructure options for increasing flood mitigation at Lake Eppalock

Technical assessment report

Summary

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Introduction

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

Lake Eppalock

Lake Eppalock was constructed between 1960 and 1964 to store water for consumptive use. The water stored at Lake Eppalock is used to supply private diverters (irrigators), meet environmental water demands along the Campaspe River, underpin urban water security for Bendigo and a number of other towns, and meet trade commitments to the River Murray

The full supply level (FSL) at Lake Eppalock is 193.91 m AHD, at which 304,650 ML (304.65 GL) is held in storage. This capacity is shared 82% : 18% between Goulburn-Murray Water (GMW) and Coliban Water respectively. The maximum capacity of the outlet for releasing water downstream is approximately 1,600 ML/d.

The storage behaviour at Lake Eppalock from the mid-1990s onwards has been distinctly different compared with the period from the mid-1960s to mid-1990s (Figure 1). Before the mid-1990s, Lake Eppalock filled and spilled most years, and was rarely drawn down below 50% of FSL (approximately 150,000 ML). Spills were typically below or slightly above the minor flood threshold at Eppalock.

Since the mid-1990s, the reservoir levels at Lake Eppalock have typically been lower and for longer periods of time compared with the earlier period. The frequency of spills from storage has therefore reduced. However, two of the spills (January 2011 and October 2022) are by far the largest in the historic record.

The Lake Eppalock catchment encompasses an area of approximately 2,030 km², and the catchment area of the Campaspe River between Lake Eppalock and Rochester is approximately 1,370 km². There is a strong correlation between the peak spill from Lake Eppalock and the peak flow at Rochester, with the peak flow at Rochester typically being 1.2 to 3.3 times the peak spill from Lake Eppalock (Figure 2).

If the flood mitigation provided by Lake Eppalock can be increased, flood frequencies in Rochester would be likely to decrease. However, the correlation between Lake Eppalock spills and flooding in Rochester is not perfect. This is because of the catchment area and the tributaries of the Campaspe River between Lake Eppalock and Rochester. If rainfall is heaviest in the region downstream of the dam rather than upstream, significant flooding at Rochester can occur even if there is minimal flooding at Lake Eppalock. For example, in August 1983 there was major flooding in Rochester, even though the spill from Lake Eppalock was just above the minor flood threshold at Eppalock.

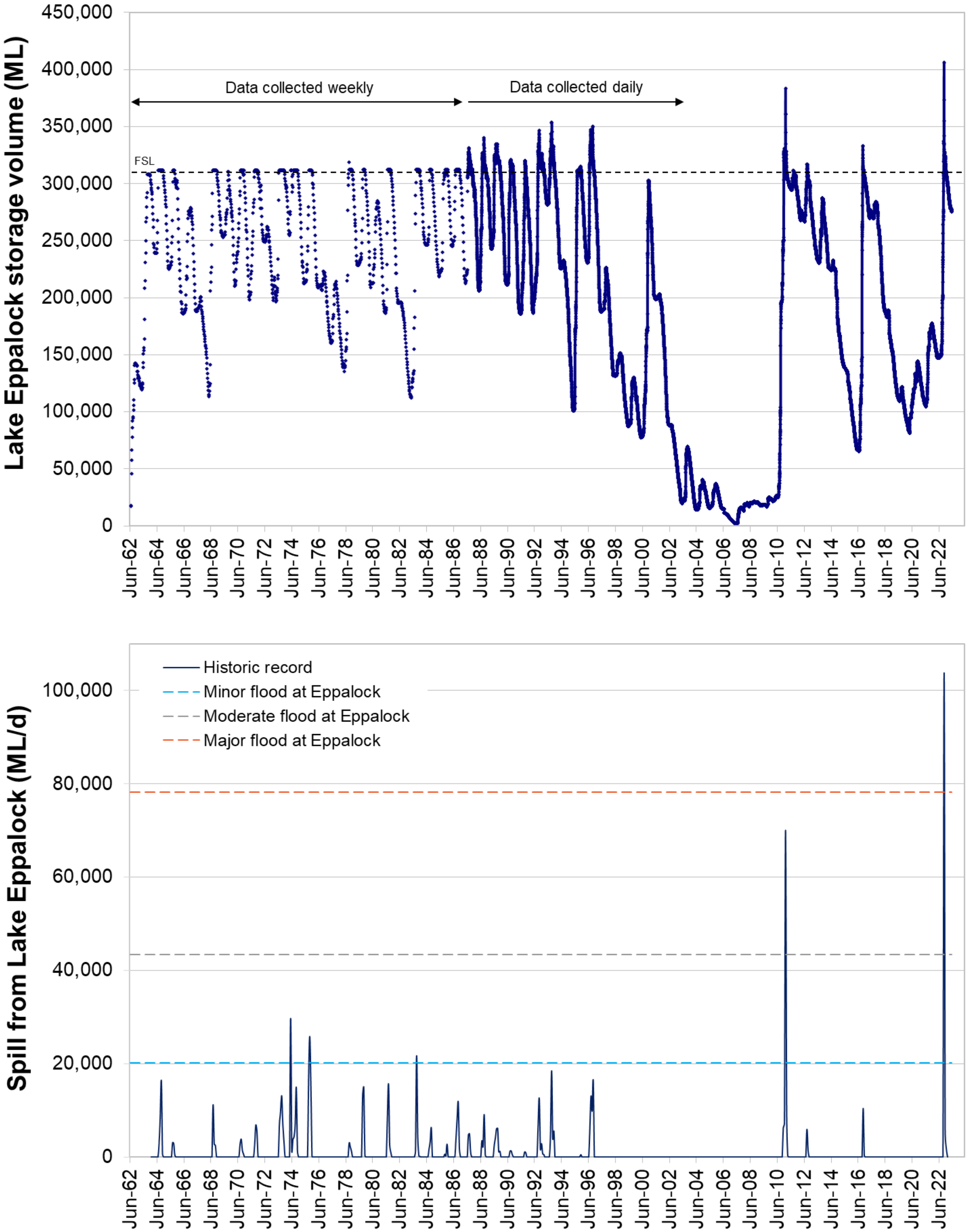


Figure 1: Recorded storage volumes (top) and spills from Lake Eppalock (bottom) for the period from June 1962 to April 2023. Data supplied by GMW.

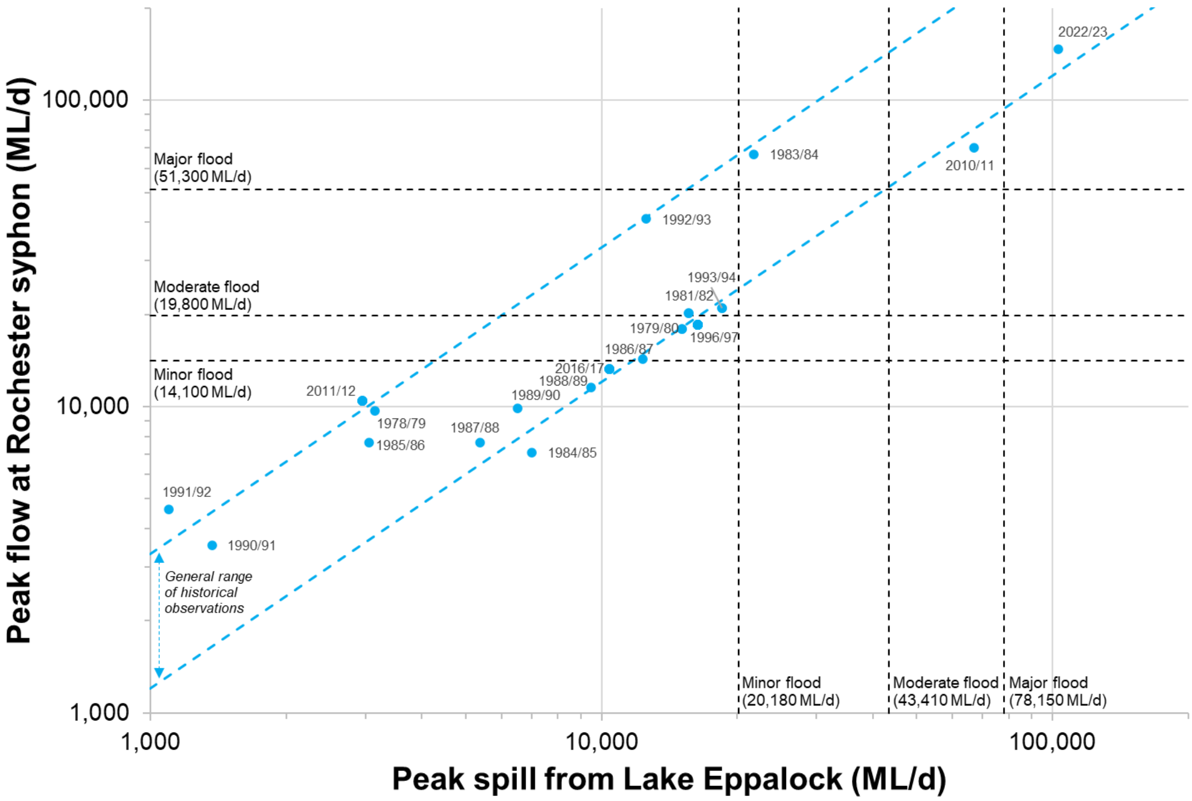


Figure 2: Peak spills from Lake Eppalock versus peak flows at the Rochester syphon for each water year post-1975, shown as a scatter plot

Options investigated for increasing the flood mitigation provided by Lake Eppalock

This technical assessment of potential operating and infrastructure options for increasing the flood mitigation provided by Lake Eppalock has examined five options:

- The first three of the options involve lowering the target storage or FSL at Lake Eppalock. These options would therefore reduce the volume of water stored in the Campaspe system for entitlement holders.
- The other two options would maintain the existing FSL at Lake Eppalock, but hold more water behind the dam wall during floods. These options would therefore increase the number of recreational and commercial tourism sites around Lake Eppalock that are inundated during floods.

These options were selected based on a workshop with DEECA, Goulburn-Murray Water, Coliban Water, Central Highlands Water, the Victorian Environmental Water Holder, the North Central Catchment Management Authority, Bendigo City Council and Campaspe Shire Council. The five options are described below.

Five other options were also considered during the workshop or later stages of the project. These included the transfer of water to Greens Lake or Lake Cooper. However, these options were not assessed to the same level of detail, because they are unlikely to significantly increase the flood mitigation provided by Lake Eppalock, or improve upon the five options selected.

For example, Greens Lake and Lake Cooper were already near or above capacity during the 2011 flood, and in October 2022 the spare capacity in Greens Lake was a small fraction of the inflows to Lake Eppalock.

Option 1: Reduce Lake Eppalock target storage using existing infrastructure

This option involves using the existing outlet for downstream releases to hold the storage – to the degree possible – below or at a targeted proportion of FSL, rather than allowing Lake Eppalock to fill to FSL. The additional airspace in Lake Eppalock would further reduce flood peaks as events passed through the storage. In this technical assessment, options to reduce the target storage to 50%, 70% or 90% of the current FSL were investigated.

The degree to which this option reduces peak outflows from Lake Eppalock would vary by event because the current outlet capacity is only 1,600 ML/d. For example, in 2011 and 2022 inflows in the months prior to the floods were such that the storage could not have been held at a defined target (e.g. 70% or 90% of FSL) before either event.

Option 2: Reduce Lake Eppalock target storage and increase outlet capacity

This option involves reducing the target storage at Lake Eppalock, and increasing the downstream outlet capacity so that operators have greater ability to release water from storage during intervals between floods. To implement this option, a second downstream outlet would be required at Lake Eppalock, because of the anticipated dam safety risks associated with expanding the existing outlet.

For this technical assessment, an outlet capacity of 5,000 ML/d was selected. A total release of 5,000 ML/d from Lake Eppalock is below thresholds that have historically caused flooding at Rochester (Figure 2), the additional 3,400 ML/d outlet capacity would be sufficient to deliver the 1,800 – 2,000 ML/d winter freshes recommended for the Campaspe River, and this outlet capacity would have been sufficient to hold Lake Eppalock at a target storage below FSL in the lead-up to the 2011 and 2022 floods.

Option 3: Reduce Lake Eppalock full supply level using a spillway slot (e.g. Figure 3)

Permanently reducing the FSL at Lake Eppalock is another way of increasing the amount of airspace in storage prior to a flood. The option considered in this technical assessment was installing a passive spillway slot to lower FSL by approximately 3 m, which would reduce the volume held when the storage is full to 70% of the current FSL. However, inflows to storage preceding a flood may mean that the lake level is above 70% of FSL before the event arrives.

Figure 3: An example of a spillway slot – Hinze Dam in Queensland

Option 4: Add spillway gates

The three options above all reduce the water stored in Lake Eppalock for entitlement holders. In contrast, this option involves adding spillway gates to the primary spillway, and maintaining the existing FSL. Having spillway gates at Lake Eppalock would potentially allow the storage operators to reduce peak outflows during floods by surcharging the reservoir to levels higher than would otherwise occur with a fixed crest spillway. However, surcharging the reservoir during floods would increase the number of recreational sites and buildings around Lake Eppalock that are inundated compared with current conditions.

The uncertainty in rainfall forecasts constrains the degree to which storage operators can confidently make pre-releases without either a) releasing water that cannot be replaced by subsequent inflows or b) exacerbating downstream flooding. Therefore, the concept design for this option was based on adding gates to the existing spillway (to minimise the cost), rather than lowering the spillway crest and using the gates to maintain the existing FSL.

Option 5: Reconfigure spillways, by installing piano key spillways (e.g. Figure 4)

The last option selected for assessment was reconfiguring the primary, secondary and tertiary spillways – without reducing FSL or adding spillway gates – so that more storage at Lake Eppalock is utilised during floods. The method selected for investigation was the installation of piano keys on part of the primary spillway and all of the secondary spillway. A piano key spillway was added to Loombah Dam in north-east Victoria in 2013.

By adding piano keys either side of the central portion of the primary spillway, a slot could be created through which Lake Eppalock outflows below a given threshold would be 'throttled'. Once flows were above this threshold the keys would engage to increase the spillway flow and thus ensure dam safety is not compromised. Piano keys would also be required on the secondary spillway, and an erodible crest raise on the tertiary spillway, so that the frequency at which these emergency spillways are operating does not increase despite the changes to the primary spillway. As per the addition of spillway gates, during floods this option would increase the number of recreational sites and buildings around Lake Eppalock that are inundated compared with current conditions

Figure 4: An example of a piano key spillway (https://www.hydropower.org/blog/climate-resilience-case-study-piano-key-weirs)

Assessment method

For each option, the water resource implications, flood frequency changes at Lake Eppalock, anticipated changes to 2011 and 2022 spills from Lake Eppalock (if the events were repeated), concept designs and initial capital costs[1], upstream water level implications, downstream flow regime changes, and potential reductions of tangible flood damages[2] have been considered.

The assessment was informed by applying existing water resource and flood hydrology models, and using historical datasets. Results from the technical analyses completed 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 2011 or 2022 events were repeated

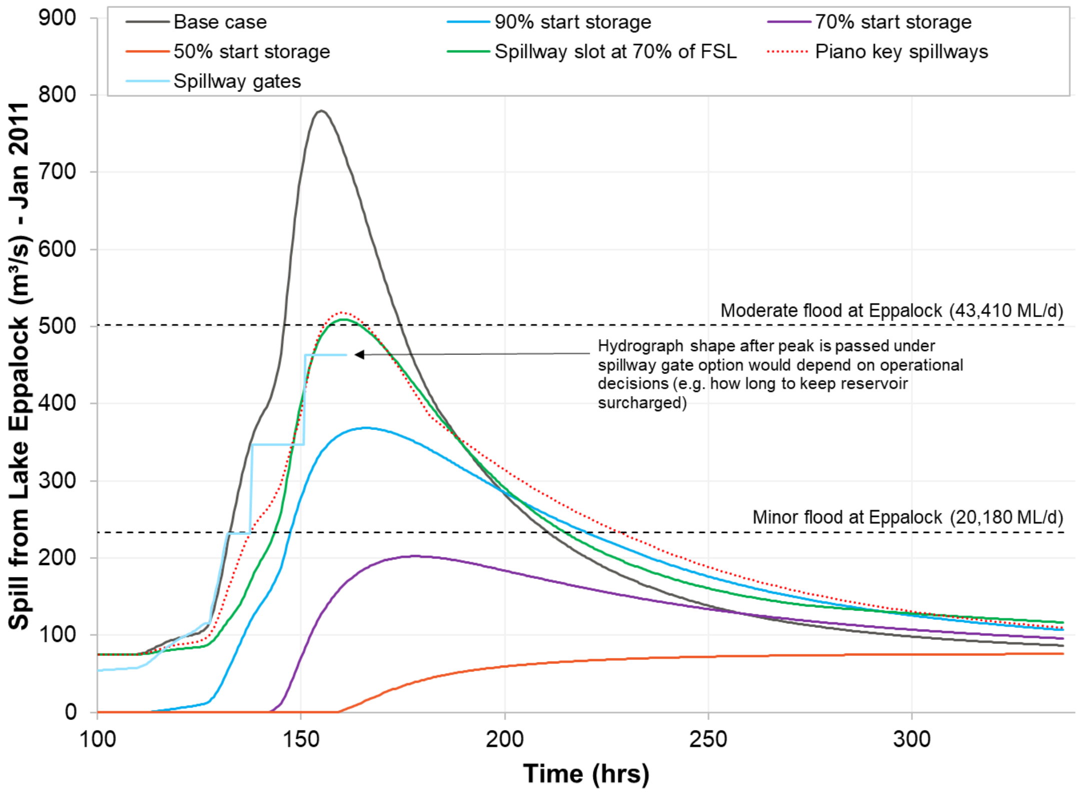
Adopting a target storage of 70% or 90% below FSL using the existing infrastructure at Lake Eppalock would not have significantly changed the outcomes observed in January 2011 and October 2022. This is because in 2011 and 2022 inflows in the months prior to the floods were such that the storage could not have been held at a defined target before either event. Likewise, releasing water from storage in response to rainfall forecasts will not be a feasible way of significantly reducing flood frequencies downstream of Lake Eppalock for the foreseeable future because of forecast uncertainties. The full technical assessment report includes more detail to support these statements.

For the other options assessed, Figure 5 shows how the outflows from Lake Eppalock and the reservoir levels would differ if the 2011 flood were repeated. The option to reduce the Lake Eppalock target storage and increase the outlet capacity is represented by the 90%, 70% or 50% start storage curves. Not surprisingly, as the start storage is lowered, the peak outflow from Lake Eppalock reduces. The spillway slot, spillway gates and piano keys spillways options all have similar peak outflows, but different upstream water levels.

Figure 6 is a similar analysis of the 2022 flood. This demonstrates that the degree to which the options will increase the flood mitigation provided by Lake Eppalock will vary from event to event. In this case the 90% start storage option provides the least additional flood mitigation. The same amount of additional flood mitigation is provided by the spillway slot and piano keys spillways options, and more flood mitigation comes from the spillway gates or lower reservoir start storages. For this technical assessment, the spillway gates design and high-level operational rules were based on the 2022 flood. If the spillway gates option is pursued further, the design and operational rules would need to be refined so that trade-off between upstream and downstream flooding is better optimised across a range of potential future flood scenarios.

[1] The design and construction costs for the works were estimated to a AACE Class 5 level, which are typically within -50% to +100% of the true cost. The scope of work did not include estimating the additional operation and maintenance costs for new infrastructure, or the ongoing socio-economic costs of reducing the volume of water stored in the Campaspe 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.



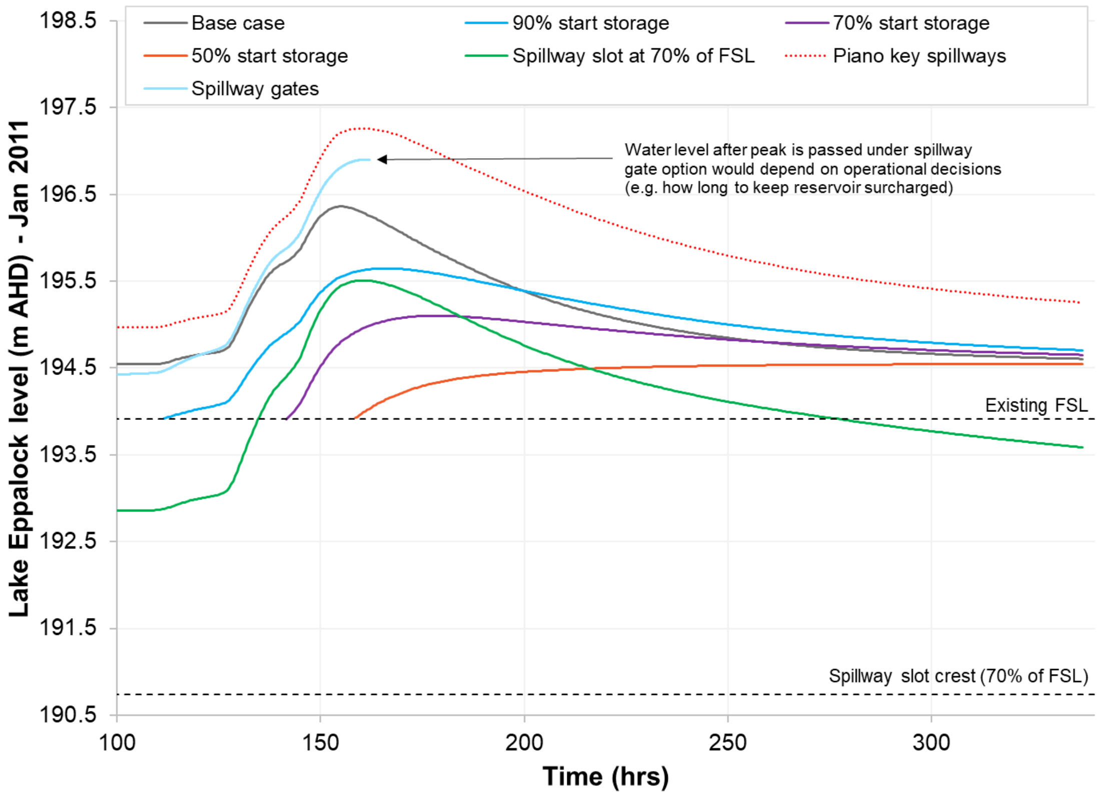
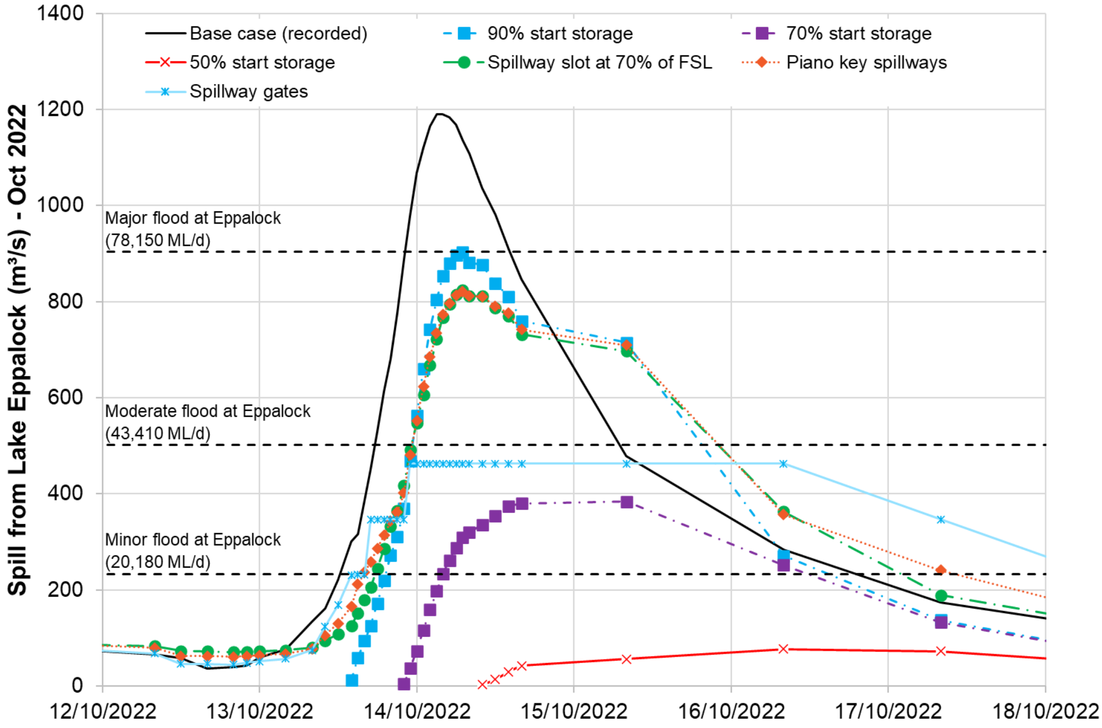


Figure 5: The modelled (in RORB) changes that various options would make to the outflows from Lake Eppalock (top) and reservoir level (bottom) if the January 2011 flood were repeated. A 90%, 70% or 50% start storage would only have been achievable with an increased outlet capacity. 1 m³/s equals 86.4 ML/d.



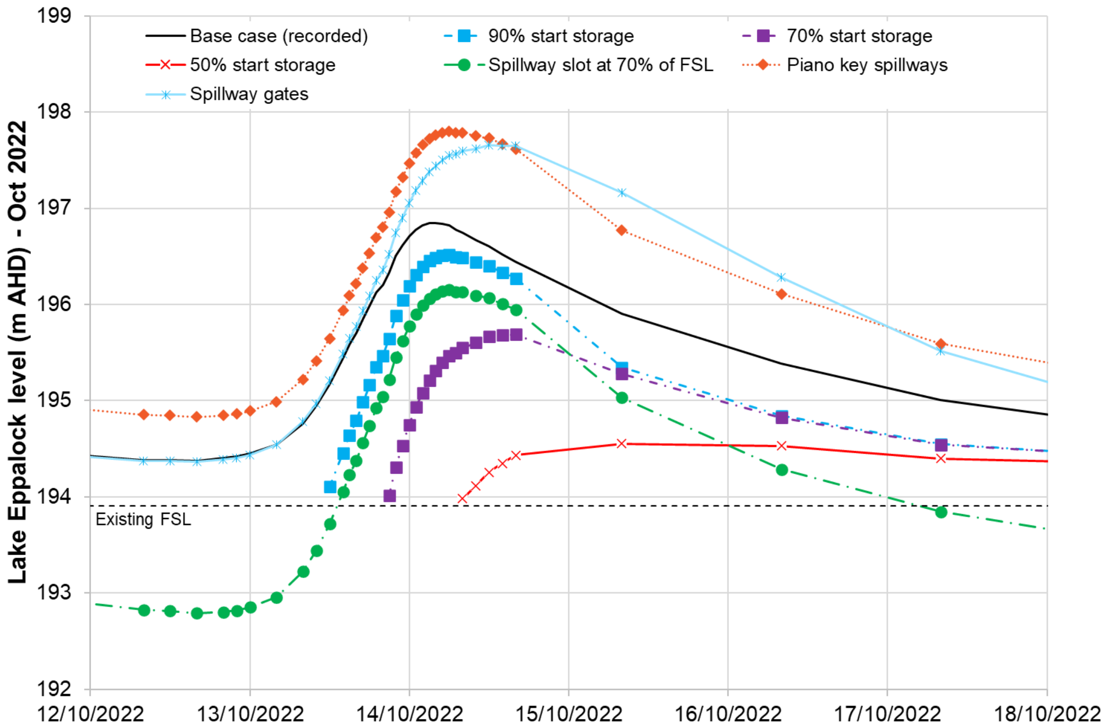


Figure 6: The modelled (in a spreadsheet) changes that various options would make to the outflows from Lake Eppalock (top) and reservoir level (bottom) if the October 2022 flood were repeated. A 90%, 70% or 50% start storage would only have been achievable with an increased outlet capacity. 1 m³/s equals 86.4 ML/d.

Table 1 summarises the peak outflows in Figure 5 and Figure 6, and provides an indicative assessment of how the options would have changed peak flows in Rochester, the flood damages upstream of Lake Eppalock, and the flood damages from Lake Eppalock to Rochester. The flood damage values combine damages estimated for buildings and contents (residential and non-residential), vehicles, road and rail, and agriculture. All options would reduce flood damages downstream, but the spillway gates and piano keys spillways options would increase flood damages upstream (Table 2).

Table 1: A summary of how the options would reduce the flood damages if the 2011 or 2022 events were repeated. A 90%, 70% or 50% start storage would only have been achievable with an increased outlet capacity.

Option	Approximate peak flow (ML/d)		Approximate flood damages (in millions)			
	Eppalock spill	Rochester syphon	Upstream of Eppalock	Eppalock to Rochester*	Total (rounded)	Difference v base case
2011 – base case	70,000	^84,000	$7	(1700) $200	$205	-
2011 – 50% start storage	7,000	8,500	-	~$0	~$0	$205
2011 – 70% start storage	17,500	21,000	-	(50) $15	$15	$190
2011 – 90% start storage	32,000	38,500	-	(340) $40	$40	$165
2011 – spillway gates	40,000	48,000	$15	(600) $75	$90	$115
2011 – slot spillway at 70%	44,000	52,800	-	(800) $95	$95	$110
2011 – piano key spillways	44,000	52,800	$20	(800) $95	$115	$90
2022 – base case	103,000	^123,500	$15	(>2000) $360	$375	-
2022 – 50% start storage	7,000	8,500	-	~$0	~$0	$375
2022 – 70% start storage	33,000	39,500	-	(360) $45	$45	$330
2022 – 90% start storage	78,000	93,500	$8	(1970) $250	$260	$115
2022 – spillway gates	40,000	48,000	$25	(600) $75	$100	$275
2022 – slot spillway at 70%	71,000	85,000	-	(1800) $220	$220	$155
2022 – piano key spillways	71,000	85,000	$30	(1800) $220	$250	$125

^ To consistently relate the peak spill from Lake Eppalock to an approximate peak flow at Rochester syphon, the lower blue-dotted lines shown in Figure 2 have been used. This means the values here are different to those recorded at the Rochester syphon gauge in 2011 (~70,000 ML/d) and 2022 (~140,000 ML/d).

* The values in brackets are the approximate number of houses affected from Lake Eppalock to Rochester.

Table 2: Estimates of the number of buildings inundated around Lake Eppalock during the 2011 and 2022 floods, and if the floods were repeated with the spillway gates or piano keys spillways options implemented

Year / option	Estimated number of buildings inundated upstream of Lake Eppalock	
	Total	Difference to base case
2011 – base case	60	-
2011 – add spillway gates	120	60
2011 – piano key spillways	170	110
2022 – base case	110	-
2022 – add spillway gates	225	115
2022 – add piano key spillways	270	160

Water resource implications

The options that involve lowering the target storage or FSL at Lake Eppalock would reduce the reliability of supply to entitlement holders in the Campaspe system (Table 3), and the volume of water supplied to urban and rural customers in the Coliban system (Table 4), if existing entitlements and water shares are maintained. This is because less water would be held in storage (Figure 7).

To return the reliability of supply to levels expected under current conditions, approximately 15%, 33% or 55% of the combined high- and low-reliability entitlements and water shares in the Campaspe system would need to be recovered if the target storage or FSL was reduced to 90%, 70% or 50% respectively. At present, irrigators and water corporations hold approximately 60% of the total entitlements and water shares in the Campaspe system, and the environment – via the Victorian and Commonwealth environmental water holders – has the other 40%.

The socio-economic consequences of additional water recovery in the Campaspe system, and the mechanisms by which this may happen (e.g. purchases via the water market or changes to bulk or environmental entitlements) have not been assessed. Lowering the Lake Eppalock target storage or FSL would also increase the distance between recreational facilities (e.g. boat ramps and holiday accommodation) and the water's edge.

Table 3: Modelled average February allocations to high-reliability water shares (HRWS) and low-reliability water shares (LRWS) in the Campaspe and Goulburn systems

Option	Average modelled February allocations (July 1891 – June 2022)			
	Campaspe system		Goulburn system	
	HRWS	LRWS	HRWS	LRWS
Base case	**94%**	**76%**	**97%**	**50%**
90% target storage	94%	71%	97%	50%
70% target storage / FSL	93%	60%	97%	50%
50% target storage	87%	45%	97%	50%

Table 4: Modelled change in average annual volume supplied to the Coliban system from Lake Eppalock

Option	Modelled supply from Lake Eppalock to Coliban system (July 1891 – June 2022)	
	Average annual volume (ML)	Difference to base case (ML)
Base case	9,200	-
90% target storage	8,900	300
70% target storage / FSL	8,600	600
50% target storage	7,700	1,500

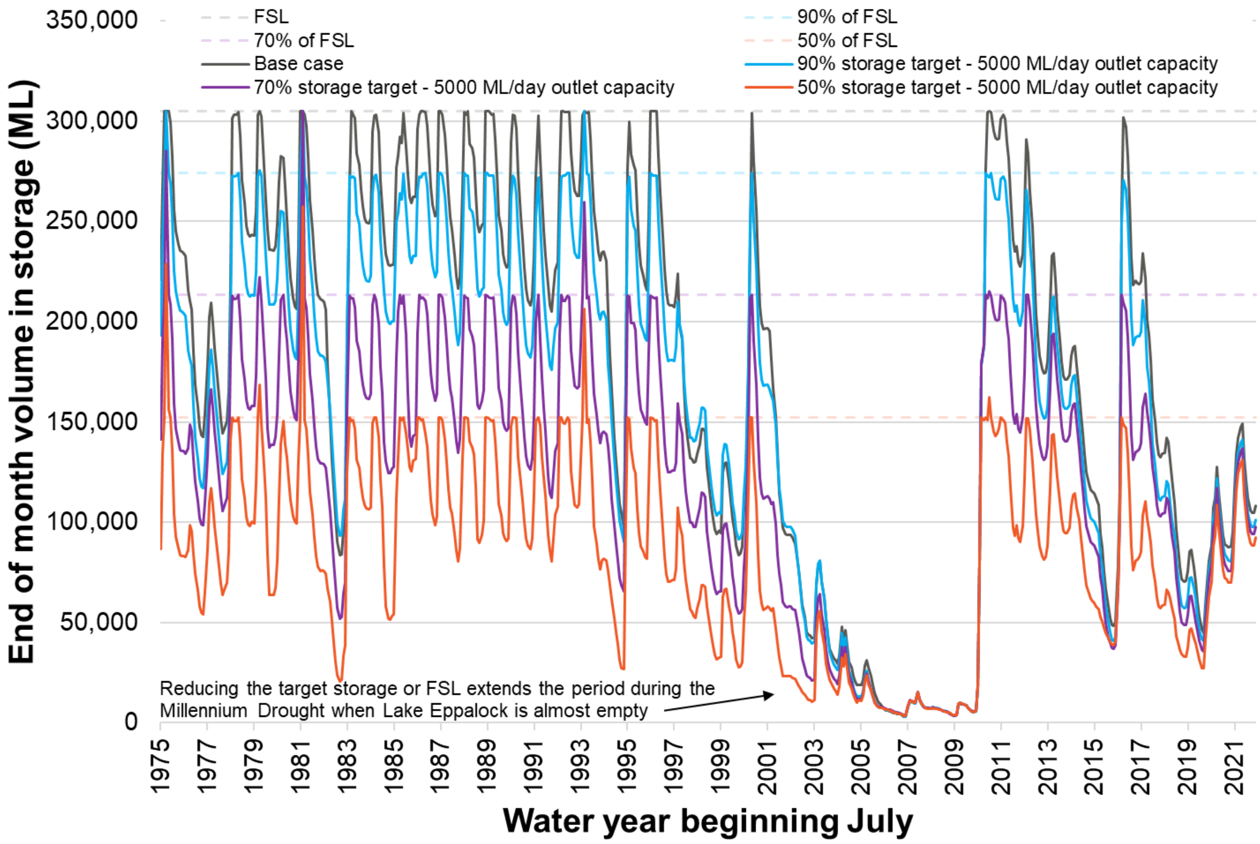


Figure 7: Monthly time-series of the modelled storage trace for Lake Eppalock, from January 1975 to June 2022, for the option to reduce target storage to 50%, 70% or 90% of FSL using a 5,000 ML/d outlet capacity

Downstream flow regime

If the target storage at Lake Eppalock is lowered using the existing outlet capacity, there will be a reduction of flows in winter and early spring and increased flows in late spring and early summer. This is because the outlet will often be operating near the 1,600 ML/d capacity during late spring and early summer to bring the reservoir level back to the target storage, and in winter and early spring there will be more airspace compared with the base case and hence less spills. This shift of the flow regime downstream of Lake Eppalock would be likely to cause some negative environmental impacts.

In contrast, the options that include an increased outlet capacity or spillway slot are likely to have a neutral or positive impact on the downstream environment, because they provide for larger (but within bank) flows in winter and early spring. For the increased outlet capacity option, this conclusion is based on the assumption that releasing flows from storage at up to 5,000 ML/d, which is higher than the 1,800 – 2,000 ML/d winter fresh flow recommendation downstream of Lake Eppalock but less than the 10,000 ML/d – 12,000 ML/d bankfull flow recommendation, will not have detrimental environmental impacts. This assumption will need to be tested in future.

Further investigation will also be required to weigh the potential benefit of having higher flows down the Campaspe River if the target storage or FSL is lowered at Lake Eppalock, against the cost of having less water stored for environmental use in dry periods (e.g. the early 2000s period in Figure 7). The minimum flows passed downstream of Lake Eppalock would also decrease under current bulk entitlement rules if less water is held in storage.

Ranking of options

Modelled flood frequencies were combined with estimates of how flood damages vary according to Lake Eppalock outflows to produce approximate values of average annual damages for the base case (current conditions) and options assessed. The estimates of average annual damages will increase once flood hydrology and hydraulic modelling is updated using rainfall, streamflow and inundated area records available for the October 2022 event, but are still useful for ranking the options investigated.

Table 5 shows how the avoided flood damages if the options were in place compare with the initial capital cost, assuming a 50-year horizon, a 6% discount rate and ignoring any increase in operation and maintenance costs. For the reasons stated below the table, the benefit to cost ratios are approximate and will change if the options are investigated in more detail.

Colours have been added to the rows to highlight three groupings across the options. The options to reduce the target storage or FSL to 70% of the current FSL using an increased outlet capacity or passive spillway slot – shaded blue – have the highest ratio of avoided damages to initial capital cost (Table 5). The ratio is lower for the options to reduce the target storage at Lake Eppalock to 90% or 50%. These are shaded yellow. The options to maintain the existing FSL and add spillway gates or piano keys spillways – coloured orange – have the lowest benefit to cost ratio. The option to reduce the target storage at Lake Eppalock using the existing outlet capacity is not shown because it is not a robust option.

This ranking of the options however, does not account for the ongoing socio-economic consequences of reducing the volume of water stored for entitlement holders in the Campaspe system, and the recreational impacts of holding the Lake Eppalock water level below FSL. Therefore, before one or more option is selected as the preferred option(s) for further investigation:

- Results from this technical assessment will need to be compared with outcomes from the update of the Rochester flood management plan that is underway.
- The socio-economic consequences of reducing the volume of water stored in the Campaspe system need to be modelled.
- An assessment – informed by consultation with entitlement holders – is needed about the mechanisms available to change water sharing arrangements, to allow airspace to be maintained in Lake Eppalock without reducing water supply reliability and/or compromising water pricing in the Campaspe system.

If changing the water sharing arrangements in the Campaspe system is not feasible, then the options to reduce the target storage or FSL at Lake Eppalock are not worth pursuing further. If the arrangements can be changed, further work is required to optimise the trade-off between the socio-economic, recreational, environmental and cultural consequences of reducing the target storage or FSL, and the additional flood mitigation provided.

Table 5: Estimates of avoided damages vs initial capital cost, assuming a 50-year horizon, a 6% discount rate and ignoring any increase in operation and maintenance costs.

Option	Approximate benefit-cost (50 years, 6% discount)		
	Avoided damages ($ m)^	Initial capital cost ($ m)*	Ratio
Slot spillway at 70% FSL	30.3 – 39.3	40	0.8 – 1.0
70% target storage + 5,000 ML/d outlet	41.8 – 60.8	65	0.6 – 0.9
90% target storage + 5,000 ML/d outlet	22.3 – 35.6	45	0.5 – 0.8
50% target storage + 5,000 ML/d outlet	51.2 – 71.2	105	0.5 – 0.7
Piano key spillways	24.5 – 32.4	60	0.4 – 0.5
Spillway gates	23.6 – 41.2	200	0.1 – 0.2

^ The estimates of avoided damages are approximate, because:

- The relationship between spills from Lake Eppalock and flood damages from Lake Eppalock to Rochester is approximate, and has been extrapolated.
- Flood damages downstream of Rochester have not been considered.
- Estimates of the avoided damages will increase once the flood hydrology and hydraulic modelling is updated using rainfall, streamflow and inundated area records available for the October 2022 event.

* For the estimates of costs:

- The design and construction costs for the works were estimated to a AACE Class 5 level, which are typically within -50% to +100% of the true cost.
- The costs associated with recovering water to offset the supply reliability impacts are approximate.
- The ongoing socio-economic costs associated with reducing the volume of water stored in the Campaspe system (if the target storage or FSL at Lake Eppalock is reduced) are not included.
- The additional operation and maintenance costs of new infrastructure are not included.

Recommended further work

Before further work is done on the potential operating and infrastructure options for increasing the flood mitigation provided by Lake Eppalock, the RORB model of the catchment and dam should be re-calibrated and re-verified using rainfall and streamflow records available for the 2022 flood. DEECA should also consider using the daily Goulburn-Broken-Campaspe-Coliban-Loddon Source model during future assessments of the water resource and downstream flow regime implications, rather than continuing to use the monthly Goulburn Simulation Model that was made available for this study.

If the water sharing arrangements in the Campaspe River catchment are able to be changed, further investigations are needed before the trade-offs can be optimised. This includes:

- Assessing the socio-economic consequences of reducing the volume of water stored in the Campaspe system
- Considering the costs and benefits of different potential ways for recovering or retiring entitlements and water shares
- Refining the assessment of flood damages, and how these vary according to peak outflows from Lake Eppalock
- Refining the initial assessments of the expected costs and benefits to existing recreational, environmental and cultural values around Lake Eppalock and downstream
- Refining the design and cost estimates for the increased outlet capacity, and optimising the outlet size by balancing the associated cost with the flood mitigation and operational benefits provided by the increased capacity.

If the water sharing arrangements cannot be changed and therefore only infrastructure options are possible for increasing the flood mitigation provided by Lake Eppalock, additional work will be required to optimise the design of the spillway gates or piano key spillways, to provide the best possible trade-off between costs, the upstream impacts from increased reservoir levels, and the additional flood mitigation for the downstream community. However, even with further optimisation, the implementation costs for these two options are likely to be greater than estimates[3] of flood damages avoided over a 50-year timespan.

Regardless of the option(s) selected for further investigation, it is also recommended that the option(s) be stress-tested using additional long-term and short-term climate sequences that are indicative of potential future conditions in the Campaspe River catchment.

[3] The extent of avoided damages varies by both the flood magnitude and option. This means that if any of the options considered were implemented, the time to recoup the costs in the form of avoided flood damages would depend on the timing and magnitude of future flooding along the Campaspe River, both of which are unknown.