Independent Expert Panel on restoring Mowamba River flows and flexibility of Jindabyne releases of Snowy River Increased Flows

Final report
September 2022

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Cover photos: Snowy River below Jindabyne Dam. Tim Haeusler, NSW DPE
Mowamba Weir. Tim Haeusler, NSW DPE

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Acknowledgements

The Panel members are most grateful to Paul Doyle, NSW Department of Planning and Environment, for his unstinting role as convenor of Panel meetings and provider of a wealth of guidance, technical information, modelling, draft text, feedback and other support to the Panel's work.

The Panel is also most appreciative of unpublished data and other information, comments on draft versions of this report, and administrative support provided by the following individuals and organisations:

Gilad Bino (information on platypus ecology)
Andrew Brooks (macroinvertebrate data and comments on draft)
Daniel Coleman (temperature modelling and comments on draft)
Neeraj Maini (administration)
Catherine Munro (editing)
Caroline Ortel (administration)
Paul Packard (draft text and administration)
Ann-Marie Rohlfs (water quality data)
Teresa Rose (geomorphological data and assessment)
Paul Simpson (background information and hydrological data and analysis)
Lisa Thurtell (administration)
Duanne White (longitudinal river profiles and information on fish barriers)
Simon Williams (water quality data)
Emma Wilson (frog data and assessments and comments on draft)
NSW Department of Primary Industries (fish data)
Snowy Advisory Committee (discussion of issues and comments on draft)
Snowy Hydro Limited (flow data and comments on draft).

In addition, the following individuals and organisations are thanked for images included in this report:

Paul Doyle
Stevenson Gawen
Tim Haeusler
Bottlebrush Media
Google Earth
Kerry and Co.

Shortened forms

BPF	base passing flow – an allowance of 9,000 ML per year for the Snowy River (which is in addition to any Snowy River Increased Flow allocation). It is split into 8,500 ML per year for the release into the Snowy River from Jindabyne and 500 ML/year for release via the lower Mowamba River from Mowamba Weir
DOC	dissolved organic carbon
MANF	mean annual natural flow
ML	megalitres
NSW DPE	NSW Department of Planning and Environment
SAC	Snowy Advisory Committee
SHL	Snowy Hydro Limited
SRIF	Snowy River Increased Flows program, or the volume of environmental water from that program
SWIOID	Snowy Water Inquiry Outcomes Implementation Deed 2002
TN	total nitrogen
TP	total phosphorus

Executive summary

From 1967 until 2002, the Snowy Mountains Scheme reduced flows in the Snowy River downstream of Jindabyne Dam to an average of 1% of natural levels. However, the Snowy Water Inquiry Outcomes Implementation Deed (SWIOID) specified environmental releases commencing in 2002 and building to a target of an average of 212,000 ML per year (21% of average natural flows) since 2011. These additional flows are called the Snowy River Increased Flows (SRIF).

The Snowy Water Licence defines rights and obligations of Snowy Hydro Limited (SHL) in relation to water in the Snowy Mountains Scheme. The 10-year review of the licence, completed in 2018, proposed 23 actions to improve water management. This report addresses actions 7 and 8A of that review. Those actions are:

Action 7: Finalise the Mowamba River investigation. This will include:

- *evaluating options for using the Mowamba River to provide environmental water to the Snowy River*
- *recommending an environmental flow regime for the Snowy River consisting of a combination of releases from Jindabyne Dam and the Mowamba River.*

Action 8(A): Investigate more flexible delivery to achieve better environmental outcomes from the available SRIF.

A panel of 3 scientific experts was formed in May 2021 to provide advice and recommendations on these actions. The Panel comprised Dr Bruce Chessman (aquatic ecologist), Professor Ian Rutherfurd (fluvial geomorphologist) and Professor Simon Mitrovic (algal and food web ecologist). The Panel's scope was limited to the potential environmental effects of various options for the future delivery of SRIF. Social, community, cultural and economic aspects are to be dealt with via separate processes.

Action 7: Investigating Mowamba River options

Background

The Snowy Mountains Scheme includes a weir on the Mowamba River and an aqueduct that diverts flows from the Mowamba Weir to Lake Jindabyne. Under current operations, only 1.3 ML/day of the Mowamba River's flow is allowed to pass the weir, except when the 500 ML/day capacity of the aqueduct is exceeded and the excess flow overtops the weir. Overtopping may not occur in dry years.

The Panel investigated the following options for using the Mowamba River to provide environmental flows to the Snowy River:

- doing nothing differently, with no changes to the current operating procedures
- removing Mowamba Weir (or a section of it) to allow the full passage of flows, animals and the full sediment load
- retaining Mowamba Weir but allowing all Mowamba River flows to pass the weir
- retaining Mowamba Weir but allowing a portion of Mowamba River flows to pass the weir (specifically, allowing all flow up to 100 ML/day to pass).

Currently, SRIF releases are entirely from Jindabyne Dam. If additional flows were provided from the Mowamba River, Jindabyne releases would have to be reduced accordingly. The Panel assessed 2 options for making such reductions:

- deducting from Jindabyne releases to match Mowamba River additional flows on a daily basis
- deducting the annual average Mowamba River additional flow from yearly Jindabyne releases.

Recommendations

The Panel recommends removal of Mowamba Weir over the other Mowamba River options investigated, for the following reasons:

- Removing the weir would restore the flow regime, water quality, geomorphology and ecology of the downstream 5 km of the Mowamba River to pre-weir conditions.
- Removing the weir would restore the bedload and suspended load from the Mowamba River, as well as natural passage for animals, including native eels and platypus.
- While weir removal would have more modest effects on the Snowy River, increased nutrient levels from the Mowamba River would promote greater growth of benthic algae and plants, which would increase the growth and reproduction of animals such as invertebrates, fish, frogs and platypus via the food web.
- The Snowy River is starved of sediment supply downstream of Jindabyne Dam, and removing the weir would contribute higher bed and suspended sediment loads from the Mowamba River, contributing to a more defined river channel in the Snowy River.
- The benefits of removing the weir would outweigh the minor loss of controlled releases from Jindabyne Dam, and reductions in both high and low flows could be minimised with the options assessed for making deductions from Jindabyne releases.

The Panel considers that both methods for making deductions are viable and would produce very similar environmental outcomes. Therefore, the Panel does not recommend one method over the other. The Panel does, however, recommend that:

- any method that uses the annual average additional Mowamba River flow include a mechanism for this average to be reviewed in light of any decrease in Mowamba River average flows due to climate change
- the carryover of a portion of annual SRIF allocations from one year to the next be enabled if the method of deducting Mowamba River flows daily from Jindabyne Dam releases is used, because carryover would be required to implement this method[1].

If social or economic considerations, which are outside of the Panel's scope, preclude weir removal, the Panel recommends allowing all flows to pass the weir. This option would deliver those environmental outcomes of weir removal that are induced by the reinstatement of pre-weir flows but would not restore coarse bedload and natural passage for animals including native eels and platypus.

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[1] Alternatively, it would require all deviations of SRIF delivery from allocations to be carried over between years, both surpluses and deficits.

The option of retaining the weir and allowing only the first 100 ML/day to pass is not recommended, because it would not restore the full range of flows in the lower Mowamba River and would create a highly unnatural flow regime, with a constant flow of 100 ML/day for long periods. This option would limit the shift of the Mowamba River channel toward its pre-weir condition and the change to a more flow-adapted biotic community. Opportunities for fish to pass natural barriers would also be more limited, and bedload would not be passed down the Mowamba River. Contributions of suspended sediment and nutrients to the Snowy River would also be lower. However, the Panel considers that passing the first 100 ML/day of Mowamba flow would be preferable to the status quo, because it would partly restore wetted area, channel morphology and ecology in the lower Mowamba River.

Action 8A: Investigating more flexible delivery to achieve better environmental outcomes from the available SRIF

Background

The SWIOID and the Snowy Water Licence restrict how SRIF can be delivered:

- **Restrictions on flushing flows:** SHL needs high Lake Jindabyne levels to release flushing flows above 5,000 ML/day and is required to release only one such flow per year, ordered only in spring. SHL is required to release flushing flows only when allocations to SRIF exceed 100,000 ML.
- **Restrictions within the year:** Monthly release volumes and the date and size of any flushing flow release must be provided to SHL by 13 February for the following water year starting on 1 May. The daily release target for each day of a month must be set 6 days before that month starts.
- **Restrictions within the day:** SHL is not required to vary releases within a day. However, SHL does deliver up to 5 flows per year with an 8-hour peak flow and reduced flows during the 8 hours on either side of the peak.
- **Restrictions between years:** No portion of a year's allocation can be carried to the next year, nor can deviations of annual delivery from allocation be carried over into the following year.

The Panel investigated the following options for relaxing such restrictions to enhance environmental outcomes from the available SRIF:

- allowing Jindabyne Dam releases to be adjusted daily in synchrony with concurrent flow in the Thredbo River or another naturally flowing reference river
- allowing releases to respond to environmental events or opportunities
- allowing more intra-day release variability, particularly to create 8-hour or other sub-24-hour peaks
- allowing the carryover of a portion of SRIF allocations (or any deviations between delivery and allocations) between years.

Recommendations

The Panel strongly recommends increasing the flexibility of SRIF delivery to enhance the achievement of environmental objectives with the water available.

The Panel has concluded that the greatest benefit would derive from improving synchronisation of Jindabyne Dam releases with flows in the Thredbo River or a similar unregulated reference stream. This synchrony would:

- align releases more closely with downstream tributary high-flow events, thereby prolonging and, on occasions, increasing the peak flow in the Snowy River resulting from such events
- strengthen channel-forming processes
- increase the flushing of fine sediment and limit accumulation of tributary sediment in the Snowy River
- increase the inundation of benches and the consequent mobilisation of nutrients
- provide more submergence of natural barriers to fish passage
- induce flora and fauna assemblages more similar to those that occurred prior to the Snowy Mountains Scheme, through greater synchrony of Snowy River flows with both tributary flows and rainfall cues for breeding events.

The Panel recommends synchronisation on a continuous daily basis, noting that this option would require the ability to carry over a portion of allocations between years.[1] If such carryover is not achievable, the Panel recommends flexibility to release monthly flow peaks based on a flow trigger in the Thredbo River.

The Panel also recommends releasing high flows from Jindabyne Dam in patterns that more closely reflect those in unregulated reference rivers, allowing higher peak flow rates to be achieved than if the same volume was delivered at a constant rate for 24 hours. An example would be providing a higher flow peak for 8 hours, with compensatory flow reduction in the preceding and following 8 hours. The effects of the higher peak would include increases in channel-forming processes, flushing and scouring of sediment, inundation of benches, mobilisation of nutrients, and fish passage. Plant and animal communities would become more similar to those that would have occurred prior to the Snowy Mountains Scheme.

The Panel also recommends increased flexibility to allow changes in daily flow releases from Jindabyne Dam during the year in response to environmental contingencies. Such flexibility could allow releases to coincide with a downstream tributary flow peak, or respond to events that deposit large amounts of ash or sediment, a pollution event, or a breeding event. Responses could also include increasing baseflows where there is a risk of the estuary mouth closing, releasing a flushing flow when dam levels allow it, or altering releases to better manage carryover. All these responses could assist in achieving specific environmental objectives. However, the Panel notes that there would be effects on other variables that could militate either for or against the achievement of other objectives. The Panel therefore qualifies its recommendation by noting that environmental water managers would need to assess potential risks or additional benefits according to the specific circumstances at the time of any proposed release. The Panel also recommends that such releases should be used sparingly. Frequently changing flows for specific objectives would risk changing the overall flow regime away from one in keeping with the natural flow paradigm that is the present basis of environmental flow releases.

Finally, the Panel recommends that carryover of environmental water between years be permitted. Carryover is a key enabler of many of the recommendations that would enhance achievement of environmental objectives with the limited SRIF allocations available. These recommendations include those that would pass Mowamba River flows with daily deductions from Jindabyne releases, and improving synchronisation of Jindabyne releases with flows in the Thredbo River. Not only is carryover crucial for such options, it also allows for reserves to be carried over for extreme dry years and environmental contingencies.

1. Introduction and background

1.1 Snowy Water Initiative

The Snowy Water Initiative was formally established in 2002 to achieve significant improvements in river health by releasing environmental water into the Snowy River, upper Murray River and Snowy Montane river systems (including the upper Murrumbidgee River). At the commencement of the Snowy Water Initiative, the NSW, Victorian and Commonwealth governments and Snowy Hydro Limited (SHL) invested in water recovery infrastructure upgrades, water management and science to allow environmental water to be released to these Snowy water sources.

The Snowy Water Inquiry Outcomes Implementation Deed (Commonwealth of Australia, State of NSW and State of Victoria 2002; hereafter SWIOID) is the legal instrument the 3 governments entered into to give effect to the outcomes of the public Snowy Water Inquiry in 1998 and the corporatisation of the Snowy Scheme. The SWIOID includes water recovery targets for the Snowy, Murray and Snowy Montane Rivers Increased Flows programs.

Targets for the Snowy River Increased Flows (SRIF) program include returning an average of 212,000 ML each year, or 21% of the average natural flow.

1.2 Snowy Advisory Committee

In July 2018, the Minister for Regional Water appointed the Snowy Advisory Committee (SAC) to provide expert and community input to the design of environmental flows to the Snowy River and Snowy montane rivers. The SAC brings together the local knowledge and expertise of individuals from Snowy River and Snowy Mountains communities and the NSW and Victorian governments. The SAC is responsible for advising the Water Administration Ministerial Corporation each year on the timing and pattern for the release of water for environmental reasons under the Snowy Water Licence.

1.3 Snowy Water Licence Review

The Snowy Water Licence defines SHL's rights and obligations in relation to water in the Snowy Mountains Scheme.

The NSW Department of Industry (2018) completed the first mandatory 10-year review of the licence, focusing on SHL's obligations under the licence. The final report on the 10-year review proposed 23 actions to improve Snowy water management.

1.4 Specific actions relevant to this report

This report addresses Action 7 and Action 8A from the Snowy Water Licence Review:

Action 7: Finalise the Mowamba River investigation. This will include:

- *evaluating using the Mowamba River to provide environmental water to the Snowy River*
- *recommending an environmental flow regime for the Snowy River consisting of a combination of releases from Jindabyne Dam and the Mowamba River.*

Action 8(A): Investigate more flexible delivery to achieve better environmental outcomes from the available SRIF.

The Snowy Water Licence Review also noted that the Mowamba River investigation should consider the benefits a new flow regime would have on temperature outcomes in the Snowy River below Lake Jindabyne. This report therefore considers whether delivering SRIF via a combination of releases from Jindabyne Dam and the Mowamba River could provide Snowy River temperatures that more closely align to those expected in the unmodified Snowy River.

1.5 Initial work and establishment of expert panel

A report commissioned by the former NSW Department of Industry – Water and former NSW Office of Environment and Heritage (Growns 2019) synthesised the various scientific investigations completed to date relevant to delivering SRIF via the Mowamba River. The report concluded that '*There is not currently enough scientific information to make a definite conclusion on the ecological benefits for the Snowy River under the various options for the future management of Mowamba Weir*'.

To further investigate the matter, a panel of 3 scientists was established to report on the expected environmental effects of the Mowamba options (Action 7) and options for the flexible delivery of the available SRIF (Action 8A). The Panel includes:

- Dr Bruce Chessman, aquatic ecologist
- Professor Ian Rutherfurd, fluvial geomorphologist
- Professor Simon Mitrovic, algal and food web ecologist, Professor of Freshwater Ecology, University of Technology Sydney.

The Panel's scope covered the environmental and ecological aspects of Snowy Licence Review Actions 7 and 8A, and included:

- review of advantages and disadvantages of delivering a portion of SRIF by restoring flows past Mowamba Weir. Recommendation of whether this should be undertaken, providing reasoning
- recommendations on an environmental flow regime consisting of a combination of releases from Jindabyne Dam and the Mowamba River, providing reasoning
- review of advantages and disadvantages of the different ways of restoring flows past Mowamba Weir, including no works (flows overtop current weir), construction of a rock-ramp fishway (with flows overtopping the weir), and complete removal of weir. Recommendation of a preferred solution, providing reasoning
- review of the advantages and disadvantages of flexible arrangements for delivery of SRIF, including (but not limited to) carryover of water allocations between years, delivery of high flows with short duration (less than 24 hour) peaks, provision of flushing flows before October, adjustment of daily release rates in timeframes that respond to rainfall events and current natural flows. Provide recommendations for changes in flexibility, providing reasoning.

The Panel's scope did not include the Aboriginal cultural and community/socio-economic aspects of Actions 7 and 8A. These are being dealt with by separate processes and the Panel recognises that it will be critical that these important values are included for the later full assessment of the options.

The Panel convened in May 2021 in Jindabyne and visited sites on the Snowy River from Dalgety up to Jindabyne as well as the Mowamba River above, below and at the Mowamba Weir. The Panel subsequently met on several occasions and presented to the SAC in June 2021 and June 2022. The Panel was provided with new analysis on hydrology from hydrologist Paul Simpson and on geomorphology from Dr Teresa Rose. It also undertook calculations of hydrological variables and nutrient concentrations for the Mowamba and Snowy rivers. Associate Professor Duanne White (University of Canberra, pers. comm. May 2022) also provided new information on fish passage in the Mowamba River.

1.6 Describing the character of the reaches

This report focuses on the Snowy River downstream of Jindabyne Dam and the Mowamba River downstream of the Mowamba Weir. Environmental flows released from Jindabyne Dam have the most impact on the 30 km of the Snowy River between the dam and the town of Dalgety. Downstream of this point, the effect of the flows is modified by tributary inputs.

We divide the 5 km of the Mowamba River downstream of the Mowamba Weir into 2 reaches:

- reach M1, extending for 1 km immediately downstream of the weir, and having a gentle gradient
- reach M2, extending for 4 km between reach M1 and the Snowy River junction, and having a steep gradient.

The most relevant section of the Snowy River is divided into 3 reaches:

- reach S1, between Jindabyne Dam and the Mowamba River junction
- reach S2, from the Mowamba River junction downstream to the junction of Iron Pot Creek
- reach S3, from Iron Pot Creek downstream to Dalgety.

We also consider a reference reach – the lower 8 km of the Thredbo River above its junction with Lake Jindabyne (reach T1, containing the Paddys Corner flow gauging station).

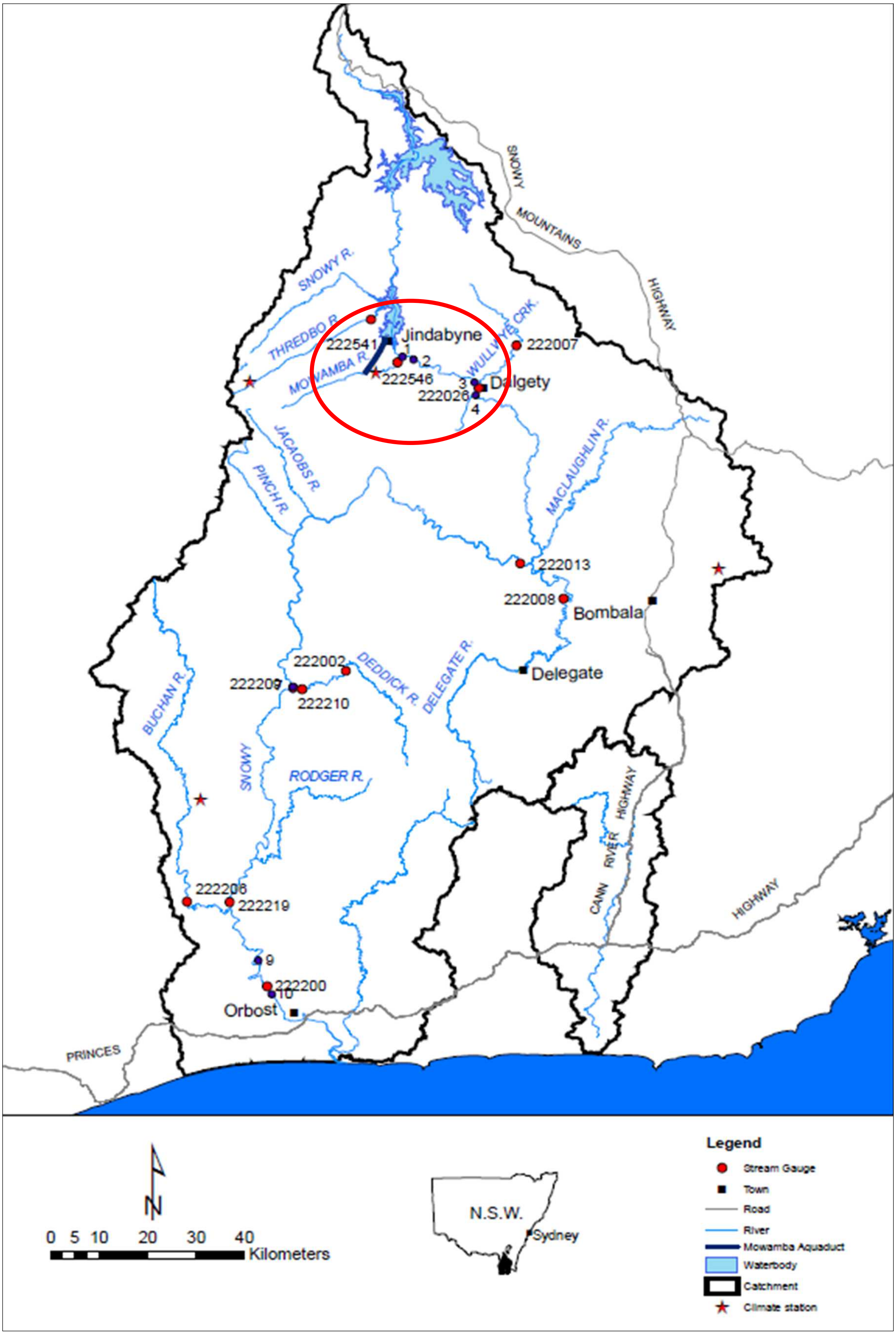


Figure 1: Location map showing the focus area for this report (red oval), including the Mowamba diversion channel (blue line) and stream gauge locations

Source: Reinfelds and Williams 2008.

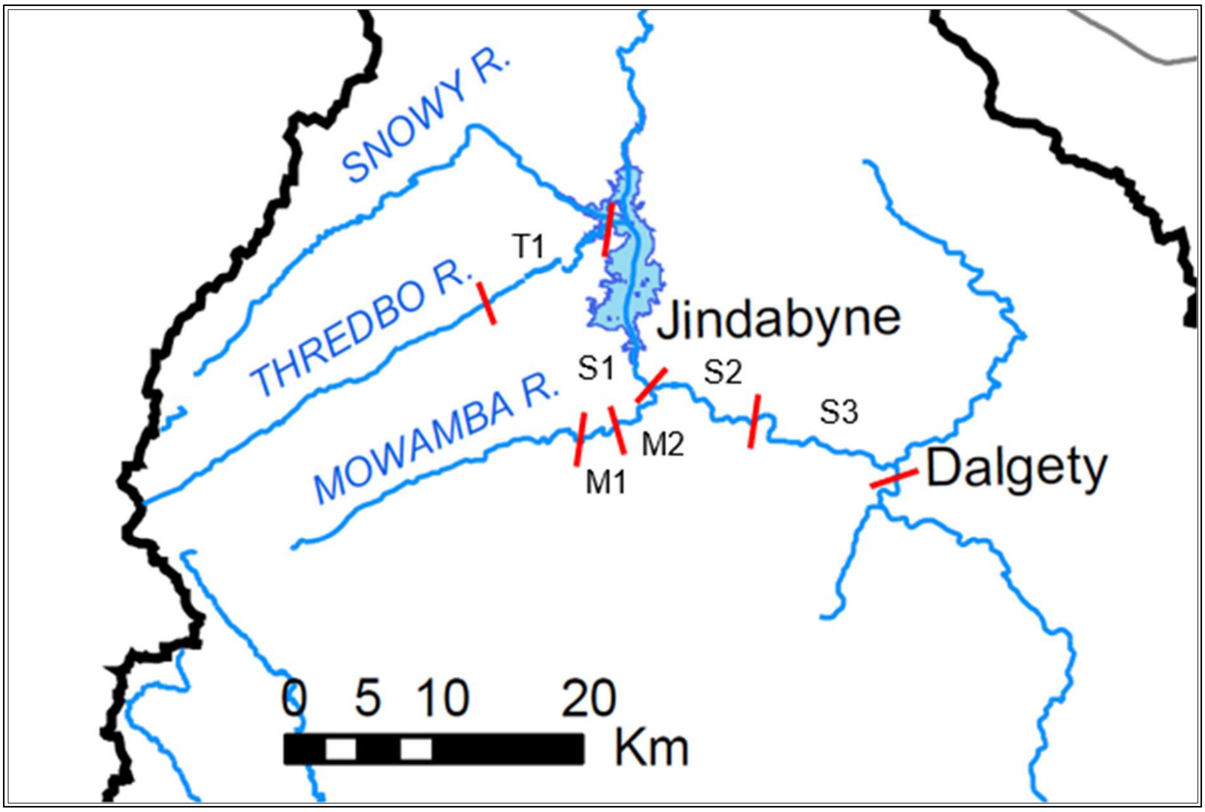


Figure 2: Locations of reaches M1 & M2, S1–S3 and T1

1.6.1 Mowamba River reach M1 (1 km)

Low-gradient section immediately downstream of the Mowamba Weir, with floodplain 50 m wide. The channel contains one pool (Figure 3); the rest of the reach is a narrow channel confined by reeds. Since construction of the Mowamba Weir, the channel has constricted to just 1–2 m wide to accommodate the baseflow of 1.3 ML/day.

Figure 3: Reach M1 – pool
Photo: Paul Doyle, NSW DPE.

(a)

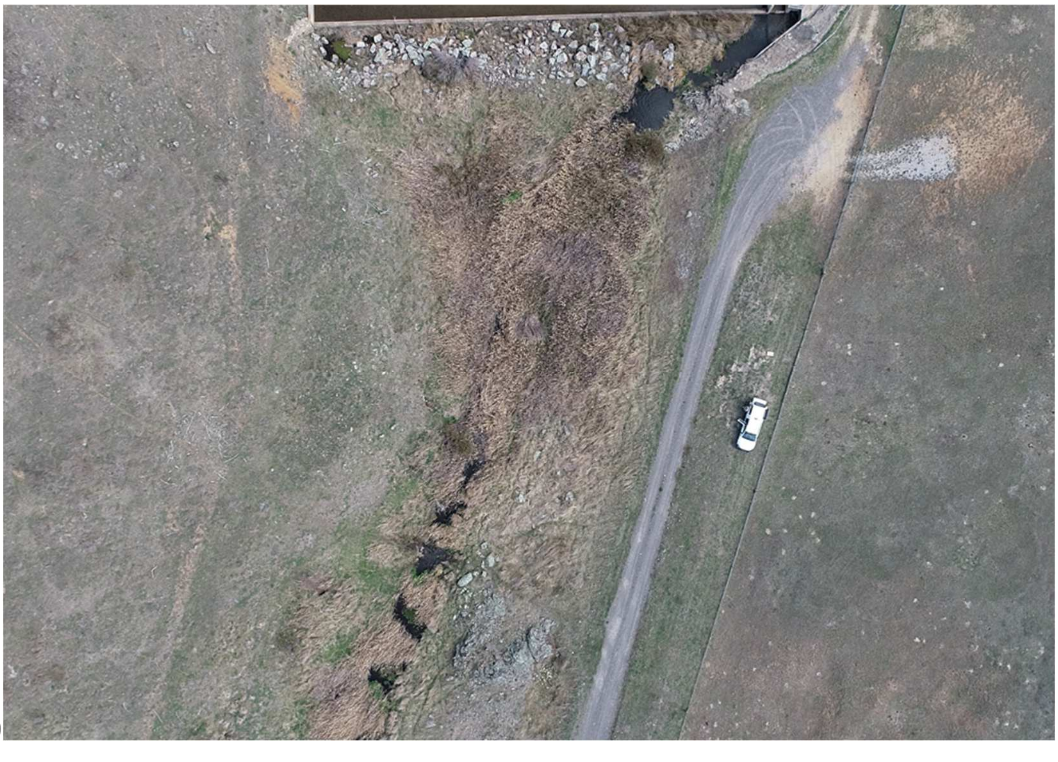

(b)


Figure 4: Comparison of the Mowamba River (pictures at the same scale) (a) upstream of the weir, and (b) in reach M1 downstream of the weir (5 m car shows scale)

Note the extreme contraction of the channel below the weir. Photos: Tim Haeusler, NSW DPE.

1.6.2 Mowamba River reach M2 (4 km)

Steep bedrock channel between reach M1 and the Snowy River. Terminates in a small fan into the Snowy River. Gorge section, includes small waterfalls, pools, and riffles. Some anabranching sections with multiple channels (similar to reach S3 on the Snowy River).

Figure 5: Reach M2 – small waterfall (cascade) and pools
Photo: Bottlebrush Media.

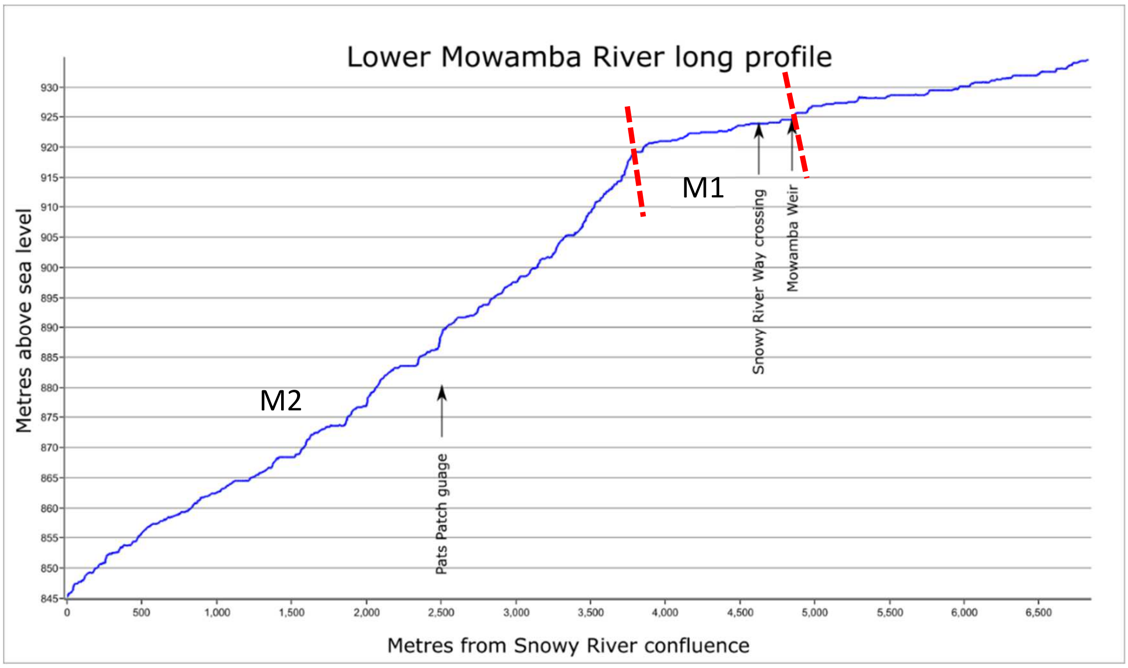


Figure 6: Longitudinal profile of the lower Mowamba River showing the steepening gradient from reach M1 to reach M2
Source: Duanne White, University of Canberra.

1.6.3 Snowy River, Jindabyne Dam reach S1 (2 km)

Straight bedrock-controlled sections, interspersed with bedrock or boulder rapids

Figure 7: Reach S1 – boulder rapids
Photo: Bottlebrush Media.

1.6.4 Snowy River, Jindabyne Gorge reach S2 (10 km)

Figure 8: Reach S2
Photo: Ian Rutherfurd.

Post-Snowy Scheme morphology

Channel contraction; vegetation invasion on channel margins; pool infilling with clastic and biogenic sediment; formation of *Phragmites australis* chokes on former riffles, tributary mouth bars and thick fine-grained sediment laminae in bed; peat formation on bedrock ledges beside inner bedrock channel. Fine sediment intrusion into bed sediment; lichen colonisation of exposed bedrock surfaces.

Figure 9: Reach S2 – bedrock rapids
Source: Google Earth.

1.6.5 Snowy River, Dalgety Uplands reach S3 (14 km)

Anabranching reach

Post-Snowy Scheme morphology

Mean annual flow reduced by 94% until the implementation of the Snowy Water Initiative, with the reduction now closer to 80%. Channel contraction, vegetation invasion of margins, bed aggradation, *Phragmites* chokes, tributary mouth bars, fine sediment accumulation in the bed. Contraction of multiple channels to a single channel.

Figure 10: Reach S3 – constricted, multiple channel sections
Source: Google Earth.

Figure 11: Reach S3 – vegetation invasion of margins
Photo: Ian Rutherfurd.

Figure 12: Photographs of the same site showing the Snowy River in the Dalgety Uplands Reach before Jindabyne Dam was built (A) and again after 30 years of flow regulation (B)

The second photograph (B) shows the extent of channel narrowing and bench formation. [Photo (A) was taken by George Bell 1890–1900 (unpublished Kerry and Co. Sydney, NSW) and photo (B) was kindly provided by Stevenson Gawen.] (Images taken from Rose and Erskine 2011).

1.6.6 Thredbo River reach T1 (8 km)

Lower Thredbo River upstream of Lake Jindabyne, including the Paddys Corner gauge. This is the hydrological reference reach for the Snowy River. Long, straight sections of open water, and occasional pool-riffle sections. One short section of anastomosing channel.

Figure 13: Reach T1 – open water section

Photo: Tim Haeusler, NSW DPE.

Figure 14: Reach T1 – pool-riffle section
Photo: Tim Haeusler, NSW DPE.

1.7 Snowy River Increased Flows – current situation

Following the construction of Jindabyne Dam, only a small constant base passing flow (BPF) was delivered to the Snowy River downstream of Jindabyne Dam between 1967 and 2002, equating to 1% of the mean annual natural flow (MANF) of the Snowy River as measured at Jindabyne. This alteration to flow resulted in a significant deterioration of the health of the river below the dam (Snowy Water Inquiry 1998).

On establishment of the Snowy Water Initiative in 2002, 3 key components of environmental flow management needed to occur in order to implement the SRIF:
(i) securing water entitlements in the western valleys, (ii) capital infrastructure upgrades at Jindabyne Dam to enable releases, and (iii) the development of SRIF release strategies.

In July 2012, the Snowy Water Initiative completed its water entitlement recovery program (NSW DPE 2022a). The Initiative's goal was to secure entitlements sufficient to provide an annual average of 212,000 ML of SRIF allocations. However, the water available for the Snowy River in any one year depends on the climatic conditions and water allocations in the Western Rivers (predominantly the Murray and Murrumbidgee rivers) from the preceding year. Consequently, SRIF allocations vary from year to year, and may not reflect the prevailing catchment conditions in the year in which the allocations are available. Moreover, annual allocations for the water years from 2013–14 to 2022–23 have averaged only 155,054 ML (NSW DPE 2022a, 2022b), and deliveries have not reached the target set out under the SWIOID on any year since its agreement in 2002 (Bender et al. 2022).

Between 2002 and 2011, Jindabyne Dam infrastructure was upgraded to enable release of a wider range of flows and to draw water from a multi-level offtake. These new infrastructure capabilities allow flow sequences reflecting natural patterns of daily flow variability together with peak flow rates with frequencies and durations reflective of natural high-flow events in montane rivers.

1.7.1 Flows up to 5,000 ML/day

Two key components of the engineering works allow flexibility in the operational delivery of environmental water. Flows up to 5,000 ML/day can be programmed into a daily release sequence to introduce a high degree of flow variability. Flows up to this rate can be released from a combination of the cone valves that draw water from the multi-level offtake and the lower-level offtake.

1.7.2 Flows above 5,000 ML/day (flushing flows)

Flows of more than 5,000 ML/day (termed flushing flows) can be delivered only via spillway gates when the level of the lake is sufficiently above the sill of the gates. The Snowy Water Licence stipulates that SHL is required to release only one flushing flow per year and it may be ordered only in spring. SHL is required to release flushing flows only when allocations to SRIF exceed 100,000 ML. If SHL is not able to raise the Jindabyne Lake level to the spillway gates in spring, it cannot release a flushing flow. SHL is required to operate Lake Jindabyne so that the risk of dam spills remains below 10%, and this requirement can restrict SHL's ability to maintain levels that enable use of the spillway.

Holding lake levels high enough to use the spillway gates increases the possibility of dam spills. If a spill occurs and some of the spill is because lake levels were being held higher for a planned flushing flow, SRIF allocations may be used to cover water 'lost' from Lake Jindabyne. This phenomenon occurred in March 2012 when 16 GL spilled from Lake Jindabyne. A total of 8,000 ML of the spill volume was accounted for from the SRIF account in a payback arrangement of 2,000 ML/year from 2015–16 to 2018–19.

1.7.3 Eight-hour peak flows

The system and operating rules enable programming of 8-hour peak flows to create high-velocity peaks within otherwise smaller daily flows. SHL requires staff to attend the dam during 8-hour releases for manual operations as well as for gauging and operational safety. The SWIOID and Snowy Water Licence do not specifically require SHL to deliver 8-hour peaks (only daily flow changes are required). SHL has nevertheless provided 8-hour flows, but limited these to 5 in any one year because of resourcing constraints.

1.7.4 Low flows and electricity generation at Jindabyne Dam

The lowest flow SHL can reliably deliver, via the lower-level offtake, is around 40 ML/day. Flows greater than around 90 ML/day are required to operate the Jindabyne hydro-electric plant. The hydro-electric plant reaches maximum generation capacity at around 170 ML/day.

1.7.5 Restrictions to flexibility of release planning

The Snowy water year begins on 1 May. Currently, for each water year, the flow regime for the SRIF is planned in a rigid framework, which requires the Water Administration Ministerial Corporation to notify SHL of the:

- annual SRIF volume, by 13 February
- target monthly SRIF volumes, by 13 February
- target daily SRIF volumes 6 days before the commencement of the next month (in practice, daily flows for the entire year are provided on 13 February)
- flushing flows strategy, by 13 February.

The available SRIF allocation for the coming water year is finalised in the second half of January. Therefore, only around 3 weeks are available for NSW DPE to complete the planning of releases, consult the SAC and other experts, and provide them time for review and to obtain approvals.

An additional point of rigidity is that allocations made in one water year are currently not able to be carried over into other water years. This restriction means that no reserve can be carried over for extreme dry years or to respond to environmental contingencies (e.g. major wildfires followed by runoff that causes severe sedimentation requiring flushing).

1.7.6 Potential effects of flows downstream of Jindabyne Dam

The flow regime has implications for downstream landholders. A private rock ford on the river becomes impassable at a flow of around 400 ML/day, and other access constraints arise at higher flows. The potential effect of flows that cause access issues will depend on the period of prior notice able to be given, the duration of flows above the threshold flow, and the timing of the flows (including whether the flow is during a weekend, school holidays or the ski season).

1.7.7 SRIF deliveries only from Jindabyne Dam

Currently, SRIF is delivered only from Jindabyne Dam. The residence of water in Lake Jindabyne for extended periods reduces its sediment and nutrient content, and buffers the temperature range of the river downstream of the dam (Growns 2019). For this and other reasons, delivery of a portion to SRIF via the downstream tributary, Mowamba River, is being investigated as part of the Snowy Water Licence Review.

1.8 Mowamba River and Mowamba Weir – current situation

The 40 km long Mowamba River is a tributary that joins the Snowy River approximately 2 km downstream of Jindabyne Dam. Approximately 15.1 km^2 or 5% of the Mowamba River catchment is affected by snow cover (Williams et al., unpublished). The 2.7 m high and 50 m wide Mowamba Weir (Figure 15), located approximately 5 km upstream of the confluence with the Snowy River, impounds a pool approximately 420 m long (Brooks et al. 2018; Figure 15). Flows in the Mowamba River up to 523 ML/day are captured by the weir and diverted by an aqueduct into Lake Jindabyne. Flows above this level, or all inflows when the aqueduct is closed, spill over the weir, providing flows to the lower Mowamba River and subsequently the Snowy River. A small outlet in the fixed-crest weir allows a BPF of approximately 1.3 ML/day (Figure 16). The Mowamba Weir BPF, totalling 500 ML/year, is accounted as part of the Snowy River BPF of 9,000 ML/year SHL is required to release. The remaining 8,500 ML/year is delivered from Jindabyne Dam. The long-term modelled median diversion rate is 51 ML/day and the modelled mean diversion rate is 98 ML/day.

Observations from 1968–2019 show that SHL diverts an average of around 33,710 ML/year from Mowamba River (and the smaller Cobbin Creek). This diversion is equivalent to around 21% of the average volume available for release from Jindabyne Dam (approximately 163,550 ML/year) since full SRIF entitlement was available from the 2013–14 water year onwards (see section 2.3.2 for details).

Figure 15: Mowamba Weir with no overtopping flow
Photo: Bottlebrush Media.

Figure 16: Mowamba Weir BPF outlet, 20 February 2022

This outlet provides the only flow past the weir when it is not overtopping.
Photo: Paul Doyle, NSW DPE.

To date, adjustments to the flows entering the Snowy River from the Mowamba River have been made only through adjustments to the setting of the aqueduct: either open and diverting up to its full capacity or closed with no diversions and flows overtopping the weir.

The Mowamba Aqueduct has been closed to allow flows to overtop Mowamba Weir for the following periods:

- 29 August 2002 to 31 January 2006 when the Mowamba River was the primary mechanism for providing SRIF while works to enable delivery of these flows from Jindabyne Dam were being undertaken
- 15 May to 23 July 2009
- 15 March to 8 April 2011
- 29 November to 22 December 2011
- 2–12 March 2012 due to flooding
- 16 June to 27 July 2012
- 2 May to 12 June 2014
- 1 May to 1 June 2015
- 30 April to 2 June 2016
- 28 April to 2 June 2017.

1.9 Objectives of SRIF

1.9.1 Background

The SWIOID states the environmental objective of the SRIF is to improve the habitat for a diverse range of plant and animal species through a combination of:

- improving the temperature regime of river water
- achieving channel maintenance and flushing flows within rivers
- restoring connectivity within rivers for migratory species and for dispersion
- improving triggers for fish spawning
- improving the aesthetics of currently degraded riverine environments.

Following further knowledge gathering, Williams (2016) provided a new overarching objective: *To facilitate the rehabilitation and evolution of the Snowy River below Jindabyne Dam into a smaller but healthy montane river.* He also detailed a series of more specific ‘expected outcomes’ (see Williams 2016).

The SAC, in setting the annual flow patterns for SRIF releases, uses the expected outcomes from Williams (2016), with modification of those related to ‘estuary health’, to incorporate recommendations from Hale (2020). SRIF objectives derived by NSW DPE from Williams (2016) and Hale (2020) are:

1. **Hydrology** – provide the natural hydrological characteristics of a smaller but unregulated montane river (including seasonality, daily variability and high flows)
2. **Channel morphology** – develop a more defined river channel within the former river channel
3. **Riverbed maintenance and nutrient translocation sites** – reduce fine sediment and algae smothering, increase clean substrate including cobbles and gravels and interstitial spaces and have biofilm primarily comprised of diatoms rather than algae
4. **Basal resources** – enhance delivery of complex dissolved organic carbon (DOC) and other basal resources, increase frequency of events that inundate lower in-channel river benches
5. **Riverine and aquatic vegetation** – limit the encroachment of terrestrial plants into the river channel and establish native aquatic and riparian vegetation
6. **Thermal regime** – provide a thermal regime similar to an unregulated montane river
7. **Benthic aquatic macroinvertebrate communities** – increase the abundance of aquatic invertebrate fauna commonly found in unregulated Snowy Montane Rivers with gravel and cobble substrate
8. **Fish assemblages** – reflect the more diverse native fish community composition of the unregulated tributaries in the main channel of the Snowy River
    a. Upper Snowy: river blackfish, long and short finned eels and mountain galaxias
    b. Lower Snowy: long and short finned eels, mountain galaxias, Australian grayling, Australian bass and estuary perch
9. **Dispersal of native fish** – increase opportunities for localised and (where possible) larger-scale movements

10. **Platypus** – provide increased opportunities for movement and feeding
11. **Estuary health** – improve the temperature regime of the estuary, maintain estuary entrance opening, restore connectivity (rivers, estuary, ocean), improve conditions in the estuary for fish spawning and recruitment, improve estuary and wetland productivity to support native fish
12. **Aesthetics** – ensure water clarity, clean substrates, a defined river channel and complex riparian native vegetation
13. **Cultural recognition** – inform Aboriginal stakeholders, improve cultural recognition and representation, link cultural and environmental water objectives where appropriate and integrate traditional knowledge.

1.9.2 Environmental variables adopted for assessment of options in this investigation

The existing suite of objectives embodies or implies many measurable environmental variables, which the Panel tabulated to provide a basis for its assessment of options (Table 1). In addition, the Panel considered variables related to the frog fauna because NSW DPE is including objectives for frogs in the 2022–23 water year and objectives for frogs are also proposed for inclusion in the future long-term water plan for the Snowy River (see Alluvium 2022).

Table 1: Environmental variables considered by the Panel (referenced against the SRIF objectives derived from Williams (2016) and Hale (2020))

SRIF objective	Environmental variable
1	Daily discharge variability
1	Discharge seasonality
1, 2, 3	High-flow magnitude Here we define high flow as ≥2,000 ML/day in the Jindabyne reach (S2). Various studies have shown that such flow inundates channel benches, scours coarse sand, flushes fine sediment from riffles, and moves sediment through pools. Rose (2010) defines a small flushing flow as ≥1,000 ML/day and a large channel-forming flow as ≥20,000 ML/day at Jindabyne.
1, 2, 3	High-flow frequency
1, 2, 3	High-flow duration
1, 2, 3	High-flow rate of rise and fall
1, 2, 3	High-flow sequencing
2 and 12	Channel morphology measures (e.g. width, depth, bench area, run area)
2	Floodplain aggradation Rate of aggradation of ‘new’ floodplain is a critical variable
2, 3	Substrate character Particle size distribution, area of active bed
3 and 12	Sediment movement Turnover rate covers both deposition and colmation

SRIF objective	Environmental variable
3	Benthic algal assemblage composition
3 and 12	Benthic algal density
4	Bench inundation frequency
4	Dissolved organic carbon concentration
4	Other basal resources including nitrogen, phosphorus and silica
5	In-stream plant assemblage composition
5	In-stream plant cover
5	Riparian plant cover
5 and 12	Riparian plant assemblage composition
6	Thermal regime of river
7	Benthic invertebrate assemblage composition
7	Benthic invertebrate density
7	Benthic invertebrate total abundance (e.g. number of individuals per river km)
8	Fish assemblage composition
9	Fish passage
9	Fish total abundance (e.g. number of individuals per river km)
10	Platypus feeding
10	Platypus movement
11	River–estuary–ocean connectivity
11	Thermal regime of estuary
11	Estuarine fish recruitment
11	Estuarine fish spawning
11	Estuarine primary production
11	Estuarine secondary production
11	Estuary entrance opening duration
11	Wetland primary production
11	Wetland secondary production
12	Water colour
12	Water turbidity
Nil	Frog species diversity and abundance

1.10 Flows to help achieve SRIF objectives (from Williams (2016))

Since 2013–14, a 'natural flow scaling approach' (Reinfelds et al. 2013a) has been used to deliver environmental water to the Snowy River downstream of Jindabyne Dam. This approach uses the natural flow regime of the unregulated Thredbo River as a reference. The historical flow record of the Thredbo River is searched to find a year with similar total annual flow to the SRIF volume available for the coming year. The flow pattern of the Thredbo River in the matched year is then used as the basis for setting the release pattern for the coming year. The Thredbo River was chosen as the reference stream because its average annual flow approximates the average annual volume of SRIF available, and it has a similar proportion of snowmelt-affected catchment to the Snowy River upstream of Jindabyne.

1.10.1 Flow thresholds

A suite of flow thresholds has been defined for the Snowy River downstream of Jindabyne. These are summarised in Table 2 and described more fully in Appendix A.

High peak flows increase stream power to mobilise and flush sediments from the stream bed. Fine sediment and sand are transported at discharge rates of >1,000 ML/day in the upper reaches of the Snowy River (Reinfelds and Williams 2008). While longer peak durations provide greater sediment movement than shorter peaks (Rose 2017), monitoring indicates that most of the fine sediment is moved in the first few hours of the releases (Coleman and Williams 2017). Coleman and Williams (2017) also found that the greater the increase in magnitude and interval since the previous high flow, the greater the amount of sediment moved by the high flow.

Flows above 1,500 ML/day support in-stream basal resources for food webs by inundating lower benches in the upper reaches and providing pulses of carbon from leaves and other organic matter (Williams 2016; Rohlfs et al. 2016b). Regular high flows also scour algae from cobbles and other substrates so that early-stage or high-disturbance biofilms may develop. Riffle re-setting through scouring of fine sediments and attached algae occurs at a flow rate of 2,000 ML/day (Williams 2014).

1.10.2 Timing of flows for fish and platypus

Several references have noted the timing of flow requirements for native fish and platypus, which are relevant to the Snowy River. Details are provided in Appendix B.

Table 2: Some geomorphic flow thresholds identified in past studies

Discharge (ML/day)	River process
~300	Initial wetting of lower benches on the old riverbed in the Dalgety Uplands (reach S3) (Rose 2010)
850–1,000	Breakdown of thermal stratification in pools of the Jindabyne Gorge (reach S2) (Snowy Scientific Committee 2008)
1,000	Movement of fine silt from the river bed and initiation of movement of unconsolidated coarse sands up to about 1.9 mm diameter (Reinfelds and Williams 2008)
1,000–2,000	Substantial deposition of fine sediment on benches in the Dalgety Uplands (reach S3) (Rose and Erskine 2011)
1,000–3,000	Entrainment of particles of 50 mm diameter in riffles (Reinfelds and Williams 2008)
Flows >12,000–16,000	Scouring of gravel from pools (Reinfelds and Williams 2008)
12,000	Channel-maintenance flow (Snowy Scientific Committee 2008)
12,000–29,000	Entrainment of cobble size material (>54 mm b-axis), & velocity reversals in pools in Jindabyne Gorge (Reinfelds and Williams 2008)

2. Mowamba River options

2.1 Do-nothing option

This option would involve making no changes to the current operating procedures. SHL would continue to operate the aqueduct as they require. The Mowamba Weir BPF of 1.3 ML/day would continue to be the only assured flow in the Mowamba River downstream of the weir (see Figure 16, Figure 17 and Figure 18), except when peak flows above the ~500 ML/day capacity of the aqueduct occur (when flows above ~500 ML/day spill over the weir).

Figure 17: Mowamba River immediately downstream of Mowamba Weir, 20 February 2022

The weir was not overtopping at the time, so this flow represents the baseflow of 1.3 ML/day that is provided to this narrowed section of channel. Photo: Paul Doyle, NSW DPE.

Figure 18: Mowamba River farther downstream of Mowamba Weir, 20 February 2022
The weir was not overtopping at the time and flow was restricted to a small section of the channel. Photo: Paul Doyle, NSW DPE.

Flows at the gauge at Pats Patch downstream of the Mowamba Weir have been measured since 2001. The aqueduct was closed for some of this period, allowing all flow to pass down the river (dates are listed on page 18).

Figure 19 shows an estimate of the flows that would have occurred at Pats Patch from 2001–2020 if the aqueduct had been open and diverting flows at all times. This figure therefore illustrates flows downstream of the Mowamba Weir under the do-nothing option.

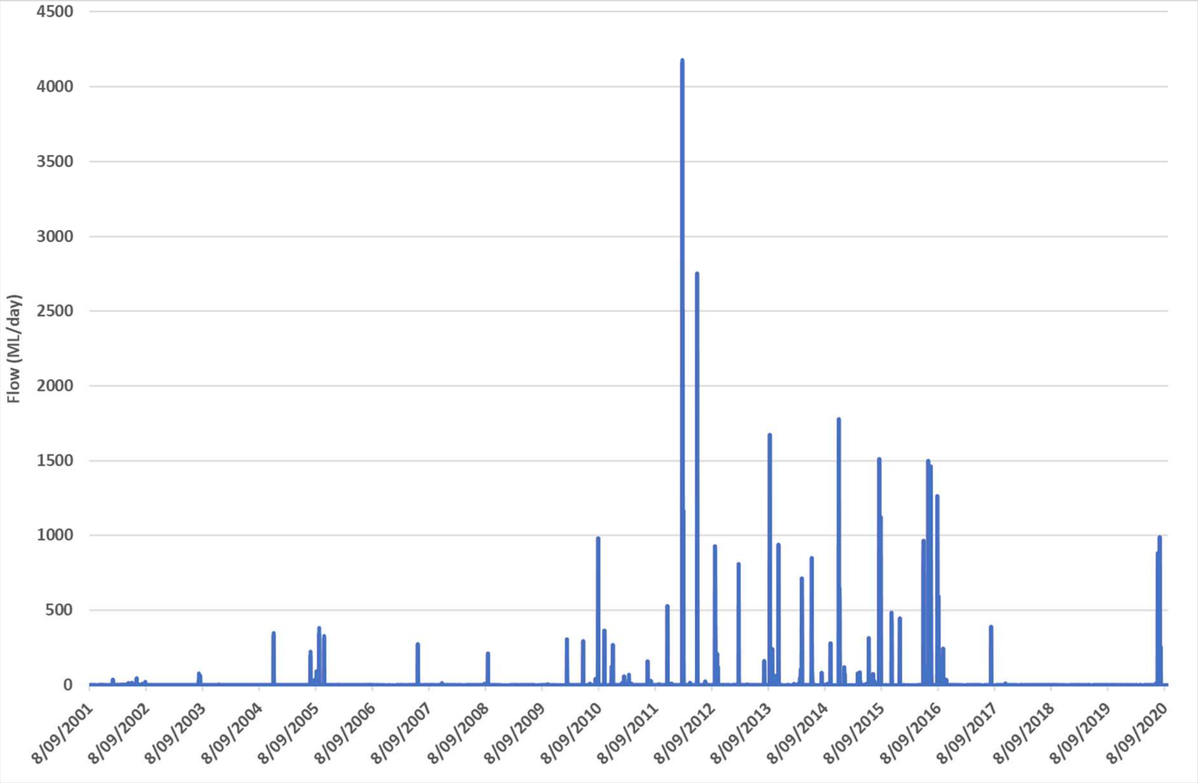


Figure 19: Flow on Mowamba River downstream of Mowamba Weir (Pats Patch gauge) that would have been expected if the aqueduct was always operating

Note that flows have been adjusted[2] to remove additional flows passed downstream when diversions from the river via the aqueduct ceased and the weir was allowed to overtop.

2.2 Options for passing flows downstream of the Mowamba Weir

The Panel considered 3 options for increasing flow in the Mowamba River downstream of the Mowamba Weir:

- removing the weir (section 2.3)
- retaining the weir but ceasing diversions so all flows overtop the weir (section 2.4)
- retaining the weir but reducing diversions so some additional flows overtop the weir (section 2.5).

These additional flows would join the Snowy River at the Mowamba–Snowy Junction, which is 2 km downstream of Jindabyne Dam. The water returned to the Mowamba River and thence the Snowy River would come from SRIF allocations. Currently, all SRIF allocations are delivered via Jindabyne Dam. Consequently, any increase in flows to the Snowy River via the Mowamba River would require a matching reduction in releases from Jindabyne Dam.

[2] For periods when the Mowamba Aqueduct was closed (see dates on page 31) all flows less than 500 ML/day (the capacity of the aqueduct) were reduced to the Mowamba Weir BPF volume of 1.3 ML/day. All flows above 500 ML/day were reduced by 500 ML/day.

For each Mowamba Weir option, this report examines the effect of 2 modes of reducing Jindabyne releases:

- **reducing each day's Jindabyne release by the additional flow passed down the Mowamba River each day**. For simplicity, this mode has been analysed by reducing the Jindabyne release concurrently. In practice, there might need to be a lag in the adjustment of Jindabyne releases
- **reducing the annual Jindabyne release by the average annual increase in flow passed down the Mowamba River**. If all flows were passed, the average would be around 34,000 ML/year.

For each option, the effects are summarised for the Mowamba River in section 2.7 and for the Snowy River in section 2.8. A more detailed analysis of the effects of each option is provided for the Mowamba River in Appendix C and for the Snowy River in Appendix D.

In assessing each option, the Panel used the following terms to describe the expected scale of any effects:

- minor change: less than 10% change
- moderate change: 10–25% change
- major change: greater than 25% change.

2.3 Mowamba option: Remove weir (full Mowamba River flow restored, full connectivity)

This option would entail removing the weir or a section of it and closing or decommissioning the aqueduct. The effects of this option with associated daily or annual reductions in Jindabyne releases are discussed below under sections 2.3.1 and 2.3.2 respectively.

Although full weir removal is the option that the Panel was charged with examining, there might be options for partial removal that would still allow fish and platypus passage, as well as passing bedload. For example, a partial-width slot could be cut in the weir wall that would be wide enough to allow animals and bedload to pass. However, the Panel notes that this option is rarely used in international examples of weir removal because it can lead to problems of fast velocities during high flows (preventing fish passage and causing scour), or blockage by debris. Options for partial removal could be explored, addressing such issues, if full removal was not viable for reasons outside the Panel's scope, such as financial cost.

2.3.1 Removing Mowamba Weir with matching daily reduction in Jindabyne releases

Main environmental effects of removing the weir

Environmental effects on the Mowamba River (see also summary in section 2.7 and further detail in Appendix C): this option would restore full flows to the 5 km of the Mowamba River downstream of the Mowamba Weir and return it to its pre-weir hydrological state (Figure 20 and Figure 21). The flow regime that this option would have produced in the Mowamba River at Pats Patch in 2001–2020 (Figure 22) is very different from the regime under the do-nothing option (Figure 19). Substantial increases are seen in daily and seasonal flow variability, the size of moderate flow peaks, and the provision of flow during the Millennium Drought and the drought of 2017–2019, when the flow was generally restricted to a constant 1.3 ML/day under the do-nothing option.

Figure 20: Mowamba River downstream of Mowamba Weir on 13 May 2021 when flow at Pats Patch gauge was 75 ML/day, substantially higher than under the usual 1.3 ML/day baseflow release from the weir
Photo: Paul Doyle, NSW DPE.

Figure 21: Mowamba River downstream of Mowamba Weir on 13 May 2021 when flow at Pats Patch gauge was 75 ML/day
Photo: Paul Doyle, NSW DPE.

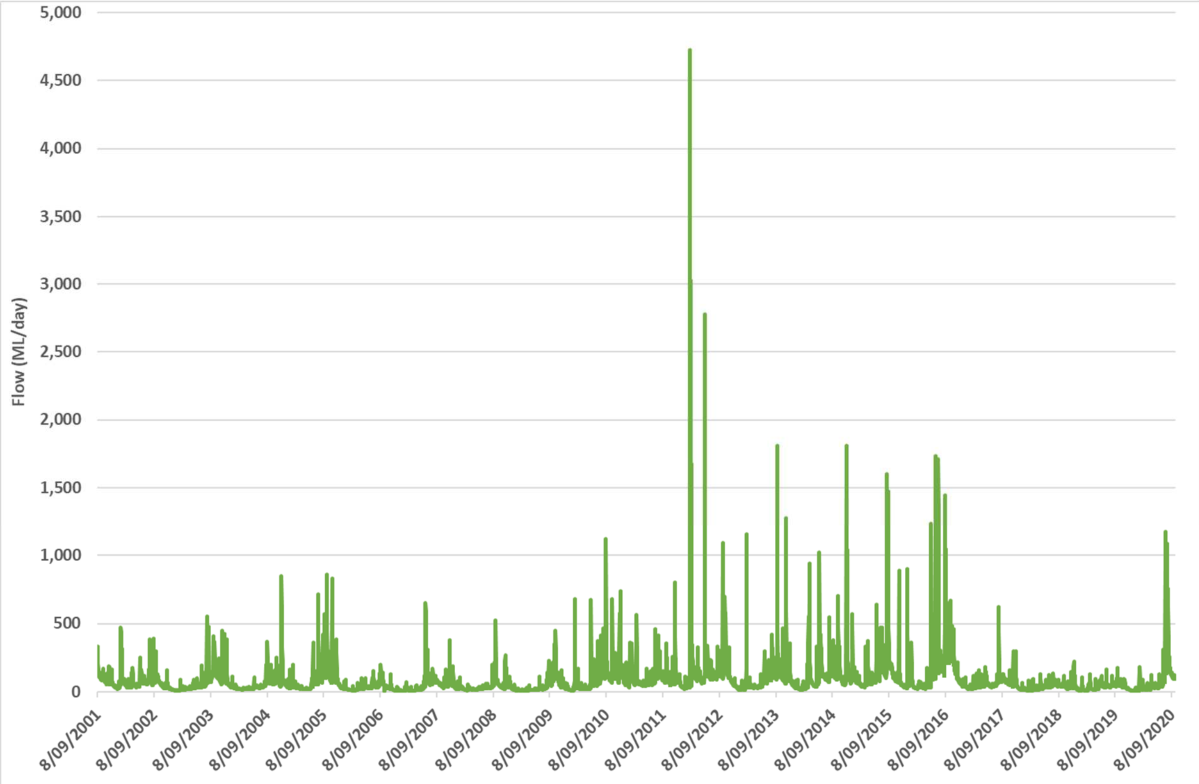


Figure 22: Total flow in Mowamba River, 2001–2020

Includes flows diverted from the river via the Mowamba Aqueduct and flows recorded at Pats Patch gauge downstream of Mowamba Weir. This flow would have occurred downstream of weir in the absence of diversions.

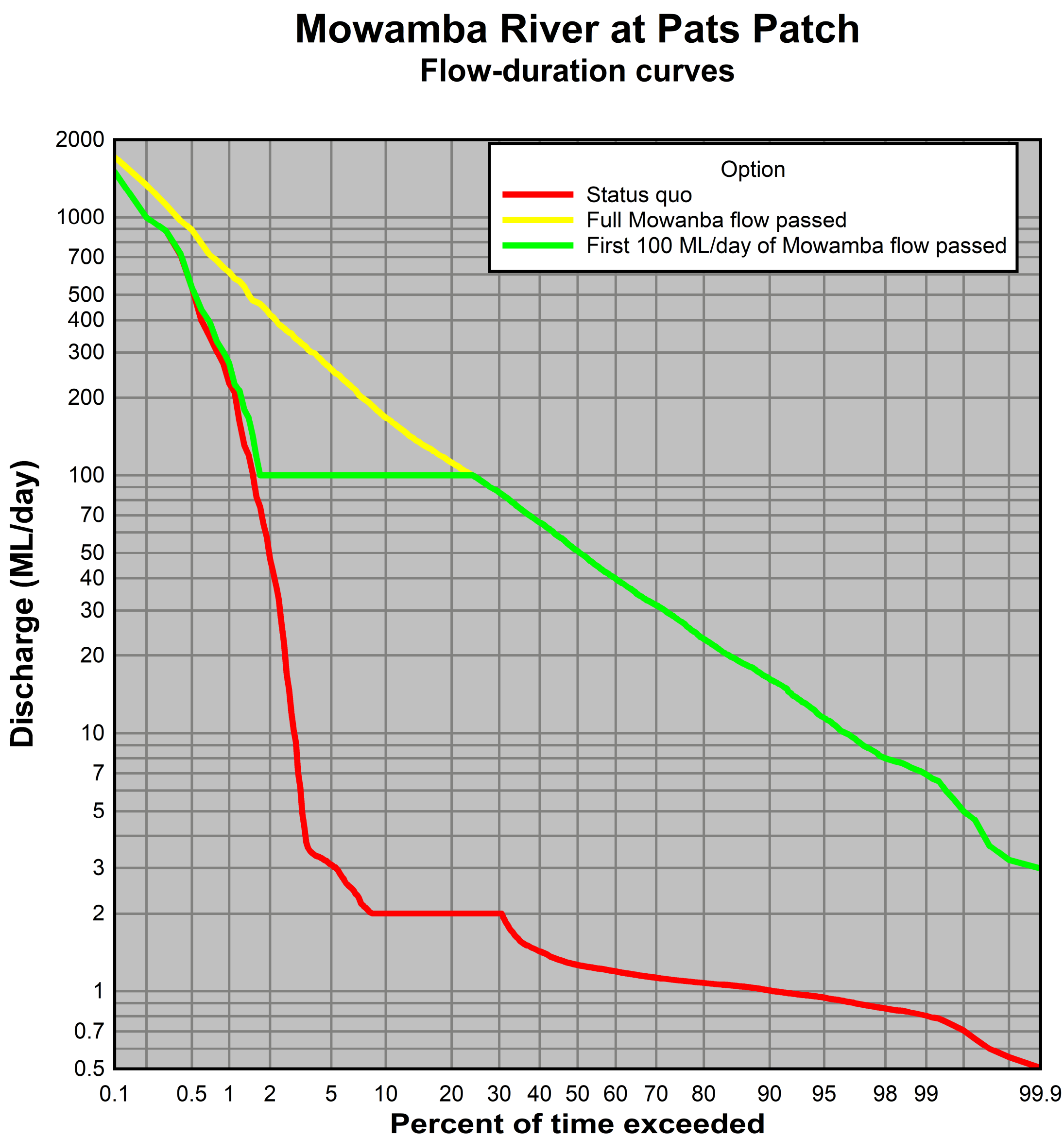


Figure 23: Flow exceedance curves for the Mowamba River at Pats Patch for the do-nothing option (status quo), full Mowamba flow passed options (covered here in section 2.3 and in section 2.4), and the options that pass only the first 100 ML/day (covered in section 2.5)

Removing the weir would lead to a short-term pulse of sediment, as well as a long-term increase in coarse sediment (described below), entering the Snowy River. A bar of ~25,000 m^3 of sand and gravel has deposited at the upstream end of the weir pool (Figure 24). All bedload entering the weir is trapped. Contractors regularly remove sediment that builds up near the weir outlet, but the Panel understands that the main volume of bedload is not removed. If the weir was removed, this stored sediment would gradually erode and be transported downstream. In addition, the 1 km of Mowamba River channel immediately downstream of the weir (reach M1) has contracted to accommodate a median flow of 1.3 ML/day. With daily flows increasing to a median of around 50 ML/day, this section would erode and widen to have dimensions more like those of the channel upstream of the weir. This new channel would be at least 10 m wide and over 1 m deep, with gravel riffles. This erosion would release around 10,000 m^3 of sediment into the lower Mowamba River and then into the Snowy River. Some of the combined 35,000 m^3 or so of eroded sediment would be added to the tributary mouth bar already deposited at the Snowy River junction, and the remainder would move into the deep pools downstream of the junction. The Panel estimates that the volume of new sediment would be about a third of that of the sediment currently stored in the bar at the mouth of the Mowamba River on the Snowy River. In the long term, the effect of removing the weir would be an increase in the coarse sediment entering the lower Mowamba River. The Panel estimates that this increase would be in the order of around 1,000–3,000 m^3 per year of bed material. Pre-weir rates of bedload transport would be re-established in the lower Mowamba River.

(a)

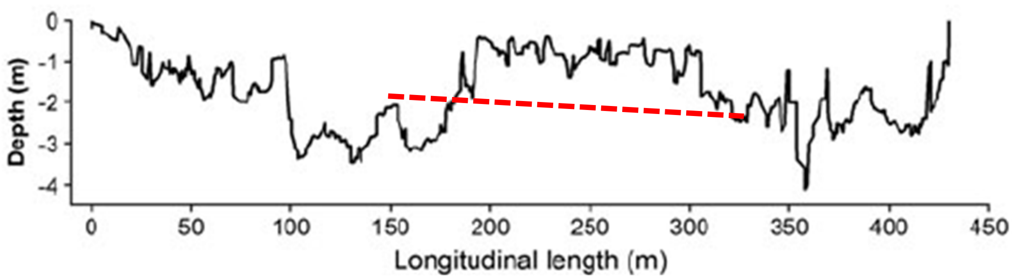

(b)


Figure 24: Long profile of the Mowamba Weir pool showing the bar of sediment accumulated in the backwater (red line in both the aerial image (a) and the long profile (b))

Note this wedge of sediment is about 50 m wide x 2.5 m deep x 200 m long = 25,000 m^3.
Source: Brooks et.al. (2018), Figure 1. Photo: Tim Haeusler, NSW DPE.

Removing the weir would also likely induce a return to benthic algal, plant, macroinvertebrate and frog assemblages with composition and densities similar to those that occurred in the pre-weir river. River temperatures would also become more like those upstream of the weir because increased flow volumes under this option would be less prone to heating or cooling from weather changes (air temperature, radiant heating, etc.). Connectivity for platypus would be expected to be greater, increasing metapopulation dynamics and long-term population viability (pers. comm. Gilad Bino). Increased flows and connectivity would also increase passage for non-native brown and rainbow trout, native eels and possibly Australian bass (if stocked). Associate Professor Duanne White (University of Canberra, pers. comm.) has surveyed the lower Mowamba and found that while reach M2 is steep, it contains numerous flow channels and would, at moderate to high flows, provide eddies, refuges and backwaters similar to a fish ladder. However, the 3-m high Cascades (Figure 25) may still limit passage for fish such as trout and bass. Although eels can usually climb or travel overland past barriers such as cascades and weirs, they were recorded downstream of the weir but not upstream in 2019–2021 fish surveys (NSW DPI–Fisheries 2022). Increasing flows and removing the weir would therefore probably increase eel migration. Movement of rainbow trout downstream of the weir might also occur, as NSW DPI–Fisheries (2022) have recorded them in the Mowamba River upstream of the weir but not downstream, although they are stocked in the Snowy River.

Figure 25: Cascades on the Mowamba River that are expected to hinder fish passage

Note gauge shed at top right of image for scale. Photo: Bottlebrush Media.

Environmental effects on the Snowy River (see also summary in section 2.8 and further detail in Appendix D): Effects of weir removal on the Snowy River would be less pronounced, being principally an increase in within-day flow variability and inputs of suspended sediments, gravel, detritus and nutrients such as DOC, nitrogen and phosphorus from Mowamba River flows.

Removing the Mowamba Weir would result in more suspended sediment entering the Snowy River (i.e. the sediment that would have been diverted from the weir, through the aqueduct, and into Lake Jindabyne). Data in Coleman and Williams (2017) suggest that flows of 150 ML/day would divert around 2 tonnes of suspended material per day, and flows up to 500 ML/day would divert substantially more. The increase in suspended load into the Snowy River if the weir was removed could mirror the increase in nutrients, which is estimated to be about a 10% increase at the median flows, but over 50% for high flows (see the comment about unpublished data from Rohlfs et al. (2012) below). However, Coleman and Williams' suspended sediment data from high flows in the Snowy River demonstrate that the additional sediment from the Mowamba River would be quickly eclipsed by inputs from tributaries downstream.

Of more significance, removing the weir would return the pre-weir rate of transport of coarse sediment (from coarse sand to gravels) from the Mowamba River into the Snowy River. Following initial transport of coarse sediment stored in the weir, the additional amount of coarse sediment entering the Snowy would be in the order of 1,000–3,000 m^3 per year on average (note this is the long-term transport rate in addition to the short-term pulse of sediment from the weir pool and erosion of the Mowamba channel described earlier). This amount represents a major input of coarse sediment at this point because no coarse sediment passes through Jindabyne Dam. This coarse sediment would only very gradually be transported through the long pools downstream of the Mowamba River junction. This source of coarse sediment would contribute to achieving several objectives in the Snowy River more quickly than the do-nothing option.

Increased nutrient inputs from the Mowamba River, which has higher average nutrient concentrations than the Snowy River downstream of Jindabyne Dam, and the increase with discharge for DOC, total nitrogen (TN) and total phosphorus (TP) (see Appendix F) would probably stimulate biofilm growth and increase food availability for grazing macroinvertebrates and tadpoles, and consequently for predatory fish and platypus. However, because the flow contribution from the Mowamba River (average of 33,710 ML/year) would be much lower than that from Jindabyne Dam (estimated[3] to average ~130,000 ML/year), these effects would probably be only minor.

NSW DPE–EHG (2022) analysed nutrient concentrations in the Mowamba River using unpublished data collected by Rohlfs et al. (2012), showing that median daily concentrations for DOC, TN and TP would increase by only 6–11%. The increase would be far greater at times of high flow in the Mowamba River; for example, the 90th percentile daily concentrations would be 55–68% higher for the remove-weir option than for the do-nothing option (see Appendix F). To provide an indicator of what a 'high flow' in the Mowamba River means in this context, the 90th percentile total daily flow in the Mowamba River is around

[3] See Table 5 – Average volume available for release from Jindabyne from 2013–14 to 2022–23 was 163,554 ML/year. With average additional flow of Mowamba River taken off, 129,844 ML/year remains.

170 ML/day. However, such events are short-lived and associated increases in suspended sediment and scouring would likely constrain any resulting stimulation of biofilm growth.

Unpublished data from the Thredbo River for DOC, TN and TP (Rohlfs et al. 2012) show that these nutrients were in lower concentrations than in the Snowy River upstream of the Mowamba River (this site has some input from the Jindabyne sewage treatment plant) and in the Mowamba River, particularly when the Mowamba River has high flows (see Appendix F). Therefore, an increase in concentrations of those nutrients in the Snowy River resulting from weir removal would move nutrient status of the Snowy River *away* from that of the reference reach. In other words, the Snowy River would probably become more biologically productive per unit area than in its pre-Scheme state, though probably not more productive in total because its wetted area would still be less than its pre-Scheme area.

Modelling by Coleman (2021) suggests that Snowy River water temperatures would reduce and move closer to modelled natural temperatures of the Snowy River because the Mowamba River is colder than the Snowy River downstream of Jindabyne Dam. However, the effect would vary depending on the relative contribution from Mowamba River at a particular time. The average effect would be moderate and would reduce as the river travels downstream towards Dalgety, adjusting to ambient air temperature.

Negligible effects would be expected in the lower reaches of the Snowy River downstream of Dalgety (including in the estuary), because tributaries entering downstream of Jindabyne Gorge contribute additional flow variability, nutrients and sediments to the river.

Effects of reduced releases from Jindabyne Dam

Under this option, increased Mowamba River flows would be compensated for by adjusting releases from Jindabyne Dam daily, according to the Mowamba River flow each day. However, releases would not be reduced below 40 ML/day, in order to maintain a flow in the 2 km Snowy River section between Jindabyne Dam and the Snowy–Mowamba junction (reach S1). If the additional Mowamba flow on a particular day was high and the SRIF allocation budgeted for that day low, total flows provided could exceed the daily SRIF allocation (see Table 3).

Table 3: Example of daily adjustment of Jindabyne release based on Mowamba additional flows

Note that on 3 May 2011 the Mowamba additional flow plus the Jindabyne release (at a minimum level of 40 ML/day) exceeds the SRIF allocation for that day.

Date	SRIF allocation	Mowamba additional flow	Jindabyne adjusted release	Exceedance of daily SRIF allocation
2 May 2011	100 ML	44 ML	56 ML	0 ML
3 May 2011	80 ML	51 ML	40 ML (minimum flow)	11 ML

Simpson (2021) and the NSW DPE – Environment and Heritage Group (NSW DPE–EHG 2022) analysed the exceedances of daily SRIF allocations that would result for the period of available data with near-full SRIF allocations (water years commencing 2011–2020). In most years, the exceedances of daily SRIF allocations would have remained at or below 2.5% of the allocation (Table 4). Further analysis by NSW DPE – EHG (2022) showed that by reducing daily SRIF release targets throughout the period by 3%, 9 out of 10 years' deliveries did not exceed the SRIF allocations, and SRIF allocations were instead under-delivered[4] (Table 4).

However, in one year (the water year beginning in 2020), the exceedances of daily SRIF allocations would have totalled 5.8% of the annual allocation. This result occurred because the allocation was very low and a drought broke halfway through the water year. The high additional Mowamba River flows in the wet summer and autumn frequently exceeded the low SRIF allocations for those days. An 8% reduction in daily SRIF release targets would have been required to ensure the overall SRIF was not exceeded in that year[5] (Table 4). However, such a large reduction would not be recommended across all years because it would be required only rarely, that is, in years when SRIF allocations are very low and Mowamba River flows are very high in the latter half of the water year (summer–autumn), after the majority of the year's SRIF allocation has already been delivered.

Table 4: Annual totals of exceedances of daily SRIF allocations that would have accrued if the Mowamba Weir was removed and Jindabyne releases had been reduced accordingly on a daily basis, but to no less than 40 ML/day

The final column shows the volume of SRIF allocation that would have been under-delivered in each year if daily release targets had been reduced by 3% and by 8%. Source for exceedance data 2011–2019: Simpson 2021; source for 2020 exceedance data and undelivered SRIF data: NSW DPE–EHG 2022.

Water year beginning	Total ML of exceedances of daily SRIF allocations	Total exceedances of daily SRIF allocations as a percentage of SRIF allocations and BPF for the year	Volume (ML) of undelivered SRIF remaining if daily release targets had been:	
			Reduced by 3%[4]	Reduced by 8%[5]
2011	2,676	1.7%	1,624	8,895
2012	3,479	2.1%	507	7,267
2013	1,420	0.7%	4,104	13,631
2014	2,898	1.8%	1,328	8,447
2015	2,410	1.6%	1,629	8,474
2016	3,143	2.4%	304	6,041
2017	97	0.0%	6,100	16,551
2018	814	0.6%	2,982	9,509
2019	2,071	1.7%	1,142	6,735
2020	5,292	5.8%	–3,298	429
Average	**2,430**	**1.94%**	**1,642**	**8,598**

[4] Daily release targets were reduced by 3% except for days that were less than 150 ML/day (these lower flow days were not reduced to protect low flows). The reduction in daily release targets left a volume of unallocated water that could be drawn on over the year to cover days when the flow provided exceeds the daily SRIF allocation. The undelivered SRIF allocation remaining is reported in the right-hand column of Table 4.

[5] As for the 3% reduction described in footnote 4, but with 8% reduction in daily flow targets and days that were less than 120 ML/day were not reduced to protect low flows.

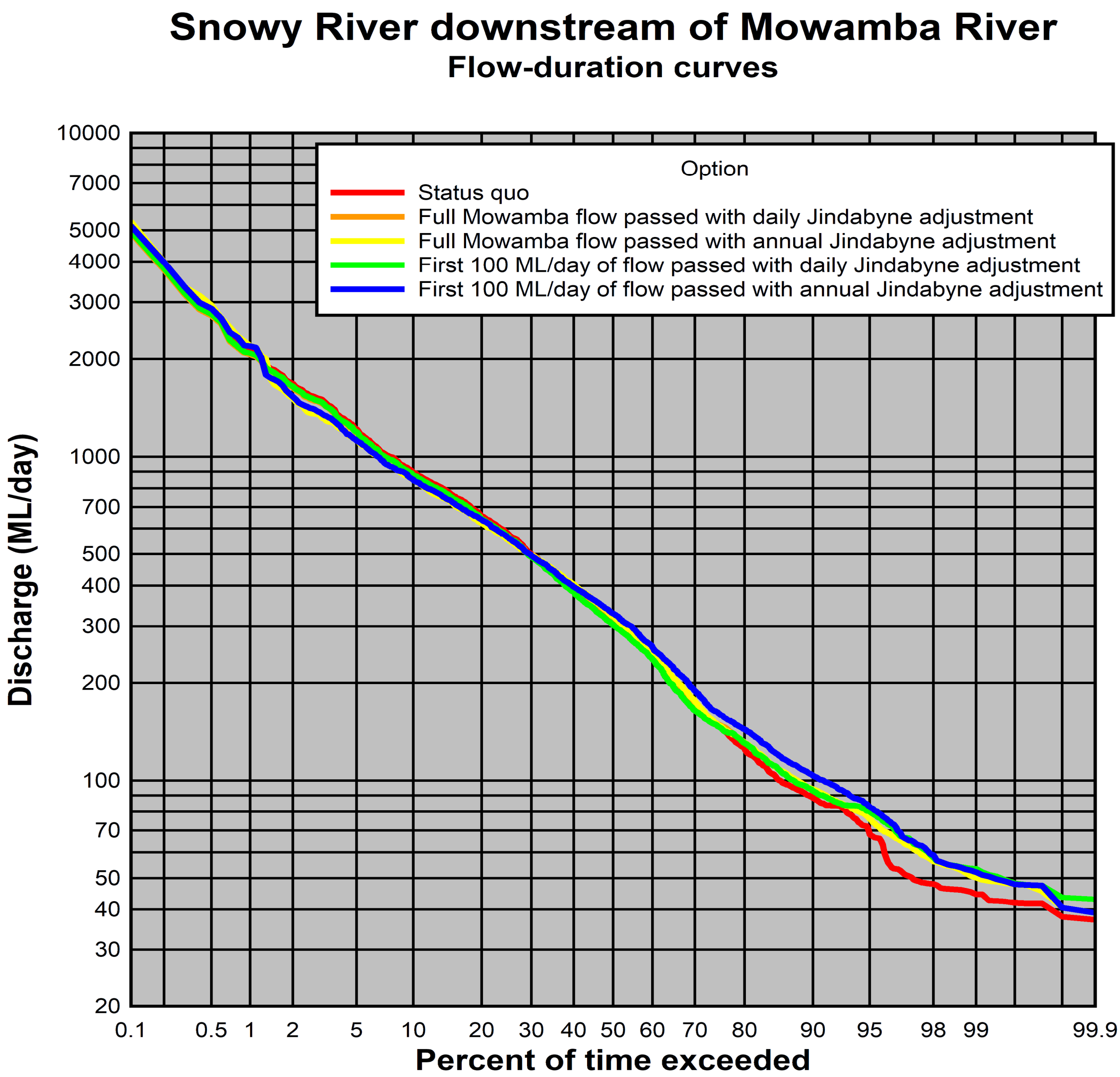


Figure 26: Flow exceedance curves for the Snowy River downstream of the Mowamba River junction for the do-nothing (status quo) option, options to pass all Mowamba River flows with daily deductions from Jindabyne matching Mowamba flows (options 2.3.1 and 2.4.1) and deductions of annual average Mowamba flow increases from the yearly Jindabyne releases (options 2.3.2 and 2.4.2); and options to pass the first 100 ML/day only of Mowamba River flows with daily deductions from Jindabyne matching Mowamba flows (option 2.5.1) and deductions of annual average Mowamba flow increases from the yearly Jindabyne releases (option 2.5.2)

The daily adjustment method for the remove-weir option would be viable only with a mechanism to credit under-delivery of SRIF in one year to the next year’s allocation. Such a mechanism would allow extreme years like 2020 to be covered without an overall reduction in SRIF delivery. Such a ‘carryover’ mechanism already exists in a limited form for under- and over-deliveries, and a modest amount of discretionary carryover across multiple years would enable the reduction in daily release targets to be only small. The Panel’s assessment of daily adjustment therefore assumes the existence of some form of carryover that would limit reduction of daily flow targets to 3% or less.

The slight reduction in releases from Jindabyne Dam under this option has some minor implications for river geomorphology. Higher flows would be reduced slightly in frequency, (a) reducing the rate at which coarse sediment is moved through pools in reach S2,

(b) reducing rates of scour of channels in reach S3, slowing the development of a larger channel, and (c) slightly reducing the frequency of inundation of benches, reducing the rate of aggradation. Overall, these geomorphic effects would be minor.

2.3.2 Removing Mowamba Weir with matching annual reduction in Jindabyne release

Like option 2.3.1, this option would remove Mowamba Weir to allow all Mowamba River flows to pass. However, this option would reduce the *annual allocation* for release from Jindabyne Dam by the *annual average volume* of flow increase in the Mowamba River. As shown in Table 5, the *modelled* average additional volume provided to the Snowy River from the Mowamba River would be 36,023 ML/year. The *observed* volume, based on actual diversions by the Mowamba Aqueduct, is 33,710 ML/year. The observed Mowamba Aqueduct value was used for this investigation because it is based on a considerable number of years (water years beginning 1968–2020). For the volume of SRIF allocations, the modelled numbers are used for calculations, because the observed period covers only the years since the recovery of entitlements for SRIF allocations was completed (2013–2022). However, for completeness, Table 5 includes both the modelled and observed values for Mowamba Aqueduct diversions and SRIF allocations.

Table 5: Observed and modelled volumes of water available for release to the Snowy River from Jindabyne Dam, noting the volume of additional flow able to be provided from the Mowamba River and the amount remaining for release from Jindabyne Dam once the yearly average flow provided from Mowamba River is accounted for

	Annual volume (ML) available for release to the Snowy River from Jindabyne Dam from observed data[6] (and modelled data[7])	Additional annual volume (ML) from Mowamba River if weir was removed, from observed[8] data (and modelled data[9])	Volume (ML) of SRIF and BPF remaining for release from Jindabyne after subtracting average additional annual Mowamba flow[10]	Proportion of total SRIF and BPF remaining for release from Jindabyne[11] compared to do-nothing option (all released via Jindabyne)
Mean	163,554 (187,304)	~33,710 (36,023)	153,594	81%
Median	153,658 (186,098)	~31,400 (33,036)	152,388	82%
Maximum	223,810 (255,802)	~93,800 (101,128)	222,092	87%
Minimum	91,476 (88,259)	~7,200 (5,312)	54,549	62%

[6] Allocation since full SRIF entitlement achieved (2013–14 to 2022–23 Snowy water year allocations) plus 8,500 ML of Jindabyne BPFs. Does not take into account adjustments for under- or over-deliveries or SHL limit on delivering SRIF of 212,000 ML/year.

[7] As for observed, but using model of SRIF allocation from years commencing 1896–2019.

[8] Based on Mowamba Aqueduct diversions for period 1968–2020, including the diversions from the smaller Cobbin Creek. For times when the aqueduct was closed, Mowamba River at Pats Patch flows were used (up to a maximum of 500 ML/day). For days with no data, the overall daily mean was used (except for the calculation of the lowest flow year, where dates with no data were replaced with the average flow of other days in that year).

[9] Modelled for water years starting 1890–2017 using source model produced for the Regional Water Strategy.

[10] The average annual observed aqueduct diversions of 33,710 ML are taken from each water year's modelled SRIF allocation and Jindabyne BPF.

[11] Proportion of remaining volume available for release from Jindabyne Dam (shown in third data column of table) compared to modelled total volume available for release in year (shown in first data column of table).

Figure 27 shows the total volume of modelled SRIF and BPF remaining for release from Jindabyne Dam after the observed annual average volumes of additional Mowamba flows are deducted. Figure 28 shows the proportion this volume represents compared to the modelled total SRIF plus BPF for the water year.

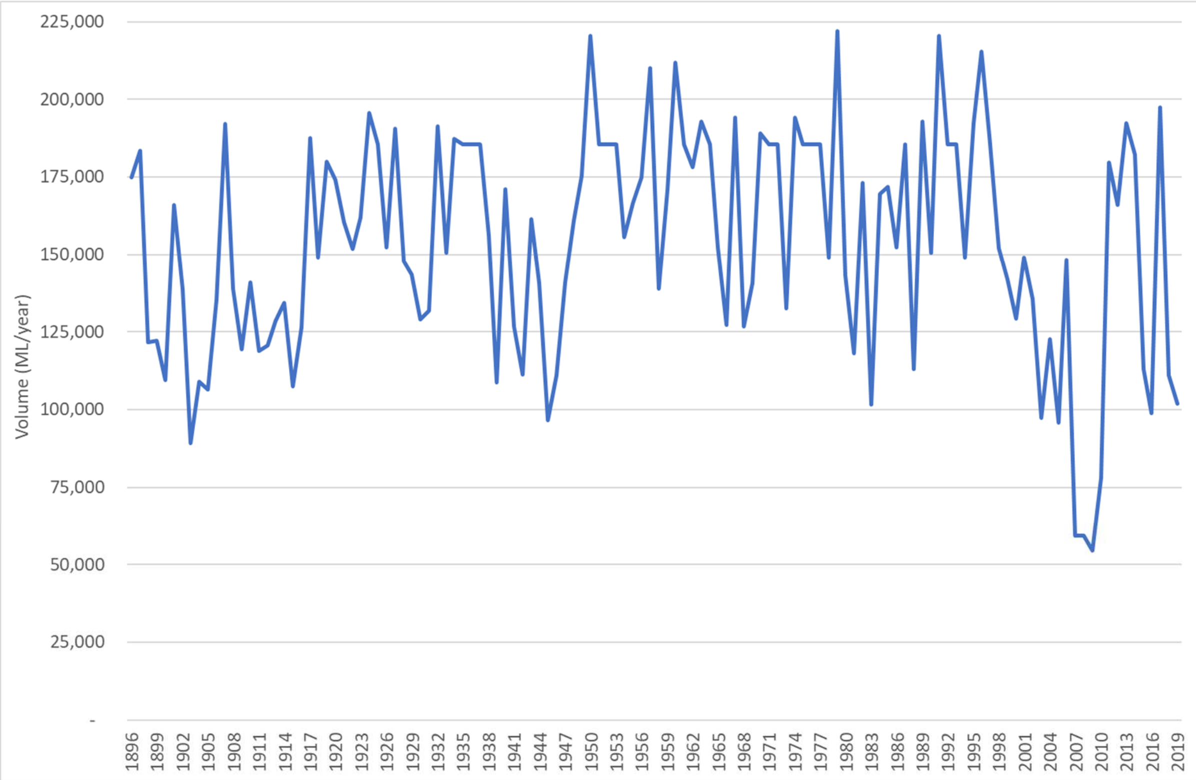


Figure 27: Volume of modelled available Snowy River release (SRIF plus Jindabyne BPF)[12] remaining for release from Jindabyne Dam after 33,710 ML is deducted to account for annual average observed flow passed downstream of Mowamba Weir

[12]Does not take into account SHL limit on delivering SRIF of 212,000 ML/year.

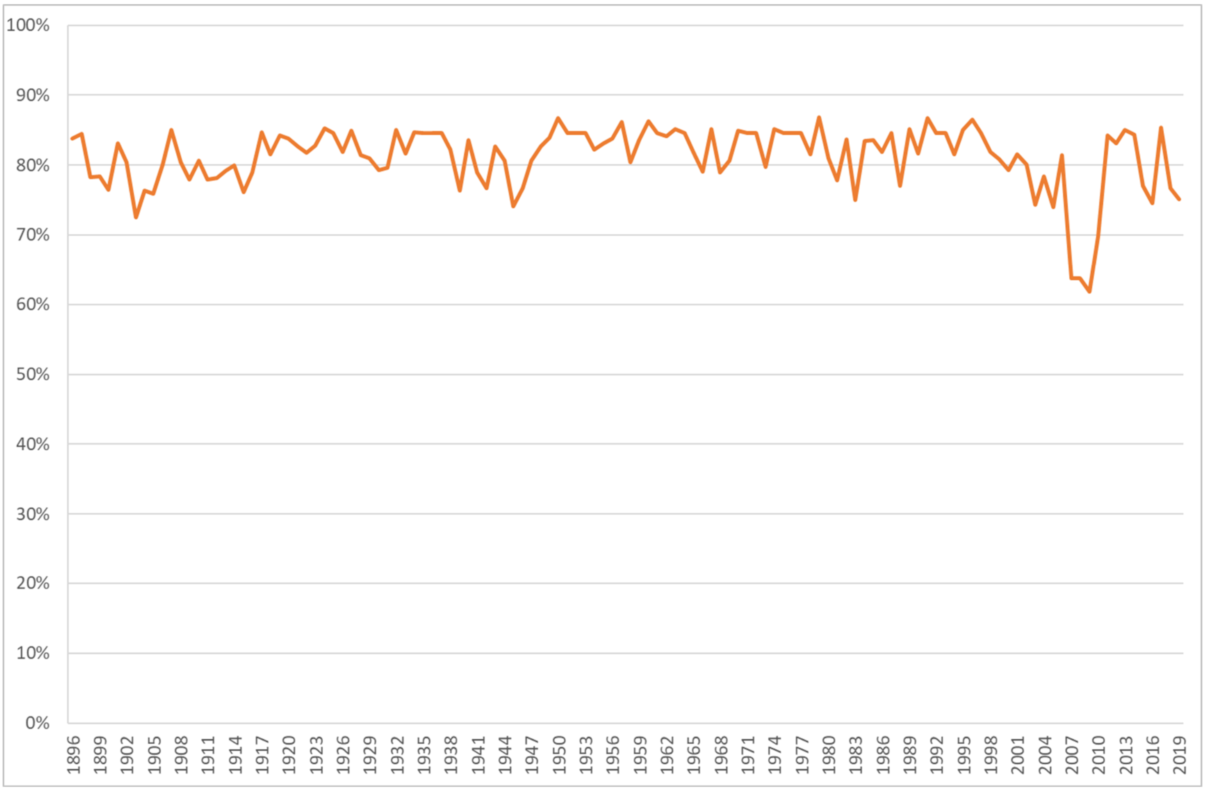


Figure 28: Proportion of modelled available Snowy River release (SRIF plus Jindabyne BPF) remaining for release from Jindabyne Dam after 33,710 ML is deducted to account for annual average observed flow passed downstream of Mowamba Weir

To see the effect on daily flows in the Snowy River, daily flows for the water years commencing 2011–2020 were generated for the following scenarios:

- **all flows reduced:** Jindabyne releases reduced by the same percentage for each day of the water year. The percentage reduction is determined by the annual percentage of water available for release from Jindabyne for that year compared to the do-nothing option
- **high and low flows protected:** Jindabyne releases reduced as above, but with flows that drop below 40 ML/day maintained at a minimum of 40 ML/day and with flows above 2,000 ML/day not reduced.

Table 6 shows the percentage reduction in daily flows required for the 2 scenarios. Figure 29 and Figure 30 show the daily flow in the Snowy River downstream of the Mowamba River junction comparing the scenario with high and low flows protected and the do-nothing option (Mowamba Weir diverting and all flows released from Jindabyne). Flows above 2,000 ML/day are generally increased marginally under the scenario with high and low flows protected. Greater differences are seen at flows below 2,000 ML/day.

Table 6: Percentage reduction in daily releases from Jindabyne Dam required after deducting annual average additional flow from the Mowamba River resulting from weir removal

The water years 2011 and 2012 are in cursive script to denote that these years preceded 2013 when full SRIF entitlements were available and when the current method of daily flow planning (natural flow scaling based on Reinfelds et al. 2013a) was begun.

	Percentage reduction in daily release from Jindabyne Dam required after deducting annual average additional flow from Mowamba River	
Water year commencing	**Scenario with all flows in water year reduced equally**	**Scenario with high and low flows protected – percentage reduction for flows 40–2,000 ML/day**[13]
2011	*21%*	*38%*
2012	*21%*	*38%*
2013	18%	20%
2014	22%	23%
2015	22%	24%
2016	25%	28%
2017	15%	17%
2018	24%	25%
2019	28%	31%
2020	37%	38%

[13] Flows reduced below 40 ML/day are maintained at a minimum of 40 ML/day. Flows above 2,000 ML/day are not reduced. Periods when the aqueduct was closed and when there is a pre-release from the Jindabyne Dam have been removed.

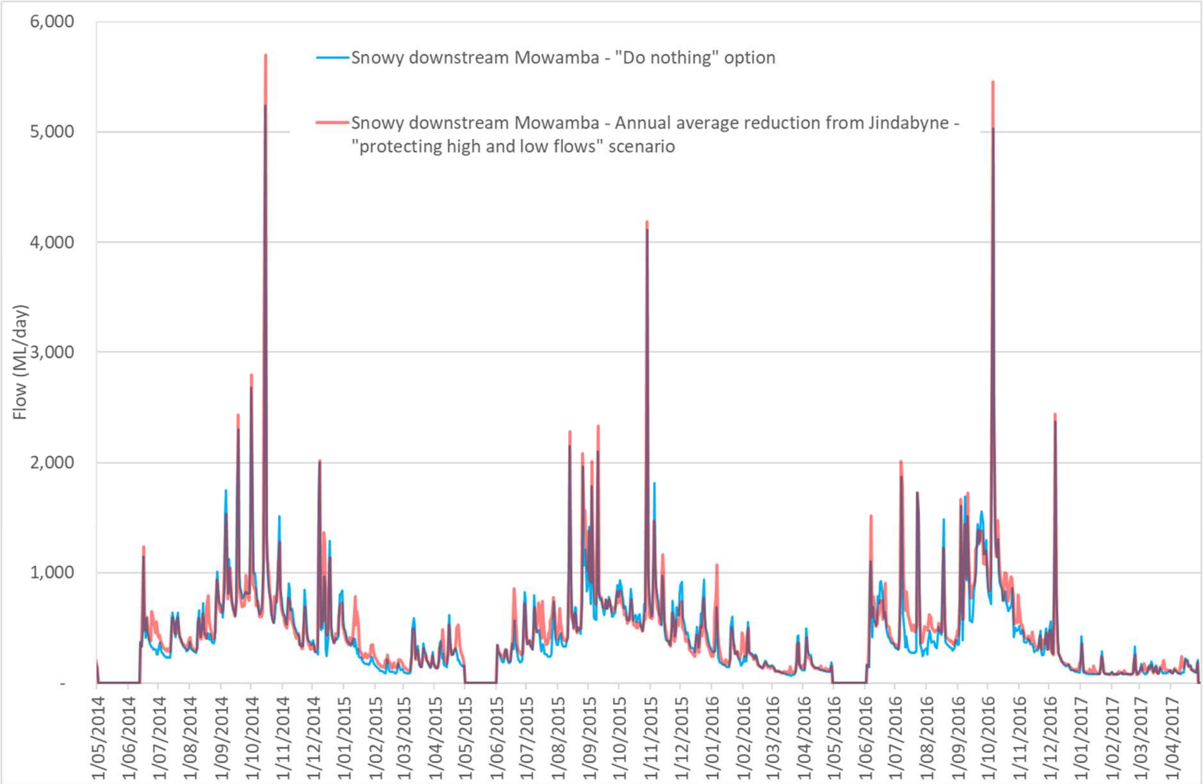


Figure 29: Snowy River flows downstream of Mowamba River junction for the water years beginning 2014–2016 under the do-nothing option (Mowamba Aqueduct diverting, all releases from Jindabyne Dam – blue line) and the Mowamba Weir removed plus yearly reductions in Jindabyne release option – with reductions in daily flows not made below 40 ML/day or above 2,000 ML/day

Where the lines overlap the colour is dark grey. This shows 3 years where the effect of reductions is relatively small; compare with Figure 30.

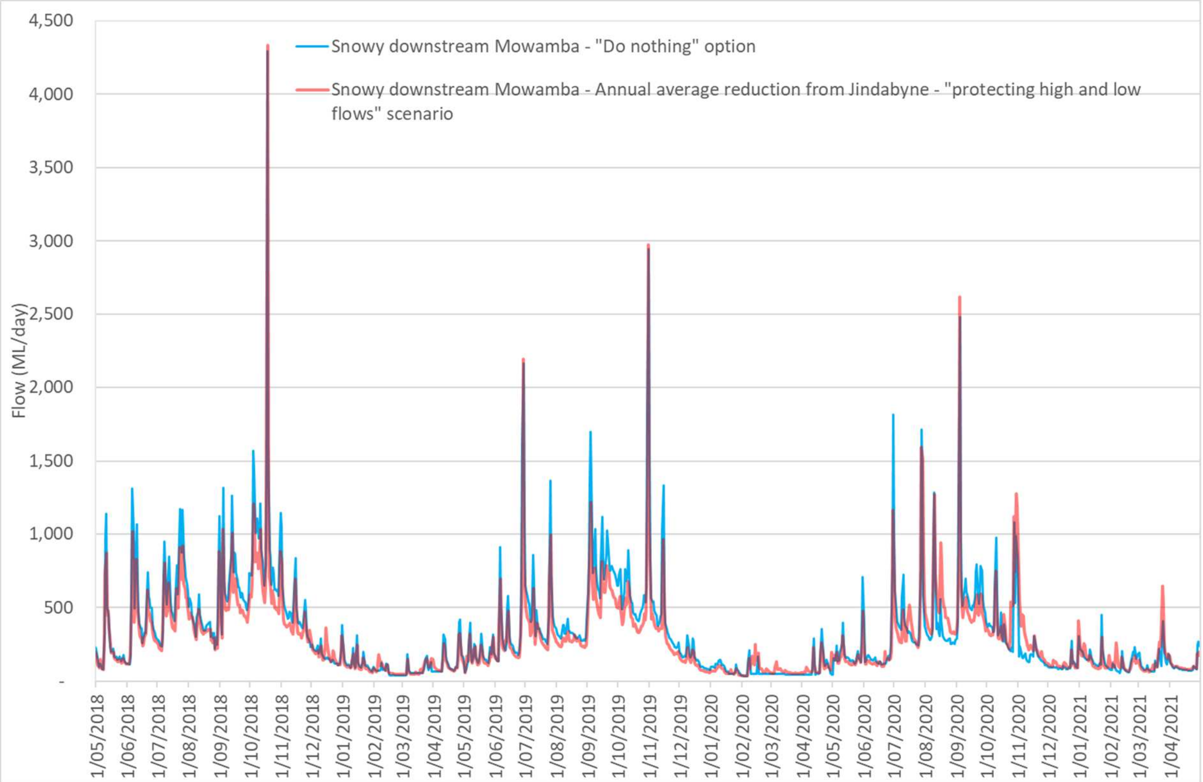


Figure 30: Snowy River flows downstream of Mowamba River junction for water years beginning 2018–2020

Shows flows under the do-nothing option (Mowamba Aqueduct diverting, all releases from Jindabyne Dam – blue line) and the Mowamba Weir removed plus yearly reductions in Jindabyne release option – with reductions in daily flows not made below 40 ML/day or above 2,000 ML/day (red line). Where the lines overlap the colour is dark grey. This shows 3 years where the effect of the reductions is greater than in most other years post 2013 when full entitlements were available and the current method of flow planning (natural flow scaling based on Reinfelds et al. 2013a) was begun; compare with Figure 29.

Main environmental effects of removing the weir

Effects on the Mowamba River: The effects on the Mowamba River would be the same as those for option 2.3.1 (removing the weir with matching daily reduction in Jindabyne release). See also summary in section 2.7 and further detail in Appendix C.

Effects on the Snowy River: The effects on the Snowy River would be similar to those for option 2.3.1, although effects on the flow regime would be slightly less. See summary in section 2.8 and further detail in Appendix D.

2.4 Retain Mowamba Weir but cease diversions and allow Mowamba Weir to overtop

This option would involve SHL closing the Mowamba Aqueduct. As a consequence, apart from rare periods of very low-flow conditions in the upper Mowamba, the weir would be continuously overtopped (Figure 31).

Figure 31: Mowamba Weir with an overtopping flow on 13 May 2021

Flows of this type can be rare, e.g. daily flows at the downstream Pats Patch did not exceed 2 ML/day from February 2018 until July 2020. Photo: Paul Doyle, NSW DPE.

Flows down the Mowamba River under this option would be the same as for the remove-weir option outlined in section 2.3 of this report and shown in the hydrograph in Figure 22.

2.4.1 Retain Mowamba Weir but allow all Mowamba River flows to overtop weir, with matching daily reduction in Jindabyne releases

The changes in Jindabyne flow releases relating to this option would be the same as for the remove-weir option outlined in section 2.3.1 of this report.

Main environmental effects of allowing all flows to overtop the weir

Effects on the Mowamba River (see also summary in section 2.7 and further detail in Appendix C), this option would:

- as for option 2.3 (removing the weir), return the 5 km of the Mowamba River downstream of the Mowamba Weir to its pre-weir hydrological state. The flow regime at Pats Patch on the Mowamba River would change from that shown in Figure 19 to that shown in Figure 22
- as for option 2.3 (removing the weir), restore algal and macroinvertebrate assemblage composition, abundance and density to values similar to those that occurred pre-weir. However, the weir would still reduce downstream macroinvertebrate drift
- as for option 2.3 (removing the weir), increase connectivity for platypus and fish along the river corridor downstream of the weir. However, the weir would still create a barrier to passage
- in contrast to option 2.3 (removing the weir), continue to trap sediment in the weir pool. There would still be no transport of bed material to the river downstream of the weir, which in association with increased downstream flow would be likely to lead to the bed becoming 'armoured', i.e. rockier and more dominated by larger gravels.

Effects on the Snowy River (see also summary in section 2.7 and further detail in Appendix D): As for option 2.3 (removing the weir), this option would increase within-day flow variability and inputs of suspended sediments, detritus and nutrients from Mowamba River flows. These inputs would be expected to increase food availability for macroinvertebrates, fish, platypus and tadpoles. Water temperatures would move closer to the modelled natural temperatures of the Snowy River. However, because the additional flows from the Mowamba River would be only about 26% of the volume that would be contributed from Jindabyne Dam[14], these effects would probably be only moderate. Effects would also reduce as the river travelled downstream towards Dalgety.

2.4.2 Retain Mowamba Weir but allow all Mowamba River flows to overtop the weir, with matching yearly reductions in Jindabyne releases

Like option 2.4.1, this option would involve SHL closing the Mowamba Aqueduct, allowing all Mowamba River flows to overtop the weir. Therefore, flows down the Mowamba River under this option would be the same as for option 2.4.1 (weir allowed to overtop with matching daily reduction in Jindabyne releases). However, this option would reduce the *annual allocation* for release from Jindabyne by the *annual average volume* of flow increase in the Mowamba River. The effect of this adjustment on Snowy River flows is explained under option 2.3.2, which would also pass all Mowamba River flows and reduce the annual allocation for release from Jindabyne Dam by the average annual volume of flow increase in the Mowamba River.

[14] See Table 5– Average volume available for release from Jindabyne from 2013–14 to 2022–23 was 163,554 ML/year. The average additional flow from the Mowamba River is 33,710 ML/year. Under this option Jindabyne releases would reduce to about 130,000 ML/year, so the ratio of additional Mowamba flows to Jindabyne releases is 26%.

Main environmental effects

Environmental effects on the Mowamba River: As for option 2.4.1 (weir allowed to overtop with daily reduction in Jindabyne flows). See summary in section 2.7 and further detail in Appendix C.

Environmental effects on the Snowy River: As for option 2.3.2 (removing Mowamba Weir with yearly reductions in Jindabyne Dam releases), except for some aspects relating to the removal of the weir (discussed in summary in section 2.8 and in detail in Appendix D).

2.5 Retain Mowamba Weir but reduce Mowamba diversions to Lake Jindabyne so low to moderate flows pass into the lower Mowamba River

This option would leave Mowamba Weir in place but allow all flow to pass the weir up to a certain threshold. Flow above the threshold would be diverted down the Mowamba Aqueduct until river flow reached a second threshold, with flow above this second threshold also passing downstream. This option would thus allow low to moderate flows to pass down the river while still allowing a portion of larger flows to be diverted.

This option could be implemented in several ways, but the feasibility, engineering requirements and operational costs and benefits have not been fully explored with SHL. The Panel considered the following scenario for exploratory purposes:

- Mowamba River flows up to 100 ML/day would be allowed to overtop the weir
- once river flow exceeded 100 ML/day, the excess would be diverted down the Mowamba Aqueduct
- diversion down the Mowamba Aqueduct would be limited to a maximum of 400 ML/day, and so the portion of river flow above 500 ML/day would also overtop the weir.[15]

Flows that would have occurred in the Mowamba River downstream of the Mowamba Weir under this option are shown in Figure 32.

[15]The available hydrological analysis was for this configuration. In practice, this option could also be implemented with the aqueduct still able to take 500 ML/day, so that Mowamba River flows above 600 ML/day would be required to overtop the weir.

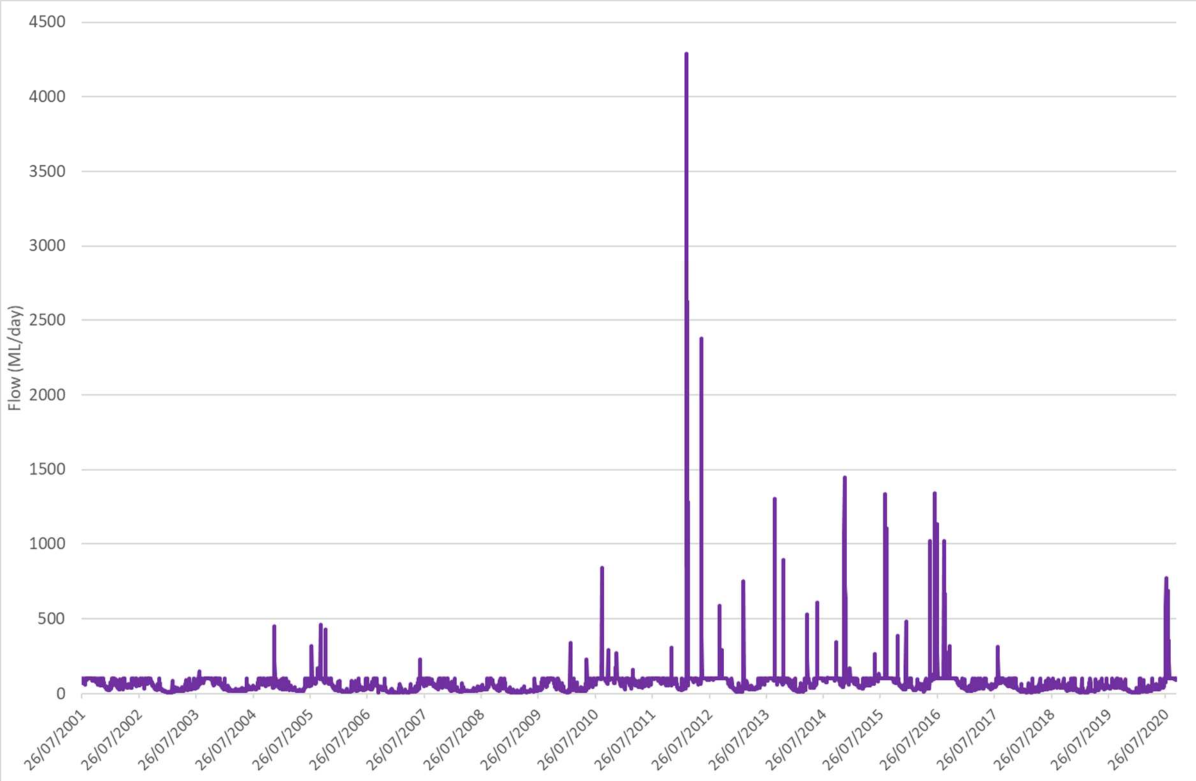


Figure 32: Total flow expected in the Mowamba River at Pats Patch under the scenario whereby the first 100 ML/day of flow is allowed to pass Mowamba Weir with flows from 100–500 ML/day diverted down the Mowamba Aqueduct

See Figure 19 for comparison with the current do-nothing option (no flows passed) and Figure 22 for the options that allow all flows to pass.

The average modelled volume of additional flow passing Mowamba Weir under this option would be 21,550 ML/year, compared with 36,023 ML/year[16] if all flows were allowed to pass.

2.5.1 Retain Mowamba Weir but allow first 100 ML/day of Mowamba River flows to overtop, with matching daily reduction in Jindabyne releases

Section 2.3.1 (removing Mowamba Weir with matching daily reduction in Jindabyne releases) outlines how Jindabyne releases would be reduced. Passing all flow only up to 100 ML/day would reduce the amount of water used and hence the amount by which Jindabyne releases would have to be reduced. Table 7 shows the total volume of exceedances in daily SRIF allocations that would result per year if the daily SRIF release allocation was not changed. It also shows that if daily SRIF allocations were reduced by 2%, the releases for the year would not have exceeded the SRIF allocation for the year, with some under-delivery of SRIF occurring.

[16] The modelled averages are for the modelled water years commencing 1890 to 2017. The full transparency modelled figure compares to an observed average of 33,710 ML/year for the water years commencing 1969 to 2020.

The 2% reduction in the daily SRIF allocation compares to a reduction of 3% for options 2.3.1 (removing the weir) and 2.4.1 (retaining the weir but allowing all flows to overtop). This 1% difference is not considered substantial.

Table 7: Annual totals of exceedances of daily SRIF allocations that would have accrued if the first 100 ML/day of Mowamba Aqueduct flows were passed downstream of Mowamba Weir and Jindabyne releases were reduced on a daily basis to no less than 40 ML/day

The final column shows the volume of SRIF allocation that would have been under-delivered in each year if daily release targets had been reduced by 2%. Source for exceedance data 2011–2019: Simpson 2021; Source for 2020 exceedance data and undelivered SRIF data: NSW DPE–EHG 2022.

Water year beginning	Total (ML) of exceedances of daily SRIF allocations	Total exceedances of daily SRIF allocations as a percentage of total SRIF allocations and BPF for the year	Volume (ML) of undelivered SRIF remaining[17] if daily release targets had been reduced by 2%
2011	1,001	0.6%	1,931
2012	643	0.4%	2,114
2013	51	0.0%	3,690
2014	344	0.2%	2,628
2015	162	0.1%	2,634
2016	573	0.4%	1,879
2017	68	0.0%	4,075
2018	609	0.4%	1,930
2019	1,865	1.6%	277
2020	842	0.9%	641

Main environmental effects

Environmental effects on the Mowamba River (see also summary in section 2.7 and further detail in Appendix C): these effects would be similar to those for option 2.4.1 (retaining the weir but allowing all flows to overtop), with the following differences:

- For the 5 km of Mowamba River below Mowamba Weir, the flow regime would change from that shown in Figure 19 to that shown in Figure 32. Substantial increases would be seen in daily and seasonal flow variability and the provision of flow during droughts. However, the diversion from the river of flows above 100 ML/day would mean that daily variability would still be restricted and moderate flow events would be truncated. Consequently, freshes above 100 ML/day would be absent in the river unless the capacity of the aqueduct in this scenario was exceeded[18]. Where the capacity of the aqueduct was exceeded, the size of these

[17] Daily release targets were reduced by 2% except for days that were less than 150 ML/day (these lower flow days were not reduced to protect low flows). The reduction in daily release targets left a volume of unallocated water that could be drawn on over the year to cover days when the flow provided exceeds the daily allocation for delivery.

[18] For options 2.5.1 and 2.5.2 the capacity of the aqueduct is limited to 400 ML/day. This was because the available hydrological analysis makes this assumption.

flows below the weir would be reduced because 400 ML/day of the flows would still be diverted down the aqueduct. For reference, the median flow of the Mowamba River (calculated as total flow including aqueduct diversions and downstream flow at Pats Patch from 2001–2020) is 51 ML/day and the 75th percentile flow is 98 ML/day.

- Macroinvertebrate and benthic algal assemblage composition and densities would change to a lesser degree than under option 2.4.1 because there would be less scouring by high flows.
- The alluvial channel immediately downstream of the weir (above the bedrock section) would widen by only about 1 m. The scouring of the riverbed and replacement of in-channel vegetation with an active gravel bed would be restricted to the area in and near the central channel path.

Environmental effects on the Snowy River (see also summary in section 2.8 and further detail in Appendix D): Effects would be similar to those of option 2.4.1 (allowing all flows to overtop Mowamba Weir), but in many cases less pronounced because the additional flows from the Mowamba River would only be about 15% of the volume that would be contributed from Jindabyne Dam[19] rather than 26% if all flows were allowed to overtop Mowamba Weir.[14]

2.5.2 Retain Mowamba Weir but allow the first 100 ML/day of Mowamba River flows to overtop, with matching yearly reduction in Jindabyne releases

Like option 2.5.1, this option would retain Mowamba Weir and allow flows up to 100 ML/day to pass. However, this option would involve reducing the annual allocation for release from Jindabyne Dam by the annual average volume of flow increase in the Mowamba River (estimated at 21,550 ML/year).

Table 8 shows the expected reduction in annual releases from Jindabyne Dam. When compared to options 2.3.2 and 2.4.2 (see Table 5), which allow all Mowamba River flows to pass, this option would provide less water from the Mowamba River and consequently would result in a lesser reduction in Jindabyne flow releases.

[19] See Table 5 – Average volume available for release from Jindabyne from 2013–14 to 2022–23 was 163,554 ML/year. The modelled average additional flow from the Mowamba River for the option to allow 100 ML/day past the weir is 21,550 ML/year[16]. Under this option Jindabyne releases would reduce to 142,004 ML/year, so the ratio of additional Mowamba flows to Jindabyne releases is 15%.

Table 8: Observed and modelled volumes of water available for release to the Snowy River from Jindabyne Dam, noting volume of additional annual flow able to be provided from the Mowamba River when the first 100 ML/day is allowed to pass and the amount remaining for release from Jindabyne once the yearly average additional flow provided from Mowamba River is accounted for

	Annual volume (ML) available for release to the Snowy River from Jindabyne Dam, from observed data[20] (and modelled data[21])	**Additional annual volume (ML) from Mowamba River if first 100 ML/day are allowed to pass, from modelled data[22]**	**Volume (ML) of SRIF and Jindabyne BPF remaining for release from Jindabyne after subtracting average additional annual Mowamba flow[23]**	**Proportion of total SRIF and BPF remaining for release from Jindabyne[24] compared to do-nothing option (all released via Jindabyne)**
Mean	163,554 (187,304)	21,550	165,754	88%
Median	153,658 (186,098)	23,305	164,548	88%
Maximum	223,810 (255,802)	33,721	234,252	92%
Minimum	91,476 (88,259)	5,312	66,709	76%

Table 9: Percentage reduction in daily releases from Jindabyne Dam required after deducting annual average additional flow from the Mowamba River resulting from passing all flows up to 100 ML/day

Water year commencing	**Percentage reduction in daily release from Jindabyne Dam required after deducting annual average additional flows from the Mowamba River**	
	Scenario with all flows in water year reduced equally	**Scenario with high and low flows protected – percentage reduction for flows 40–2,000 ML/day[25]**
2011	13%	25%
2012	13%	24%
2013	11%	13%
2014	14%	15%
2015	14%	15%
2016	16%	18%
2017	10%	11%
2018	16%	16%
2019	18%	19%
2020	24%	24%

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[20] Allocation since full SRIF entitlement achieved (2013–14 to 2022–23 Snowy water year allocations) plus 8,500 ML of Jindabyne BPF. Does not take into account adjustments for under or over-deliveries or SHL limit on delivering SRIF of 212,000 ML/year.

[21] As for observed, but using model of SRIF allocation from years commencing 1896–2019.

[22] Modelled for water years starting 1890–2017 using source model produced for the Regional Water Strategy.

[23] The average annual modelled aqueduct diversions up to 100 ML/day of 21,550 ML are taken from each water year's modelled SRIF allocation and BPF.

[24] Proportion of remaining volume available for release from Jindabyne Dam (shown in third column of table) compared to total volume available for release in year (shown in first column of table).

[25] Flows reduced below 40 ML/day are maintained at a minimum of 40 ML/day. Flows above 2,000 ML/day are not reduced. Periods when the aqueduct was closed and when there is a pre-release from the Jindabyne Dam have been removed.

Main environmental effects

Effects on the Mowamba River: See summary in section 2.7 and further detail in Appendix C.

Effects on the Snowy River main stem: See summary in section 2.8 and further detail in Appendix D.

2.6 Other options for Mowamba Weir release

2.6.1 Fishway

The Panel considered the provision of a fishway on Mowamba Weir for options where the weir was left in place. The main effect of a fishway would be on passage for fish, some invertebrates, and possibly platypus. This effect would be only marginal for the following reasons:

- The 3 m-high Cascades in reach M2 of the Mowamba River might inhibit upstream fish passage even with a fishway in place.
- There might be benefits for native southern shortfin and longfin eels, which NSW DPI–Fisheries (2021) have recorded as the most common large-bodied fish in the Snowy River downstream of the Mowamba River. Southern shortfin eels were also the dominant fish recorded in the small NSW DPI–Fisheries (2021) dataset for Mowamba Lodge, downstream of the Mowamba Weir (record for this site: 14 southern shortfin eels from 18 fish caught). In contrast, the NSW DPI–Fisheries data available for sites upstream of the weir do not record eels (data available from 2019–21, 96 fish recorded – all exotic trout). However, the return of water to the lower Mowamba River might overcome most of the impediments to eel movement and, although the weir would hinder passage, eels could migrate overland around the weir.
- A fishway might provide passage for Australian bass, but it is not clear that they could overcome the barriers presented by the natural cascades. Australian bass do not appear able to migrate upstream of the Snowy River Falls under the current flow regime, and their presence upstream of the falls is due to stocking in 2007–09 (Cameron et al. 2012). Numbers of Australian bass in the Snowy River above the Snowy River Falls have subsequently diminished, and without a sustained population (from stocking or otherwise) and evidence of accessibility to the weir, the Panel is unable to recommend a fishway for Australian bass. In addition, the upper Mowamba River may be only a marginal habitat for Australian bass because of its low water temperatures and distance from the estuary.
- Exotic brown and rainbow trout are stocked annually at several sites in the Mowamba River upstream of the weir, and in the Snowy River at several sites upstream of Dalgety. Brown trout have been recorded both upstream and downstream of the weir (NSW DPI–Fisheries 2021). Rainbow trout have been recorded regularly upstream of the weir but not downstream. Given the annual stocking, it is likely that factors other than passage are influencing the distribution of this species.
- A fishway would be less effective for movement of fish and other aquatic animals than having no barrier at all.

The fishway would not enable the passage of bedload material past the weir.

2.6.2 Drainage gate

To enable draining of the Mowamba Weir pool for maintenance and desilting, the weir has a drain gate (120 cm x 90 cm) on the intake structure, which is capable of passing more than 100 ML/day (James Pirozzi, SHL, pers. comm. 20 October 2021). Permanently opening this drain gate could be considered for options under which the weir is left in place (options 2.4 and 2.5), in order to increase the downstream transmission of bedload and provide fish passage.

While the drainage gate could be considered as part of the configuration of the weir for options 2.4 and 2.5, the Panel does not consider the opening of the drain gate to be critical for these options for the following reasons:

- The weir traps all of the coarse sand and gravel delivered to the weir pool. At present, most of this material deposits at the upstream end of the weir pool. If the weir were drained, a channel would develop across the floor of the weir pool, transporting some bedload through the opening. However, the contribution of this bedload to geomorphic processes in the Snowy River would be minor.
- As noted above for fishways (section 2.6.1), the Mowamba River cascades already present natural barriers to passage for some fish. Eels, which are likely to overcome these impediments, should be able to pass around the weir, but the drainage gate may provide a better route under the right conditions. Downstream fish passage might be increased, especially for rainbow trout. However, they are stocked upstream of the weir and in the Snowy River downstream, and so other factors are probably restricting their distribution.
- The ability of the drainage gate to provide fish passage would depend on the flow. At high flow, the velocity could be too great for upstream migration.

Figure 33: Mowamba Weir showing drain gate (dark rectangle), with the weir crest to the left
Photo: Paul Doyle, NSW DPE

2.7 Summary of effects on Mowamba River from different options for passing flows downstream of Mowamba Weir

A summary of effects of different options for the Mowamba River is provided in Table 10. More detailed analysis is provided in Appendix C.

Table 10: Summary of effects on Mowamba River from options to return flows to the river

Environmental variable	Option 2.3: Remove weir	Option 2.4: Allow all flows to overtop weir	Option 2.5: Allow first 100 ML/day to overtop weir
Daily discharge variability	Fully restore pre-weir variability	Fully restore pre-weir variability	Mostly restore pre-weir variability
Discharge seasonality	Fully restore pre-weir seasonality	Fully restore pre-weir seasonality	Mostly restore pre-weir seasonality
High-flow magnitude	Increase by 500 ML/day	Increase by 500 ML/day	Increase by 100 ML/day
High-flow frequency	Major increase	Major increase	Minor increase
High-flow duration	Major increase	Major increase	Minor increase
High-flow rate of rise and fall	Fully restore pre-weir rates	Fully restore pre-weir rates	Partly restore pre-weir rates
High-flow sequencing	Fully restore pre-weir sequencing	Fully restore pre-weir sequencing	Partly restore pre-weir sequencing
Channel morphology measures	Fully restore pre-weir morphology	Partly restore pre-weir morphology	Slightly restore pre-weir morphology
Floodplain aggradation	Fully restore pre-weir aggradation	Fully restore pre-weir aggradation	Slightly restore pre weir aggradation
Substrate character	Fully restore pre-weir substrate	Slightly restore pre-weir substrate	Slightly restore pre-weir substrate
Sediment movement	Fully restore pre-weir sediment movement	Slightly restore pre-weir sediment movement	Slightly restore pre-weir sediment movement
Benthic algal assemblage composition	Major change toward flora more adapted to high flow	Major change toward flora more adapted to high flow	Moderate change toward flora more adapted to high flow
Benthic algal density	Major decrease	Major decrease	Moderate decrease
Bench inundation frequency	Not applicable (Mowamba River lacks benches)	Not applicable (Mowamba River lacks benches)	Not applicable (Mowamba River lacks benches)
DOC concentration	No change	No change	No change
Concentration of other basal resources including nitrogen, phosphorus and silica	No change	No change	No change

Environmental variable	Option 2.3: Remove weir	Option 2.4: Allow all flows to overtop weir	Option 2.5: Allow first 100 ML/day to overtop weir
In-stream plant assemblage composition	Major change in places toward flora more adapted to high flow	Major change in places toward flora more adapted to high flow	Moderate change in places toward flora more adapted to high flow
In-stream plant cover	Major decrease in density in places	Major decrease in density in places	Moderate decrease in density in places
Riparian plant cover	Major loss in places	Major loss in places	Minor loss in places
Riparian plant assemblage composition	Major change in places toward flora more adapted to fast flow	Major change in places toward flora more adapted to fast flow	Minor change in places toward flora more adapted to fast flow
Thermal regime of river	Fully restore pre-weir regime	Fully restore pre-weir regime	Partly restore pre-weir regime
Benthic invertebrate assemblage composition	Major change toward fauna more adapted to fast flow	Major change toward fauna more adapted to fast flow	Moderate change toward fauna more adapted to fast flow
Benthic invertebrate density	Major decrease to pre-weir levels	Major decrease to pre-weir levels	Moderate decrease towards pre-weir levels
Benthic invertebrate total abundance	Minor increase	Minor increase	Minor increase
Fish assemblage composition	Composition would become much more similar upstream and downstream of the weir	Composition would become somewhat more similar upstream and downstream of the weir	Composition would become somewhat more similar upstream and downstream of the weir
Fish passage	Fully restore pre-weir passage, especially for eels	Partly restore pre-weir passage, especially for eels	Partly restore pre-weir passage, especially for eels
Fish total abundance	Moderate increase	Moderate increase	Minor increase
Platypus feeding	Fully restore pre-weir feeding	Fully restore pre-weir feeding	Partly restore pre-weir feeding
Platypus movement	Fully restore pre-weir movement	Partly restore pre-weir movement	Partly restore pre-weir movement
Water colour	No change	No change	No change
Water turbidity	No change	No change	No change
Frog species diversity and abundance	Moderate increase	Moderate increase	Minor increase

2.8 Summary of effects on the Snowy River from different options of passing flows downstream of Mowamba Weir

A summary of effects of different options for the Mowamba River is provided in Table 11. More detailed analysis is provided in Appendix D.

Table 11: Summary of effects on the Snowy River below Jindabyne from options to pass flows downstream of Mowamba Weir

Environmental variable	Option 2.3.1: Remove weir + matching daily cut in J'byne releases	Option 2.3.2: Remove weir + annual average M'ba flow cut from J'byne releases	Option 2.4.1: All flows to overtop weir + matching daily cut in J'byne releases	Option 2.4.2: All flows to overtop weir + annual average M'ba flow cut from J'byne releases	Option 2.5.1: First 100 ML/day to overtop weir + matching daily cut in J'byne releases	Option 2.5.2: First 100 ML/day to overtop weir + annual average M'ba flow cut from J'byne releases
Daily discharge variability	No change	No change	No change	No change	No change	No change
Discharge seasonality	Minor decrease toward seasonality of Thredbo reference reach	Minor decrease toward seasonality of Thredbo reference reach	Minor decrease toward seasonality of Thredbo reference reach	Minor decrease toward seasonality of Thredbo reference reach	Minor decrease toward seasonality of Thredbo reference reach	Minor decrease toward seasonality of Thredbo reference reach
High-flow magnitude	Minor decrease	No change	Minor decrease	No change	Minor decrease	No change
High-flow frequency	Minor decrease	No change	Minor decrease	No change	Minor decrease	No change
High-flow duration	Minor decrease	No change	Minor decrease	No change	Minor decrease	No change
High-flow rate of rise and fall	Minor increase within days and decrease between days	Minor increase within days and increase or decrease between days	Minor increase within days and decrease between days	Minor increase within days and increase or decrease between days	No change	No change
High-flow sequencing	Minor decrease	No change	Minor decrease	No change	Minor decrease	No change

Environmental variable	Option 2.3.1: Remove weir + matching daily cut in J'byne releases	Option 2.3.2: Remove weir + annual average M'ba flow cut from J'byne releases	Option 2.4.1: All flows to overtop weir + matching daily cut in J'byne releases	Option 2.4.2: All flows to overtop weir + annual average M'ba flow cut from J'byne releases	Option 2.5.1: First 100 ML/day to overtop weir + matching daily cut in J'byne releases	Option 2.5.2: First 100 ML/day to overtop weir + annual average M'ba flow cut from J'byne releases
Channel morphology measures	Minor change toward Thredbo River reference reach	Minor change toward Thredbo River reference reach	Minor change toward Thredbo River reference reach	Minor change toward Thredbo River reference reach	No change	No change
Floodplain aggradation	Minor aggradation	Minor aggradation	Minor aggradation	Minor aggradation	No change	No change
Substrate character	Major increase in coarse sediment	Major increase in coarse sediment	Minor increase in fine sediment	Minor increase in fine sediment	Minor increase in fine sediment	Minor increase in fine sediment
Sediment movement	Minor increase in fine sediment movement, and major increase in coarse sediment movement	Minor increase in fine sediment movement, and major increase in coarse sediment movement	Minor increase in fine sediment movement	Minor increase in fine sediment movement	Minor increase in fine sediment movement	Minor increase in fine sediment movement
Benthic algal assemblage composition	Minor increase in proportion of green algae	Minor increase in proportion of green algae	Minor increase in proportion of green algae	Minor increase in proportion of green algae	Minor increase in proportion of green algae	Minor increase in proportion of green algae
Benthic algal density	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase
Bench inundation frequency	Minor decrease	No change	Minor decrease	No change	Minor decrease	No change
DOC concentration	Moderate increase in average and variability, exceeding values in Thredbo River reference reach	Moderate increase in average and variability, exceeding values in Thredbo River reference reach	Moderate increase in average and variability, exceeding values in Thredbo River reference reach	Moderate increase in average and variability, exceeding values in Thredbo River reference reach	Minor increase in average and variability, exceeding values in Thredbo River reference reach	Minor increase in average and variability, exceeding values in Thredbo River reference reach

Environmental variable	Option 2.3.1: Remove weir + matching daily cut in J'byne releases	Option 2.3.2: Remove weir + annual average M'ba flow cut from J'byne releases	Option 2.4.1: All flows to overtop weir + matching daily cut in J'byne releases	Option 2.4.2: All flows to overtop weir + annual average M'ba flow cut from J'byne releases	Option 2.5.1: First 100 ML/day to overtop weir + matching daily cut in J'byne releases	Option 2.5.2: First 100 ML/day to overtop weir + annual average M'ba flow cut from J'byne releases
Other basal resources including nitrogen, phosphorus and silica	Minor increase in average and variability, exceeding values in Thredbo River reference reach	Minor increase in average and variability, exceeding values in Thredbo River reference reach	Minor increase in average and variability, exceeding values in Thredbo River reference reach	Minor increase in average and variability. exceeding values in Thredbo River reference reach	Minor increase in average and variability, exceeding values in Thredbo River reference reach	Minor increase in average and variability, exceeding values in Thredbo River reference reach
In-stream plant assemblage composition	Minor change toward flora adapted to higher nutrient levels	Minor change toward flora adapted to higher nutrient levels	Minor change toward flora adapted to higher nutrient levels	Minor change toward flora adapted to higher nutrient levels	Minor change toward flora adapted to higher nutrient levels	Minor change toward flora adapted to higher nutrient levels
In-stream plant cover	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase
Riparian plant cover	No change	No change	No change	No change	No change	No change
Riparian plant assemblage composition	No change	No change	No change	No change	No change	No change
Thermal regime of river	Moderate cooling	Moderate cooling	Moderate cooling	Moderate cooling	Minor cooling	Minor cooling
Benthic invertebrate assemblage composition	Minor change in proportions of feeding groups	Minor change in proportions of feeding groups	Minor change in proportions of feeding groups	Minor change in proportions of feeding groups	Minor change in proportions of feeding groups	Minor change in proportions of feeding groups
Benthic invertebrate density	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase

Environmental variable	Option 2.3.1: Remove weir + matching daily cut in J'byne releases	Option 2.3.2: Remove weir + annual average M'ba flow cut from J'byne releases	Option 2.4.1: All flows to overtop weir + matching daily cut in J'byne releases	Option 2.4.2: All flows to overtop weir + annual average M'ba flow cut from J'byne releases	Option 2.5.1: First 100 ML/day to overtop weir + matching daily cut in J'byne releases	Option 2.5.2: First 100 ML/day to overtop weir + annual average M'ba flow cut from J'byne releases
Benthic invertebrate total abundance	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase
Fish assemblage composition	No change	No change	No change	No change	No change	No change
Fish passage	No change	No change	No change	No change	No change	No change
Fish total abundance	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase
Platypus feeding	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase	Minor increase
Platypus movement	No change	No change	No change	No change	No change	No change
Water colour	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Minor increase	Minor increase
Water turbidity	Moderate increase	Moderate increase	Moderate increase	Moderate increase	Minor increase	Minor increase
Frog species diversity and abundance	Minor increase	Minor increase	Minor increase	Minor increase	No change	No change

3. More flexible delivery of SRIF

3.1 Do-nothing option

The current situation is outlined in section 1.7.

Options for flexible delivery to achieve better environmental outcomes from the available SRIF are outlined below.

3.2 Flexibility option: Adjust Jindabyne Dam releases daily to be synchronised with concurrent flow in the Thredbo River or another naturally flowing reference river

Currently, daily releases from Jindabyne Dam are set at the beginning of the water year and are based on historical flows in the Thredbo River (see section 1.10). Under this arrangement, large releases can occur in the middle of a dry period when flow in the Snowy River would naturally be low, and small releases can occur in a period of high rainfall when flow in the Snowy River would naturally be high. The flexibility option investigated here would create a more natural flow regime in the Snowy River and align Snowy River flows more closely with flows in the Mowamba River and other western tributaries.

3.2.1 Releasing flows from Jindabyne Dam that are based on the size and timing of flows in the Thredbo River for every day of the year

Hydrologist Paul Simpson investigated options for linking daily Jindabyne releases to flows in the unregulated Thredbo River. He used the modelled SRIF allocations[26] over the period 1986–2020 (the period of full-year Paddys Corner gauge records). The average annual SRIF[26] allocation was just above the average Thredbo River annual flow volume. However, the mismatches in individual years were substantial – the SRIF allocation[26] ranged from 118,000 ML higher than the Thredbo River flow volume for the same year to 140,000 ML below the Thredbo River flow volume for the same year. Over some sequences of years, the difference accumulated to the point where undelivered SRIF[26] allocations totalled 485,000 ML, or conversely SRIF allocations were exceeded by a cumulative 365,000 ML. Paul Simpson concluded such discrepancies would be too large to manage even if SRIF allocations were able to be carried forward from one year to the next.

No attempt was made to use the Mowamba River rather than the Thredbo River as the reference for Jindabyne release targets. Although 5% of the Mowamba River catchment is affected by snow cover (Williams et al., unpublished), it is a poor match for the Snowy River at Jindabyne, which has 43% of its catchment affected by snow cover (Reinfelds et al. 2013a). Snow cover of the catchment of the Thredbo River at Paddys Corner is closer at

[26] Here we refer to SRIF allocations plus Jindabyne BPF of 8,500 ML/year, which together is the total available for release from Jindabyne. For years post 2013 (when full entitlement was recovered) actual SRIF rather than modelled SRIF was used.

63%. Consequently, matching Jindabyne releases to Mowamba River flows would not provide the full seasonal signal of the pre-Scheme Snowy River. However, the Thredbo River and Mowamba River catchments are adjacent, and so matching Jindabyne releases to Thredbo River flows would achieve some commonality in flow timing (discussed below). Hence, allowing Mowamba flows to pass the weir (see options in section 2) would provide a degree of synchrony with pre-Scheme Snowy River flow timing.

3.2.2 Jindabyne Dam releases adjusted to synchronise with Thredbo River flow, but scaled to better match SRIF allocations

Because exact matching of Jindabyne releases with concurrent Thredbo River flows was operationally impractical, an option was investigated that scaled Jindabyne releases upward or downward each day of the year according to Thredbo River flows on the previous day, ensuring that cumulative Jindabyne releases during a year were more closely matched to the SRIF[26] allocation. The scaling method is described in detail in Appendix G, the hydrograph that would result in the Snowy River is in Figure 34, and the resulting flow exceedance curve for the Snowy River is in Figure 35. Further flow statistics are provided in Appendix H.

Several issues may affect the feasibility of this option:

- It was necessary to increase the scaling factor to 300% or reduce it to 30% (i.e. Jindabyne releases were increased to 300% or reduced to 30% of the concurrent Thredbo River discharge) for long periods in several years.
- Even with this level of scaling, the end-of-year imbalances ranged from an under-delivery of SRIF[26] allocations of 7,000 ML to an over-delivery (releases exceeding SRIF[26] allocations) of 25,000 ML. Therefore, an ability to carry a portion of the allocations from one year over to the next year's allocation would be needed for this option[27]. This carryover would ensure that any undelivered allocation would not be forfeited, and would also allow a continency to be carried through to cover delivery volumes that exceed the year's allocations. However, the scaling method outlined at Appendix G was developed only as an initial test of concept, and could probably be refined to reduce annual discrepancies and therefore the amount of carryover required.
- Monthly release totals could not be set in advance. This limitation might affect SHL's ability to manage Lake Jindabyne storage levels in some circumstances.
- The time of year of peak flows could not be known in advance. This limitation might create problems for stakeholders on the river and for the management of Jindabyne Dam for flushing flows (releases of greater than 5,000 ML/day). The SWIOID requires the water manager to notify SHL of the volume and other aspects of the flushing flow prior to the beginning of the water year. The SWIOID also states that SHL is required to deliver flushing flows only in spring. However, nothing precludes exceptions to the matching process such as having peak flows capped and having the size and date of the flushing flow fixed at the beginning of the water year.

[27] Alternatively, it would require deviations of SRIF delivery from allocations to be carried over between years.

Given the constraints on releases above 5,000 ML/day, the Panel has assessed the effects of this option only for flows up to 5,000 ML/day. The timing and size of flows above 5,000 ML/day would have to be set at the beginning of the year.

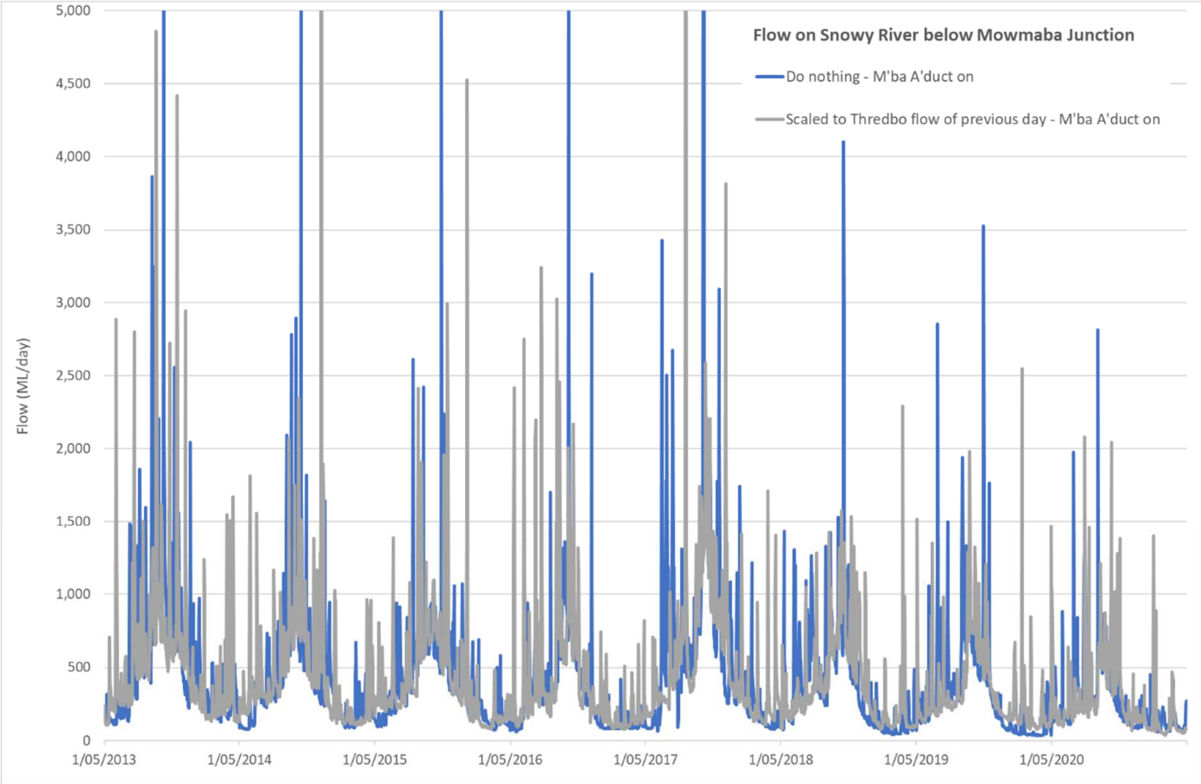

Figure 34: Flow in the Snowy River from 2013–2020 under the current regime (do-nothing option) and under an option that would change the Jindabyne releases daily according to the Thredbo River flow of the previous day (scaled to better align with the available allocation and done for every day of the year)

Note that this graph does not show flow peaks above 5,000 ML/day. In practice, flows above 5,000 ML/day would need to be planned and their timing and size locked in at the beginning of the water year. Therefore, this option does not propose for the timing of flows greater than 5,000 ML/day to be altered as shown in this graph.

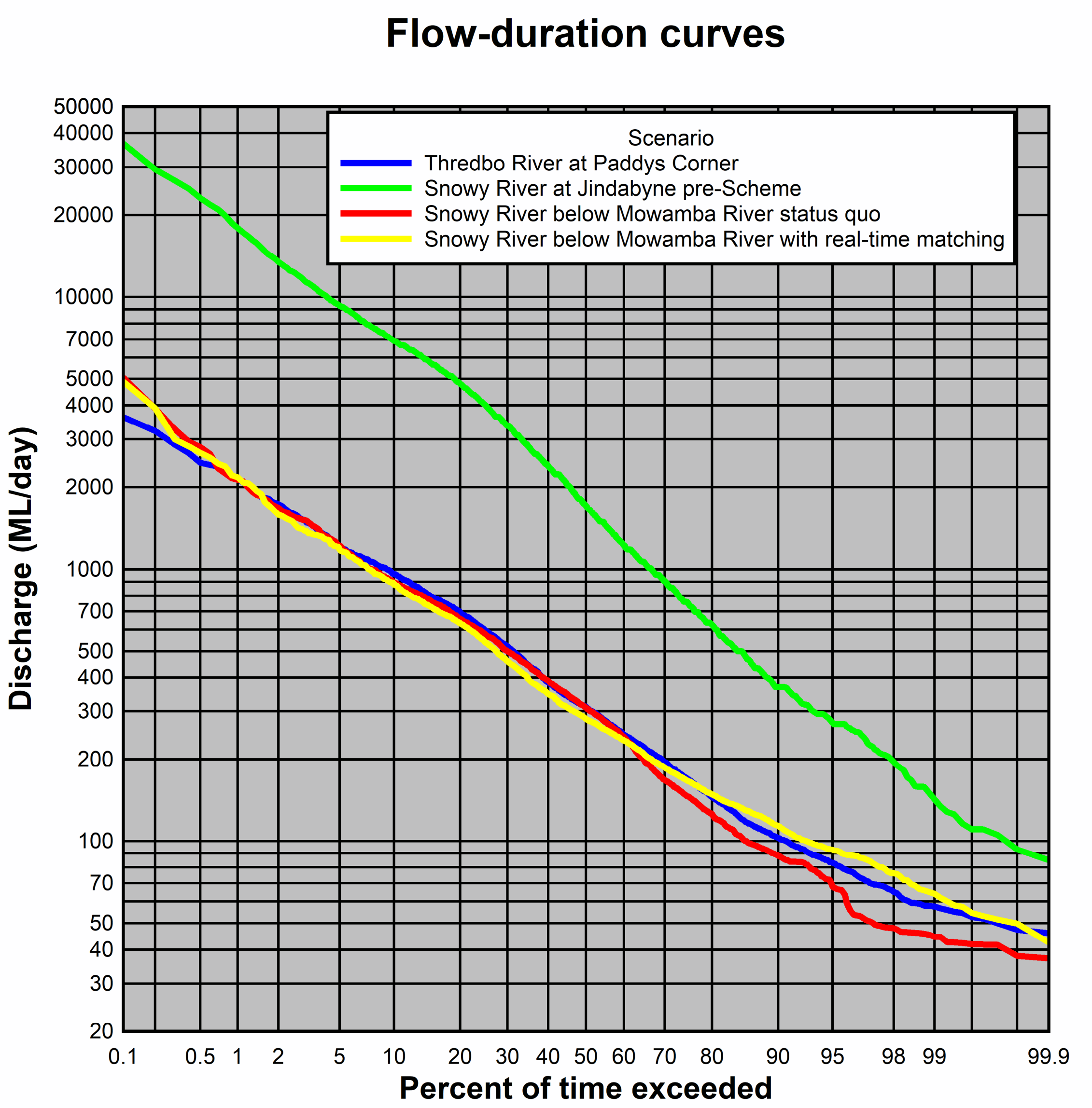

Figure 35: Flow exceedance curves for the Snowy River at Jindabyne (pre-Snowy Scheme), the Thredbo River at Paddys Corner, the Snowy River downstream of the Mowamba River junction under the current delivery mechanism (status quo), and the Snowy River downstream of the Mowamba River junction under the option that would change the Jindabyne releases daily according to Thredbo flow of the previous day (scaled to better align with the available allocation and done for every day of the year)

Data from the water years commencing 2013–2020 were used for all datasets except the Snowy River at Jindabyne (pre-Snowy Scheme).

3.2.3 Simplified option: Change only the timing of the release of the monthly peak flow from Jindabyne Dam (using a Thredbo River high-flow trigger)

Noting the potential problems described above, the Panel also considered a simplified option. This option would maintain the current daily flow planning that occurs annually (see section 1.10). However, it would allow the timing of the release of the peak flow of the month to be triggered by a high flow in a naturally unregulated river such as the Thredbo River or the Mowamba River upstream of Mowamba Weir. For illustration, the Panel again used the Thredbo River at Paddys Corner. Under this option, if a high flow was planned for the month, it would not be released until a rainfall event occurred and flow in the Thredbo River exceeded a threshold set for that month. An above-threshold flow in the Thredbo River would trigger the release of the high flow from Jindabyne Dam on the following day. This release would apply only to flows up to 5,000 ML/day (because of the limitations on releasing flows above 5,000 ML/day, which require the dam gates to be used). A default date could be set for the release of the high flow of the month (e.g. 25th of the month) if the flow threshold in the Thredbo River was not reached by that date.

How release peaks timed to coincide with high Thredbo River flows would align with peak flows in downstream tributaries

Paul Simpson compared the timing of high flows in the Thredbo River at the Paddys Corner gauge and in the Mowamba River (Mowamba Aqueduct flow plus flow at the Pats Patch gauge). He found that synchronisation was strongest when the Thredbo River flow was lagged by one day (i.e. Mowamba River flow was compared with Thredbo River flow on the previous day). This lag is logical because a flow peak in the Thredbo River at Paddys Corner would have taken time to travel ~20 km to the Mowamba–Snowy junction before the construction of Jindabyne Dam.

The synchronisation between the Thredbo River and Mowamba River is shown in Table 12 for moderately high flows (around the highest 90th to 95th percentile of flows) and in Table 13 for higher flows.

Table 12: Synchronisation of high-flow days in the Thredbo River at Paddys Corner with high-flow days of >250 ML/day in the Mowamba River (Pats Patch and Mowamba Aqueduct combined), >500 ML/day in the Delegate River at Quidong, and >250 ML/day in the Pinch River at Barry Way for flows from 2001–2020

River and high-flow threshold (ML/day)	Mowamba >250	Delegate >500	Pinch >250
Number of days exceeding flow threshold	358	694	682
Number of these high flows that synchronise with **583** Thredbo high-flow days of **>1,000** ML/day	222 (1-day lag)	108 (2-day lag)	329 (1-day lag) 249 (3-day lag)

Synchronisation between the Thredbo River and the larger Delegate River was not as strong, possibly because the latter's more easterly catchment is more influenced by weather systems from the east (see Table 12 and Table 13). However, there was still a weak synchronisation with a 2-day lag applied. The Pinch River which, along with the Jacobs River, has its catchment in the mountains neighbouring the Mowamba River catchment, had a similar synchronisation to that of the Mowamba River with a one-day lag applied (see Table 12 and Table 13).

Table 13: Synchronisation of high-flow days at Thredbo River at Paddys Corner with high-flow days of >500 ML/day at Mowamba River (Pats Patch and Mowamba Aqueduct combined), >1,000 ML/day at Delegate River at Quidong, and >500 ML/day at Pinch River at Barry Way for flows from 2001–2020

River and high-flow threshold (ML/day)	Mowamba >500	Delegate >1,000	Pinch >500
Number of days exceeding flow threshold	86	233	37
Number of these high flows that synchronise with **583** Thredbo high-flow days of **>1,000** ML/day	70 (1-day lag)	31 (2-day lag)	33 (1-day lag) 10 (3-day lag)
Number of these high flows that synchronise with **90** Thredbo high-flow days of **>2,000** ML/day	36 (1-day lag)	10 (2-day lag)	24 (1-day lag) 3 (3-day lag)
Number of these high flows that synchronise with **31** Thredbo high-flow days of **>3,000** ML/day	18 (1-day lag)	3 (2-day lag)	18 (1-day lag) 3 (3-day lag)
Number of these high flows that synchronise with **11** Thredbo high-flow days of **>4,000** ML/day	9 (1-day lag)	0 (2-day lag)	10 (1-day lag) 2 (3-day lag)

The Panel also considered how the release of water matching a high flow in the Thredbo River could be timed to synchronise with tributary flows. The one-day lag between Thredbo River and Mowamba River peaks could be accommodated by timing Jindabyne releases to be one day after the Thredbo River peak occurred. This delay would be practical operationally because it would allow the dam operator some lead time between the Thredbo River peak occurring and the release from Jindabyne Dam being made.

A flow peak's travel time from Jindabyne Dam to the Delegate River confluence (near Burnt Hut) is likely to be in the range of about 24 hours[28] to 29–33 hours (NSW DPIE 2020). Therefore, a large release from Jindabyne Dam one day after a peak flow occurred in the Thredbo River would reach the Snowy–Delegate junction about 2 days after the peak occurred in the Thredbo River. This 2-day lag would be appropriate because it is the lag that produces the strongest synchronisation between the Thredbo River and the Delegate River, albeit still rather weak.

The travel time from Jindabyne Dam to the Pinch River is likely to be around 2 days (NSW DPIE 2020). Therefore, a large release from Jindabyne Dam one day after a peak occurred in the Thredbo River would reach the Snowy–Pinch junction about 3 days after the peak occurred in the Thredbo River. Consequently, the release would reach the Snowy–Pinch junction (and most likely the nearby Snowy–Jacobs junction) too late for maximum synchrony. It could, however, extend the duration of the high-flow period in the Snowy River downstream of the Pinch River junction.

[28] From analysis of hourly flow data from the peak SRIF releases of the year from Jindabyne from 2014, 2015, 2019 and 2020. See Figure 37 for example.

Effects on environmental variables

The environmental effects, relative to the current do-nothing option, of option 3.2.2 (aligning Jindabyne Dam releases on a daily basis to the scaled Thredbo River flow of the previous day) and of option 3.2.3 (triggering the high release of the month from Jindabyne Dam the day after a high Thredbo River flow) are summarised in Table 14.

Table 14: Likely effects, compared to the do-nothing option, on environmental variables of option 3.2.1 (aligning Jindabyne Dam releases on a daily basis to the scaled Thredbo River flow of the previous day) and of option 3.2.2 (triggering the high release of the month from Jindabyne Dam on the day after a high Thredbo River flow)

Variables relating to the Snowy River estuary are not included because any effect is expected to be only marginal by the time the flows have reached the estuary. The effects on plants, invertebrates, fish, platypus and frogs are covered together at the end of the table.

Environmental variable	Effect of option 3.2.2: daily change in Jindabyne releases based on the Thredbo River flow of the previous day (scaled and done for every day of the year)	Effect of option 3.2.3: change in timing of release of the planned high flow of the month from Jindabyne Dam – timing triggered by a high flow occurring on previous day in the Thredbo River
Daily discharge variability	Minor increase in daily variability, though still lower than variability of the pre-Scheme Snowy River	Unchanged upstream of the Mowamba River junction, with a minor increase downstream once per month when peak flow coincides with tributary flow events
Discharge seasonality	Major decrease in the ratio of spring flows to autumn flows, bringing it closer to that of the pre-Scheme Snowy River. Major decrease in the winter to summer ratio, reducing it below that of the pre-scheme Snowy River	Unchanged
High-flow magnitude	The size of planned flows greater than 5,000 ML/day would not change. Flow peaks downstream of the Mowamba River junction would increase because of greater synchrony with downstream tributary inflows	
High-flow frequency	Would not alter appreciably at the Mowamba River junction (see flow duration curve in Figure 35). However, further downstream there would be a slight increase because some releases would be made into higher peaks when they aligned with tributary peaks	Unchanged at the Mowamba River junction. Very slight increase further downstream because some releases would be made into higher peaks when they aligned with tributary peaks
High-flow duration	Unchanged to the Mowamba River junction, but increased downstream of tributaries such as the Jacobs and Pinch rivers	
Rate of rise and fall of high flow	The average rate of rise downstream of the Mowamba River junction would increase to be greater than that of the pre-Scheme Snowy River but less than that of the Thredbo River. Further downstream it would decrease because inputs from tributaries such as the Pinch and Jacobs rivers would often provide an initial rise prior to the Jindabyne peak arriving.	Unchanged at Jindabyne, but potentially closer to pre-Scheme levels (i.e. less rapid) further downstream because inputs from tributaries such as the Pinch and Jacobs rivers would provide an initial rise prior to the Jindabyne peak arriving

Environmental variable	Effect of option 3.2.2: daily change in Jindabyne releases based on the Thredbo River flow of the previous day (scaled and done for every day of the year)	Effect of option 3.2.3: change in timing of release of the planned high flow of the month from Jindabyne Dam – timing triggered by a high flow occurring on previous day in the Thredbo River
	The rate of fall would not change downstream of the Mowamba River junction, but would probably decrease further downstream because Jindabyne releases would extend the duration of higher flows produced by tributary inputs	
High-flow sequencing	No change at the Mowamba River junction. However, there would be slightly shorter intervals between high flows expected further downstream because some releases would be made into higher peaks when they aligned with tributary peaks	Unchanged at Mowamba River junction. Very slight decrease in intervals between high flows downstream because some releases would be made into higher peaks when they aligned with tributary peaks
Channel morphology measures	The increase in peak flows could slightly increase channel width and depth in reach S3	
Floodplain aggradation	Slight increase in deposition rates on benches and inset floodplains. Benches would build higher	
Substrate character	Substrates would coarsen slightly because of larger peak flows downstream of the Mowamba River junction, flushing fine sediment from riffles	
Sediment movement	Sediment from tributaries would move further downstream for redistribution onto benches because of high Jindabyne releases coinciding with tributary flow events (especially for the Delegate River and for the Mowamba River in the case of weir removal). Coarse sediment transport through pools and riffles would increase slightly	
Bench inundation frequency	Would increase downstream of the Mowamba River junction because of high Jindabyne releases coinciding with tributary flow events	
DOC concentration	Higher DOC concentrations contributed by high tributary inflows would be more diluted by releases from Jindabyne. However, lower DOC concentrations contributed by low tributary inflows would be less diluted. Greater flow peaks would also be likely to mobilise more DOC from benches in the Snowy River	
Concentration of other basal resources including nitrogen, phosphorus and silica	As for DOC	
Thermal regime of river	Higher Jindabyne Dam releases would be more likely to coincide with high tributary flows, which would act to moderate the deviation from expected natural temperatures during these events downstream of the tributary confluences. Cooling effects of tributary inflows would decrease when releases from Jindabyne are high but increase when Jindabyne releases are low	
Fish passage	Expected to increase because natural triggers for movement from rainfall events and tributary inflows would more often coincide with high-flow releases from Jindabyne, and flow peaks in the Snowy River would be higher, providing more submergence of natural barriers	

Environmental variable	Effect of option 3.2.2: daily change in Jindabyne releases based on the Thredbo River flow of the previous day (scaled and done for every day of the year)	Effect of option 3.2.3: change in timing of release of the planned high flow of the month from Jindabyne Dam – timing triggered by a high flow occurring on previous day in the Thredbo River
Platypus movement	Might also increase as for fish passage	
Water colour	Colour (e.g. tannins) in high flows from tributaries would be diluted by clearer water from Jindabyne. However, higher peak flows would also mobilise DOC from Snowy River benches, increasing colour	
Water turbidity	Turbidity of high flows from tributaries would be diluted by clearer water from Lake Jindabyne, and so a combined peak would be more turbid than a Jindabyne release on its own, but less turbid than a tributary-induced peak on its own. Therefore, there would be an overall reduction in variability of turbidity. However, higher peak flows would also entrain more sediment from the Snowy River channel, increasing turbidity	
In-stream floral and faunal assemblage composition and abundance (e.g. algae, plants, invertebrates, fish, frogs and platypus)	Increased synchrony of high flows would produce more scouring, reducing the overall density of sessile species and favouring species requiring or tolerating fast current. Conversely, increased synchrony of low flows would favour species adapted to slow current. The combined effect of these opposing forces is difficult to predict, but the flora and fauna would probably become more similar to the flora and fauna that occurred prior to the Snowy Mountains Scheme. Greater synchrony between flow and rainfall would be likely to benefit those species that rely on rainfall cues as breeding triggers	

3.3 Flexibility option: Allow changes in flows within the year to respond to environmental contingencies

NSW DPE defined objectives for specific ecosystem components, based on Williams (2016) and Hale (2020) (section 1.9). Option 3.3 allows for short-term flexibility in releases to achieve such objectives, or allows for them to be achieved more quickly. Examples are outlined below, noting the key ecosystem variables likely to be affected. For each of these examples, there would be effects on other variables that could militate either for or against the achievement of other objectives (i.e. serendipitous or perverse outcomes). Accordingly, environmental water managers would need to assess potential risks or additional benefits according to the specific circumstances at the time of any proposed event. Note that any increased release would need to be accounted for from the remaining monthly or yearly flow allocation.

3.3.1 Release high flow to coincide with or prolong downstream flow peaks caused by tributary inflows

If a high inflow from a tributary or tributaries is forecast, a release from Jindabyne Dam could be made to coincide with such an event, increasing or prolonging the peak flow in the Snowy River. However, there are risks involved in releasing high flows based only on forecast tributary flow, because the tributary flow might exceed the forecast and the resultant total flow might reach levels that cause unacceptable effects on third parties downstream. To reduce this risk, river operators and managers would probably usually release only after the peak flow size of the tributaries was known. However, it can take several days for Jindabyne releases to reach tributary confluences other than that of the Mowamba River. For example, travel time is about 1–1.5 days to the junction of the Delegate River and 2 days to the junction of the Pinch and Jacobs rivers (NSW DPIE 2020). Consequently, Jindabyne releases made after the peak tributary flow is known are likely to arrive one or several days after the tributary-induced peak. This lag would extend the duration of the tributary-induced flow peak, which would have the following potential effects depending on the combined flow:

- Higher or prolonged flow peaks would accelerate the formation of a more defined river channel (NSW DPE objective 2) by enhancing channel-forming processes (see Table 2 above) (e.g. acceleration of movement of sediment through pools and riffles, widening of the channel, deposition on benches/low floodplains). These impacts could also be extended further downstream from the tributary junctions than without synchronisation.
- Higher or more prolonged flows in the Snowy River estuary could help to keep the estuary entrance open (NSW DPE objective 11). Water Technology (2010, cited in Hale (2020)) estimated that a flow of ~17,300 ML/day at Jarrahmond was required to scour out the estuary entrance. Smaller flows could contribute to flushing salt wedges from the lower Snowy River channel. Water Technology (2010, cited in Hale (2020)) estimated that a flow of greater than 2,750 ML/day at Jarrahmond, sustained for several days was required for this purpose.
- Higher or more prolonged flows in the river would produce greater inundation of benches, increasing the mobilisation of carbon and nutrients from those benches (NSW DPE objective 4).
- Higher or prolonged flows in the river might increase fish passage past natural barriers (NSW DPE objective 9).
- Jindabyne releases coinciding more closely with tributary flow peaks could better align releases with natural cues for fish movement (NSW DPE objective 9).

3.3.2 Bringing forward a high-flow release directly after a tributary event that has deposited significant amounts of sediment or ash in the river channel

Following a wildfire, large amounts of ash and sediment could be transported into the Snowy River by a tributary flow event. Such materials can deplete dissolved oxygen and their deposition can smother cobbles and other in-stream substrata. Under current arrangements, the next high-flow release from Jindabyne might not be planned until several months after the post-fire tributary flow, and releases cannot be brought forward to flush the ash and sediment. Allowing high-flow releases to be brought forward could allow sediment and ash to be flushed in a timely manner (NSW DPE objective 3) (see a full discussion of this option in Snowy Scientific Committee (2008)).

Even without wildfire, some tributaries with high levels of catchment erosion might contribute large amounts of sediment to the Snowy River. A similar management strategy could be employed for such tributary events. Redistributing this sediment downstream could accelerate the development of a more defined channel (NSW DPE objective 2).

3.3.3 Responding to a water quality event such as an algal bloom or pulse of pollutant

Water could be released from Jindabyne Dam to ameliorate water quality problems such as algal or cyanobacterial blooms or pollution events (NSW DPE objective 12). The volume and timing of releases would depend on the problem and the quantity of water needed to ameliorate it. Flushing flows might be needed for several days to disperse an algal bloom developing downstream of Jindabyne Dam under low-flow conditions. Although algal and cyanobacterial blooms are not currently a problem, the situation might change with climate change increasing temperatures and possibly decreasing flows. Other problems such as pollutant spills or localised low-oxygen events could be managed as well. The flow required to ameliorate such events would depend on their location and extent, and potential attenuation of releases during downstream transmission would warrant consideration.

3.3.4 Responding to a breeding event or other life-cycle phenomenon

A water delivery could also be released from Jindabyne Dam to support a life-cycle event such as fish spawning (NSW DPE objectives 8 and 9); for example, where known flow triggers have been reached but reproductive failure could occur unless high flow is maintained for sufficient duration. Thresholds for and timing of such events are listed in Appendix B.

3.3.5 Increasing baseflow releases when the estuary mouth is in danger of closing

Water Technology (2010, cited in Hale (2020)) noted that the mouth of the estuary may close when Snowy River flows fall below 260 ML/day at Jarrahmond for 30 days or longer (see Appendix A). If tributary flows to the Snowy River downstream of Jindabyne Dam are low and planned Jindabyne releases are insufficient, flows at Jarrahmond can fall below this level. Adjusting Jindabyne releases to maintain higher baseflows at such times might prevent closure (NSW DPE objective 11).

3.3.6 Better managing carryover (if available)

If intensifying dry conditions were forecast in the coming year and the SRIF allocation for that year was expected to be low, and carryover of the unused portion of a year’s allocation to the following year was possible, releases could be scaled back to reserve more allocation for the dry year. (Note that the option of carryover in general is covered below in section 3.5).

3.3.7 Allowing flushing flows to be delivered when Jindabyne Dam levels have reached the release gates

The SWIOID requires SHL to release only one flushing flow (a flow greater than 5,000 ML/day) from Jindabyne Dam per year, with no obligation to deliver a flushing flow if the SRIF allocation of the year is lower than 100,000 ML. The release of flushing flows requires reservoir levels to be raised to the dam’s release gates, which increases the likelihood of uncontrolled dam spills if inflows to the dam are high. If an uncontrolled spill does occur, the SRIF allocations in future years can be debited by the spill volume. To avoid this risk, environmental water managers may avoid planning flushing flows.

When dam levels reach the gates because of unexpectedly high dam inflows, an opportunity to release a flushing flow arises, even in years where no flushing flow was planned. An unscheduled release could also be made in years where a flushing flow has been planned but not yet delivered and either:

- the planned flushing flow could be brought forward to lower dam levels, reducing the risk of an uncontrolled spill, or
- an extra flushing flow could be delivered to provide additional channel-forming and other environmental effects.

In many cases, SHL will seek to undertake pre-releases to avoid uncontrolled spills, and allowing these releases to be shaped, including by increasing the peak above 5,000 ML/day, could increase the effects of the flow, particularly in terms of channel-forming processes.

However, bringing forward flows within the year to implement any of the above options might necessitate reducing releases in the period after the higher flow. If carryover was available, it would enable some allocation to be set aside for such eventualities.

3.4 Flexibility option: Allow intra-day variability (changing release rates so flows are not held constant for 24 hours), particularly more 8-hour, or other sub-24-hour peaks

Currently SHL delivers most flows with a constant 24-hour flow rate. It does, however, deliver up to 5 events per year that have 8-hour peaks. This flexibility option involves varying more flows within a 24-hour period.

Natural flow events do not normally remain constant for 24 hours; for example, Figure 36 shows the flow rate each hour over 24-hours of a natural event in the Thredbo River in 1998 (blue line). Under current arrangements, a release of the same total volume from Jindabyne Dam over the same period would be at a constant rate (red line). An alternative would be to deliver a shorter flow peak more reflective of the natural event. Figure 36 shows how the release pattern might be altered to allow an 8-hour peak flow and a lower release rate for the remainder of the 24-hour period (green line), thereby better approximating the hydrograph of the natural event. The total volume released over the 24-hour period would not change. Thus, shorter flow peaks would be higher than peaks spread over 24 hours for the same total volume of release. Immediately downstream of the dam, these peaks reflect the dam release pattern as shown in Figure 37. However, as the flow peak moves downstream, it more closely resembles a natural flow event, having similar rise and fall characteristics (Figure 38).

Flows could also be changed at other sub-24-hour intervals (not just every 8 hours); for example, flows could be varied every 6 hours within a day or every 4 hours. These shorter intervals would provide the opportunity for even higher peaks and a hydrograph that more closely resembles a natural flow event.

Changes in releases made at any interval (including the current 24-hour interval) should, however, avoid unnaturally rapid rates of fall, in order to prevent the stranding of fish and other aquatic organisms.

This proposal applies only to flows up to 5,000 ML/day. Only one flow per year is allowed above 5,000 ML/day and this flow is already usually released as an 8-hour flow.

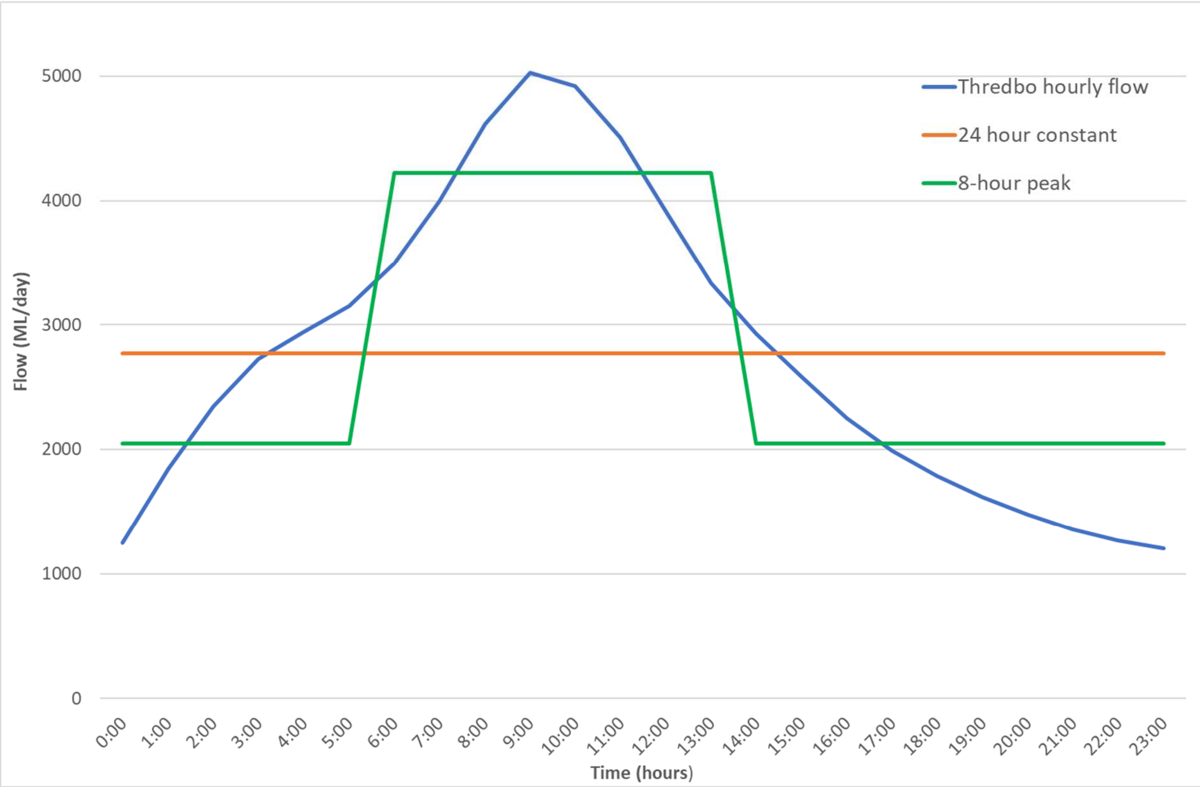

Figure 36: Potential variation in flow rate over 24 hours for a release of 2,772 ML from Jindabyne Dam

The blue line shows flow variation over 24 hours for an event of the same total volume in the Thredbo River in June 1998. The red line shows the flow rate for a constant 24-hour release of the same volume. The green line shows variation in flow rate if the same volume was released with an 8-hour peak and a lower release rate for the remaining 16 hours.

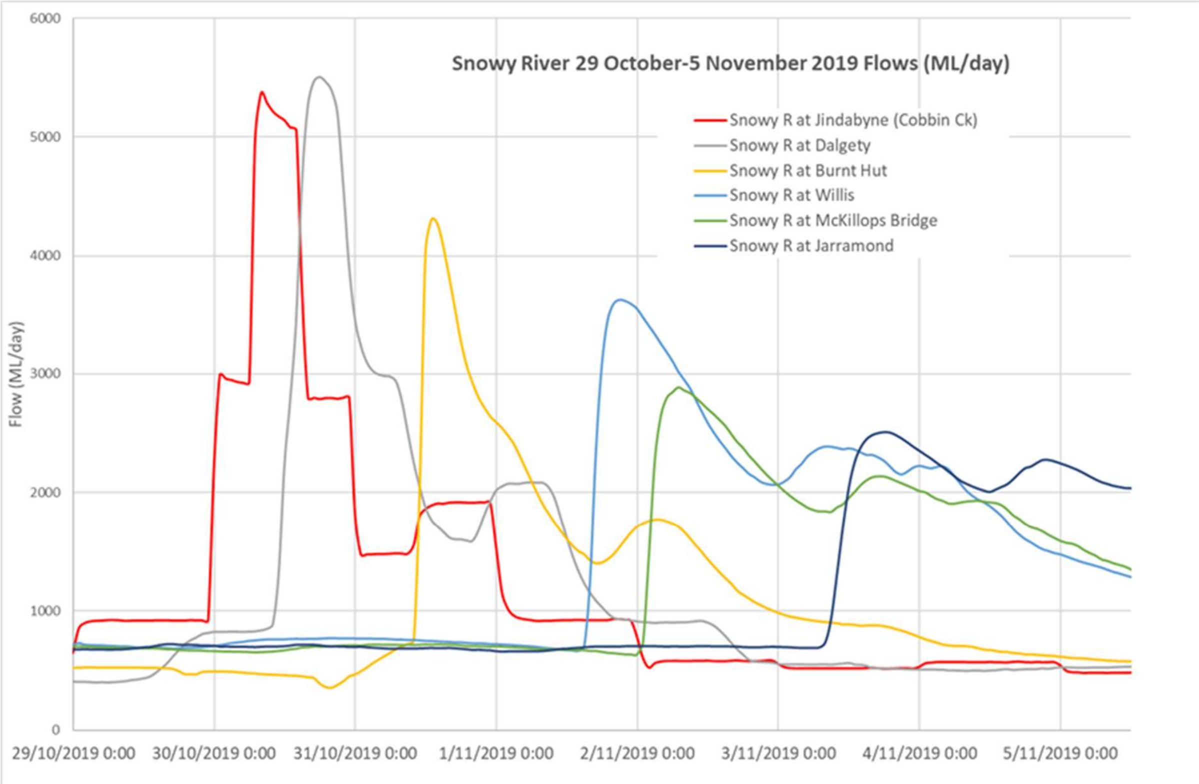

Figure 37: Hydrographs for a Jindabyne Dam release, showing attenuation with downstream distance and changes in the pattern of rise and fall

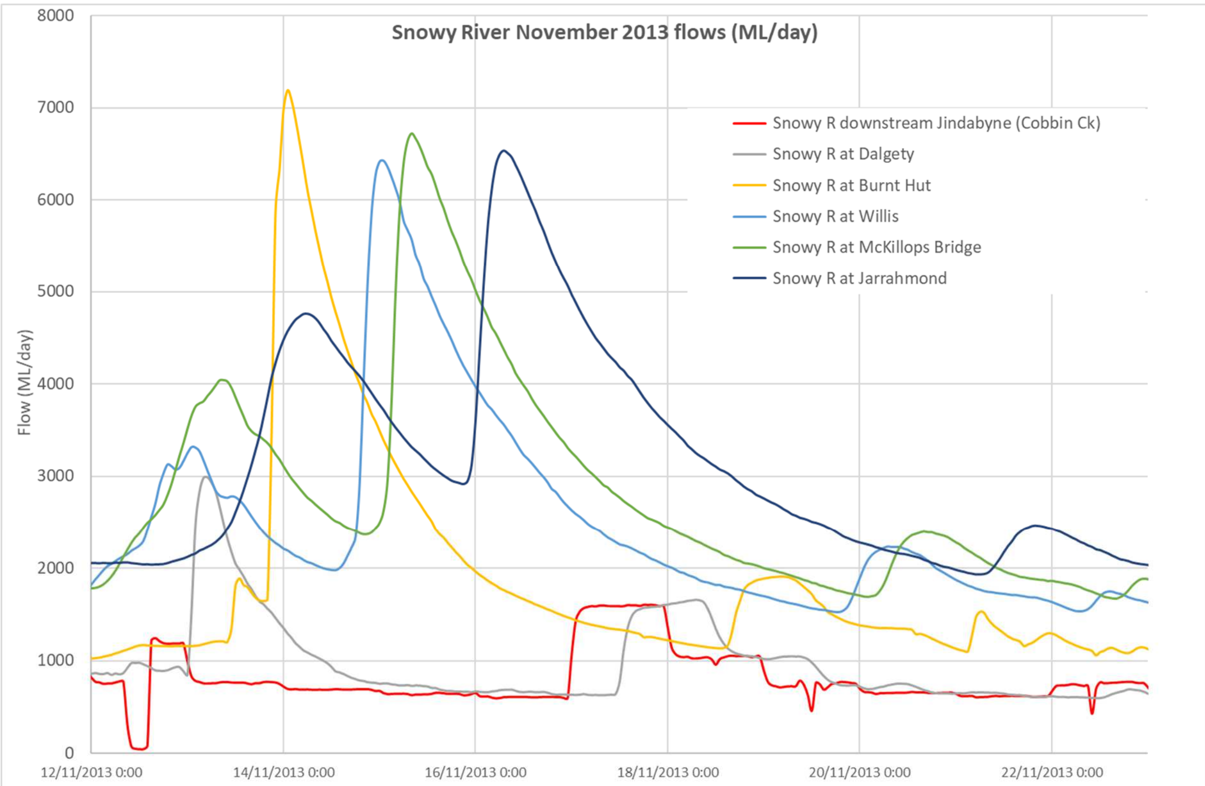

Figure 38: Hydrographs for a natural tributary flow event along the Snowy River for comparison with Figure 37

The potential effects of more peaks of less than 24 hours are:

- **Hydrology:** A major increase would occur in intra-day variability and in high-flow magnitudes (but only for a few days per year). The effect would decrease downstream because the flow rise would attenuate, but there would likely still be effects to Burnt Hut and potentially beyond (see Figure 37).
- **Geomorphic processes:** Higher, shorter flow peaks would do more geomorphic work than the same total flow spread over a longer duration (Rose 2022) (Appendix E). For example, flows in the Snowy River from 1,700–4,700 ML/day build banks and flows from 2,000–5,000 ML/day maintain channel width. Increased sediment would be provided onto inset floodplains and benches, increasing their depth. The coarse bed in pools and riffles would be maintained. Increased gravel movement through pools and across riffles would be expected. The effects of the higher flow peaks on geomorphic processes would be greatest in reaches S1, S2 and S3, diminishing further downstream as the channel enlarges.
- **Nutrients:** Higher peak flows with greater river height would result in more wetting of benches, leading to greater mobilisation of DOC and other nutrients such as nitrogen and phosphorus, better reflecting natural mobilisation prior to the construction of Jindabyne Dam.
- **Plants and animals:** A higher peak flow with greater flow velocity would result in more scouring and further change the community to one more adapted to frequent disturbances, with a reduction in benthic algal density, more reflecting the natural biota prior to the construction of Jindabyne Dam.

A minor increase in passage over small natural barriers during flow peaks would also be expected.

3.5 Flexibility option: Carryover of SRIF allocations between years

Allowing the carryover of unused portions of SRIF allocations from one year to the next would allow:

- a reserve to be carried over for extreme dry years. This reserve would better allow sufficient baseflows and moderate peaks to be provided
- the banking of allocation for use in longer-lasting high flows for greater channel-forming effect
- a reserve to respond to environmental contingencies (e.g. those outlined in section 3.3)
- SRIF allocations of greater than 212 GL in a year to be delivered. SHL does not currently deliver more than 212 GL of the SRIF in any one year
- the removal of an impediment for implementing other flexibility options, including:
  - passing flows from the Mowamba River with daily deduction from Jindabyne releases (see options in section 2.3.1, 2.4.1 and 2.5.1). These options would require the carryover of allocation between years, otherwise higher daily flow reductions would be required to ensure SRIF allocations were not exceeded. Additionally, without carryover, an unreleased SRIF allocation at the end of the year would be forfeited

- allowing real-time daily changes in Jindabyne releases based on the Thredbo River flow of the previous day (scaled) for every day of the year (section 3.2). Even with scaling, each year would have an under- or over-delivery of SRIF allocation that would need to be managed by carryover.

An alternative to carrying over unused portions of SRIF allocations from one year to the next would be to allow all deviations of SRIF delivery from allocations to be carried over between years (i.e. allow the carryover of both surpluses and deficits).

4. Conclusions and recommendations

4.1 Options for providing environmental flows to the Snowy River via the Mowamba River

Conclusions on the effects of the different options on the Mowamba River and on the Snowy River are provided below, along with the Panel's recommendations in light of the current environmental objectives of SRIF.

4.1.1 Effects on the Mowamba River

All change options would bring the lower Mowamba River closer to its pre-weir condition and increase habitat availability for those plant and animal species that are adapted to faster flows.

Removing the weir (option 2.3 (encompassing 2.3.1 and 2.3.2)) would cause the greatest change.

Hydrology would revert to pre-weir conditions, with near-natural variability and peak-flow size and frequency.

Geomorphic processes of flushing and scouring would be restored to their pre-weir levels, widening the wetted channel in the flatter reach M1, restoring it to a series of riffles and pools, and deepening pools in the steeper gorge (reach M2). The built-up sediment that would be eroded from the weir pool and from erosion of the channel would likely move quickly downstream. Suspended sediment, and bedloads would be restored through the former weir pool and into the lower Mowamba River.

Nutrient concentrations would not change from their present level because the source of water would remain the same (the upper Mowamba River).

Plants and animals that require or tolerate fast flow, including some macroinvertebrates, fish, frogs and platypus, would be provided with far more habitat because median flows would increase from 1.3 ML/day to 51 ML/day, wetting more of the channel, creating backwaters and small connected ponds. The restoration of natural flow variability and flushing would return the river's ecological community (including primary producers such as benthic algae) to one that is more tolerant of flow disturbance (hence more natural). However, increased scouring would also reduce the population density of many species adapted to the current modified low-flow conditions.

The ability of organisms to disperse would also be increased. In the current low-flow regime, platypus may be exposed to fox predation when moving between pools, limiting metapopulation dynamics and reducing long-term population viability. Returning flows would help to overcome this constraint. Passage for fish would be fully restored to pre-weir levels, although a natural rock barrier (the Cascades) may still impede passage to some degree. Increased passage may induce upstream movement of native eels, which NSW DPI–Fisheries records (2022) indicate are no longer found upstream of the weir though they are the dominant large-bodied fish species caught downstream.

Retaining the weir but allowing all flows to overtop it (option 2.4 (encompassing 2.4.1 and 2.4.2)) would induce similar changes to those resulting from removing the weir (option 2.3). The main difference would be the persistence of the dispersal barrier that the weir creates and the absence of bedload passing through the weir. While the weir would still prevent upstream passage of fish such as introduced brown and rainbow trout and native Australian bass (if they are stocked), such passage might also be constrained by a natural barrier to fish passage downstream of the weir (the Cascades). Platypus and native eels could probably detour around the weir, but it would still impede them. On the balance of information available, the Panel feel that while the removal of the weir would enable some additional passage of animals and bedload, it is the restoration of flow that would cause the biggest changes to the condition of the lower Mowamba River, bringing it closer to its pre-weir condition.

A fishway could be constructed if the weir remained. However, a fishway would not allow bedload to pass the weir, which would be important for channel-building processes. A fishway would also be less effective for movement of fish and other aquatic animals than having no barrier at all.

Retaining the weir but allowing all flows up to 100 ML/day to overtop it (option 2.5 (encompassing 2.5.1 and 2.5.2))

This option would still induce many of the changes outlined for the above options, including providing more wetted channel (median flows would still increase from 1.3 ML/day to 51 ML/day). However, some effects would be reduced because flows above 100 ML/day would be truncated, so average flows would only increase from 10 ML/day to 63 ML/day (compared to an average of 87 ML/day if all flows were passed downstream of the weir)[29].

Hydrology: The upstream flow regime would be truncated downstream to exclude events from 100–500 ML/day, and flows greater than this value would still have 400 ML/day diverted. The effect of this diversion would be greatest in dry periods when there could be years between events greater than 100 ML/day (see Figure 32).

Geomorphic processes: The restriction in flow would mean that channel morphology would only partly be restored, with the return of pool and riffle sequences in reach M1 and the deepening of pools in reach M2 occurring to a much-reduced extent. No bedload would pass through the weir.

Plants and animals: The shift to more flow-adapted communities would be somewhat reduced. The opportunities for fish and other organisms to pass natural barriers would also be more limited.

4.1.2 Effects on the Snowy River

The effects of the 6 options on the Snowy River are generally much smaller and less differentiated than their effects on the lower Mowamba River.

Removing the weir with matching daily reduction in Jindabyne releases (option 2.3.1)

Hydrology would change slightly, principally via a minor reduction in the ratio of average spring flow to average autumn flow, bringing the ratio closer to that of the Thredbo River reference reach. A minor decrease in the magnitude, duration and frequency of high flows would also occur.

[29] Based on calculations from observed data at Pats Patch and Mowamba Aqueduct gauges from 2001–2020.

Geomorphic processes: There would be a short-lived mobilisation of sediment as the Mowamba River channel erodes, and as sediment stored in the weir pool is flushed out. In the long term, the most important geomorphic effect would be the contribution of increased bedload to the Snowy River from the Mowamba River (suspended sediment supply would also be increased because it would not be diverted to Lake Jindabyne). The volume of new bedload would be substantial compared to the bedload passing from upstream of the Mowamba River junction, but small relative to the load contributed from tributaries downstream of Dalgety. Under the regulated flows from Jindabyne Dam, the bedload would move slowly through the long pools in reach S2 and have a modest impact on the morphology of the Snowy River. Deposition on benches would increase slightly because of the additional fine sediment load.

Nutrient concentrations (e.g. DOC, TN and TP) would increase to a moderate extent because concentrations of these constituents are higher in the Mowamba River than in Lake Jindabyne, and because the Mowamba River would make a greater volumetric contribution to the Snowy River. As a result, nutrient concentrations would generally substantially exceed those in the Thredbo River reference reach.

Plants and animals would generally increase somewhat in overall abundance and diversity because increased nutrient levels would promote greater growth of benthic algae and plants, which would increase the growth and reproduction of animals such as invertebrates, fish, frogs and platypus via the food web. Benthic algal growth would likely exceed that in the Thredbo River reference reach.

Removing the weir with annual average Mowamba flow deducted from Jindabyne releases (option 2.3.2)

Hydrology would change slightly, principally via a minor reduction in the ratio of average spring flow to average autumn flow. Flows below 2,000 ML/day would be reduced, but those above 2,000 ML/day would not be altered, and additional flows from the Mowamba River would increase the peak flow when flows coincided (up to 500 ML/day of additional flow).

Geomorphic processes: As for option 2.3.1.

Nutrient concentrations: As for option 2.3.1.

Plants and animals: As for option 2.3.1.

Retaining the weir but allowing all flows to overtop it with matching daily reduction in Jindabyne releases (option 2.4.1)

Hydrology: As for removing the weir (option 2.3.1).

Geomorphic processes: As for removing the weir (option 2.3.1), except that there would be no bedload movement through the weir pool, and only minor geomorphic changes.

Nutrient concentrations: As for removing the weir (option 2.3.1).

Plants and animals: As for removing the weir (option 2.3.1).

Retaining the weir but allowing all flows to overtop it with annual average Mowamba flow deducted from Jindabyne releases (option 2.4.2)

Hydrology: As for removing the weir (option 2.3.2).

Geomorphic processes: As for removing the weir (option 2.3.2), except that there would be no bedload movement through the weir, and only minor geomorphic changes.

Nutrient concentrations: As for removing the weir (option 2.3.2).

Plants and animals: As for removing the weir (option 2.3.2).

Retaining the weir but allowing the first 100 ML/day to overtop the weir with matching daily reduction in Jindabyne releases (option 2.5.1)

Hydrology would change slightly, principally via a minor reduction in the ratio of average spring flow to average autumn flow and a minor decrease in the magnitude, duration and frequency of high flows.

Geomorphic processes: There would be very minor geomorphic changes to benches in the Snowy River.

Nutrient concentrations would increase to a lesser extent because although concentrations of these elements are higher in the Mowamba River than in Lake Jindabyne, the Mowamba River would make a smaller volumetric contribution to the Snowy River under this option. Nevertheless, nutrient concentrations would still sometimes appreciably exceed those in the Thredbo River reference reach.

Plants and animals would generally increase in abundance and diversity because increased nutrient levels would promote greater growth of benthic algae and plants, which would increase the growth and reproduction of animals such as invertebrates, frogs, fish and platypus via the food web. However, the effects would be smaller than for the options 2.3.1–2.4.2 because the increase in nutrient levels would be less. Benthic algal growth would still likely exceed that in the Thredbo River reference reach.

Retaining the weir but allowing the first 100 ML/day to overtop the weir with annual average Mowamba flow deducted from Jindabyne releases (option 2.5.2)

Hydrology would change slightly, principally via a minor reduction in the ratio of average spring flow to average autumn flow.

Geomorphic processes: As for allowing the first 100 ML/day to pass the weir with matching daily reduction in Jindabyne releases (option 2.5.1).

Nutrient concentrations: As for allowing the first 100 ML/day to pass the weir with matching daily reduction in Jindabyne releases (option 2.5.1).

Plants and animals: As for allowing the first 100 ML/day to pass the weir with matching daily reduction in Jindabyne releases (option 2.5.1).

4.1.3 Recommendations for Mowamba flow options (considering effects on the Mowamba and Snowy rivers)

The Panel recommends the removal of Mowamba Weir (option 2.3) for the following reasons:

- Removal of the weir would fully restore the flow regime of the downstream 5 km of the Mowamba River.
- Removal of the weir would induce a major downstream change towards pre-weir conditions, in particular in the 1 km of channel immediately downstream of the weir.
- Removal of the weir would restore bedload transport and natural passage for animals including native eels and platypus.
- While weir removal would have more modest effects on the Snowy River, the increased nutrient levels would promote greater growth of benthic algae and plants, which would increase the growth and reproduction of animals such as invertebrates, frogs, fish and platypus via the food web. Any potential adverse aesthetic impact of greater algal growth would be limited by the modest size of the nutrient increase.
- The effect of the increase in bedload sediment transport down the Mowamba River on the Snowy River would be major at the junction of the 2 rivers but would become minor further downstream.
- Two methods of making deductions from Jindabyne releases to account for increased flow down the Mowamba River have been assessed, and both have been found able to limit the effect of such deductions on high flows and other aspects of hydrology.

The Panel considers that both methods for making deductions, as outlined in section 2.3.1 (deducting from Jindabyne releases on a daily basis to match Mowamba additional flows) and 2.3.2 (deducting the annual average Mowamba River additional flow from yearly Jindabyne releases) are viable and would produce very similar environmental outcomes. Therefore, the Panel does not recommend one method over the other. The Panel does, however, recommend that:

- any method that uses the annual average additional Mowamba flow includes a mechanism for this average to be reviewed in light of any decrease in Mowamba average flows due to climate change
- the carryover of a portion of annual SRIF allocations from one year to the next be enabled if the method deducting Mowamba River flows from Jindabyne Dam releases is used, because carryover would be required to implement this method[30] (see section 2.3.1). Carryover is further discussed in sections 3.5 and 4.2.

If social or economic considerations, which are outside the Panel's scope, preclude weir removal, the Panel recommends allowing all flows to pass the weir. This option would deliver most of the environmental outcomes predicted for weir removal, as most of these would be induced by the reinstatement of pre-weir flows. However, the return of coarse

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[30] An alternative would be to allow all deviations of SRIF delivery from allocations to be carried over between years (i.e. allow the carryover of both surpluses and deficits).

bedload and full passage for animals including native eels and platypus would not be achieved with this option. The panel notes that removing the weir is in line with general recommendations for weirs outlined in the NSW *Detailed Weir Review* carried out by the NSW Department of Primary Industries (NSW DPI 2006).

The option of retaining the weir and passing only the first 100 ML/day downstream of the weir is not recommended because it would not restore the full range of flows in the lower Mowamba River and would create a highly unnatural regime with a constant flow of 100 ML/day for long periods. This option would limit the shift of the Mowamba River channel toward its pre-weir condition and the change to a more flow-adapted biotic community. Opportunities for fish to pass natural barriers would also be more limited, and this option would not return bedload to the Mowamba River. Moreover, contributions of nutrients to the food web of the Snowy River would increase by a lesser amount. However, the Panel considers that passing the first 100 ML/day of Mowamba flow would nevertheless be preferable to the do-nothing option, because it would partly restore channel morphology and provide more wetted habitat in the lower Mowamba River and its effects on Jindabyne releases would be modest.

4.2 Recommendations for more flexible delivery of SRIF

The Panel strongly recommends increasing the flexibility of the delivery of SRIF, because greater flexibility would enhance the achievement of environmental objectives and provide better outcomes with the water available.

4.2.1 Synchronisation recommendation

The Panel has concluded that the greatest benefit is likely to come from improving synchronisation of Jindabyne Dam releases with flows in the Thredbo River or a similar unregulated reference stream (discussed in section 3.2). Greater flow synchrony could achieve a large range of objectives. The releases would more often align with downstream tributary high-flow events, prolonging and, on occasions, increasing the peak flow in the Snowy River resulting from these events. This alignment would:

- strengthen channel-forming processes
- increase the flushing of fine sediment and limit accumulation of tributary sediment in the Snowy River channel
- increase the inundation of benches and the mobilisation of nutrients through this process
- provide more submergence of natural barriers to fish passage
- induce flora and fauna assemblages more similar to those that occurred prior to the Snowy Mountains Scheme, through greater synchrony of Snowy River and tributary flows and in addition, the synchrony between Snowy River flow and rainfall cues for breeding event triggers.

The Panel recommends the provision of synchrony on a continuous daily basis (option covered in section 3.2.2), noting that this option would require the ability to carry over a portion of SRIF allocation between years[30] (see recommendation below). If such carryover is not achievable, the Panel recommends that flexibility be provided to release monthly flow peaks based on a flow trigger in the Thredbo River (option covered in section 3.2.3).

The Panel also recommends provision of more intra-day variability in releases. This option would release high flows from Jindabyne Dam in patterns that more closely reflect those in unregulated reference rivers, and would allow higher peak flow rates to be achieved than if the same volume was delivered at a constant rate for 24 hours. An example of this option would be providing a higher flow peak for 8 hours, with equivalently reduced flow rates on the 8-hour shoulders to provide a build-up to, and a recession from, the peak (see Figure 36). The effects of the higher flow peaks would include increases in channel-forming processes, flushing of sediment, inundation of benches, mobilisation of nutrients, fish passage and scouring, inducing plant and animal communities more similar to those that would have occurred prior to the Snowy Mountains Scheme.

The Panel also recommends that increased flexibility be provided to allow changes in daily flow releases from Jindabyne Dam during the year in response to environmental contingencies (option covered in section 3.3). Such flexibility could allow releases to coincide with a downstream tributary flow peak, or respond to events that deposit large amounts of ash or sediment, a pollution event, or a breeding event. Responses could also include increasing baseflows where there is a risk of the estuary mouth closing, releasing a flushing flow when dam levels allow it, or altering releases to better manage carryover. All these responses could assist in achieving specific environmental objectives. However, the Panel notes that there would be effects on other variables that could militate either for or against the achievement of other objectives. The Panel therefore qualifies their recommendation by noting that environmental water managers would need to assess potential risks or additional benefits according to the specific circumstances at the time of any proposed release. The Panel also recommends that such releases should be the exception to general SRIF management, not the rule. Frequently changing flows for specific objectives risks changing the overall flow regime away from one in keeping with the natural flow paradigm that is the present basis of environmental flow releases.

4.2.2 Carryover recommendation

Finally, the Panel recommends that carryover of environmental water between years be permitted. Carryover is a key enabler of many of the recommendations that would enhance achievement of environmental objectives with the limited SRIF allocations available. These recommendations include those that would return Mowamba River flows and account for these flows with daily deductions from Jindabyne releases. It also includes the flexibility option of improving synchronisation of Jindabyne releases with flows in the Thredbo River. Not only is carryover crucial for such options, it also allows for reserves to be carried over for extreme dry years and environmental contingencies.

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Appendix A: Flow thresholds for the Snowy River below Jindabyne Dam

Table 15: Snowy River flow thresholds from noted references

Flow (at Jindabyne unless stated)	Reason/ comment	Duration	Frequency	Timing	Reference
68 ML/day	Minimum natural flow pre-dam				Pre-dam flow data 1902–1967
260 ML/day at Jarrahmond	To keep estuary entrance open. Also noted as possibly 760 ML/day	30 days			Hale (2020)
300 ML/day	Initial wetting of lower benches (within old riverbed)				Williams (2010)
864 ML/day	Hydrodynamic modelling shows needed to mix deep pools by intense interfacial entrainment	At least a week		During hot spells in summer	Erskine (unpublished) in Snowy Scientific Committee (2008)
1,000 ML/day	Modelling shows fine-grained sediment laminae in the Jindabyne Gorge and Dalgety Uplands Reach entrained		Every year		Reinfelds and Williams (2008)
1,240–3,270 ML/day	Highly effective in scouring silt to sand size sediment from the current Snowy River low-flow channel and depositing it onto the inset floodplain				Rose and Erskine (2011)
1,500 ML/day	Many of the lower benches in the upper reaches are inundated				Williams (2016)
1,700 ML/day	Median (50th %ile) natural flow pre-dam. Suggested as trigger for Australian bass movement based on work in Shoalhaven	~5 days including recession	Annually	~July to October	Analysis of pre-dam flow data 1902–1967 for median value. Bass movement is Reinfelds et al. (2013b)
1,000–3,000 ML/day	Riffle maintenance – scour removes fines and possibly attached algae in riffles. Shear stress velocities across riffles are substantially greater than in pools				Reinfelds and Williams (2008)

Flow (at Jindabyne unless stated)	Reason/ comment	Duration	Frequency	Timing	Reference
2,000 ML/day	Riffle maintenance (the scour of fine sediment and attached algae)				Williams (2014)
2,469 ML/day	Median daily flow at Dalgety prior to the construction of the Snowy Scheme				Morton et al. (2010)
3,948 ML/day	Mean daily flow at Dalgety prior to the construction of the Snowy Scheme				Morton et al. (2010)
8,000 ML/day	Flow required to entrain loosely packed 256 mm diameter gravel				Erskine et al. (1999a) and Snowy Scientific Committee (2008)
7,000 ML/day at Jarrahmond	To stimulate productivity		Annual		Hale (2020)
8,640 ML/day at Pinch Falls (10,370 ML/day at McKillops Bridge)	Passage for adult Australian bass (Pinch Falls)				Haeusler and Bevitt (2007) Williams (2010) (from modelling)
12,000 ML/day	Recommended size of channel-maintenance flow	About 1 week	Should occur every year	During the spring snow melt period	Expert Panel (anon. 1996) and Snowy Scientific Committee (2008)
12,000–20,000 ML/day	Large-scale fluvial disturbance to remove invading vegetation, to rework encroaching bars and benches and to scour pools				Erskine et al. (1999b)
11,230 ML/day at Pinch Falls (13,350 ML/day at McKillops Bridge)	Passage for juvenile Australian bass (Pinch Falls)				Williams (2010) (from modelling) Haeusler and Bevitt (2007)
>15,000 ML/day at Jarrahmond	For estuary perch		2 per year	Winter	Hale (2020)
>17,300 ML/day at Jarrahmond	To scour the estuary opening		At least once every 2 years		Hale (2020)

Flow (at Jindabyne unless stated)	Reason/ comment	Duration	Frequency	Timing	Reference
28,600 ML/day	Scouring of pools. Modelling showed velocity reversal between pools and riffles occurs at the monitoring site downstream of the Mowamba River junction				Reinfelds and Williams (2008)

Appendix B: Flow timing requirements for the Snowy River downstream of Jindabyne Dam

Several references have noted timing requirements for native fish and platypus that are relevant to the Snowy River. These requirements are provided in Table 16.

Table 16: Flow timing considerations likely to be relevant from fish and platypus in the Snowy River

	Australian bass	Estuary perch	Australian grayling	Platypus
May			~1,100 ML/day at Jarrahmond for movement downstream for spawning	Higher mean monthly flows improve recruitment next season
June		Two high winter spells to stimulate spawning activity (>15,000 ML/day at Jarrahmond)		Higher mean monthly flows improve recruitment next season
July	Movement downstream – ~1,700 ML/day (at Jindabyne), ~5 days including recession			Higher mean monthly flows improve recruitment next season
August	Movement downstream – ~1,700 ML/day (at Jindabyne), ~5 days including recession			
September	Movement downstream – ~1,700 ML/day (at Jindabyne), ~5 days including recession. **Ideal month**			
October	Movement downstream – ~1,700 ML/day (at Jindabyne), ~5 days including recession			
November	Movement upstream (less critical) and productivity			Flushing flows in late November detrimental to juvenile platypus
December				

	Australian bass	Estuary perch	Australian grayling	Platypus
January				Flushing flows detrimental to juvenile platypus
February				
March			~1,100 ML/day at Jarrahmond for movement downstream for spawning	Higher mean monthly flows improve recruitment next season
April			~1,100 ML/day at Jarrahmond for movement downstream for spawning	Higher mean monthly flows improve recruitment next season
References	Reinfelds et al. (2013b – Shoalhaven River), Brown (2011), Hale (2020)	Hale (2020)	Dawson and Koster (2018 – Bunyip River). Snowy flow estimated using flow percentiles from bom.gov.au/waterdata.	Serena and Grant 2017 (Upper Shoalhaven River)

Appendix C: Expected effects on the lower Mowamba River of different options for passing flows below Mowamba Weir

Environmental variable	Option 2.3: Remove Mowamba Weir	Option 2.4: Allow all Mowamba River flows to overtop Mowamba Weir	Option 2.5: Allow first 100 ML/day of Mowamba River flows to overtop the weir
Daily discharge variability	Major change from current situation of constant 1.4 ML/day flow punctuated by occasional weir spills (see Figure 19) to full restoration of natural discharge variability (see Figure 22)	As for option 2.3 (remove Mowamba Weir)	Restoration of natural discharge variability would be only up to 100 ML/day (see Figure 32) and there would be no increase in variability above 100 ML/day. Analysis shows that between 2011 and 2020, about 29% of days would have been held at 100 ML/day. Therefore, daily variability would still be restricted
Discharge seasonality	Currently, drier years have almost constant flow across seasons, with only occasional spills (see Figure 19). Removing the weir would fully restore natural discharge seasonality (see Figure 22)	As for option 2.3 (remove Mowamba Weir)	Although allowing the first 100 ML/day of flow to pass the weir would provide more natural discharge seasonality (see Figure 32), the effect would be less than if all flow was allowed to pass
High-flow magnitude	High flows would increase by 500 ML/day	As for option 2.3 (remove Mowamba Weir)	High flows would increase by only 100 ML/day
High-flow frequency	Currently, only flows above 500 ML/day overtop the weir, and overtopping flows are 500 ML/day less than weir inflows. Consequently, removing the weir would markedly increase the frequency of high flows (see Figure 19 and Figure 22)	As for option 2.3 (remove Mowamba Weir)	The frequency of high flows would not increase markedly because they would increase by only 100 ML/day (see Figure 19 and Figure 32)
High-flow duration	Removing the weir would pass an additional 500 ML/day of any high flow, keeping it above the high-flow threshold for longer (see Figure 19 and Figure 22)	As for option 2.3 (remove Mowamba Weir)	Would not increase markedly because high flows would increase by only 100 ML/day

Environmental variable	Option 2.3: Remove Mowamba Weir	Option 2.4: Allow all Mowamba River flows to overtop Mowamba Weir	Option 2.5: Allow first 100 ML/day of Mowamba River flows to overtop the weir
High-flow rate of rise and fall	Currently, the first 500 ML/day of high flow is diverted, passing the sharper part of the flow rise, which is seen above 500 ML/day. Removing the weir would remove this effect	As for option 2.3 (remove Mowamba Weir)	Allowing the first 100 ML/day to pass would not markedly change the rate of rise or fall
High-flow sequencing	Currently, high-flow events that partly pass the weir can cluster, with long periods between clusters. Removing the weir would reduce this clustering (see Figures 19 and 22)	As for option 2.3 (remove Mowamba Weir)	Would not change markedly because flows would increase by only 100 ML/day
Channel morphology measures	The morphology of downstream reaches would return to the pre-weir state. Sediment stored in the weir pool would flush downstream initially, filling the channel in reach M1. After a few high flows, this sediment would flush into reach M2, whence it would move quickly to the Snowy River. After the coarse sediment had moved through reach M1, its channel would adjust to the full flow regime and expand to the same dimensions as upstream of the weir backwater. Narrowed sections of channel would widen from <2 m to >10 m, and depth would increase to around 1 m. A pool and riffle morphology like that upstream of the weir would develop in reach M1, with a gravel riffle about every 100 m (~8–10 in total). Gravel riffles would be formed by exhuming buried gravels, and by coarse sediment passing from upstream. Perhaps 10,000 m^3 of sand and silt would be eroded from reach M1 and pass downstream to the Snowy River. In reach M2, bedrock sections would probably not be affected, but the anabranching/floodplain sections might also adjust to the increase in discharge by widening and deepening	The morphology of downstream reaches would return to the pre-weir state. As for option 2.3 (remove the weir), reach M1 would widen from 2 to >10 m. Its channel would adjust to larger discharge and become more like the channel upstream of the weir (but without gravel input), and its pools would deepen. The level of scouring would be the same as for option 2.3, but no new gravel would pass downstream. Therefore, gravel beds would coarsen only marginally	The morphology of downstream reaches would change toward the pre-weir state, but only slightly. Vegetation encroachment would reduce. The channel would probably become wider in sections between pools. Pools would probably deepen. Sediment input would not increase

Environmental variable	Option 2.3: Remove Mowamba Weir	Option 2.4: Allow all Mowamba River flows to overtop Mowamba Weir	Option 2.5: Allow first 100 ML/day of Mowamba River flows to overtop the weir
Floodplain aggradation	Would return floodplain aggradation of downstream reaches to the pre-weir state: minor aggradation from flushed weir-pool sediment along the margins of reach M1, with aggradation unlikely in reach M2, which is steeper and has a rocky bed (see Figure 21). For the first 1 km of channel downstream of the weir, the floodplain would narrow as the channel widens through scouring. In the anabranching sections of M2, the channel could fill with sediment, and floodplains aggrade slightly. Additional fine sediment would aggrade floodplains more rapidly	Would return floodplain aggradation of downstream reaches to the pre-weir state. The main impact would be from erosion of the channel of reach M1, releasing a pulse of fine sediment into reach M2, which could aggrade the anabranching sections of this reach slightly. Also increased fine sediment that is not diverted to Lake Jindabyne would assist in this process	Would induce only a minor shift toward the pre-weir state. Aggradation would not be likely. There would be some scouring of the first 1 km of channel downstream of the weir, where the channel gradient is lower and the substrate is composed of finer sediments, but this would be more limited than for options 2.3 (remove the weir) and 2.4 (retain the weir but allow all flows to overtop)
Substrate character	Would return the substrate of downstream reaches to the pre-weir state. Reach M1 bed is now gravel covered with silt and clay, which would scour down to a stable gravel bed and develop short riffles and deeper pools. More coarse sediment would be provided to this reach, being no longer trapped by the weir. This sediment would lead to bed coarsening (an increase in gravel content)	Would move the substrate of downstream reaches towards the pre-weir state, but only because of scour of the bed rather than new sediment passing from upstream of the weir. A very small increase in suspended sediment would occur, because Mowamba Weir has low trap efficiency. With no fine gravel input, but with more flow, bed coarsening would be expected, leaving only larger gravels in the bed and a small flush of sediment downstream as it is removed from the bed	Would cause a minor shift toward the pre-weir bed substrate. Effects would be similar to those of option 2.4 (retain the weir but allow all flows to overtop), but would be less because only the first 100 ML/day would be passed, limiting the amount of channel erosion and flushing of sediment
Sediment movement	Would return downstream sediment movement to the pre-weir state. Sediment trapped in the weir would move downstream, partly stabilising and becoming part of the floodplain. Fine sediment (sands and finer) would also be liberated by widening of the channel in reach M1. The maximum volume of sediment liberated by all of these processes would be less than 40,000 m^3, which is about 2/3 of the	Would result in a minor return of downstream sediment movement toward the pre-weir state. The major effect on sediment movement would be from erosion of the channel in reach M1, leading to a short-term flush of sediment into reach M2. Suspended sediment movement past the weir would increase because it is not being	Would cause only a slight shift toward pre-weir rates of sediment movement. Effects would be similar to those of option 2.4 (retain the weir but allow all flows to overtop), but smaller because only the first 100 ML/day of flow would be passed, limiting the movement of sediment

Environmental variable	Option 2.3: Remove Mowamba Weir	Option 2.4: Allow all Mowamba River flows to overtop Mowamba Weir	Option 2.5: Allow first 100 ML/day of Mowamba River flows to overtop the weir
	volume estimated to be in the existing tributary fan at the junction of the Mowamba and Snowy rivers. Some of the pulse of sediment could deposit on the fan, but most would enter the Snowy River. Suspended sediment loads would return to pre-weir levels because it is no longer being diverted into Jindabyne, leading to increase in sediment movement onto floodplains. Bedload would return to pre-weir levels. Sediment would move through reach M2 from upstream, having little impact on the bedrock section	diverted to the aqueduct. Bedload would not pass the weir under this option	
Benthic algal assemblage composition	Would change to an assemblage adapted to faster velocities and more frequent flow disturbance. There would probably be less loosely attached algal growth and more that is firmly attached. More benthic algae that colonise soon after scouring flows (e.g. diatoms) would be expected	As for option 2.3 (remove the weir)	Would change as for options 2.3 (remove the weir) and 2.4 (retain the weir but allow all flows to overtop), but to a lesser degree because a smaller proportion of high flows would be passed downstream
Benthic algal density	Would probably decrease due to scouring and become more like pre-weir density	As for option 2.3 (remove the weir)	Would probably decrease due to scouring, but to a lesser degree than under options 2.3 (remove the weir) and 2.4 (retain the weir but allow all flows to overtop) because a smaller proportion of high flows would be passed downstream
Bench inundation frequency	N/A. There do not appear to be any benches in the Mowamba River below the weir (reaches M1 and M2)	N/A	N/A

Environmental variable	Option 2.3: Remove Mowamba Weir	Option 2.4: Allow all Mowamba River flows to overtop Mowamba Weir	Option 2.5: Allow first 100 ML/day of Mowamba River flows to overtop the weir
DOC concentration	DOC concentrations would not change greatly. Currently some DOC may be taken up in the weir pool, or alternatively released by decay processes, but most passes down the aqueduct. DOC concentrations are higher in high flows, but downstream passage of these high concentrations is episodic, with no spills occurring in some years (see Figure 19). Weir removal would increase the DOC load downstream, but DOC concentrations would not change appreciably	As for option 2.3 (remove the weir), except that any uptake or release in the weir pool would persist, though in diminished form at higher flows because of decreased residence time	As for option 2.4 (retain the weir but allow all flows to overtop), there would be minimal change in DOC concentration. However, the load passed downstream would increase to a lesser extent because a smaller proportion of high flows would be passed downstream
Other basal resources including nitrogen, phosphorus and silica	Concentrations would not change greatly. For TN and TP, concentrations would continue to increase during high-flow events, with concentrations of filtered available nutrients not being so strongly linked to flow. Flow-concentration relationships for silica are unclear from the limited data available	As above for TN and TP	As above for TN and TP
In-stream plant assemblage composition	In the less steep reach M1, the plant community would be expected to shift towards one more tolerant of flow disturbance, with in-channel low-flow plants such as *Phragmites* likely to be scoured. In the steeper, rockier reach M2, the amount of vegetation is already limited, and so significant change would not be expected	As for option 2.3 (remove the weir)	As for option 2.3 (remove the weir), except that the change would probably be only in and near the central channel path, because a smaller proportion of high flows would be passed downstream
In-stream plant cover	A decrease in density due to scouring would be expected in the less steep reach M1, providing more open riverbed. Plant cover is already limited in reach M2	As for option 2.3 (remove the weir)	See above

Environmental variable	Option 2.3: Remove Mowamba Weir	Option 2.4: Allow all Mowamba River flows to overtop Mowamba Weir	Option 2.5: Allow first 100 ML/day of Mowamba River flows to overtop the weir
Riparian plant cover	Scouring of riparian plants on low benches would be expected. Plants on the channel margins of reach M1 would be dislodged by channel widening. The same process would occur in reach M2, particularly in the anabranching sections, but to a lesser extent in the bedrock sections	As for option 2.3 (remove the weir)	Scouring of riparian plants on the edges of the current inset channel and smaller benches would be expected; however, the effect would be significantly less than for options 2.3 and 2.4 because a smaller proportion of high flows would be passed downstream
Riparian plant assemblage composition	Major change in places toward flora more adapted to fast flow	As for option 2.3 (remove the weir)	As for options 2.3 (remove the weir) and 2.4 (retain the weir but allow all flows to overtop) but with a minor change because a smaller proportion of high flows would be passed downstream
Thermal regime of river	The temperatures of current low flows of 1.3 ML/day are probably strongly affected by variation in air temperatures and solar heating. Higher baseflows with the weir removed would buffer these effects. Therefore, there would be less thermal variability and the thermal regime would return towards that of the pre-weir river	As for option 2.3 (remove the weir)	As for options 2.3 (remove the weir) and 2.4 (retain the weir but allow all flows to overtop) but with less flow, the amount of thermal buffering would be slightly less
Benthic invertebrate assemblage composition	Would change to an assemblage adapted to faster velocities and more frequent flow disturbance. This change has been seen in the Snowy River as flows and disturbance increased, and a similar response is expected in the Mowamba River. The removal of the weir would increase macroinvertebrate drift, which it currently impedes (Brooks et al. 2018)	As for option 2.3 (remove the weir), but with the weir remaining, macroinvertebrate drift would still be impeded (Brooks et al. 2018). The weir would also prevent downstream bedload transport, and coarsening of the substrate would be greater, further limiting burrowing macroinvertebrates	As for option 2.4 (retain the weir but allow all flows to overtop), there would be a shift to species that are adapted to faster velocities and more disturbance; however, the effect would be less because a smaller proportion of high flows would be passed downstream

Environmental variable	Option 2.3: Remove Mowamba Weir	Option 2.4: Allow all Mowamba River flows to overtop Mowamba Weir	Option 2.5: Allow first 100 ML/day of Mowamba River flows to overtop the weir
Benthic invertebrate density	Density would reduce to pre-weir levels because of the return of more scouring events	As for option 2.3 (remove the weir)	As for options 2.3 (remove the weir) and 2.4 (retain the weir but allow all flows to overtop) but to a lesser extent because a smaller proportion of high flows would be passed downstream
Benthic invertebrate total abundance	Would probably increase because of an increase in wetted area, though counterbalanced by the decrease in density	As for option 2.3 (remove the weir)	As for option 2.3 (remove the weir)
Fish assemblage composition	Fish species recorded since 2005 in the Mowamba River are limited to introduced brown and rainbow trout and native southern shortfin eels (NSW DPI–Fisheries data 2021). Small native fish species such as galaxiids are probably absent because of predation by and competition with trout. More flows would provide more habitat and more food (see macroinvertebrate density above) for trout, eels and (if present in the future) Australian bass (but see fish passage issues below). NSW DPI–Fisheries data (2021) record rainbow trout at Moonbah Hut and the Barry Way (both upstream of Mowamba Weir) but not at Mowamba Lodge downstream of Mowamba Weir (18 records from 2019–21: 14 southern shortfin eels and 4 brown trout). It is possible that the removal of the weir and return of flows could enable rainbow trout to colonise the reach below the weir if they are not already there. Removing the weir and restoring flows to the lower Mowamba River might also establish or increase upstream eel populations. See further discussion in the fish passage section below.	As for option 2.3 (remove the weir), except that the presence of the weir would reduce the potential for colonisation of the Mowamba River downstream of the weir by introduced rainbow trout, and also reduce the potential establishment or increase of upstream eel populations	As for option 2.4 (retain the weir but allow all flows to overtop)

Environmental variable	Option 2.3: Remove Mowamba Weir	Option 2.4: Allow all Mowamba River flows to overtop Mowamba Weir	Option 2.5: Allow first 100 ML/day of Mowamba River flows to overtop the weir
Fish passage	Removing the weir would mean the elimination of a barrier to fish passage, and could increase passage of introduced trout, native eels, and possibly Australian bass if they are stocked. Eels are the dominant large-bodied fish recorded in NSW DPI–Fisheries data (2021) at Mowamba Lodge, downstream of the weir, and in the Snowy River downstream of the Mowamba River junction (297 eels from a total of 353 large-bodied fish in 2000–2015). Eels are adept at overcoming barriers by climbing and overland movement, and so might be able to migrate past the weir under current restricted flows. However, they have not been recorded in NSW Fisheries data (2021) from upstream of the weir (96 fish, all trout, in 2019–2021), which suggests the weir and current low-flow conditions may inhibit their upstream migration. The effect on trout populations is likely to be limited because brown and rainbow trout are stocked annually upstream of the Mowamba Weir and in the Snowy River from Jindabyne to Dalgety (NSW DPI-Fisheries 2022). However, as noted above, rainbow trout have not been recorded in the lower Mowamba River, and this option might enhance their passage into this area. Duanne White (University of Canberra, pers. comm. May 2022) assessed that higher daily flows would improve fish passage through the Mowamba River downstream of the weir, but the steep 3 m natural cascades in reach M2 might still impede passage.	The weir would remain a barrier to fish passage. Higher daily flows would enhance fish passage through many parts of the Mowamba River downstream of the weir, especially for native eels; however, the steep 3 m natural cascades might limit the effect for some species	Fish passage would not increase greatly because the weir would continue to form a barrier and flows would seldom be sufficient to submerge natural barriers

Environmental variable	Option 2.3: Remove Mowamba Weir	Option 2.4: Allow all Mowamba River flows to overtop Mowamba Weir	Option 2.5: Allow first 100 ML/day of Mowamba River flows to overtop the weir
	A further consideration is that passing all flows to the lower Mowamba River would provide flow cues (in terms of changes in flow and in the concentration of constituents in the water, such as nutrients) in line with environmental conditions and rainfall events. Such cues might stimulate fish movement between the Snowy River and the Mowamba River and between the lower and upper sections of the Mowamba River		
Fish total abundance	Moderate increase due to increase in macroinvertebrate availability, increase in habitat and increase in ability for populations to colonise and move for breeding, seeking refuge and other requirements	As for option 2.3 (remove the weir)	As for option 2.3 (remove the weir), but with lesser increase because opportunities to move would be more limited
Platypus feeding	The upper Mowamba River and the weir pool are known to provide platypus habitat. Removing the weir would provide 5 km of natural stream habitat in the Mowamba River downstream of the weir. The lower 4 km (reach M2) are steep and rocky, but nonetheless contain some pools that could support platypuses. Although the weir pool would be lost, the flatter section of the Mowamba River (reach M1) would change to a series of runs, riffles and pools providing platypus habitat. The increased wetted area and river productivity (macroinvertebrates) would aid in supporting more platypuses (Gilad Bino, pers. comm.).	As for option 2.3 (remove the weir), except that the weir-pool habitat would remain	As for option 2.4 (retain the weir but allow all flows to overtop), but because only up to 100 ML/day of flows would be passed, the change in reach M1 of the Mowamba River to a series of runs, riffles and pools would be reduced, potentially reducing the feeding habitat for platypus

Environmental variable	Option 2.3: Remove Mowamba Weir	Option 2.4: Allow all Mowamba River flows to overtop Mowamba Weir	Option 2.5: Allow first 100 ML/day of Mowamba River flows to overtop the weir
Platypus movement	Platypuses are currently able to disperse around the weir, but in doing so are vulnerable to predation by foxes. Movement between the Snowy River and the upper Mowamba River requires passage across 5 km of exposed river channel with minimal in-stream water for shelter, increasing the risk of fox predation, particularly during dry periods. The risk of predation may inhibit platypus dispersal and colonisation of unoccupied habitat, restricting metapopulation dynamics and reducing the long-term viability of platypus populations in the Mowamba River. Removing the weir and passing all flows would likely reduce risk of predation and improve population viability (Gilad Bino, pers. comm.)	As for option 2.3 (remove the weir), except that the weir would continue to inhibit (but not prevent) platypus movement and increase the risk of predation by foxes (Gilad Bino, pers. comm.)	As for option 2.4 (retain the weir but allow all flows to overtop)
Water colour	The concentration of tannins and other dissolved constituents would not be appreciably altered by weir removal. Therefore, water colour in the lower Mowamba River would not be expected to change	As for option 2.3 (remove the weir)	As for options 2.3 (remove the weir) and 2.4 (retain the weir but allow all flows to overtop)
Water turbidity	While there is currently some sediment deposition in the weir pool, the suspended fine material causing turbidity would remain in the water column because the pool is small. Therefore, water turbidity in the lower Mowamba River would not be expected to change	As for option 2.3 (remove the weir)	As for options 2.3 (remove the weir) and 2.4 (retain the weir but allow all flows to overtop)
Frog species diversity and abundance	Little extra breeding habitat would be created in the lower Mowamba River because of the steep gradient. *Litoria lesueuri* is a stream specialist, but predation by exotic trout and native eels could limit its populations	As for option 2.3 (remove the weir)	As for options 2.3 (remove the weir) and 2.4 (retain the weir but allow all flows to overtop)

Appendix D: Expected effects on the Snowy River below Jindabyne Dam of different options for passing flows below Mowamba Weir

Environmental variable	Option 2.3.1 – Remove Mowamba Weir with matching daily reduction in Jindabyne releases	Option 2.3.2 – Remove Mowamba Weir with annual average Mowamba flow deducted from Jindabyne releases	Option 2.4.1 – Retain Mowamba Weir but allow all flows to overtop with matching daily reduction in Jindabyne releases	Option 2.4.2 – Retain Mowamba Weir but allow all flows to overtop with annual average Mowamba flow deducted from Jindabyne releases	Option 2.5.1 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with matching daily reduction in Jindabyne releases	Option 2.5.2 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with annual average Mowamba flow deducted from Jindabyne releases
Daily discharge variability	Only minor differences would be expected, with among-day variability remaining greater than natural variability as represented by the Thredbo River and the pre-Scheme Snowy River at Jindabyne, because daily SRIF release targets would remain the same (with potentially a decrease of 3% for flows above 150 ML/day – see Table 4). There would be an increase in within-day variability. Jindabyne Dam releases are generally constant for 24 hours. The Mowamba River would provide flows that vary significantly within 24 hours. However, this effect would be limited by the relative contribution of the Mowamba River. When Mowamba River peaks occur, there might be more variability. The reach from Jindabyne Dam to the Mowamba River junction would have more constant low flows	Similar to option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases) in terms of intra-day variability. However, variability in releases from Jindabyne below 2,000 ML/day would be more heavily reduced (see Table 6 for daily flow reductions)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.2 (remove Mowamba Weir with yearly reductions in Jindabyne Dam releases)	Similar to option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases), in that only minor changes would be expected, because daily SRIF release targets would remain the same (with potentially a decrease of 2% for flows above 150 ML/day – see Table 7). Intra-day variability would also increase, but to a lesser extent because the Mowamba River contribution would be limited to an additional 100 ML/day. As for option 2.3.1, low flows from Jindabyne Dam to the Mowamba River junction would be more constant, but there would be a lesser effect because Jindabyne releases would be restricted to 40 ML/day less often	Similar to option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases). However, the yearly reduction in Jindabyne releases of 11–25% for flows below 2,000 ML/day (see Table 9) would result in less variability in this flow range. However, this effect would be compensated to an extent by additional Mowamba flows of up to 100 ML/day
Discharge seasonality	Given that daily flow targets would remain effectively the same, seasonality would be little changed, and would remain greater than natural seasonality as represented by the Thredbo River and the pre-Scheme Snowy River at Jindabyne. Making up for daily exceedances of SRIF allocations via a 3% reduction in releases spread across the year would not change seasonality. Flows would increase on days when the additional Mowamba River flow exceeded the daily allocation. This pattern would be in line with natural seasonality (driven by local rainfall events).	While daily flow targets would reduce by the proportion outlined in Table 6 (for flows greater than 40 and less than 2,000 ML/day), the reduction would probably be consistent across seasons. As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases), the additional Mowamba River flows would be in line with natural seasonality (driven by local rainfall events)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.2 (remove Mowamba Weir with yearly reductions in Jindabyne Dam releases)	As for options 2.3 (remove the weir) and 2.4 (retain the weir but allow all flows to overtop). Given that daily flow targets would remain effectively the same, seasonality would also be effectively unchanged. However, the effect of Mowamba River flows providing variability in line with natural seasonality (driven by local rainfall events) would be reduced relative to those options because only the first 100 ML/day would be allowed to overtop the weir	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases), seasonality would probably not change greatly. Similarly, the effect of Mowamba River flows providing variability in line with natural flows would be reduced relative to options 2.3 and 2.5.1

Environmental variable	Option 2.3.1 – Remove Mowamba Weir with matching daily reduction in Jindabyne releases	Option 2.3.2 – Remove Mowamba Weir with annual average Mowamba flow deducted from Jindabyne releases	Option 2.4.1 – Retain Mowamba Weir but allow all flows to overtop with matching daily reduction in Jindabyne releases	Option 2.4.2 – Retain Mowamba Weir but allow all flows to overtop with annual average Mowamba flow deducted from Jindabyne releases	Option 2.5.1 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with matching daily reduction in Jindabyne releases	Option 2.5.2 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with annual average Mowamba flow deducted from Jindabyne releases
	The seasonality of the Mowamba River is less influenced by snowmelt than that of the Thredbo River and the pre-Scheme Snowy River, and so the Mowamba River provides a weaker snowmelt signal. The 2 km reach from Jindabyne Dam to the Mowamba River junction would still be dominated by high seasonal flows, and so effects on seasonality would be limited					
High-flow magnitude	A 3% reduction in daily flow targets would see a commensurate reduction in peak flow magnitudes. However, if partial carryover of allocation between years was allowed, undelivered water from one year (see Table 4) could be used to bolster peak flows in subsequent years	Daily flow targets would reduce by the proportion outlined in Table 6; however, flows greater than 2,000 ML/day would not be altered	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.2 (remove Mowamba Weir with yearly reductions in Jindabyne Dam releases)	A 2% reduction in daily flow targets would see a commensurate reduction in peak flow magnitudes. However, if partial carryover of allocation between years was allowed, undelivered water from one year (see Table 7) could be used to bolster peak flows in subsequent years	While daily flow targets would reduce by the proportion outlined in Table 9, flows greater than 2,000 ML/day would not be altered
High-flow frequency	Unlikely to be markedly changed, and likely to remain greater than natural frequency as represented by the Thredbo River and the pre-Scheme Snowy River at Jindabyne. Peaks from the Mowamba River could be piggybacked upon if Jindabyne Dam releases were able to be more flexibly managed. Analysis (Simpson 2021) shows that around half of the Mowamba River peaks above 1000 ML/day coincide with peaks in the Thredbo River (2001–2020 data) with a 1-day lag. Therefore, some moderately-sized flows may be raised above thresholds in Appendix A. However, the effect would be limited to an additional 500 ML/day, and so would be unlikely to have a large material effect	While daily flow targets would reduce by the proportion outlined in Table 6, flows greater than 2,000 ML/day would not be altered. Flows below 2,000 ML/day would be reduced, but Mowamba River flows would provide some additional peaks. The same opportunity for piggybacking applies as outlined for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.2 (remove Mowamba Weir with yearly reductions in Jindabyne Dam releases)	Unlikely to be markedly changed. The Mowamba River would provide only up to an extra 100 ML/day. The reduction in Jindabyne releases would be only 2% or less	While daily flow targets would reduce by the proportion outlined in Table 9, flows greater than 2,000 ML/day would not be altered. Flows below 2,000 ML/day would be reduced, but Mowamba River flows might provide some additional flow on minor peaks
High-flow duration	As above, unlikely to be markedly changed	As above, unlikely to be markedly changed	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.2 (remove Mowamba Weir with yearly reductions in Jindabyne Dam releases)	As above, unlikely to be markedly changed	As above, with flows above 2,000 ML/day not affected

Environmental variable	Option 2.3.1 – Remove Mowamba Weir with matching daily reduction in Jindabyne releases	Option 2.3.2 – Remove Mowamba Weir with annual average Mowamba flow deducted from Jindabyne releases	Option 2.4.1 – Retain Mowamba Weir but allow all flows to overtop with matching daily reduction in Jindabyne releases	Option 2.4.2 – Retain Mowamba Weir but allow all flows to overtop with annual average Mowamba flow deducted from Jindabyne releases	Option 2.5.1 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with matching daily reduction in Jindabyne releases	Option 2.5.2 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with annual average Mowamba flow deducted from Jindabyne releases
High-flow rate of rise and fall	Mowamba River high flows would have a natural rate of rise and fall rather than the near instantaneous change in flow volumes provided from Jindabyne Dam releases between days. However, any effect on rates of rise and fall in the Snowy River would be limited because flow from the Mowamba River would be contributing only an additional 500 ML/day	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases), except that the rate of rise and fall would increase for flows that move from below 2,000 ML/day to above (because flows below 2,000 ML/day would be reduced, but those above would not). However, this effect could be alleviated by adjusting the daily flow targets	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.2 (remove Mowamba Weir with yearly reductions in Jindabyne Dam releases)	Unlikely to change markedly because only the first 100 ML/day would pass Mowamba Weir	Unlikely to change markedly because only the first 100 ML/day would pass Mowamba Weir
High-flow sequencing	As for high-flow frequency above	As for high-flow frequency above	As for high-flow frequency above	As for high-flow frequency above	As for high-flow frequency above	As for high-flow frequency above
Channel morphology measures	(See Appendix E for justification for this section.) Overall, the impact on morphology would be small. Widening of the Mowamba River downstream of the weir (reach M1) and flushing of sediment stored in the weir, would move >20,000 m^3 of silt, clay and some gravels into reach M2. This material would flush rapidly into the Snowy River and form a delta at the mouth of the Mowamba River that would be redistributed downstream over time. The major impact would be a return of increased (pre-weir) coarse tributary sediment from the Mowamba River, perhaps 2,000–3,000 m^3 of gravels per year, that would slightly fill pools in the Snowy River. Larger flow releases from Jindabyne Dam (>2,000 ML/day) would gradually move the coarser sediment through the long pools in reach S2. The suspended sediment load would increase with the addition of the proportion that would have diverted through the aqueduct. This would produce a slight increase in floodplain deposition. The reduction of only 3% in Jindabyne Dam releases (and potentially less if partial carryover of allocation between years was allowed) would not significantly reduce scouring	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases), except that the reduction in flows from Jindabyne is different. Additional flow from the Mowamba River (up to 500 ML/day greater), when combined with Jindabyne Dam releases, would slightly increase deposition rates on floodplains (especially on benches in reach S3), and slightly increase gravel transport rates. Little impact on morphology overall. Because most sediment transport occurs at flows above 2,000 ML/day, and these are not reduced by this regime, the overall geomorphology would not alter much	Unlike for option 2.3.1, there would be no flush of coarse sediment from the weir pool, and no long-term increase in coarse bedload. However, increased flows in the Mowamba River would erode M1 and temporarily increase sediment supply into the Snowy River. All suspended sediment that would have been diverted to Jindabyne would enter the Snowy, slightly increasing deposition rates on benches. The overall impact on morphology in the Snowy River would be minor	As for option 2.4.1	The additional base flow of up to 100 ML/day in the Mowamba River would be unlikely to have a substantial impact on the morphology of the Snowy River in reaches S2 and S3 because the overall flow regime in these reaches would be barely changed. Evidence in Appendix E suggests that these consistent lower flows could transport fine sediment into the pools and riffles of the Snowy River possibly leading to slightly increased clogging (colmation) of gravel beds	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)

Environmental variable	Option 2.3.1 – Remove Mowamba Weir with matching daily reduction in Jindabyne releases	Option 2.3.2 – Remove Mowamba Weir with annual average Mowamba flow deducted from Jindabyne releases	Option 2.4.1 – Retain Mowamba Weir but allow all flows to overtop with matching daily reduction in Jindabyne releases	Option 2.4.2 – Retain Mowamba Weir but allow all flows to overtop with annual average Mowamba flow deducted from Jindabyne releases	Option 2.5.1 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with matching daily reduction in Jindabyne releases	Option 2.5.2 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with annual average Mowamba flow deducted from Jindabyne releases
Floodplain aggradation	In the short term, additional fine sediment stored in the Mowamba Weir pool would be scoured, and erosion would occur in reach M1 leading to a short-term increase in deposition on inset floodplains. In the long term, increased suspended sediment load from Mowamba (due to cessation of diversion via the aqueduct) would also contribute to increased deposition on benches and inset floodplains	As for option 2.3.1	Slight increase in deposition rates of fine sediment on floodplains (benches) in reach S3 due to greater suspended sediment load from the Mowamba	As for 2.4.1	No real effect on floodplain aggradation	No real effect on floodplain aggradation
Substrate character	Major increase in coarse gravel would be delivered to the Snowy River at the Mowamba River junction	As for option 2.3.1 (remove the weir with daily reductions in flow)	No change in substrate character. While suspended sediment would increase slightly, the effect would be expected to be minor because the overall contribution from the Mowamba River to the larger Snowy River channel would be low. Coarse sediment supply would not change	As for option 2.4.1	Minor increase in fine sediment	Minor increase in fine sediment
Sediment movement	Minor increase in suspended sediment load. Major increase in gravel bedload entering the Snowy pools. Slight decrease in transport rate due to reduced flow peaks	As for option 2.3.1	No change in coarse sediment movement. Minor increase in suspended sediment movement	Minor decrease in coarse sediment movement due to reduced flow peaks	No effect	No effect. Evidence from past investigations (Appendix E) suggest that a flow of 100 ML/day is not sufficient to trigger transport of sand or gravels (at least 1,000 ML/day is required)
Benthic algal assemblage composition	The increase in nutrient concentrations from the Mowamba River might be favourable to green algae compared to diatoms and red algae. Provision of silica could be beneficial to diatoms, but silica is probably not limiting relative to nitrogen and phosphorus	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow) but with reduced effect, because of the lower increase in nutrient concentrations	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)
Benthic algal density	Increased nutrient concentrations would increase benthic algal density. This effect would be partly counteracted by an increase in turbidity and colour, reducing light available for photosynthesis. However, the effect of turbidity would be significant only in higher flows and would have a limited effect because water depth is generally low	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow) but with reduced effect	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)

Environmental variable	Option 2.3.1 – Remove Mowamba Weir with matching daily reduction in Jindabyne releases	Option 2.3.2 – Remove Mowamba Weir with annual average Mowamba flow deducted from Jindabyne releases	Option 2.4.1 – Retain Mowamba Weir but allow all flows to overtop with matching daily reduction in Jindabyne releases	Option 2.4.2 – Retain Mowamba Weir but allow all flows to overtop with annual average Mowamba flow deducted from Jindabyne releases	Option 2.5.1 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with matching daily reduction in Jindabyne releases	Option 2.5.2 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with annual average Mowamba flow deducted from Jindabyne releases
Bench inundation frequency	Given that daily flow targets would remain the same, the effect would be small; however, some minor benches can be wetted at flows above 300 ML/day, and so the increased intra-day variability of Mowamba River flows up to 500 ML/day would slightly increase the inundation of minor benches	Some minor benches can be wetted at flows above 300 ML/day, and so the reduction in flows of this size by the proportions outlined in Table 6 may have a minor effect. However, the passing of flows of up to 500 ML/day from the Mowamba River would partly counteract this effect	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.2 (remove Mowamba Weir with yearly reductions in Jindabyne Dam releases)	Given that daily flow targets would remain the same and the increase in flow would be only up to 100 ML/day, there would be little change	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)
DOC concentration	Increases in concentrations would be expected in the Snowy River. When Mowamba River flows are diverted to Lake Jindabyne, terrestrial Mowamba River DOC will enter the lake food web via bacteria and phytoplankton. The DOC concentration will reduce in the lake and the DOC in Jindabyne Dam releases will be mainly derived from algal exudates and breakdown products. DOC concentrations are constant in Jindabyne releases regardless of release volume (Rohlfs et al. 2016a). Removing Mowamba Weir would pass more allochthonous DOC to the Snowy River, in excess of natural concentrations as represented by DOC concentrations in the Thredbo River. See Appendix F for more detail. With no weir diversion the Mowamba River would pass around 200 tonnes of DOC per annum. With diversions it would be 40 tonnes per annum (Rohlfs et al. 2016b). The effect of this increased contribution would be greatest in reach S2. Further downstream, input from the Snowy River's benches and riparian soils and vegetation would tend to reduce the relative contribution from the Mowamba River	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases), but with reduced effect, because of the lower increase in DOC concentrations	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)

Environmental variable	Option 2.3.1 – Remove Mowamba Weir with matching daily reduction in Jindabyne releases	Option 2.3.2 – Remove Mowamba Weir with annual average Mowamba flow deducted from Jindabyne releases	Option 2.4.1 – Retain Mowamba Weir but allow all flows to overtop with matching daily reduction in Jindabyne releases	Option 2.4.2 – Retain Mowamba Weir but allow all flows to overtop with annual average Mowamba flow deducted from Jindabyne releases	Option 2.5.1 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with matching daily reduction in Jindabyne releases	Option 2.5.2 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with annual average Mowamba flow deducted from Jindabyne releases
Other basal resources including nitrogen, phosphorus and silica	For TN and TP, the effect would be similar to that for DOC, with increased concentrations during higher flows, in excess of natural concentrations as represented by the Thredbo River. The greater the proportion of Mowamba River flow, the higher the concentrations will be. See Appendix F. Concentrations of dissolved nutrients are not as closely linked to flow in the Mowamba River as those of total nutrients. However, concentrations in the Mowamba River are nevertheless higher than in the Thredbo River, possibly because of more intensive land use in the Mowamba River catchment. Silica concentrations in the Mowamba River are higher and more variable than those in the Thredbo River and Jindabyne Dam releases. However, silica may not be limiting to diatom growth given its ratio to phosphorus concentrations	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases), but with reduced effect, because of the lower increase in nutrient concentrations	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)
In-stream plant assemblage composition	Increased nutrients and sediments may promote in-stream plant growth, but there are already extensive plant beds (e.g. *Phragmites*) in the Snowy downstream of the Mowamba River junction. Changes in assemblage composition are expected to be small	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases), but with reduced effect, because of the lower increase in nutrient concentrations	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)
In-stream plant cover	Increased nutrients and sediments may cause a small increase	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases), except that the slight reduction in high flows might reduce vegetation removal slightly	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.2 (remove Mowamba Weir with yearly reductions in Jindabyne Dam releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases), but with reduced effect, because of the lower increase in nutrient concentrations	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)
Riparian plant cover	Little change would be expected because the flow regime would not be appreciably changed	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases), except that the slight reduction in high flows might reduce vegetation removal slightly	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.2 (remove Mowamba Weir with yearly reductions in Jindabyne Dam releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)

Environmental variable	Option 2.3.1 – Remove Mowamba Weir with matching daily reduction in Jindabyne releases	Option 2.3.2 – Remove Mowamba Weir with annual average Mowamba flow deducted from Jindabyne releases	Option 2.4.1 – Retain Mowamba Weir but allow all flows to overtop with matching daily reduction in Jindabyne releases	Option 2.4.2 – Retain Mowamba Weir but allow all flows to overtop with annual average Mowamba flow deducted from Jindabyne releases	Option 2.5.1 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with matching daily reduction in Jindabyne releases	Option 2.5.2 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with annual average Mowamba flow deducted from Jindabyne releases
Riparian plant assemblage composition	Little change would be expected because the flow regime would not be appreciably changed	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)
Thermal regime of river	Modelling by Coleman (2021) found that increased flows from the Mowamba River into the Snowy River result in water temperatures being more similar to those of the Mowamba River and predicted natural Snowy River water temperatures. The modelling shows Mowamba River contributions of 90% or more could bring the Snowy River temperature to within 1°C of the Mowamba River temperature compared to up to 4°C difference with no Mowamba River contribution. Changes towards the modelled natural regime would be seen for mean, minimum and maximum temperatures. As the Snowy River flows towards Dalgety, it would be expected to warm naturally, and the effect of Mowamba River flows would reduce	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases), but with reduced effect, because of the lower Mowamba River contribution	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)
Benthic invertebrate assemblage composition	A minor increase in particulate organic matter might increase the proportion of filter feeders, and a small nutrient-induced increase in algal growth might increase the proportion of grazers, but both effects are likely to be limited	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow), but with reduced effect, because of the lower Mowamba River contribution	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)
Benthic invertebrate density	The slight increase in particulates and algal growth would result in a small increase	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow), but with reduced effect, because of the lower Mowamba River contribution	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)
Benthic invertebrate total abundance	The slight increase in particulates and algal growth would result in a small increase	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow), but with reduced effect, because of the lower Mowamba River contribution	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)

Environmental variable	Option 2.3.1 – Remove Mowamba Weir with matching daily reduction in Jindabyne releases	Option 2.3.2 – Remove Mowamba Weir with annual average Mowamba flow deducted from Jindabyne releases	Option 2.4.1 – Retain Mowamba Weir but allow all flows to overtop with matching daily reduction in Jindabyne releases	Option 2.4.2 – Retain Mowamba Weir but allow all flows to overtop with annual average Mowamba flow deducted from Jindabyne releases	Option 2.5.1 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with matching daily reduction in Jindabyne releases	Option 2.5.2 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with annual average Mowamba flow deducted from Jindabyne releases
Fish assemblage composition	Species sampled since 2000 in the reach from Jindabyne Dam to Dalgety have included introduced brown trout, gambusia and goldfish, native longfin and southern shortfin eels, and stocked Australian bass (NSW DPI–Fisheries data 2021). A small increase in production (see macroinvertebrate density above) might increase fish numbers marginally; however, assemblage composition would be unlikely to change	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)
Fish passage	Little change would be expected in the Snowy River because the flow regime would not change appreciably. There might be greater connectivity between the Snowy River and the Mowamba River (including the section above the current weir), depending on the natural barrier to fish passage caused by the Mowamba River Cascades. A further consideration is that passing all flows to the lower Mowamba River would provide flow cues (in terms of intra-day changes in flow and in the concentration of constituents in the water, such as nutrients) associated with environmental conditions and rainfall events. This change might induce movement of fish between the Snowy River and the Mowamba River	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow); however, with the Mowamba Weir remaining in place, there would be no increase in connectivity to the Mowamba River populations of most species upstream of the weir (although natural barriers may prevent this connectivity anyway)	As for option 2.4.1 (allow all Mowamba River flows to overtop weir with daily reductions in Jindabyne Dam releases)	No change because Snowy River hydrology would not change appreciably and fish passage to the Mowamba River would not increase	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)
Fish total abundance	Minor increase due to increase in invertebrate abundance	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow) but to a lesser extent	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)
Platypus feeding	A small increase in production (see macroinvertebrate density above) might increase food availability marginally	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow)	As for option 2.3.1 (remove the weir with daily reductions in flow), but with reduced effect, because of the lower Mowamba River contribution	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)
Platypus movement	Movement between the upper Mowamba River and Snowy Rivers might increase. No increase in movement in the Snowy River itself would be expected because flows in the Snowy River would not change appreciably	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	No change	No change	No change	No change

Environmental variable	Option 2.3.1 – Remove Mowamba Weir with matching daily reduction in Jindabyne releases	Option 2.3.2 – Remove Mowamba Weir with annual average Mowamba flow deducted from Jindabyne releases	Option 2.4.1 – Retain Mowamba Weir but allow all flows to overtop with matching daily reduction in Jindabyne releases	Option 2.4.2 – Retain Mowamba Weir but allow all flows to overtop with annual average Mowamba flow deducted from Jindabyne releases	Option 2.5.1 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with matching daily reduction in Jindabyne releases	Option 2.5.2 – Retain Mowamba Weir but allow first 100 ML of Mowamba River flows to overtop with annual average Mowamba flow deducted from Jindabyne releases
River–estuary–ocean connectivity	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible
Thermal regime of estuary	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible
Estuarine fish recruitment	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible
Estuarine fish spawning	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible
Estuarine primary production	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible
Estuarine secondary production	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible
Estuary entrance opening duration	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible
Wetland primary production (relating to estuaries)	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible
Wetland secondary production (relating to estuaries)	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible	Effect likely to be negligible
Water colour	DOC causes colours (tannins). Water colour is expected to increase in line with DOC, in proportion to the relative and absolute volumes of Mowamba River flow (higher flows have greater colour)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases), but with reduced effect, because of the lower increase in DOC concentrations	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)
Water turbidity	Water in the Mowamba River is more turbid than water in Lake Jindabyne. Turbidity would increase in proportion to the relative and absolute volumes of Mowamba River flow (higher flows have greater turbidity)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases), but with reduced effect because of the lower Mowamba River contribution	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)
Frog species diversity and abundance	A slight increase in algal growth and detritus could result in a small increase in tadpole density, though likely limited by fish predation	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases)	As for option 2.3.1 (remove Mowamba Weir with matching daily reduction in Jindabyne releases), but with reduced effect because of the lower Mowamba River contribution	As for option 2.5.1 (allow the first 100 ML/day of Mowamba River flows to overtop weir with daily reductions in Jindabyne releases)

Appendix E: Evidence for the geomorphic effect of altered flow and sediment through Mowamba Weir

Environmental objective 2 used by NSW DPE and the SAC (based on Williams 2016), relates to channel morphology and aims to 'develop a more defined river channel within the former river channel'. This appendix relates to that objective.

Here we make some observations about the potential impact of altered flows and sediment supply from Mowamba Weir on the Snowy River. Substantial geomorphic investigations, particularly by Dr Teresa Rose, provide relevant information. The information that is most relevant is (a) the geomorphic work done by altered flows down the Mowamba River, and (b) the influence of additional bedload from removing Mowamba Weir. Particularly relevant (and not yet covered here in detail) is the relative geomorphic effects of a free-flowing Mowamba River against the geomorphic effects of the peak flows that could have been released from Jindabyne but have been foregone due to transfer of 33,710 ML/year of water from Mowamba Weir along the aqueduct (see section 1.8 above).

Geomorphically effective flows in the Snowy River (down to Dalgety)

Rose (2022) (p.52) characterised the geomorphic effectiveness of a range of flows in the Snowy River as follows:

> Whatever flows are released to the Snowy River, if they are at least overbank, they will contribute to channel forming and channel maintenance (Rose 2017). Channel forming flows can occur through eroding the channel boundary to make it deeper and wider. Flows can also deepen the channel through overbank flows depositing sediment vertically onto the banks of the inset floodplains (Rose and Erskine 2011). Channel maintenance flows (flushing flows) are those flows that maintain the channel's dimensions as the boundary is reformed towards a desired endpoint. Channel forming flows that erode the channel and mobilise large sediments require a combination of high peak stream power per unit boundary area, medium to long duration and moderate to large total energy expenditure (Table1 and Table 2; Costa and O'Connor 1995). Channel forming flows by erosion and large sediment mobilisation equate to the most effective flows. Channel maintenance flows, to maintain a reformed channel boundary, equate to the moderately effective flows, and channel forming flows that increase channel depth by depositing sediments vertically onto the banks equate to the less effective flows. (p.52).

She defined the magnitude of these 3 classes of flow:

- The *most* geomorphically effective flows are **channel forming flows** that erode the channel boundary to make it deeper and wider. These flows had a peak discharge ranging from 7,432–11,108 ML/day (86–128.6m^3/s), peak stream power of 97–118 W/m^2 and total energy expenditure of 116,057,980–171,697,106 joules over event durations of 15.8–29 days.
- The *moderately* geomorphic effective flows are **channel maintenance flows** that flush instream sediments to maintain the channel shape created by the channel-forming flows. Channel-maintenance flows had a peak discharge ranging from 2,300–9,416 ML/day (26.6–109m^3/s), peak stream power of 45–108 W/m^2 and total energy expenditure of 28,586,423–79,293,428 joules over an event duration of 12–22 days.

- The *less* geomorphically effective flows are **bank-building flows that deposit sediment onto the banks**. This increases their height and, hence, the depth of the river channel. Bank-building flows had a peak discharge of 1,719–4,768 ML/day (19.9–55.2m^3/s), peak stream power of 36–75 W/m^2 and total energy expenditure of 19,593,117–51,187,260 joules over an event duration of 3–15 days.

Erskine writing in Snowy Scientific Committee (2008) suggested a slightly higher **channel-maintenance flow** than Rose above. He concluded that, and as a rule of thumb, channel-maintenance flows of about 12,000 ML/day should occur every year, and last for about one week during the spring snow melt period. Such flows would ensure all of the following functions:

- gravels are overturned and stripped of biofilms
- substrate sediments are moved and interstitial fines and organic matter are removed so hyporheic flow is not blocked; pool, riffle and run margins (bed and banks) are trimmed of encroaching sediment and vegetation so that channel shrinkage is reversed and aquatic habitat is maintained
- fine sediment infilling pools is totally stripped and replaced with coarser sediment
- pools are scoured and riffles are filled, so maintaining the pool–riffle sequence
- pools are fully mixed by turbulent flows
- marginal bars and benches are inundated and their surficial sediment reworked to reverse recent terrestrialisation of the riparian corridor.

Rose and Haeusler (2004) placed particles on the bed of the Snowy River below the Mowamba River junction to see what flows were required to move them. They concluded that there is little gravel movement below flows of around 100 ML/day, but there is a reasonable likelihood that flow rates in the range given below will initiate movement of freely placed rocks on the riverbed:

- 8–16 mm – 50–150 ML/day
- 16–32 mm – 60–170 ML/day
- 32–64 mm – 60–180 ML/day
- 64–128 mm – 80–230 ML/day
- 128–256 mm – 230–800+ ML/day.

Note that most particles are embedded in the bed and probably require a higher flow than this to initiate movement. These can be considered absolute minimum threshold flows for transport.

Impact of Snowy flows on bench deposition

Rose and Erskine (2011) monitored the amount of sediment deposition on marginal benches in the Jindabyne and Dalgety Uplands reaches of the Snowy River (our reaches S2 and S3) following 3 environmental flows in 2010. Vertical growth of these benches was identified (in that paper) as an important mechanism of 'river recovery' (the premise being that vertical accretion will eventually deepen the channel, increase stream power, and deepen the stream further). Note that these benches can be considered the future 'floodplains' of the new Snowy River that has the 'characteristics of a smaller montane river'.

Using sediment traps, they found that deposition rates were between 0.8 and 7.7 cm per year for flows above about 1,000 ML/day, and the higher the flow above that threshold the greater the deposition. Flows below 1,000 ML/day contributed little deposition. 60% was sand, 40% silts. Interestingly, deposition rates showed little relationship with distance downstream of Jindabyne Dam (we might have expected rates to increase as the area of supply increased). Deposition rates correlate well (and positively) with stream power. The deposition rates from the environmental releases exceeded vertical accretion rates of these benches before the environmental flows were introduced.

This research suggests that (a) flows below about 1,000 ML/day do not contribute much sediment to benches (i.e. new floodplain) deposition, (b) there is sufficient sediment available in reaches S2 and S3 to accrete these benches, even close to the Mowamba River junction. This sediment must be sourced from small tributaries and erosion of the channel. Rose and Erskine do not identify the absence of sediment as a concern in their paper.

From Reinfelds et.al. (2013a, p.22):

> The geomorphic effectiveness of small flow pulse and flood events in facilitating the recovery of the Snowy River below Jindabyne Dam was assessed by Rose and Erskine (2011) who investigated sediment deposition on the developing inset floodplain as a result of three environmental flow releases and one natural tributary flood event during 2010. Their results and those of Williams et al. (2011) show that flow pulses and small floods with peak flow magnitudes ranging from 1,240-3,270 MLd^{-1} are highly effective in scouring silt to sand size sediment from the current Snowy River low flow channel and depositing it onto the inset floodplain developing across the abandoned sections of the pre-regulation Snowy River bed. These relatively small flow pulses produced rapid floodplain sedimentation rates of up to 4.0 cm yr^{-1}, with predictions that future environmental flow releases with exactly the same magnitude and duration as the 2010 events will deposit up to 66 cm of sediment by 2025. Importantly, Rose and Erskine (2011) cautioned that release of larger floods may exceed thresholds for floodplain deposition and cause floodplain stripping and re-working, thereby slowing or reversing the positive river recovery trajectory achieved by the relatively small flow pulses released in 2010.

How much sediment will removing Mowamba Weir introduce into the Snowy River?

Jindabyne Dam traps over 99% of the incoming suspended sediment load from upstream sources and 100% of the bedload (Rose 2017; Erskine et al. 1999b). One of the rationales for removing Mowamba Weir is to allow all sediment from the river to enter the Snowy and replace a proportion of the sediment lost to Jindabyne. The proposals for altering flows from Mowamba Weir involve allowing all flows to pass over the weir (and various iterations of this option), or removing the weir. How will these options alter sediment supply to the Snowy River? We do not consider the effect of the temporary pulse of sediment that would come from widening of the Mowamba River, or from the sediment stored in the weir pool. We are interested in the long-term contribution from the catchment.

Mowamba Weir presently traps all gravels and bedload entering the weir but allows a proportion of suspended sediment to pass over the wall. The effect on suspended sediment depends on the trap efficiency of the weir. The trap efficiency of a reservoir is usually estimated empirically as a ratio of the annual inflow to the reservoir volume. The volume of Mowamba Weir is estimated to be 21,000 m^3 (estimated from data in Brooks et.al. 2018), and the median annual flow of the river is about 50 ML/day. Using any of a range of methods described in the literature the weir will have low trap efficiency for fine sediment that enters the reservoir in suspension (certainly less than 10%). The larger the flow through the weir the greater the proportion of fine sediment that will be transported over the wall. The vast majority of sediment will be transported in high flows that pass over the wall. We are concerned here with the proportion of suspended sediment that is diverted into the aqueduct by flows below 500 ML/day.

We can roughly estimate the amount of sediment diverted from the Mowamba River into the aqueduct using data from Coleman and Williams (2017). They explored suspended sediment loads during 5 environmental floods in the Snowy River. They established a monitoring site on the Mowamba River upstream of the weir. The Mowamba River did not experience any floods, but flows varied from 69–216 ML/day, providing some idea of the suspended sediment loads being carried at flows below 500 ML/day. Load increased with discharge, with a flow of 100 ML/day (the mean diverted flow from Mowamba) carrying about 1.8 tonnes of sediment a day (Figure 39), and this would likely increase to 4–5 tonnes per day at flows around 500 ML/day. Thus, diverting this into the Snowy River would provide an increase in suspended load. This load can be compared with the load carried by a small flood past the Mowamba–Snowy junction (site S1 in Coleman and Williams), which carried 5–10 times the sediment load of the Mowamba flows. Larger floods carried over 100 times the load. Perhaps more important, the amount of suspended load mobilised as the flood moves downstream quickly eclipses the contribution of suspended sediment from the Mowamba River (Figure 40). For example, Caitcheon et al. (1991) identified Wullwye Creek, which joins the Snowy River at the upstream of Dalgety, as the single largest contributor of sediment to the entire Snowy River. These results mean that (a) relative to environmental floods down the Snowy River, flows in the Mowamba River (below 500 ML/day) divert several tonnes of sediment a day, providing important base-load sediment into the Snowy, (b) during floods, contributions from the Mowamba River would be quickly exceeded by local sources produced as the flood moves downstream.

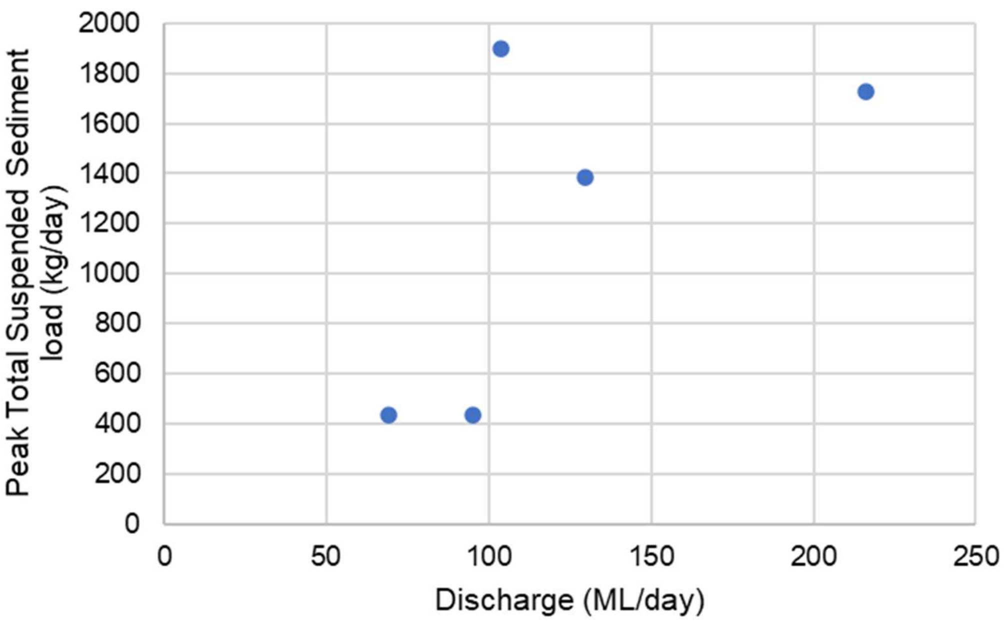


Figure 39: Suspended sediment load versus discharge for the Mowamba River upstream of the weir From Coleman and Williams (2017).

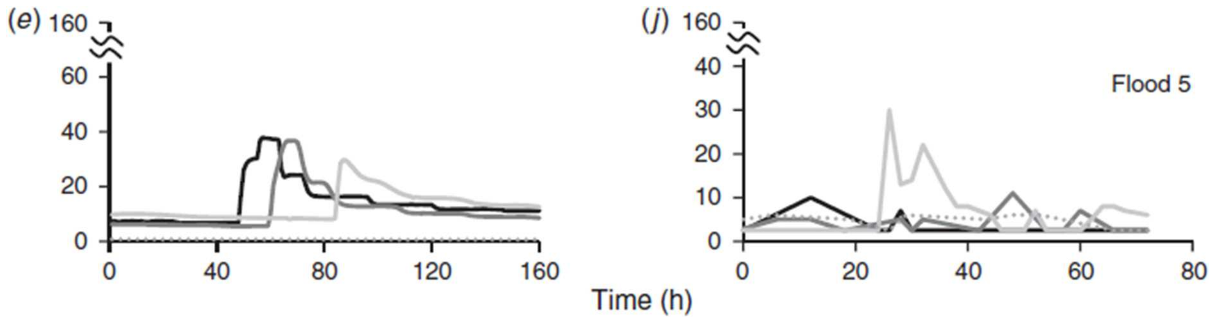


Figure 40: Example of a flood wave moving down the Snowy River (figure e) and the peak in suspended sediment at the most downstream site (Burnt Hut Gorge)
From Coleman and Williams (2017).

No coarse sediment passes through the Jindabyne Dam and the river is starved of coarse sediment. Gravels are important for the goal of re-establishing a new montane river morphology. The Mowamba is the largest tributary to join the Snowy above the Delegate River and it could be a source of coarse sediment if the weir wall was removed. However, we note that the Mowamba River makes up around 2% of the catchment area of Lake Jindabyne, so by any measure the contribution of sediment from Mowamba cannot compensate for the loss of sediment from that catchment area. We assume that all coarse sediment transported into Mowamba Weir is trapped (there is no way for it to pass the wall). We also understand that the weir is occasionally 'cleared out'. It is not entirely clear what this process involves. Earlier we estimated that the weir pool holds around 25,000 m^3 (40,000 tonnes) of sediment at present; however, it is also clear that the weir has not filled to the crest with coarse sediment. This suggests that the bed load is not huge. If we assume that the sediment has accumulated over 10 years, then that suggests bed load of say, 2,500 m^3 per year. This would be a substantial load of gravel passing into the Snowy River (equivalent to a bar 50 x 50 x 1 m). There is no doubt that this would assist in the development of specific bed features (mid-channel bars, riffles and point bars), and in the maintenance of features over time. However, there are many other short, but steep tributaries in the Jindabyne Gorge delivering coarse load to the Snowy River. Evidence for this are the substantial tributary bars formed at the mouth of tributaries such as Sugarloaf, Devils Hole and Iron Pot creeks.

A key point to recall is that the dominant geomorphic processes that are the target of the artificial flow regime is erosion of the contracted channel; nevertheless, in the long term the bedload supply from the Mowamba catchment would be useful.

Can flows released from Jindabyne transport the gravels entering from Mowamba?

Reinfelds and Williams (2008) estimated threshold shear stress required to move gravels on riffles at 3 sites on the Snowy River. At the riffles immediately below the Mowamba River junction the modelling suggests that flows of 1,000–3,000 ML/day are sufficient to entrain the d50 particle size by a comfortable margin under the Neill (1968) dimensionless shear stress threshold of 0.03 but would be at about the entrainment threshold under a dimensionless shear value of 0.06. However, much larger flows are required to maintain gravel transport through pools onto riffles. They also concluded that the maximum environmental flow requirement flushing flow of 12,000 ML/day as noted in the 'Draft

Methods for Hydrology' document (DLWC, unpublished), as well as the pre-regulation 90% exceedance probability annual flood of 16,388 ML/day, were insufficient to induce velocity reversal in the Snowy River downstream of the Mowamba River. This reversal is required to move sediment through pools and onto riffles. They drew roughly the same conclusions for their site in the Dalgety Uplands (our reach S3). We do not know the grain size of material transported out of the Mowamba River but it is unlikely to be coarser than the gravels in the Snowy now. Thus, we conclude that the gravels from Mowamba will only very gradually move through the long pools below the junction with the Snowy and transport downstream if Mowamba is opened.

Evidence provided by the 2002–2006 Mowamba flow period

We have a basis for predicting the geomorphic impact of removing Mowamba Weir. Between 29 August 2002 and 31 January 2006 the Mowamba River was the primary mechanism for providing SRIF while works to enable delivery of these flows from Jindabyne Dam were being undertaken. Assessment of the geomorphic changes during this period of flows provides some useful insights into the geomorphic effects of modifying flows from the Mowamba River into the future. Note however that environmental flows from Jindabyne mean that the situation today is considerably different than in 2002.

The 2002–2006 flow period does not, of course, mimic the removal of the weir, so no coarse sediment passed into the Snowy River from the Mowamba River during this period. Instead, this reflects the option to allow all flow to overtop the weir and pass downstream. The effects of this period of flow were documented in detail by Rose in her PhD thesis (2017) (see chapter 3 of the thesis) and in a report to the NSW Office of Water in 2010. She focused on the effect of the highest flow from the Mowamba River in this period in August 2002. The flow event from the Mowamba River commenced in August 2002 and continued for 119 days, with an average baseflow of 43 ML/day, and largest instantaneous peak of 500 ML/day. This equated to a 1.1-year ARI flood post Jindabyne at the time, so Rose calls this an 'experimental flood' as it exceeded the bankfull capacity of the Snowy River. However, in terms of the natural flow in the Snowy River this was a small flow (recall that post-dam, the Snowy channel contracted and shallowed, and the riffles became in-filled with fine sediment). Note that this has some relevance to this present study because all flows under 500 ML/day are presently diverted into the aqueduct from the Mowamba River. The experimental release from the Mowamba River was followed by a larger flood peak post-bushfire in March 2003 (6,400 ML/day).

Geomorphic effects of the flood were monitored at 4 sites: 2 in the valley confined Jindabyne Gorge (sites 1 and 2) (our reach S2) and 2 in the valley partly-confined Dalgety Uplands (sites 3 and 4) (our reach S3).

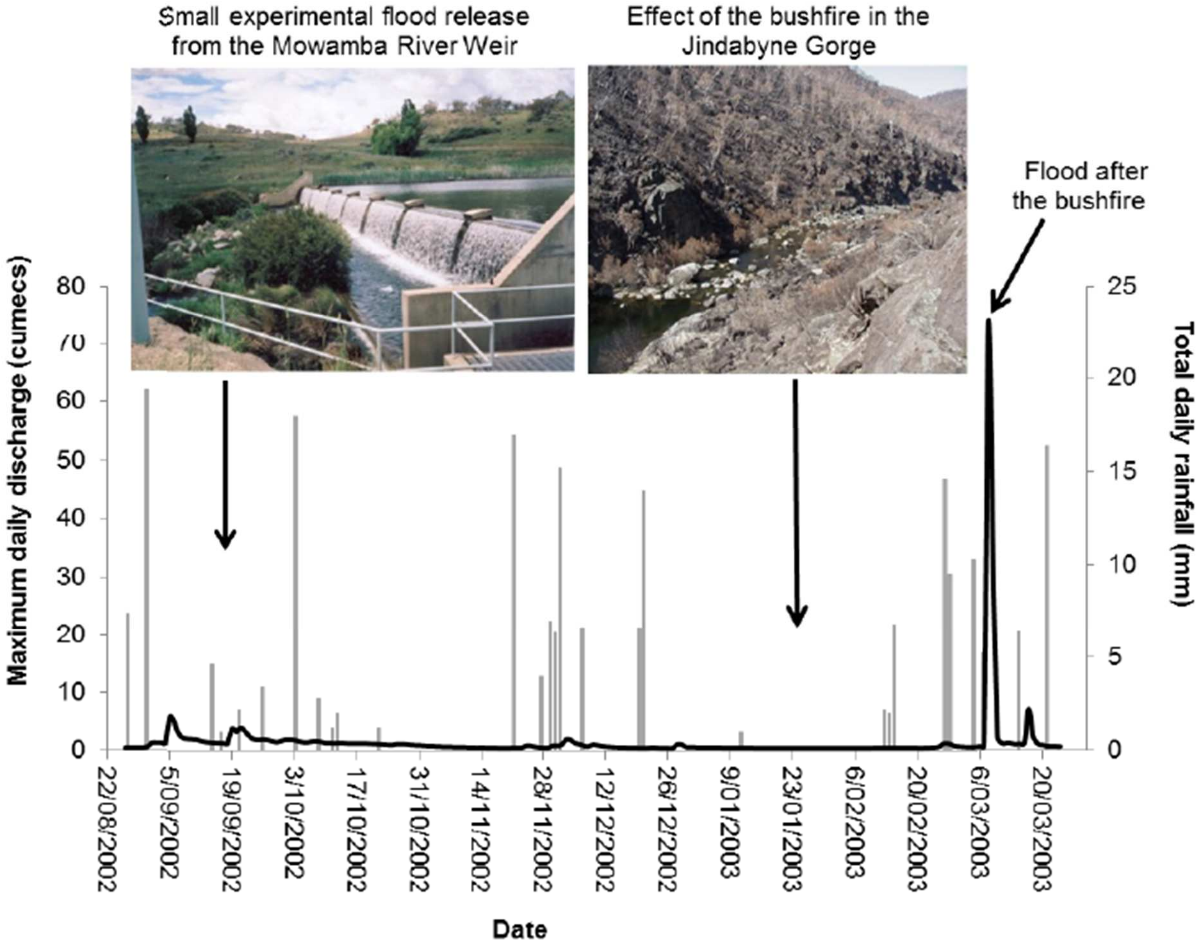


Figure 41: Hydrograph of the August 2002 small experimental flood and bushfire flood at gauge 222026 Snowy River at Dalgety Weir including the rainfall recorded at gauge 71021 (Figure 3.1 from Rose 2017)

Rose found it difficult to disentangle the geomorphic effects of the first experimental release from the Mowamba River from the much larger post-bushfire flood. Nevertheless, it is possible to conclude that the effect of the 2002 releases were modest and could be considered negative in relation to the recovery objectives that Rose defined for these reaches. A key objective was to erode the artificially contracted channel, flush riffles of fine sediment, and return conveyance and gravel substrate. The dominant geomorphic process or processes in the Jindabyne Gorge and Dalgety Uplands, based on the percentage change from the experimental flood in 2002, were decreased conveyance capacity of riffles (36%) in the Jindabyne Gorge, and pools (14%) and riffles (19%) in the Dalgety Uplands. There were some improvements in the conveyance of runs. Overall, this flow led to narrowing and shallowing of the channel. Nonetheless, Rose emphasises that the flow was geomorphically effective in that it did move sediment and produce minor erosion. The post-fire flood (2003) was much more geomorphically effective, producing 5–10% widening and deepening. Most sites became muddier after the floods, mostly because of high erosion rates from the fire.

These changes have to be seen in context. These flows were being released into a channel that was artificially contracted, and clogged with sediment. Rose concludes that '*The experimental flood in 2002 was 119 days long with a peak stream power of only 2.2 W/m^2…. It was not sufficiently powerful to perform any positive geomorphic work that was more than just a measurable 1% change …. The post-bushfire flood in 2003 was 2.7 days long with* *a peak stream power of 17.1 W/m^2 …. [The bushfire flood] had a peak stream power value nearly eight times larger [than the 2002 Mowamba release] and was able to perform the most and largest positive morphological changes. This suggests that higher values of peak stream power are important for relatively small floods.*' (p.77). Rose (2010) concludes ' *flows of greater magnitude than the first flow release [2002 from Mowamba] and the natural flows that occurred during the sampling period are required to induce significant increases in channel width, thalweg deepening, grain size coarsening, improved sorting, flushing of fines and bed-material transport'.* Note that the post-bushfire flood had a peak discharge of about 6,400 ML/d, which is comparable with the small environmental flow peaks released from Jindabyne in recent years.

From this analysis, we conclude that flow smaller than 500 ML/day that would be released from a translucent Mowamba Weir would not produce substantial (and positive) geomorphic change in the Snowy River down to Dalgety on its own. Also critical (but not covered in this report) would be the corresponding decrease in geomorphically effective floods that could no longer be released from Jindabyne if Mowamba Weir was removed. Another key point is that, since the 2002 release, the Snowy has experienced long periods of higher environmental releases from Jindabyne that have succeeded in expanding the constricted channel. We suspect that sub-500 ML/day flows from Mowamba would be even less geomorphically effective than they were in 2002 if they were not combined with environmental flow releases from Jindabyne (as they would be now). With increased flow flexibility Jindabyne releases could be piggy-backed with Mowamba peaks.

Conclusion

Overall, the Mowamba River releases in 2002 have some relevance for this investigation. The options for the Mowamba Weir relate to adding flows from 1.3 ML/day up to 500 ML/day (i.e. the range of flows now being diverted to the aqueduct). The 2002 events demonstrate that, on their own (up to a flow of 500 ML/day), Mowamba River flows will have little geomorphic impact on the Snowy River, especially if the weir stays in place and no additional sediment is contributed by the Mowamba River. The sediment contribution is critical for this investigation. The differences between the 2002 Mowamba River flows and the present investigation are (a) any additional flows from the Mowamba River (0–500 ML/day) will be combined with Jindabyne flows, (b) the Snowy channel has been modified by a series of larger environmental releases from Jindabyne.

Appendix F: Nutrient concentrations for the Snowy River below Mowamba River junction and Mowamba and Thredbo rivers

Analysis from nutrient data collected for DOC and nutrients based on data collected by Rohlfs, Mitrovic and Williams.

The figures below show that average nutrient concentrations for DOC, TN, TP and silica were greater in the Mowamba River than the Thredbo River reference site and other sites.

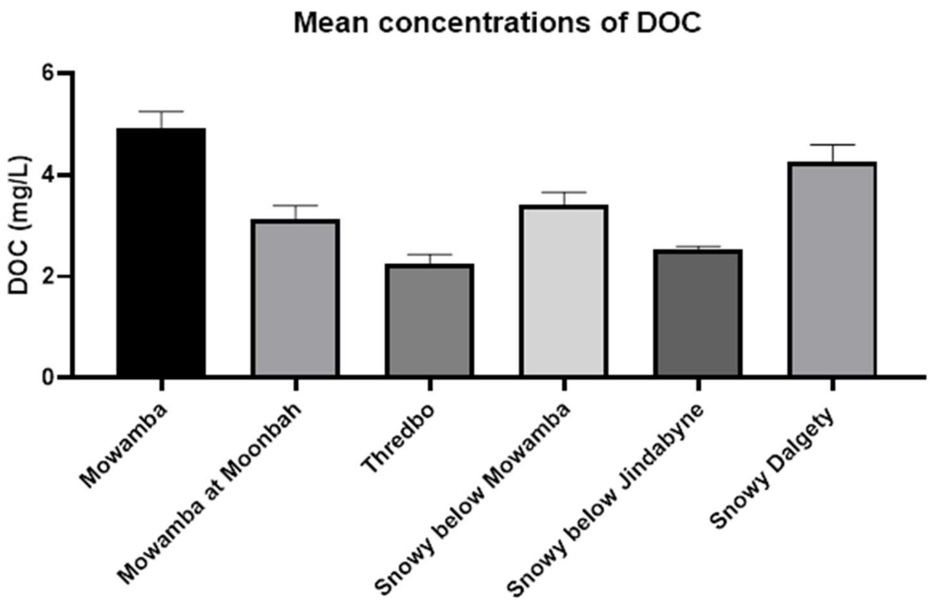
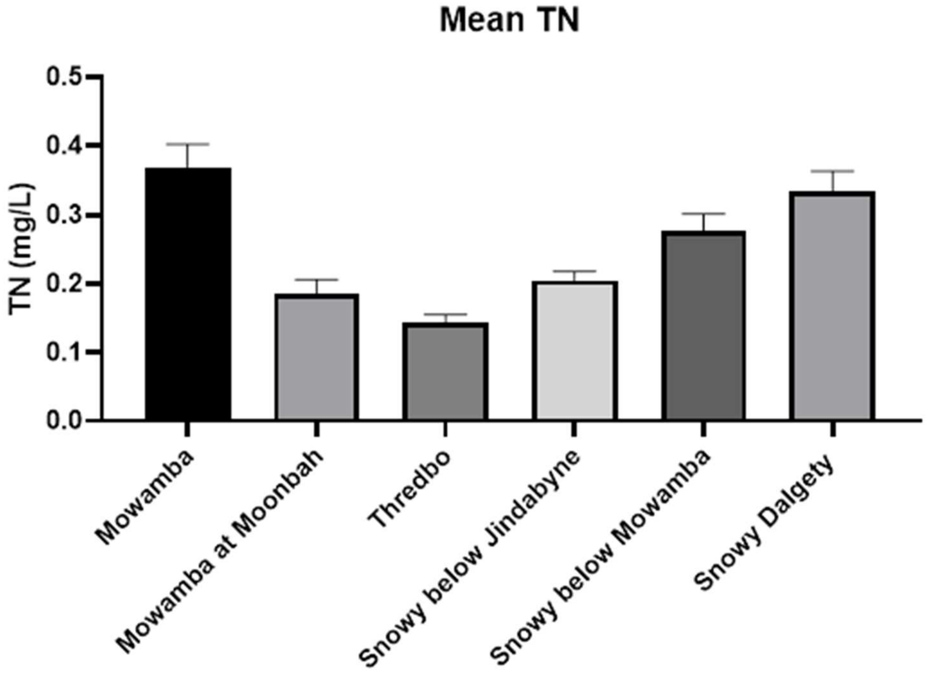


Figure 42: Mean DOC concentrations for different sites

Error bars are standard error.



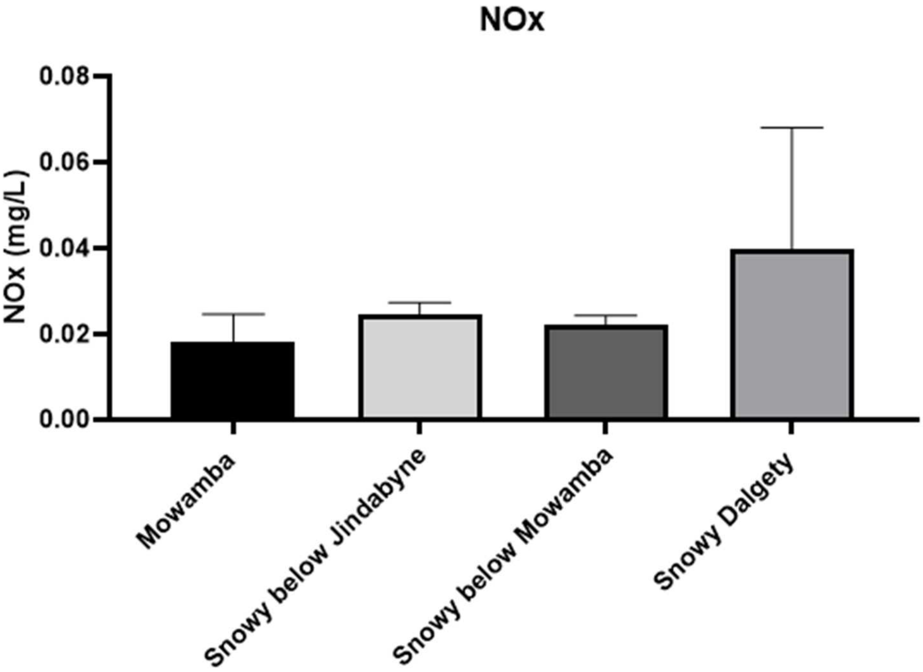
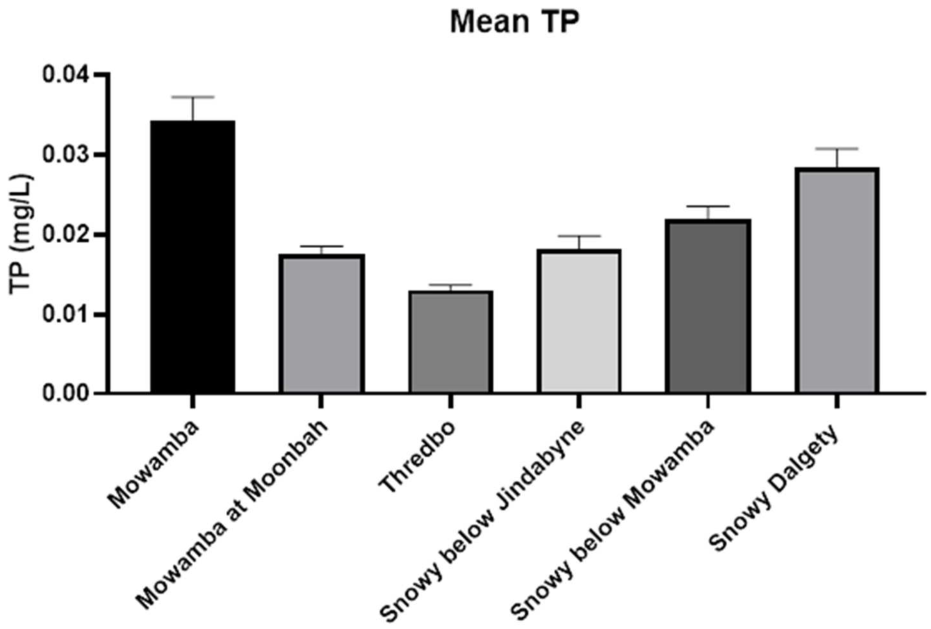


Figure 43: Mean TN (top) and nitrate/nitrite (NOx) (bottom) concentrations for different sites
Error bars are standard error.



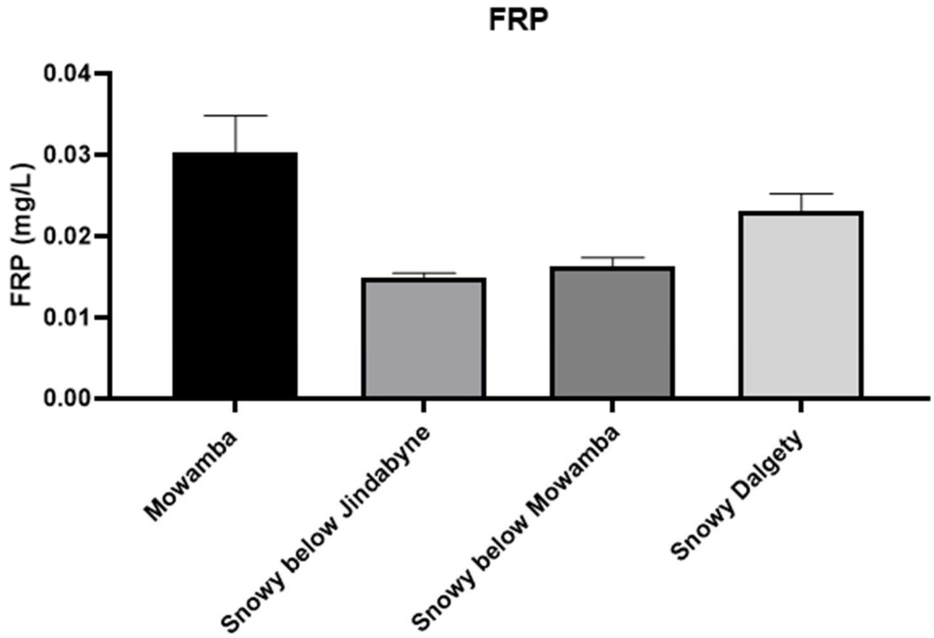


Figure 44: Mean TP concentrations (top) and filterable reactive phosphorus (bottom) for different sites
Error bars are standard error.

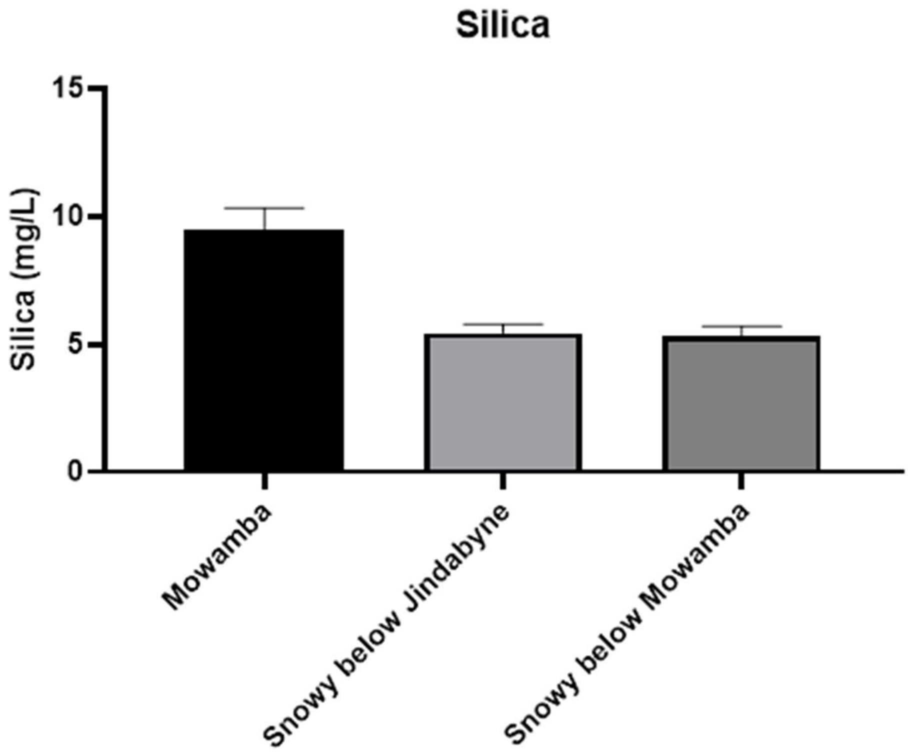


Figure 45: Mean silica concentrations for different sites

Figure 46 shows the DOC, TN and TP concentrations and their relationships to increased discharge. There was no relationship between nutrient concentration and discharge in the Snowy River upstream of the Mowamba confluence (data not shown) and very little change in DOC concentrations during flow releases from Jindabyne (Rohlfs et al. 2012).

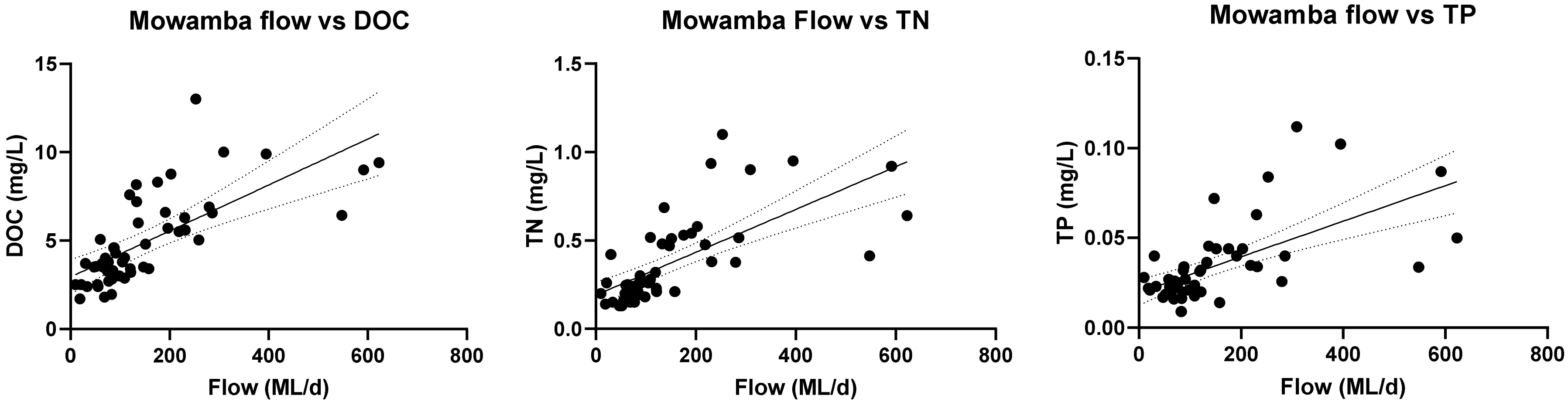


Figure 46: Nutrient concentrations versus flow (ML/day) in the Mowamba River upstream of Mowamba Weir for DOC, TN and TP from data from Rohlfs et al. 2012
Graphs supplied by Simon Mitrovic.

Concentrations predicted in the Snowy River downstream of the Mowamba River junction for different options for passing Mowamba River flows are provided in Table 17 for DOC, TN and TP based on the relationships with flow in Figure 46.

Table 17: DOC concentrations (mg/L) predicted in the Snowy River downstream of the Mowamba River junction for different options for passing flows downstream of Mowamba Weir

		All Mowamba flows passed (options 2.3 and 2.4)		First 100 ML of Mowamba flow passed (option 2.5)	
	Do-nothing option	**Jindabyne releases reduced by *annual* average Mowamba flow[31]**	***Daily* Jindabyne release reduced by daily Mowamba flow; daily targets reduced by 3%[32]**	**Jindabyne releases reduced by *annual* average Mowamba flow[33]**	***Daily* Jindabyne release reduced by daily Mowamba flow; daily targets reduced by 2%[34]**
Mean	2.69	3.22	3.33	3.05	3.06
Median	2.53	2.81	2.80	2.78	2.79
75th %ile	2.53	3.15	3.21	3.03	3.09
90th %ile	2.54	3.91	4.28	3.44	3.61
95th %ile	2.58	4.97	5.91	3.83	4.02

Equations used (based on data from Rohlfs et al. (2012)):

- Jindabyne release DOC concentration = 2.5 mg/L (did not vary with discharge)
- Mowamba release DOC concentration = (0.01300*X + 2.943) mg/L, where X = Mowamba discharge in ML/day (combined Mowamba Aqueduct and Pats Patch gauges).

[31] The annual Jindabyne release is reduced by the average annual additional Mowamba River contribution. Daily flow targets from Jindabyne reduced by a constant percentage on all days but flows are maintained at a minimum of 40 ML/day. Flows above 2,000 ML/day are not reduced. See section 2.3.2 for details.

[32] Releases from Jindabyne were reduced by the daily additional flow from the Mowamba River. However, Jindabyne releases were not reduced below 40 ML/day. Daily release targets for the Snowy (from Jindabyne and Mowamba increased releases combined) were reduced by 3% except for days that were less than 150 ML/day (these lower flow days were not reduced to protect low flows). See section 2.3.1 for details.

[33] As for footnote 31. See section 2.5.2 for details.

[34] As for footnote 32, except the reduction in release targets for the Snowy (from Jindabyne and Mowamba increased releases combined) is 2%. See section 2.5.1 for details

Table 18: TN concentrations (mg/L) predicted for the Snowy River downstream of the Mowamba River junction for different options for passing flows downstream of Mowamba Weir

		All Mowamba flows passed (options 2.3 and 2.4)		**First 100 ML of Mowamba flow passed (option 2.5)**	
	Do-nothing option	**Jindabyne releases reduced by *annual* average Mowamba flow**[31]	***Daily* Jindabyne release reduced by daily Mowamba flow; daily targets reduced by 3%**[32]	**Jindabyne releases reduced by *annual* average Mowamba flow**[33]	***Daily* Jindabyne release reduced by daily Mowamba flow; daily targets reduced by 2%**[34]
Mean	0.21	0.25	0.26	0.24	0.24
Median	0.20	0.21	0.21	0.21	0.21
75th %ile	0.20	0.24	0.24	0.23	0.24
90th %ile	0.20	0.31	0.33	0.27	0.28
95th %ile	0.20	0.40	0.48	0.30	0.32

Equations used (based on data from (Rohlfs et al. 2012)):

- Jindabyne release TN concentration = 0.2 mg/L (did not vary with discharge)
- Mowamba release TN concentration = (0.001210*X + 0.1913) mg/L, where X = Mowamba discharge in ML/day (combined Mowamba Aqueduct and Pats Patch gauges)

Table 19: TP concentrations (mg/L) predicted for the Snowy River downstream of the Mowamba River junction for different options for passing flows downstream of Mowamba Weir

		All Mowamba flows passed (options 2.3 and 2.4)		**First 100 ML of Mowamba flow passed (option 2.5)**	
	Do-nothing option	**Jindabyne releases reduced by *annual* average Mowamba flow**[31]	***Daily* Jindabyne release reduced by daily Mowamba flow; daily targets reduced by 3%**[32]	**Jindabyne releases reduced by *annual* average Mowamba flow**[33]	***Daily* Jindabyne release reduced by daily Mowamba flow; daily targets reduced by 2%**[34]
Mean	0.021	0.024	0.025	0.023	0.023
Median	0.020	0.021	0.021	0.021	0.021
75th %ile	0.020	0.023	0.024	0.023	0.023
90th %ile	0.020	0.029	0.031	0.026	0.027
95th %ile	0.020	0.037	0.043	0.029	0.030

Equations used (based on data from (Rohlfs et al. 2012)):

- Jindabyne TN release concentration = 0.02 mg/L (did not vary with discharge)
- Mowamba TN release concentration = (0.00009919*X + 0.01962) mg/L, where X = Mowamba discharge in ML/day (combined Mowamba Aqueduct and Pats Patch gauges)

Appendix G: Method for scaling Thredbo River daily flows to match available allocations for the Snowy River

Step 1 – determining daily allocations

Allocations for Snowy River release are made for the entire year. To determine daily allocations we used the following method for the purposes of analysis.

The average yearly proportion of flow in each month was determined from the 38-year Thredbo River flow record (e.g. May had on average 5% of the yearly flow). For each year the allocation available for release (i.e. SRIF plus Jindabyne BPF) was divided into monthly allocations according to these proportions. Daily flow allocations were then calculated by dividing the monthly allocation by the days in the month.

Step 2 – determining the scaling required

Initially the Snowy River release was matched to the Thredbo flow without scaling (i.e. the Jindabyne release equals the Thredbo flow). From day 2 of the year onwards, the accumulated difference between the Thredbo flow and daily allocations was calculated.

When the accumulated differences between the daily allocations and Thredbo flows became too great, scaling began.

When releases exceeded allocations

When the accumulated exceedance of available allocation was more than 3 times the daily allocation, the Thredbo flow was scaled down for the next day to 90% of its volume. When the size of the accumulated difference increased, the scaling factor became stronger in the pattern shown in Table 20.

When allocations exceeded releases

When the accumulated undelivered allocation was more than 3 times the daily allocation, the release was scaled up for the next day to be 120% of the Thredbo flow. When the size of the accumulated undelivered allocation increased, the scaling factor became stronger in the pattern shown in Table 20.

Table 20: Scaling factors used for matching Snowy River releases to Thredbo River flows

Accumulated difference between Snowy releases and daily allocation	Scaling of Snowy release when releases exceed allocation (over-release of allocations is accumulating)	Scaling of Snowy release when allocation exceeds releases (under-release of allocations is accumulating)
>3 times daily allocation	90% of Thredbo daily flow	120% of Thredbo daily flow
>6 times daily allocation	80% of Thredbo daily flow	140% of Thredbo daily flow
>8 times daily allocation	70% of Thredbo daily flow	160% of Thredbo daily flow
>10 times daily allocation	60% of Thredbo daily flow	180% of Thredbo daily flow
>12 times daily allocation	50% of Thredbo daily flow	200% of Thredbo daily flow
>14 times daily allocation	40% of Thredbo daily flow	220% of Thredbo daily flow
>16 times daily allocation	30% of Thredbo daily flow	240% of Thredbo daily flow
>10,000 ML	NA	300% of Thredbo daily flow

Appendix H: Flow statistics for flow options

Flow statistics for the following options are provided below.

'Status quo' (the 'do-nothing' option): This is the scenario whereby SRIF flows are delivered using the current methods (the 'natural flow scaling approach' (Reinfelds et al. 2013a; see section 1.10)) and the Mowamba Aqueduct diverts flows from the Mowamba River at its full capacity. The data used are the observed flows in the Snowy River at Cobbins Crossing (2013–2021) plus the flow contribution from Mowamba River as measured at Pats Patch. Dates where the Mowamba Aqueduct was closed were not used, as during these dates additional flows were passed down the Mowamba River that would have been diverted by the aqueduct under the do-nothing (aqueduct always diverting) scenario. They are also not used because we cannot determine what the Jindabyne planned release on those days would have been if the aqueduct was diverting.

Full Mowamba flow passed with daily Jindabyne adjustment: This is the flow expected for the options of removing the weir or for retaining the weir but allowing all flows to pass, where Jindabyne releases are adjusted on a daily basis to account for the increased Mowamba River flows (options 2.3.1 and 2.4.1). Mowamba flows are the combined flows at Pats Patch and the Mowamba Aqueduct gauges. The Jindabyne release is an adjustment to the do-nothing scenario daily discharges as outlined under option 2.3.1; that is, the release is reduced by 3% and then the additional flow of the day in the Mowamba River (the Mowamba Aqueduct flow) is deducted from the Jindabyne release. Jindabyne releases are not reduced below 40 ML/day and reductions were not made where the flow in the Snowy River below the Mowamba River junction would fall below 150 ML/day.

Full Mowamba flow passed with annual Jindabyne adjustment: This is the flow expected for the options of removing the weir or for retaining the weir but allowing all flows to pass, where Jindabyne releases are reduced from the do-nothing scenario by the annual average increased Mowamba River flow (options 2.3.2 and 2.4.2). Mowamba flows are the combined flows at Pats Patch and the Mowamba Aqueduct gauges. Note that the annual reduction in Jindabyne flows is apportioned across each day of the year; however, Jindabyne releases are not reduced below 40 ML/day and releases above 2,000 ML/day are also not reduced.

First 100 ML/day of flow passed with daily Jindabyne adjustment: This is the flow expected for the option of retaining the weir but allowing the first 100 ML/day of Mowamba Aqueduct diversions to pass, where Jindabyne releases are adjusted on a daily basis to account for the increased Mowamba River flows (option 2.5.1). Mowamba River flows are the combined flows at Pats Patch gauge and the first 100 ML/day of Mowamba Aqueduct gauged flow. The Jindabyne release is an adjustment to the do-nothing scenario daily figures as outlined under option 2.5.1; that is, the release is reduced by 2% and then the additional flow of the day in Mowamba River (the first 100 ML/day of Mowamba Aqueduct flow) is deducted from the Jindabyne release. Jindabyne releases are not reduced below 40 ML/day and reductions are not made where the flow in the Snowy River below the Mowamba River junction would fall below 150 ML/day.

First 100 ML/day of flow passed with annual Jindabyne adjustment: This is the flow expected for the option of retaining the weir but allowing the first 100 ML/day of Mowamba Aqueduct diversions to pass, with Jindabyne releases reduced from the do-nothing scenario by the annual average increased Mowamba River flow (option 2.5.2). Mowamba River flows are the combined flows at Pats Patch gauge and the first 100 ML/day of Mowamba Aqueduct gauged flow. Note that the annual reduction in Jindabyne flows is apportioned across each day of the year; however, Jindabyne releases are not reduced below 40 ML/day and releases above 2,000 ML/day are also not reduced.

Mowamba status quo with Jindabyne release synchronised and scaled to Thredbo flow: Jindabyne releases are based on Thredbo flows at Paddys Corner from 2013–2021. We scaled these Thredbo flows using the method outlined in section 3.2.2 and Appendix G based on actual SRIF allocations for those years. Jindabyne releases were timed to align with the Thredbo flow of the previous day. Mowamba River flows were those used for the status-quo scenario outlined above.

Calculation of flow statistics

Daily flow series for the Mowamba River at Pats Patch and the Snowy River downstream of the Mowamba River junction were constructed for each scenario as described above for the period 1 May 2013 to 30 April 2021. For comparison, flow series were also tabulated for the Thredbo River at Paddys Corner over the same period, and for the Snowy River at Jindabyne for the period 25 May 1902 to 4 May 1967, prior to the completion of the Snowy Mountains Scheme and the closure of Jindabyne Dam. These series were used to calculate the following flow statistics relevant to the SWIOID and Williams (2016) environmental objectives:

- annual mean daily discharge (ML)
- mean daily discharge in autumn (ML)
- mean daily discharge in winter (ML)
- mean daily discharge in spring (ML)
- mean daily discharge in summer (ML)
- ratio of mean daily discharge in winter to mean daily discharge in summer – a measure of flow seasonality
- ratio of mean daily discharge in spring to mean daily discharge in autumn – a measure of flow seasonality
- coefficient of variation (CV) of daily discharge – a measure of flow variability over the whole period of record
- average ratio of discharge on one day to discharge on the previous day when the stream level rose from the earlier day to the later day (rising stage) – a measure of flow variability from one day to the next
- average ratio of discharge on one day to discharge on the previous day when the stream level fell from the earlier day to the later day (falling stage) – a measure of flow variability from one day to the next.

Results of these analyses are presented in Table 21.

Table 21: Flow statistics for the Mowamba River at Pats Patch and the Snowy River downstream (d/s) of the Mowamba River junction under various scenarios
For comparison, statistics are also provided for the pre-Scheme Snowy River at Jindabyne and the Thredbo River at Paddys Corner.

Location	Scenario	Mean daily discharge (ML)	Autumn mean daily discharge (ML)	Winter mean daily discharge (ML)	Spring mean daily discharge (ML)	Summer mean daily discharge (ML)	Winter/ summer ratio	Spring/ autumn ratio	CV of daily discharge	Average consecutive day ratio rising stage	Average consecutive day ratio falling stage
Mowamba Pats Patch	Status quo	14	5	27	17	9	3.10	3.69	7.24	9.62	0.91
Mowamba Pats Patch	Full Mowamba flow passed	100	51	143	143	63	2.28	2.78	1.51	1.56	0.88
Mowamba Pats Patch	First 100 ML/day of Mowamba flow passed	71	44	96	93	51	1.87	2.11	1.45	1.53	0.89
Snowy d/s Mowamba junction	Status quo	439	158	480	816	254	1.89	5.17	1.07	1.36	0.87
Snowy d/s Mowamba junction	Full Mowamba flow passed with daily Jindabyne adjustment	433	163	475	796	255	1.86	4.89	1.05	1.37	0.87
Snowy d/s Mowamba junction	Full Mowamba flow passed with annual Jindabyne adjustment	430	163	490	773	251	1.95	4.73	1.06	1.33	0.87
Snowy d/s Mowamba junction	First 100 ML/day of flow passed with daily Jindabyne adjustment	432	160	471	800	252	1.87	5.02	1.06	1.37	0.87

Location	Scenario	Mean daily discharge (ML)	Autumn mean daily discharge (ML)	Winter mean daily discharge (ML)	Spring mean daily discharge (ML)	Summer mean daily discharge (ML)	Winter/ summer ratio	Spring/ autumn ratio	CV of daily discharge	Average consecutive day ratio rising stage	Average consecutive day ratio falling stage
Snowy d/s Mowamba junction	First 100 ML/day of flow passed with annual Jindabyne adjustment	437	170	485	788	261	1.86	4.62	1.03	1.31	0.88
Snowy d/s Mowamba junction	Mowamba status quo with real-time Jindabyne adjustment	429	231	429	762	297	1.45	3.30	1.17	1.59	0.86
Snowy Jindabyne	Actual 1902–1967 (pre-Snowy Scheme)	3,015	1,554	2,892	5,976	1,637	1.77	3.85	1.27	1.42	0.87
Thredbo Paddys Corner	Actual 2013–2021	452	257	500	797	254	1.97	3.09	0.97	1.60	0.88