Modelling management options that improve streamflow pattern within the Barossa Prescribed Water Resources Area

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81-95 Waymouth St, ADELAIDE SA 5000
Telephone +61 (8) 8463 6946
Facsimile +61 (8) 8463 6999
ABN 36702093234

www.environment.sa.gov.au

Report prepared by:

Kumar Savadamuthu and Daniel McCullough
Water Science Unit
Water, Science and Monitoring Branch
Water and River Murray Division
Department for Environment and Water

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Foreword

The Department for Environment and Water (DEW) is responsible for the management of the State's natural resources, ranging from policy leadership to on-ground delivery in consultation with government, industry and communities.

High-quality science and effective monitoring provide the foundation for the successful management of our environment and natural resources. This is achieved through undertaking appropriate research, investigations, assessments, monitoring and evaluation.

DEW's strong partnerships with educational and research institutions, industries, government agencies, Landscape Boards and the community ensures that there is continual capacity building across the sector, and that the best skills and expertise are used to inform decision making.

John Schutz
CHIEF EXECUTIVE
DEPARTMENT FOR ENVIRONMENT AND WATER

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Contents

List of figures

List of tables

1 Summary

This technical report presents the methodology and results of the modelling undertaken to investigate a selection of possible management options to improve streamflow within the Barossa Prescribed Water Resources Area. This investigation is a continuation of prior work undertaken by the Department for Environment and Water (DEW) (DEWNR Technical Report 2014/14 and DEW-TR-2022-13) to inform the review of the Water Allocation Plan for the area.

The modelling has been undertaken in the context of consecutive dry years (2017 to 2021) with significant community concerns about future water availability, for both consumptive and environmental needs. DEW is currently working with communities in the area to develop an integrated water security strategy for the region.

The scope of this work was to model of three scenarios aimed at improving surface water availability and the flow regime of the streams. Selection of the targeted dams was based on the interception-extent of individual dams, which is a measure of the size and location of the dams. The interception-extent of each dam was calculated using two metrics: effective flow intercepted (EFI) and inflow to dam size ratio (ISR). Based on the results of these metrics, the dams were grouped into three interception-extent categories for further investigation: large, high and medium.

The scenario modelling involved consideration of three separate management options for targeted dams and/or watercourse extractions (WCE), namely *Scenario 1* – dam removal; *Scenario 2* – reduction of dam capacity; and *Scenario 3* – releasing low flows from dams and WCE. For each of the three scenarios, dams were sequentially treated against the three interception-extent dam categories – commencing with large priority dams and progressively treating dams in lower priority categories – to evaluate the additional flow volumes and the additional flow days that could expected under each scenario relative to current conditions.

Results of the scenario modelling suggest that, of the management options simulated:

- Targeted dam removal has the highest impact on improving the 'annual flow volumes' metric through the North-Para river system, relative to current conditions.
- Incorporating low flow releases to targeted dams and watercourse extractions has the highest impact on increasing the 'number of flow days' metric, which is a key indicator metric for health of water dependent ecosystems and for community values of having 'streams flowing for longer periods'.
- Reducing dam capacities of the targeted dams to 1.5 times the inflow results in minimal impact on either of the 'annual flow volumes' and 'number of flow days' metrics, which may partly be due to assigning a fixed value 1.5 for all dams.
- A preliminary investigation of available licensing data for a small selection of dams suggests that a more targeted approach i.e. a dam-scale analysis, may be possible to improve the impacts of dam capacity modifications, by basing the management scenarios on actual usage and allocation data.
- The usage data also suggests that in most cases, the average annual water use from these dams are much closer to long-term modelled mean annual inflows than to their allocations or dam capacities. This provides some insight to future investigations and scenario modelling exercises related to managing dam capacities to increasing flows through the system.

The logic and reasoning behind the scenario selection in this work was built from previous and ongoing technical investigations related to WAP reviews and implementation of WAP policies in other South Australian PWRAs, notably, the *Flows for the Future* program implementation currently in progress across the Eastern Mount Lofty Ranges (EMLR) PWRA. The results and findings of this scenario modelling exercise are consistent with outcomes of those previous and ongoing investigations in regards to management options and achieving outcomes (increase in flow volumes and increase in flowing periods). The main point of difference of this investigation is the more spatially targeted, from a flow interception perspective, approach, rather than the larger scale, catchment / management zone scale, approach of previous investigations.

2 Background

The Barossa Prescribed Water Resources Area (PWRA) has a large number of runoff capturing farm dams of various sizes and with varying upstream catchment areas, as well as numerous watercourse extractions (WCE) and large in-stream weirs. Given the surface water resource impacts of this development on the region's water resources and water dependant ecosystems (WDEs), surface water resources were prescribed in 1992 and a Water Allocation Plan (WAP) adopted in 2009.

To meet changing demands, environmental influences and statutory review obligations, the WAP is currently being reviewed, with a range of technical investigations informing the review, including:

- Hydro-ecological investigations to inform the Barossa PWRA WAP review – Hydrology Report, Jones-Gill A and Savadamuthu K, 2014. DEWNR Technical Report 2014/14, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide
- Barossa Valley Prescribed Water Resources Area Hydro-Ecological Risk Assessment, Green, D., Maxwell, S., VanLaarhoven, J., and Deane, D., 2014, DEWNR Technical Report 2014/08, Department of Environment, Water and Natural Resources, Government of South Australia, Adelaide.
- Interactions between groundwater and surface water systems, Barossa Valley. Hancock, M, Green, G and Stewart, S. 2014. Department of Environment, Water and Natural Resources, Government of South Australia, Adelaide.
- Modelling the impacts of water use, urban development and climate projections on surface water resources in the Barossa Prescribed Water Resources Area, DEW-TR-2022-13, Government of South Australia, Department for Environment and Water, Adelaide.

Longer-term effect of changing climate, as well three recent consecutive dry years (2018-19, 2019-20 and 2020-21) has had an observed impact on water resource availability, for both consumptive and environmental needs. DEW is currently working with the Barossa Valley and Eden Valley communities to develop an integrated water security strategy as part of DEW's approach to targeted water security planning for the region (https://www.environment.sa.gov.au/topics/water/water-security/barossa-water-security-strategy).

3 Scope

This work builds on the hydrological assessments, modelling and system understanding developed across a number of previous investigations. This work seeks to use scenario modelling of targeted water management options and assess their impacts on surface water availability and the flow regime within the PWRA. The scenarios for this exercise were selected in consultation with the Barossa WAP Review Committee and are intended to provide an example of management options that could possibly be considered, to complement other water planning and management options in support of reviewing the current WAP. The results of this assessment provide data and insight to further inform plausible policy and management options, for consideration in the ongoing measures (Water Security project, Barossa WAP review) to address the water security issues in the PWRA.

The targeted scenarios were designed to assess a selections of simple management options, aimed at improving surface water availability and the flow regime, specifically to:

- Provide additional flow volumes to the riverine systems, and
- Increase the flowing period, which is a key measure of environmental flow provisions and community values for the North-Para river system.

The Barossa Source Model (DEW-TR-2022-13) was used to model the scenarios for this assessment. This model was previously calibrated for the period 1/06/2003 to 31/12/2016, as described in DEWNR Technical Report 2014/14. For this assessment, rainfall and evaporation input data were appended in the model with the latest available data up to 28/06/2021. Data for the Heggies Vineyard community rainfall station was updated using patched point data from SILO[1] for the nearest spatial location. The previous calibration parameters were retained for the purposes of these scenarios, and so it should be noted that for this scenario modelling exercise the available calibration was not validated to the post 2016 streamflow data, which includes three consecutive very dry years. The scenarios were subsequently run over the period 1961 to 2020, resulting in 59 annual records for assessment in this analysis.

The scenarios modelled included targeted management (alterations) of targeted dams and watercourse extractions in the PWRA. The term 'management' in this document refers to either reducing dam capacity, removal of dams and/or releasing low flows. This project has identified and termed 'strategic' water points, referring to those dams and watercourses anticipated to offer maximised water volumes returned to the system. The highest impacts are expected from the treatment of the 'Large' and 'high interception' dams i.e. dams that have large storage capacity, located in the higher rainfall uplands and with large catchment areas, hence intercept large inflows. Such dams and watercourses are predominantly located in headwaters of the Upper Flaxman Valley, Upper Tanunda Creek, Upper Jacobs and Stone Chimney Creek management zones (Figure 1). These dams, along with the four large instream weirs in the Mid-Flaxman valley, are understood to have significant impact on the downstream flows in the North-Para River.

The Barossa PWRA is divided into a number of surface water management zones, identified by the different area colours in Figure 1. These zone boundaries represent a geo-morphological spatial unit and commonly incorporate a single drainage point from the zone, representing the outlet location of the surface water management zone (EoZ). The effectiveness of the management options for improving the flow regime in each location are thus assessed in this report via a relative comparison of total annual flows and number of flowing days at all EoZ locations. The furthest downstream zone within the Barossa PWRA, Barossa Valley Gorge, represents the outlet of the PWRA with the Yaldara flow monitoring site located at its outlet and termed End of System (EoS). The flow regime at this location is used to assess the effectiveness of the management options on a PWRA-wide scale.

[1] Queensland Government, https://www.longpaddock.qld.gov.au/silo/point-data/

4 Identification of strategic dams

The intention of this scenario modelling exercise is to progressively evaluate the relative benefits ('additional flows' and 'increase in flowing period') of treating groups or combinations of strategically located dams and watercourse extractions. The strategic dam categories were developed by calculating two metrics, effective flow intercepted (EFI) and inflow (long-term mean annual modelled inflow) to dam size ratio (ISR), for all dams in the PWRA, as explained below.

4.1 Flow interception

Effective flow intercepted (EFI) is the flow that is expected to be returned to the system when a dam is removed or its capacity reduced. It is calculated as the lesser of the dam capacity and the inflow to the dam (long-term mean annual modelled inflow). The methodology used to estimate dam capacities and inflow to dams are provided in DEWNR Technical Report 2014/14 and DEW-TR-2022-13. Data on the size category, number of dams (both licensed and unlicensed[2]) and their combined capacity is provided in Table 1. This is provided for information, as the more relevant EFI metric is used to further categorise the dams. While there are six dams that have a capacity of 200 ML or greater (Table 1), EFI data in Table 2 indicates that none of them actually intercept inflows of 200 ML or greater. There are two dams that intercept flows between 100 ML and 200 ML. There are a total of nine dams that intercept flows between 50 ML and 100 ML, with the cumulative flow intercepted by them being 656 ML. Given this, dams with EFI greater than 50 ML was chosen as the 'high EFI' dam category. The other two categories are provided for dams with EFI values between 25 – 50 ML and 10 – 25 ML. Dams with EFI values less than 10 were not considered for inclusion at this modelling stage.

Table 1. Dam size categories

Size category	No. of dams	Cumulative volume (ML)	No. of dams (% of total)	Cumulative volume (% of total)
≥200 ML	6	1479	2%	15%
100 – 200 ML	10	1293	3%	14%
50 –100 ML	11	783	4%	8%
25 – 50 ML	32	3799	11%	40%
10 – 25 ML	79	1479	26%	15%
≤ 10 ML	162	746	54%	8%

Table 2. Dam categories based on Effective Flow Intercepted (EFI)

EFI category	No. of dams	Cumulative volume (ML)	Cumulative volume (% of total)
≥200 ML	0	0	0%
100 – 200 ML	2	254	9%
50 –100 ML	9	656	23%
25 – 50 ML	22	762	27%
10 – 25 ML	38	604	21%
≤ 10 ML	229	555	20%

2 Excludes minor unlicensed dams that have been combined, or 'lumped' in the hydrological model based on their proximity to other similar unlicensed dams.

4.2 Dam sizing

The inflow (long-term mean annual modelled inflow) to dam size ratio (ISR) metric provides a measure of the capacity of the dam in relation to the inflow to the dam. A dam that has a capacity much higher than the expected inflow can be considered as an over-sized dam. Over-sized dams rarely spill, and in general would be able to intercept more runoff than a smaller dam with the same runoff. Removing or reducing the storage capacity of over-sized dams is thus more beneficial than removing an undersized dam. Based on analysis of dam data in the PWRA and for the purposes of this investigation, dams with an inflow less than 75% of their capacity (ISR < 0.75) were categorised as 'over-sized' dams. On the other hand, dams with inflows greater than twice their capacity (ISR ≥ 2.0) were categorised as 'low-interception' dams, as they are expected to spill during most years. The dams between those two categories i.e. with an ISR between 0.75 and 2.0 were considered 'average-interception' dams. It is to be noted that the actual ISR classification values for the different categories is subjective and can be varied. It is interesting to note that, based on these classification values, 60% of the dams in the PWRA are over-sized (Table 3).

These results align with the understanding that in semi-arid areas with variable rainfall such as the Barossa PWRA, that historical dam construction included over-sized dams to provide individual property-scale water security i.e. to maximise water capture when available.

Table 3. Dam sizing categories based on Inflow-to-Size ratio

ISR Category	No. of Dams	% of Total
≥ 2.0 *(Medium)*	73	24%
0.75 - 2.0 *(Large)*	47	16%
< 0.75 *(Over-sized)*	180	60%

4.3 Combined 'ISR – EFI' dam categories

Grouping dams by combining both the ISR and EFI metrics, three categories of dams for the PWRA were developed (Table 4). The first category 'Large and high interception dams' includes the over-sized dams (ISR < 0.75) that have a large and wet upstream catchment area (EFI ≥ 50 ML). There are six dams in this category with total intercepted flow of 517 ML. The other two categories are 'High' and 'Medium' interception categories as provided in Table 4. 'Low' interception dams are not included as the additional flows returned to the system are considered to be low. The locations of the dams in the three interception categories are provided in Figure 1.

Table 4. Combined ISR-EFI dam categories

Combined ISR-EFI Categories	ISR	EFI	No. of dams	Flow intercepted (ML)
A. Large interception dams: - *Over-sized dams with high interception*	< 0.75	≥ 50 ML	6	517
B. High interception dams: - *Over-sized dams with medium interception*	< 0.75	25 – 50 ML	13	546
- *Large dams with high interception*	0.75 – 2.0	≥ 50 ML		
C. Medium interception dams: - *Over-sized dams with low interception*	< 0.75	10 – 25 ML	21	624
- *Large dams with medium interception*	0.75 – 2.0	25 – 50 ML		
- *Medium-sized dams with high interception*	>2.0	< 0.75		

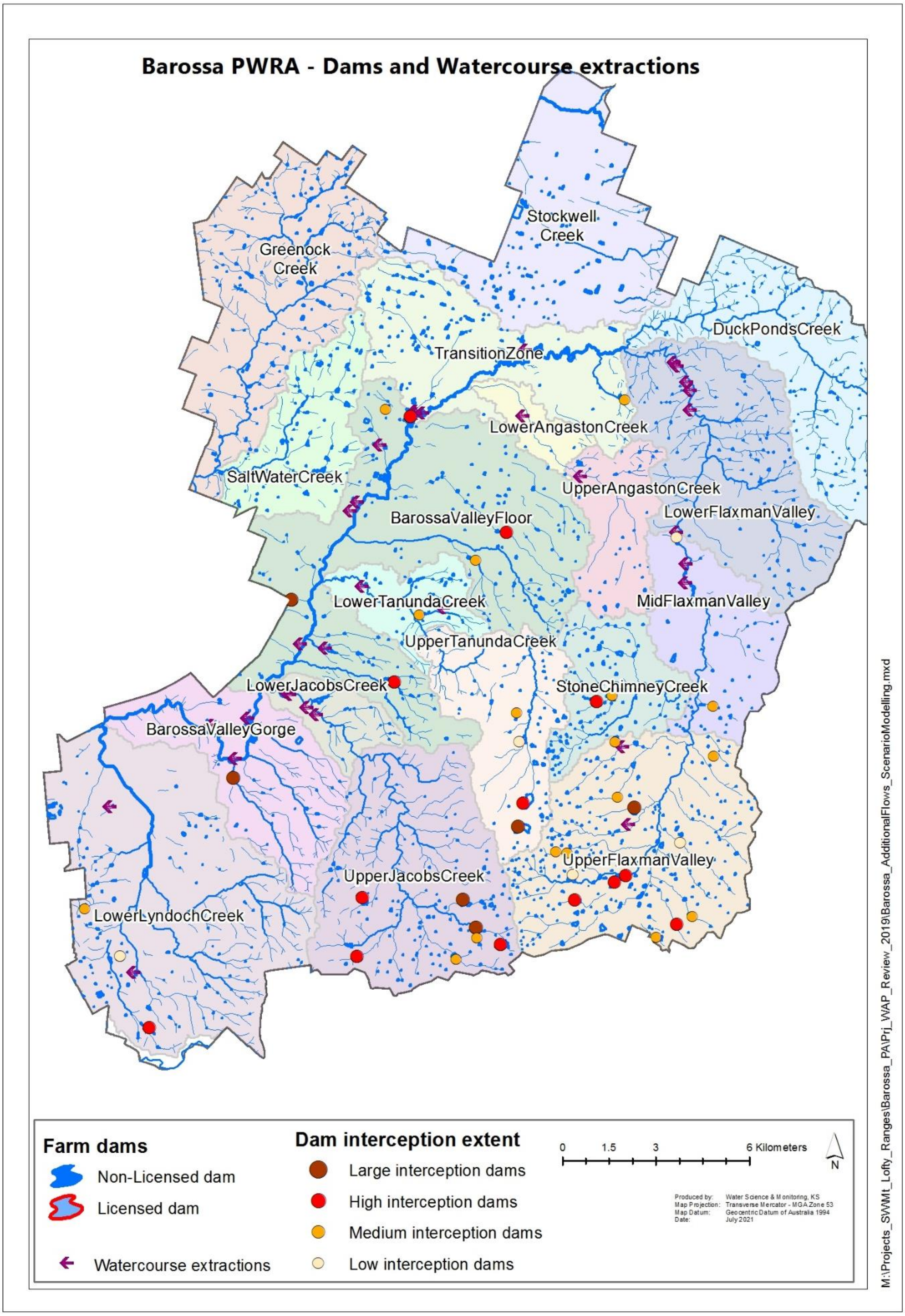


Figure 1. Barossa PWRA, dams and watercourse extractions

5 Scenarios

5.1 Scenario details

A targeted range of scenarios were tested as described in Table 5. Note that there are three different sets of dam combinations in each scenario, covering Category A dams (Set A), Category A and B (Set B) and Category A, B and C (Set C) combinations. Note also that an additional dam was included in each scenario, representing the large Mid Flaxman Valley weirs (estimated total volume of approximately 93 ML) – given its high impact location in the main watercourse, despite being classified only as a Category C medium interception dam.

Table 5. Scenarios

Scenario group	Scenario name	Description	No. of dams
Base model	*SceCurrent*	Base model, calibration period: 2003-2016, Run: 1961-2020	
Scenario 1: Removal of targeted dams	*Sce1A*	Remove Category A Dams	7
	Sce1B	Remove Category A & B Dams	20
	Sce1C	Remove Category A, B & C Dams	40
Scenario 2: Reduce storage volume of targeted dams	*Sce2A*	Reduce dam capacity to 1.5 times current inflow - Category A dams	6
	Sce2B	Reduce dam capacity to 1.5 times current inflow - Category A & B dams	15
	Sce2C	Reduce dam capacity to 1.5 times current inflow - Category A, B & C dams	23
***Scenario 3*:** Low flow release	*Sce3A*	Apply LFR to Category A licensed dams and all WCEs	6
	Sce3B	Apply LFR to Category A & B licensed dams and all WCEs	18
	Sce3C	Apply LFR to Category A, B & C licensed dams and all WCEs	33
	Sce3LicLFR	Apply low flow release to all licensed dams & WCEs	154

In addition to the Set A, B and C dam combinations, a scenario representing the base case of 'do nothing' (SceCurrent) is included, which allows for a relative comparison of the effectiveness of each management measure of improving system flows. Also, a full Low Flow Release (LFR)[3] simulation is included in Scenario 3, which simulates including LFR to all licensed dams and WCE (Sce3LicLFR), to allow the relative impact of maximising LFR through the system to be ascertained.

Note that numbers of dams in each category per scenario differ due to the following reasons:

- For Scenario 2, reduction in dam capacity was not performed on dams with existing capacity less than 1.5 times the current inflow, and
- For Scenario 3, only licensed dams in each category had LFR applied.

[3] Describes a mechanism for diverting low flows from being intercepted by a dam into the downstream watercourse, for improving flows through the system.

5.2 Results – Additional flow volumes

Additional flow volumes expected to be made available, returned by targeted dam management options, are presented at the EoS scale. Comparison of the relative impact of the different dam interception categories on additional flows (**Error! Reference source not found.**) indicates that removal of six of the highest interception dams across the PWRA (Category A dams), with a combined capacity of 1200 ML, plus the Mid Flaxman Valley Weirs at 93 ML, is expected to provide an average of 451 ML of additional EoS flows per year (Sce1A).

Table 6. Scenario results - Additional flows

Scenario group	Scenario name	Description	No. of dams	EoS* Add. flows** (ML)
Base model	*SceCurrent*	Base model, calibration period: 2003-2016, Run: 1961-2020		
Scenario 1: Removal of targeted dams	*Sce1A*	Remove Category A Dams	7	451
	Sce1B	Remove Category A & B Dams	20	875
	Sce1C	Remove Category A, B & C Dams	40	1181
Scenario 2: Reduce storage volume of targeted dams	*Sce2A*	Reduce dam capacity to 1.5 times current inflow - Category A dams	6	92
	Sce2B	Reduce dam capacity to 1.5 times current inflow - Category A & B dams	15	192
	Sce2C	Reduce dam capacity to 1.5 times current inflow - Category A, B & C dams	23	211
Scenario 3: Low flow release	*Sce3A*	Apply LFR to Category A licensed dams and all WCEs	6	152
	Sce3B	Apply LFR to Category A & B licensed dams and all WCEs	18	202
	Sce3C	Apply LFR to Category A, B & C licensed dams and all WCEs	33	207
	Sce3LicLFR	Apply low flow release to all licensed dams & WCEs	154	244

** EoS – End of System, Outlet of PWRA, EoZ – End of Management Zone*

*** Modelled mean annual additional flows (1961 – 2020)*

The annual variability of this 'additional flow availability' is illustrated in Figure 2. For example, under scenario Sce1A, the annual 'additional flows' varies between 1173 ML to 61 ML, with the median (i.e. 50% of the years at or below) being 470 ML and the mean being 451 ML.

Average annual additional flows reduces to 92 ML when the capacity of those dams is reduced to 1.5 times the current long-term mean inflow (Sce2A). Instead applying low flow releases to the same set of dams (Sce3A) increases the mean annual EoS flow to 152 ML.

Expected additional flow availability under other scenarios are presented in **Error! Reference source not found.**. The relatively low 'additional flows' available due to reduction in dam capacity (Sce 2A, 2B and 2C) is attributed to the fact that those dams still capture all the upstream runoff, except in wet years, when they are expected to fill and spill. In comparison, releasing low flows (Sce 3A, 3B and 3C) ensures that a consistent quantity of flows are not captured and are available to the system irrespective of whether it is a wet or a dry year as indicated by the low variability under 'Releasing low flows (Sce3A)' in Figure 2.

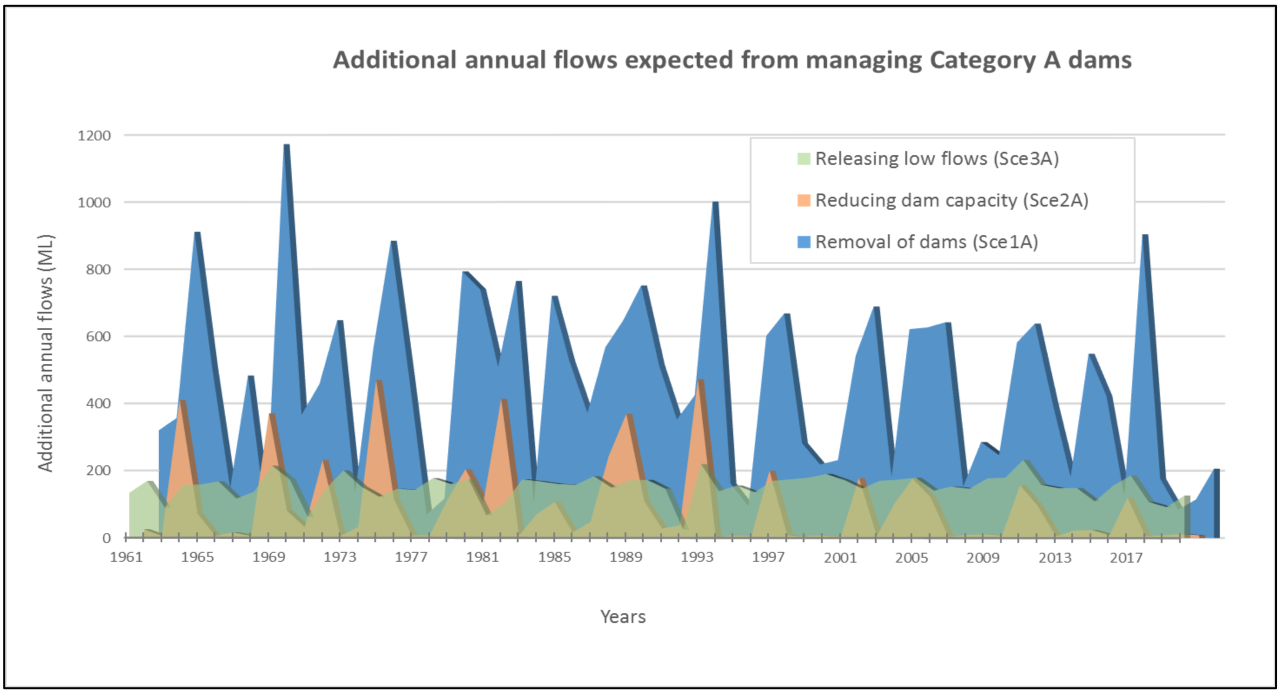


Figure 2. Expected EOS additional flows, annual time series, managing Category A dams

5.3 Results – Additional flow days, Upper Flaxman Valley Zone

The expected number of additional flow days, achieved by targeted dam management, is presented here at the EoZ scale for the Upper Flaxman Valley management zone. The results from this zone are presented as the focus of this section, given a large proportion of significant dams within the system, relative to other headwater zones, are located in this zone. It also sits at the top of the North Para River, and is thus influential in flows through the entire system. The importance of Upper Flaxman Valley to flows in the system can be seen in Figure 3, which provides a graphical representation of the EoZ results for all dams investigated (i.e. Category A, B and C combined) for all headwater zones within the PWRA. For the dam removal scenarios (Sce1C), EoZ flowing days at Upper Flaxman Valley are increased by a median of 20 days, whereas all other zones demonstrate median increases of less than 10 flowing days. In addition, for application of LFR to targeted dams and WCEs, only Upper Tanunda Creek has a comparable increase in annual flowing days.

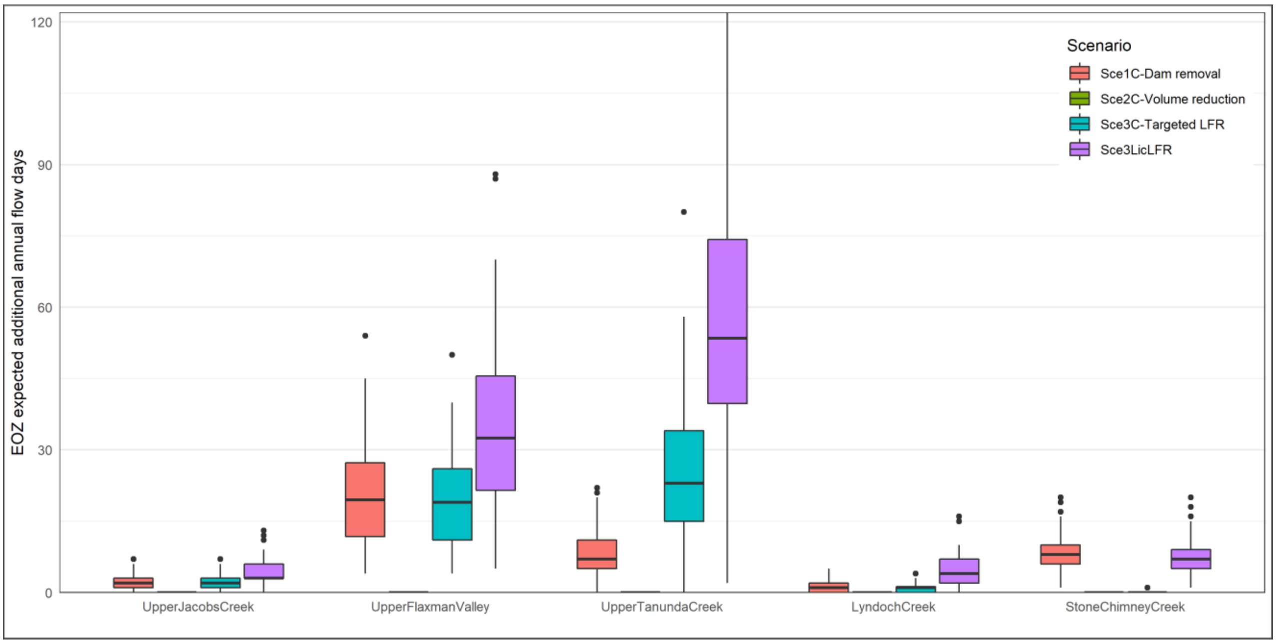


Figure 3. Increase in number of flowing days, Scenario Set C dams and watercourse extractions for headwater zones in the Barossa PWRA

The increase in the number of flowing days modelled at the outlet of Upper Flaxman Valley management zone under different scenarios, in comparison to the 'Current' scenario, is presented in Table 7. The full set of results for the other management zones are presented in the Appendix.

The results indicate that releasing low flows from targeted dams (Scenarios 3A, 3B and 3C) and removing those dams (Scenarios 1A, 1B, 1C) have similar impacts in increasing the number of flowing days at the end of Upper Flaxman Valley. In comparison, reducing dam capacity to 1.5 times the average annual inflow has negligible impact on increasing the number of flowing days (Scenarios 2A, 2B and 2C).

Table 7. Scenario Results for Upper Flaxman Valley - Increase in number of flowing days

Scenario group	Scenario name	Description	Additional flowing days / year		
			Mean	Median	Max
Scenario 1: *Removal of targeted dams*	*Sce1A*	Remove Category A Dams **(1 dam)**	5	5	10
	Sce1B	Remove Category A and B Dams **(5 dams)**	13	12	31
	Sce1C	Remove Category A, B & C Dams **(14 dams)**	21	20	54
Scenario 2: *Reduce storage volume of targeted dams*	*Sce2A*	Reduce dam capacity to 1.5 times current inflow - Category A dams **(1 dam)**	0	0	0
	Sce2B	Reduce dam capacity to 1.5 times current inflow - Category A & B dams **(5 dams)**	0	0	0
	Sce2C	Reduce dam capacity to 1.5 times current inflow - Category A, B & C dams **(14 dams)**	0	0	0
Scenario 3: *Low flow release*	*Sce3A*	Apply LFR to Category A Dams and all WCEs **(1 dam)**	5	5	10
	Sce3B	Apply LFR to Category A & B Dams and all WCEs **(5 dams)**	13	12	31
	Sce3C	Apply LFR to Category A, B & C Dams and all WCEs **(14 dams)**	20	19	50
	Sce3LicLFR	Apply low flow release to all licensed dams & WCEs **(37 dams)**	36	33	88

As an example of the relative influence of targeted dams on flows within the zone (in comparison to other licensed dams), releasing low flows from one Category A dam and the two WCEs (Sce3A) increases the flowing period at the outlet of Upper Flaxman Valley zone by an average of 5 days per year, with the maximum increase in a given year being 10 days. This increases to an average of 20 days per year and a maximum increase of 50 days under scenario Sce3C, which includes all 14 Upper Flaxman Valley Category A, B and C dams.

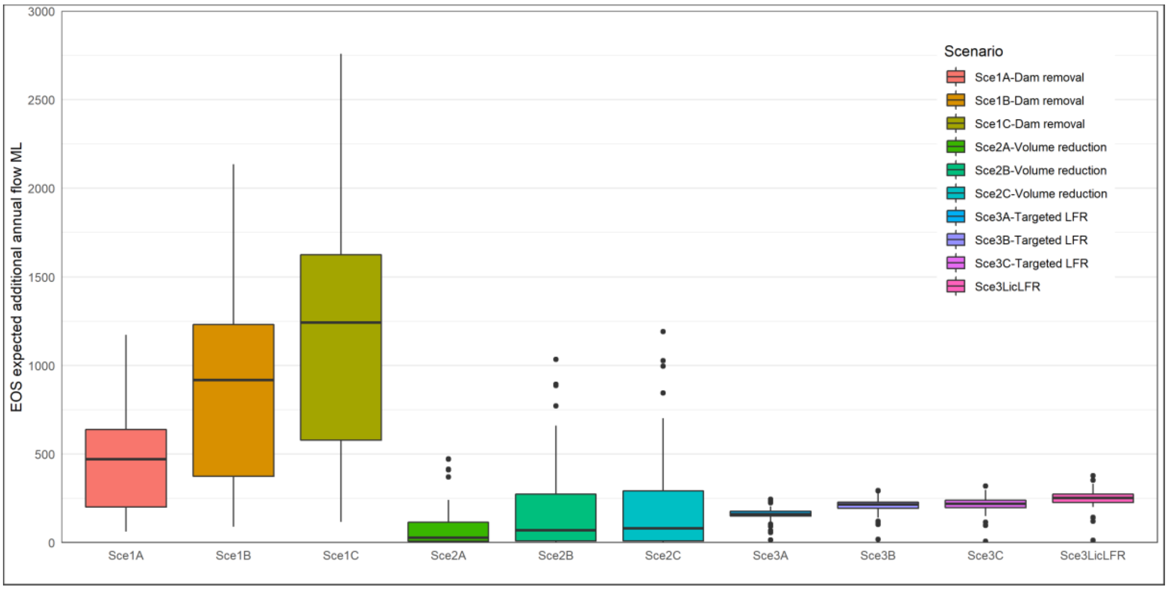
5.4 Discussion

The modelled results suggest that targeted removal of dams results in the largest increase in additional flows, while the application of LFR to targeted dams and all WCEs results in the largest increase in the additional number of annual flowing days.

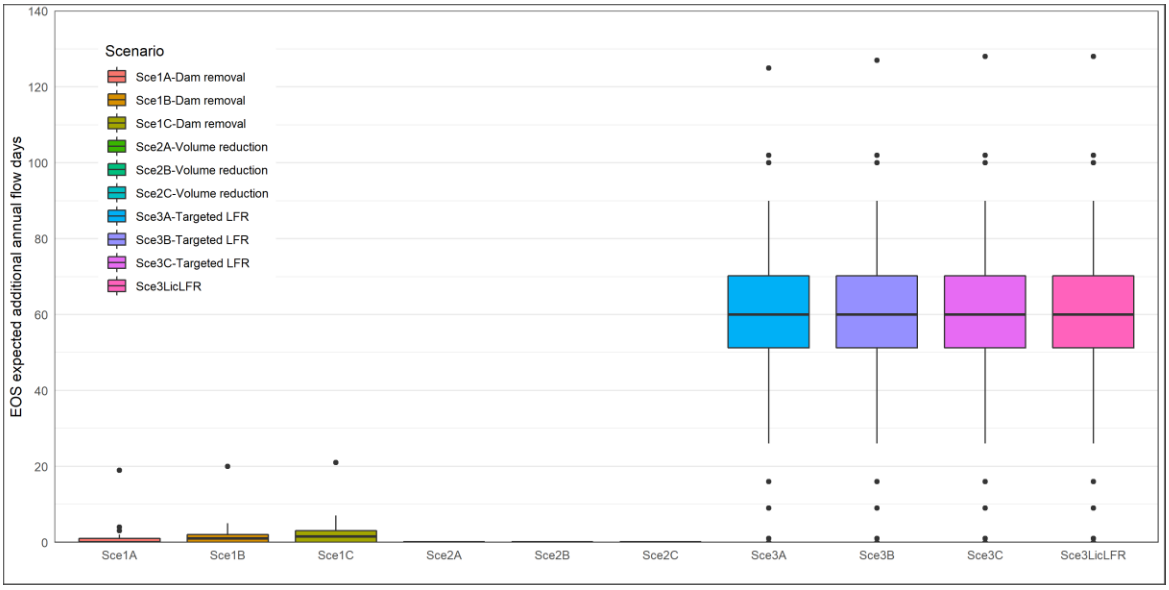
For each scenario, a comparison of EoS additional flows and additional flowing days, relative to 'Current' are shown in Figure 4. The removal of all targeted dams (Sce1C) provides the greatest median increase in annual EOS flows of all considered scenarios, at approximately 1250 ML. In comparison, the application of LFR to all licensed dams and WCEs (SceLicLFR) results in approximately 1000 ML less median additional EOS flows, at 250 ML. However, the magnitude of variability of additional EOS flows for the dam removal scenarios is much greater than compared to the LFR scenarios, as indicated by a comparison of the interquartile range of each scenario. This comparison confirms LFR scenarios provide a more consistent additional EOS annual flow compared with targeted dam removals.

Low flow release scenarios highlight the critical nature of WCEs on impacting flows through the system. In terms of the 'annual flowing days' metric, the median increase in the number of EOS flowing days of approximately 60 per year is consistent across all dam categories of Scenario 3 (Figure 5b), with the progressive addition of higher category dams across the scenario sets not significantly impacting on the number of flowing days.

Conversely, for dam removals in Scenario 1, there are only limited impacts on EoS additional flowing days, with a median increase of 2 under Sce1C relative to Current. The significantly greater number of additional annual flowing days of LFR scenarios (Scenario 3) compared to dam removal scenarios (Scenario 1), coupled with the consistent numbers of additional flowing days across all LFR scenarios despite differing numbers of dams with LFR, suggests that the application of LFR on all WCEs has the largest impact on flow conditions through the system.



(a)



(b)

Figure 4. (a) Additional flows and (b) additional flowing days for each scenario, at Barossa Valley Gorge End of System, over the period 1961 to 2020

The impact of LFR on targeted dams and WCEs is illustrated in Figure 5, which presents an example of detailed outputs for additional EOS flows for Scenarios 1C, 2C and 3C over the 2019 calendar year. The results indicate that for all targeted dam removals (Scenario 1C), the period from approximately May to October shows a large response in additional daily EOS flows. The largest daily flow increase modelled for the period, in August 2019, peaks at approximately 11 ML/d. In comparison, the LFR option shown by Scenario 3C has a relatively lower peak at approximately 2.4 ML/d additional flow. Conversely, in the warmer months from January to April 2019, and November to December 2019, the presence of consistent low flows is evident under Scenario 3C, and exceed the additional flows generated through dam removals (Scenario 1C). Note that for the targeted dam volume reduction scenario (2C) additional EOS flows occur only at the time of the large event in August, with the remainder of the period remaining the same as for the 'Current' scenario. This example highlights that dam removals provide the greatest impact on flows through the system during high rainfall periods, while LFR on targeted dams and, in particular, all WCEs has a greater impact in distributing flows through the system during warmer months coinciding with low rainfall rates.

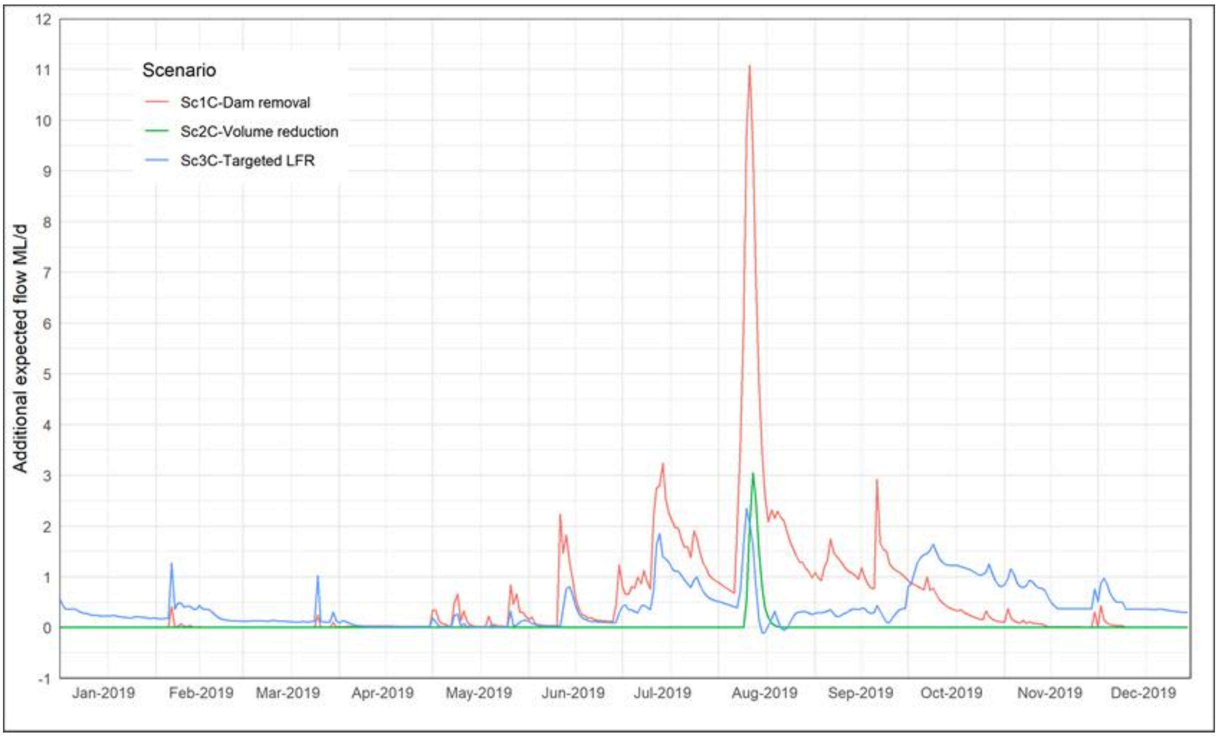


Figure 5. Additional flows at EOS for Scenarios 1C, 2C and 3C over calendar year 2019

The largest impact on additional flowing days in the system appears to be predominantly related to the four large weirs in Mid Flaxman Valley. Figure 6 shows Category A results for EOZ additional flowing days along the main flow path through the system, from Upper Flaxman Valley to Barossa Valley Gorge (EOS), presented left to right. A median increase of 100 flowing days above Current was modelled when applying LFR to Category A licensed dams and all WCEs plus the Mid Flaxman Valley weirs (Scenario 3A), which increased to approximately 126 days when applying LFR to all licensed dams and WCEs (Sce3LicLFR). This is despite the Upper Flaxman Valley zone generating only 5 additional flowing days under the Category A scenario. The impact can also be seen under the dam removal scenario (1A), which includes removal of the Mid Flaxman Valley weirs. A median additional 48 flowing days was modelled in this case, while only an additional 5 days was again contributed by dam removals in the Upper Flaxman Valley.

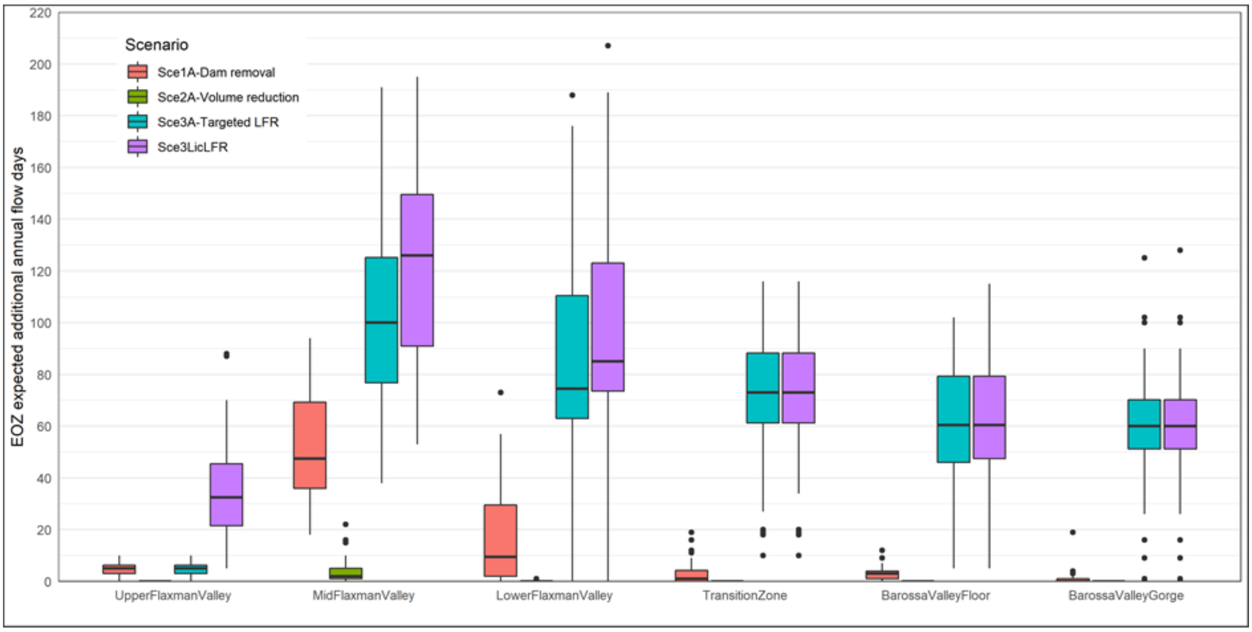
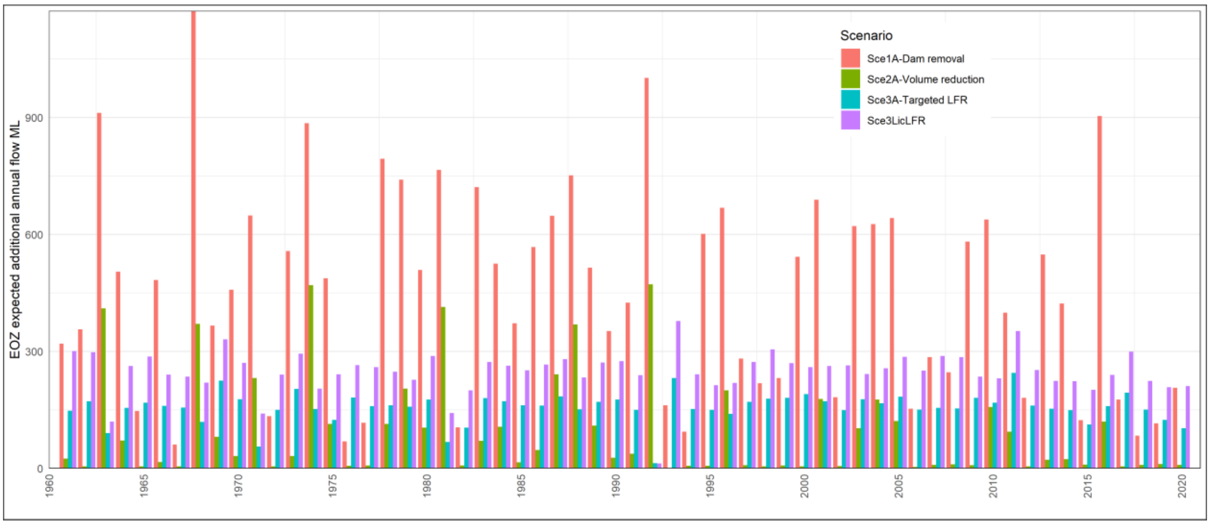
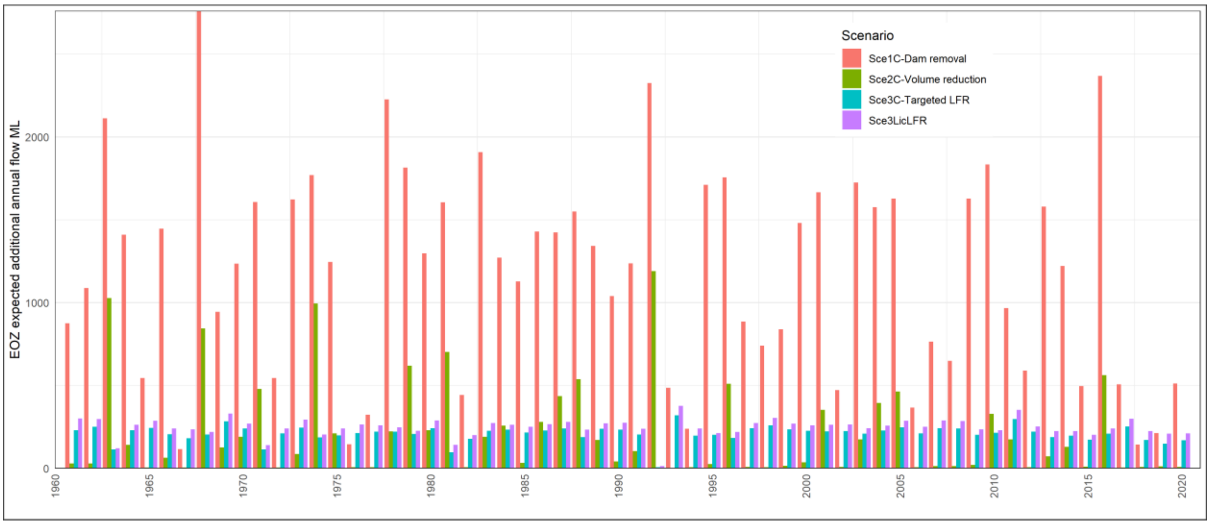


Figure 6. Additional EOZ annual flowing days for zones along main flow path, through to EOS Barossa Valley Gorge, for Scenario Set A

The variability of annual additional EOS flows over the simulated period (1961 to 2020) for the various scenarios is demonstrated in Figure 7. The results indicate that dam removals result in the greatest improvement in EOS flows, particularly the removal of the Mid Flaxman weirs as suggested in the preceding analysis. Increasing the number of dams removed acted to increase the annual flow peaks, as indicated in the comparison between Set A (Figure 7a) and Set C (Figure 7b). The results also provide further evidence that LFR implementation generates a lower, yet more consistent EOS flow increase over the simulation period, in particular during drier periods where LFR on targeted dams is approximately equivalent to EOS with dam removals.



(a)



(b)

Figure 7. Time series of additional EOS flow (Barossa Valley Gorge) between 1961 and 2020 for (a) Scenario Set A (Category A), and (b) Set C (Category A + B + C)

5.5 Summary of results

Increasing annual flow volumes: Comparison of modelled flows across the various scenarios tested indicates that *Scenario 1* (Removal of targeted dams, Scenarios 1A, 1B and 1C) has the highest impact on increasing total annual flows (volume) through the system. Removal of six of the highest interception dams, with a combined capacity of 1200 ML, plus the large Mid Flaxman Valley Weirs with estimated total volume of 93 ML, is expected to provide an average of 451 ML of additional flows per year. This varies annually between a maximum of 1173 ML per year to a low of 61 ML per year.

Scenario 3 (Releasing low flows from targeted dams) and *Scenario 2* (Reducing dam storage volume) have similar orders of magnitude of impact on increasing the total annual flows, with Scenario 3 producing a greater consistency in annual flow increase. In contrast to results of *Scenario 1* (Removal of targeted dams) discussed above, reducing the capacity of those six dams plus Mid Flaxman Weirs to 1.5 times their current inflow is expected to provide an average of 92 ML of additional flow per year, with 152 ML of additional average annual flows expected when low flows are released from those dams and all WCE.

The relatively low 'additional flows' available due to reduction in dam capacity is attributed to the fact that those dams still capture all the upstream runoff, except in wet years, when they are expected to fill and spill. In comparison, releasing low flows ensures that a consistent quantity of flows are not captured and are available to the system irrespective of whether it is a wet or a dry year.

Increasing 'flowing period': *Scenario 3* has the highest impact on increasing the flowing period of the streams and providing additional water security, including for water dependant ecosystems and to community values linked to streams flowing for longer periods. In comparison, *Scenario 1* has only a minor impact on improving the system-wide flowing period, while *Scenario 2* has negligible impact on increasing the flowing period.

5.6 Managing dam storage capacity (Scenario 2) and further investigation

In case of *Scenario 2* (reducing dam capacity), further detailed investigation may be warranted with regards to individual dam relationships of dam capacity, expected mean annual dam inflow, allocated volume and actual annual use, in order to gain a better understanding of operational limitations. This information may inform a more nuanced scenario modelling rather than a set reduction of 1.5 times inflow as applied in this study i.e. dam resizing could be based on additional dam specific information.

A preliminary investigation of available licensing data for a few dams suggests that a more nuanced approach on a dam scale basis may be possible by basing the dam modifications on available usage and allocation data. Table 8 shows the case of five licensed dams in Category A, with dam capacity, estimated inflows, allocated volume and usage data identified in the three years from 2018 to 2021. The data indicate that dams with the greatest usage as a percentage of allocated volume, namely Dam #4 (90%) and Dam #5 (87%), also have the greatest overall dam capacities of the Category A dams, at 268 and 280 ML, respectively. These dams have allocated volumes that are less than half that of the physical dam capacities, suggesting that a reduction of approximately 50% dam capacity or greater in these cases could be considered without adversely impacting on typical usage or allocation volumes.

Table 8. Category A licensed dams with allocation and usage data (from 2018-21)

Dam #	Project Zone	Dam capacity (ML)	Inflow * (ML)	Allocated Volume (ML)	Usage 18-19 (ML)	Usage 19-20 (ML)	Usage 20-21 (ML)	Max. usage (ML) (% of allocation)	Avg. usage (ML) (% of allocation)
1	Upper Flaxman Valley	**101**	**51**	**94**	48	12	43	48 (51%)	**34** (37%)
2	Upper Jacobs Creek	**163**	**58**	**290**	99	59	120	120 (42%)	**93** (32%)
3	Barossa Valley Gorge	**200**	**98**	**55**	12	8	0	12 (21%)	**7** (12%)
4	Upper Jacobs Creek	**268**	**93**	**115**	103	44	58	103 (90%)	**68** (59%)
5	Upper Tanunda Creek	**280**	**91**	**120**	105	83	92	105 (87%)	**93** (77%)

* Long-term (1960 – 2020) modelled mean annual inflow to dam

The dam with the smallest percentage of usage to allocated volume, namely Dam #3 with only 21% of maximum usage to allocated volume, shows only limited usage over the three-year period from 2018 to 2021. This dam has an allocated volume (55 ML) of approximately a quarter of the physical dam capacity (200 ML), suggesting a greater scope for a higher percentage dam volume reduction. The sparse usage totals also raise the possibility that complete dam removal may be a possibility if alternative water sources were made available to make up the shortfall.

Conversely, Dam #2 has a dam capacity (163 ML) that is substantially less than the allocated volume (290 ML), with a maximum usage of only 42% of the allocated volume. Given the negative discrepancy between dam capacity and allocated volume, there may be limited ability to reduce this specific dam volume. The application of other measures however may be beneficial in this case e.g. implementation of LFR. Note that the allocated volume being much higher that the dam capacity may indicate, for instance, the presence of alternative usage data that was not accounted for in this analysis, and as such further investigation is required in this case.

Notwithstanding the lower confidence levels of the modelled inflow data at an individual dam scale, it is interesting to note that, the actual average annual water use from the dams is much closer to the modelled 'Inflow' data than to the 'Allocated Volume' or 'Dam Volume' in most cases. It is also acknowledged that the data presented in only a small sub-set of all the complete licensed dams data set.

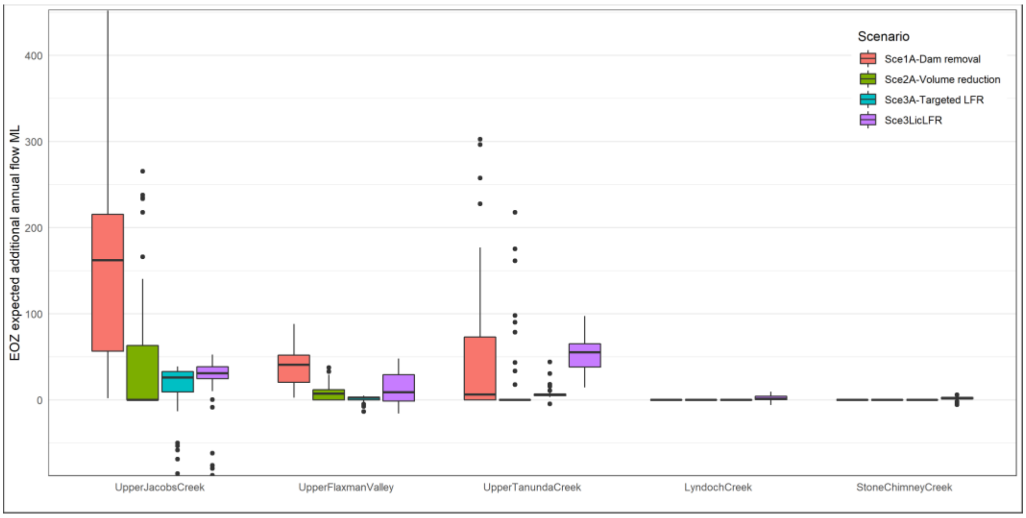
6 Conclusions

The results of the scenario modelling suggest that, of the measures simulated:

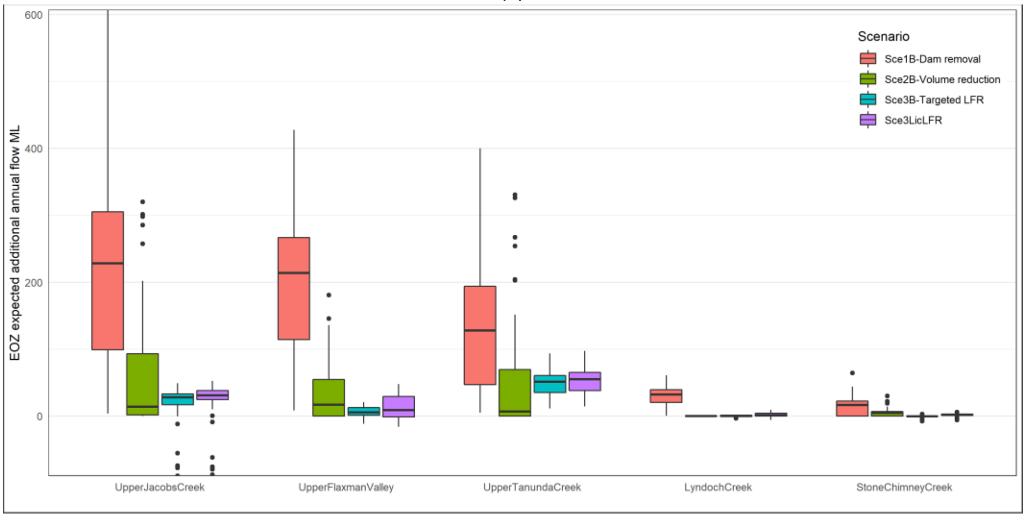
- Targeted dam removals have the greatest impact on improving the 'annual flow volumes' metric through the North Para river system, relative to current conditions.
- Incorporating low flow releases to targeted dams and watercourse extractions has the highest impact on increasing the 'flowing period' metric, which is a key indicator metric for health of water dependent ecosystems and for community values of having 'streams flowing for longer periods'.
- Reducing dam capacities of the targeted dams to 1.5 times the inflow results in minimal impact on either of the total flows and flowing days metrics, which may partly be due to assigning a fixed value 1.5 for all dams.
- A preliminary investigation of available licensing data for a small selection of dams suggests that a more nuanced approach i.e. a dam-scale analysis, may be possible to improve the impacts of dam capacity modifications, by basing the management scenarios on usage and allocation data.
- The usage data also suggests that in most cases, the average annual water use from these dams are much closer to long-term modelled mean annual inflows than to their allocations or dam capacities. This provides some insight to future investigations and scenario modelling exercises related to managing dam capacities for increasing flows through the system.

The logic and reasoning behind the scenario selection in this work was built from previous and ongoing technical investigations related to WAP reviews and implementation of WAP policies in other South Australian PWRAs, notably, the *Flows for the Future* program implementation currently in progress across the Eastern Mount Lofty Ranges (EMLR) PWRA. The results and findings of this scenario modelling exercise are consistent with outcomes of those previous and ongoing investigations in regards to management options and achieving outcomes (increase in flow volumes and increase in flowing periods). The main point of difference of this investigation is the more spatially targeted, from a flow interception perspective, approach, rather than the larger scale, catchment / management zone scale, approach of previous investigations.

7 Appendix – Zone-scale data



(a)



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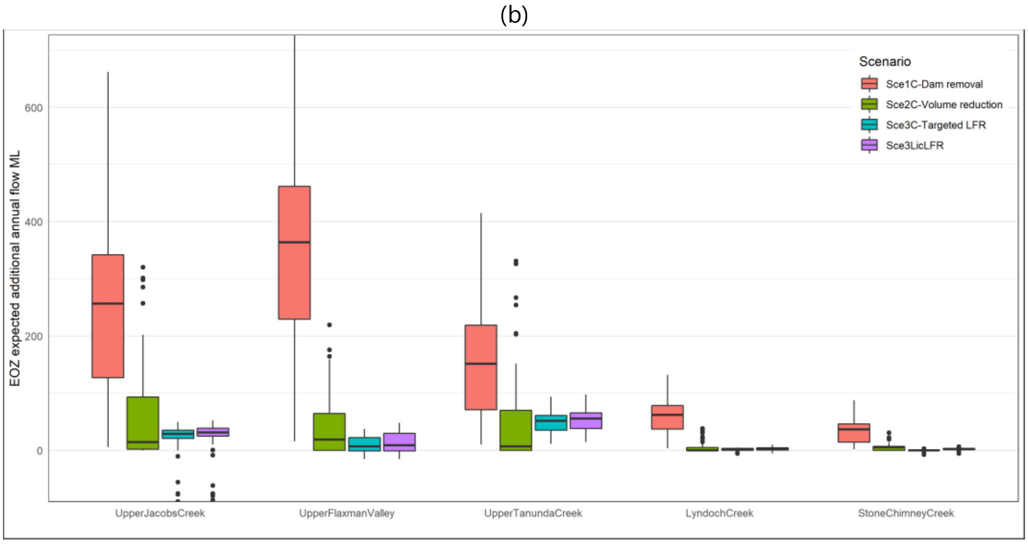


(c)

Figure 8. Summary of EOZ flows: difference from 'Current', for headwater zones with targeted dams for (a) Scenario Set A (Category A), (b) Set B (Category A + B) and (c) Set C (Category A + B + C)

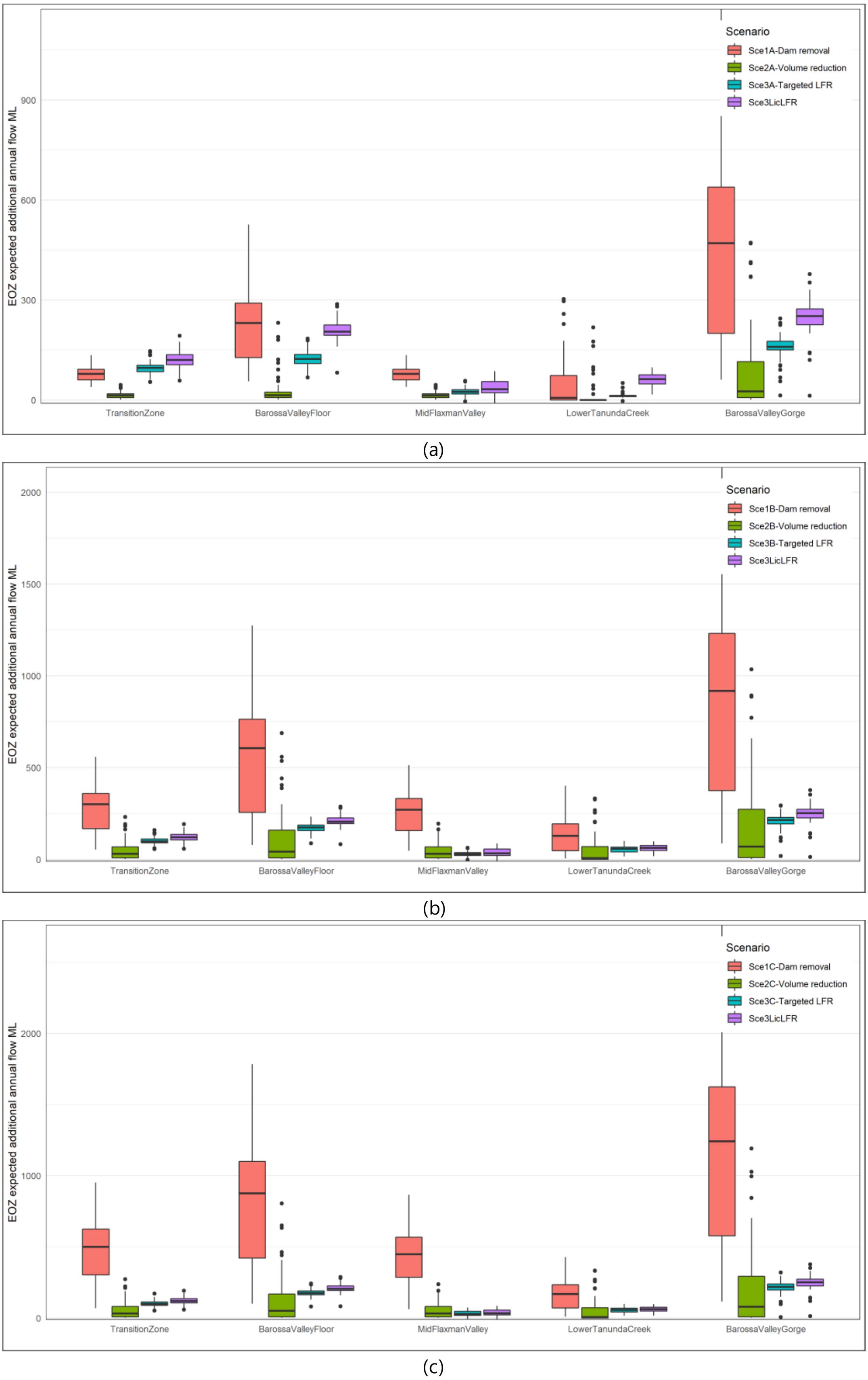
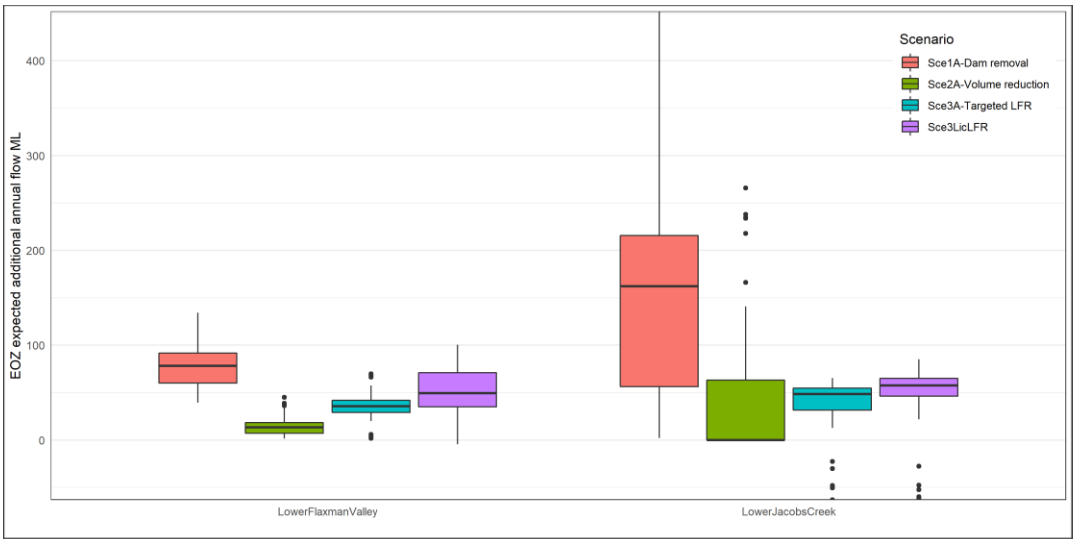
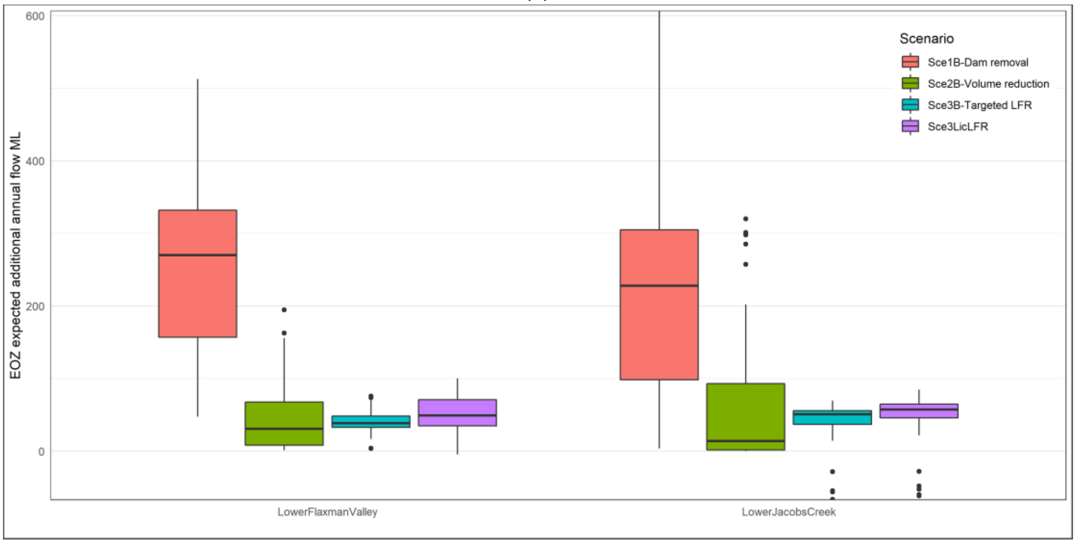


Figure 9. Summary of EOZ flows: difference from 'Current', for receiving zones with targeted dams for (a) Scenario Set A (Category A), (b) Set B (Category A + B) and (c) Set C (Category A + B + C)



(a)



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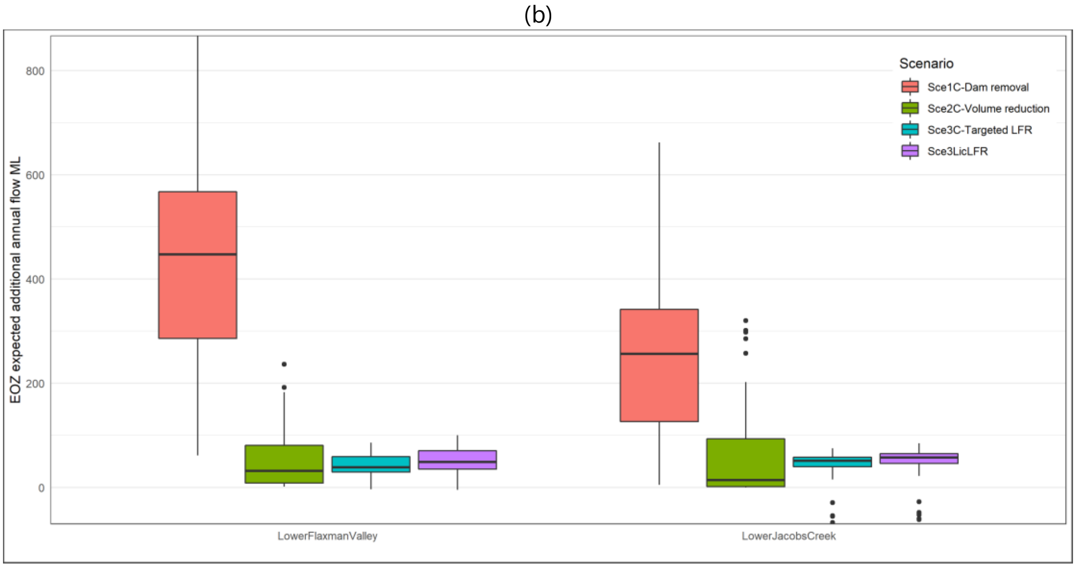
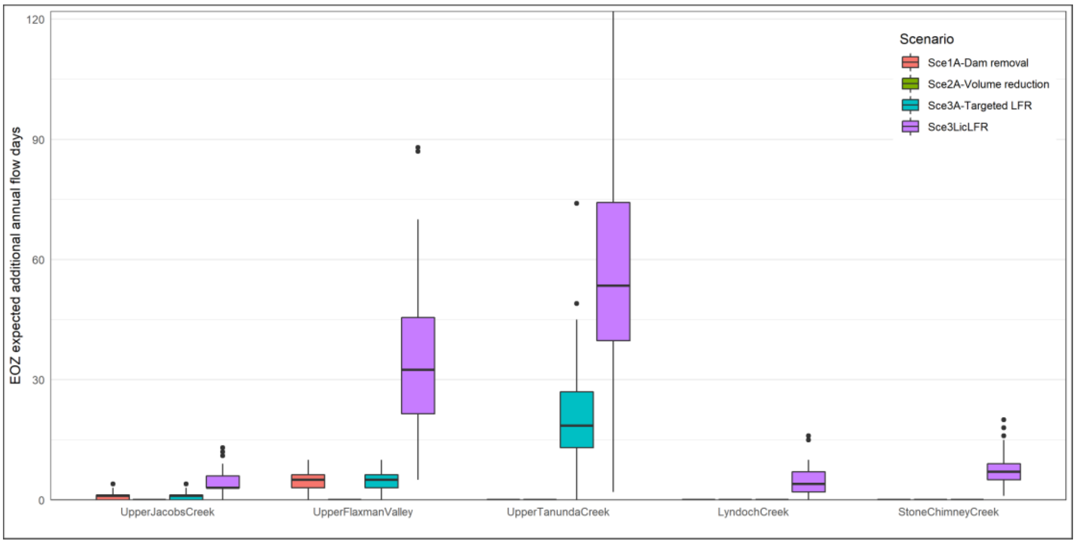


(c)

Figure 10. Summary of EOZ flows: difference from 'Current', for receiving zones with targeted dams in upstream zones for (a) Scenario Set A (Category A), (b) Set B (Category A + B) and (c) Set C (Category A + B + C)



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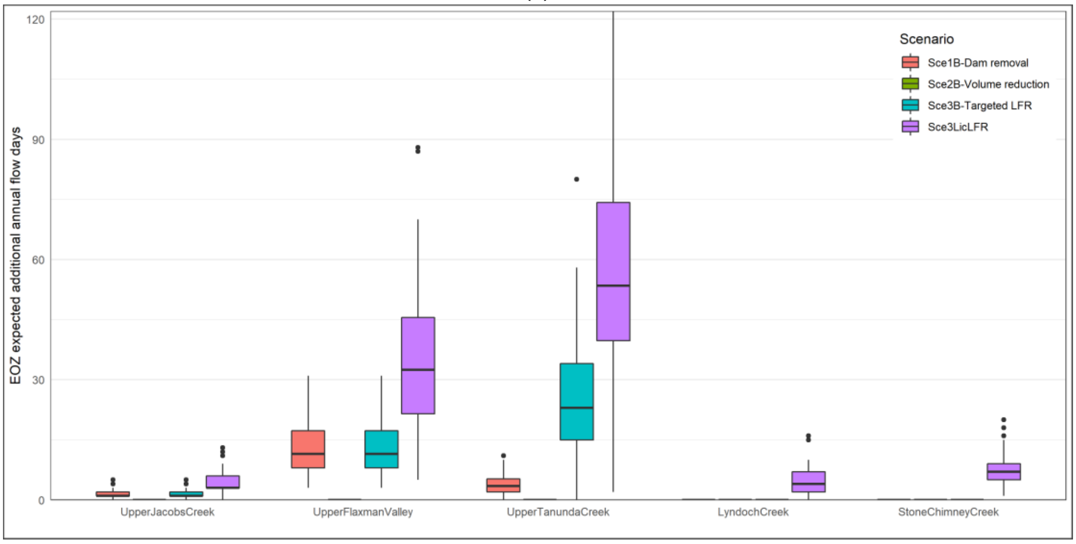

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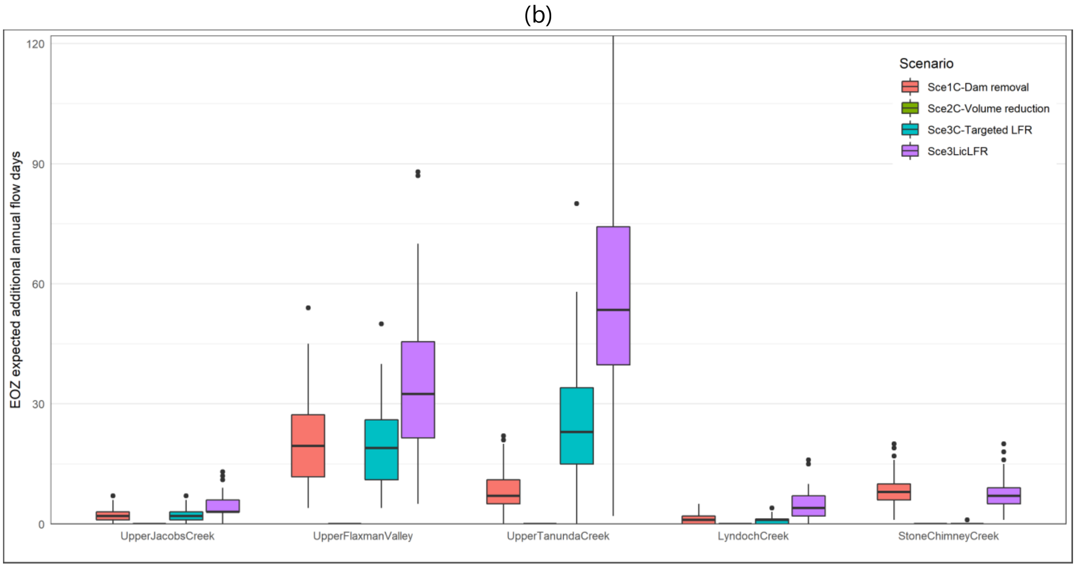


(c)

Figure 11. Summary of management zone flowing days: difference from 'Current', for headwater zones with (a) Scenario Set A (Category A), (b) Set B (Category A + B) and (c) Set C (Category A + B + C) targeted dams

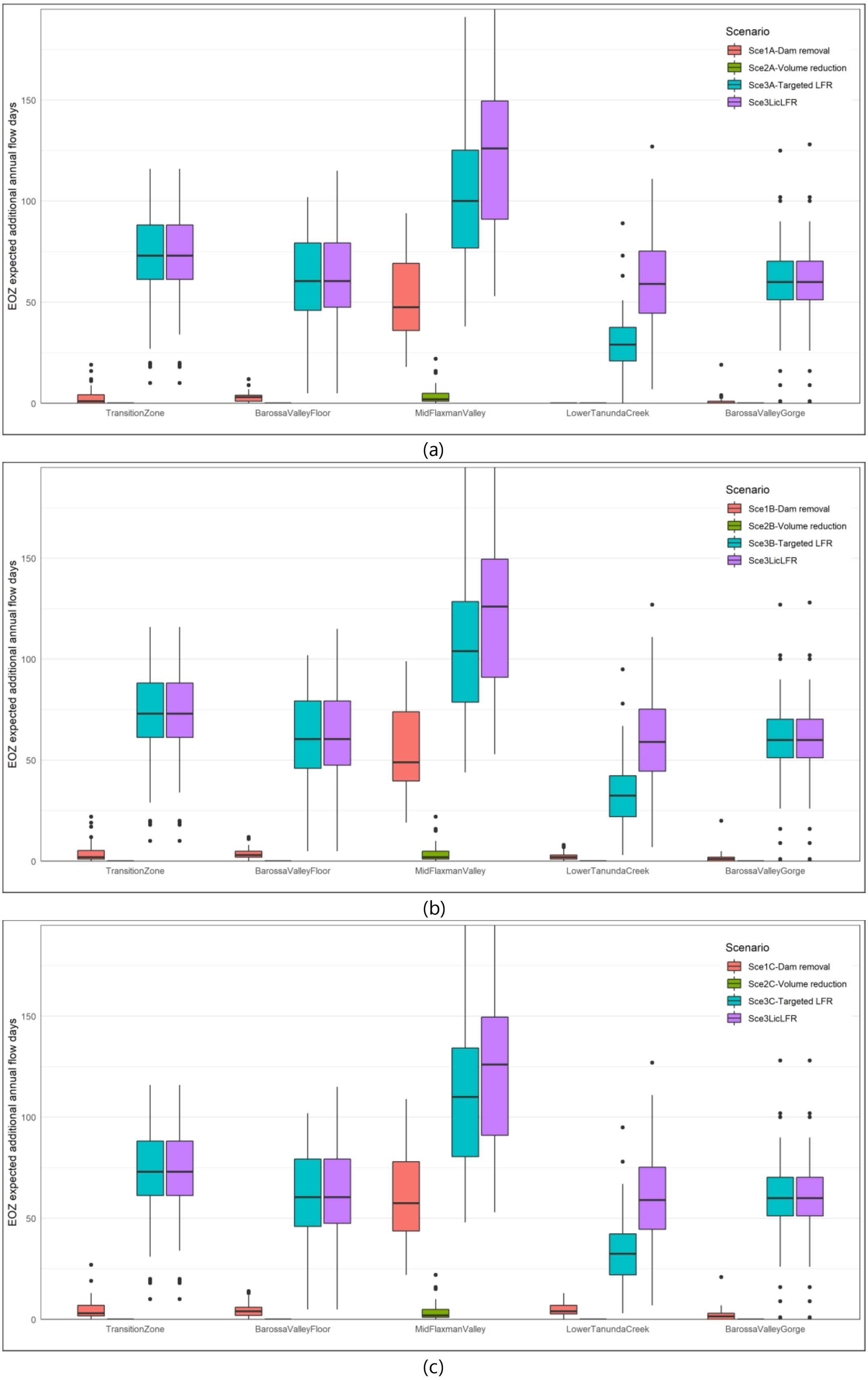
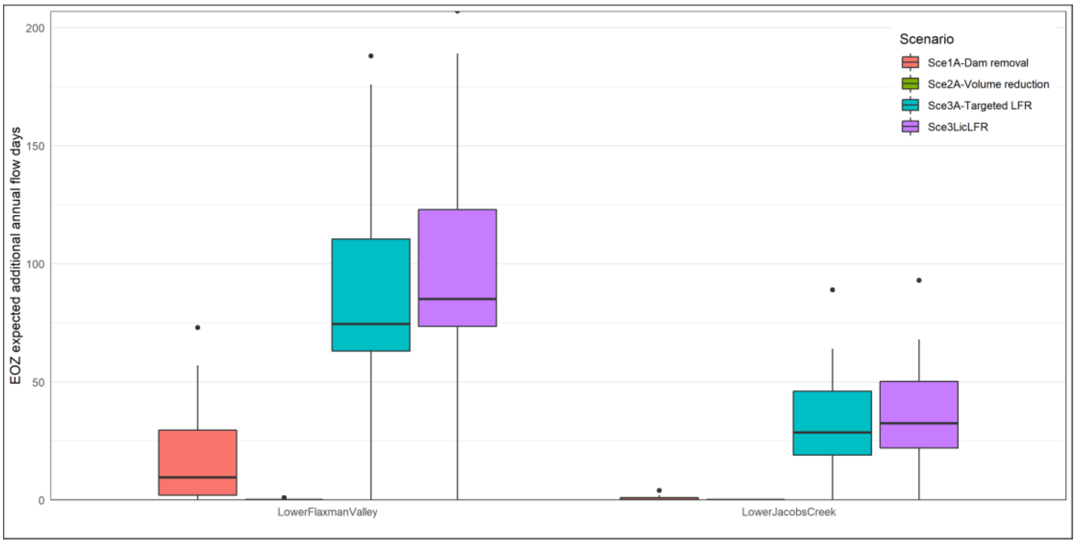
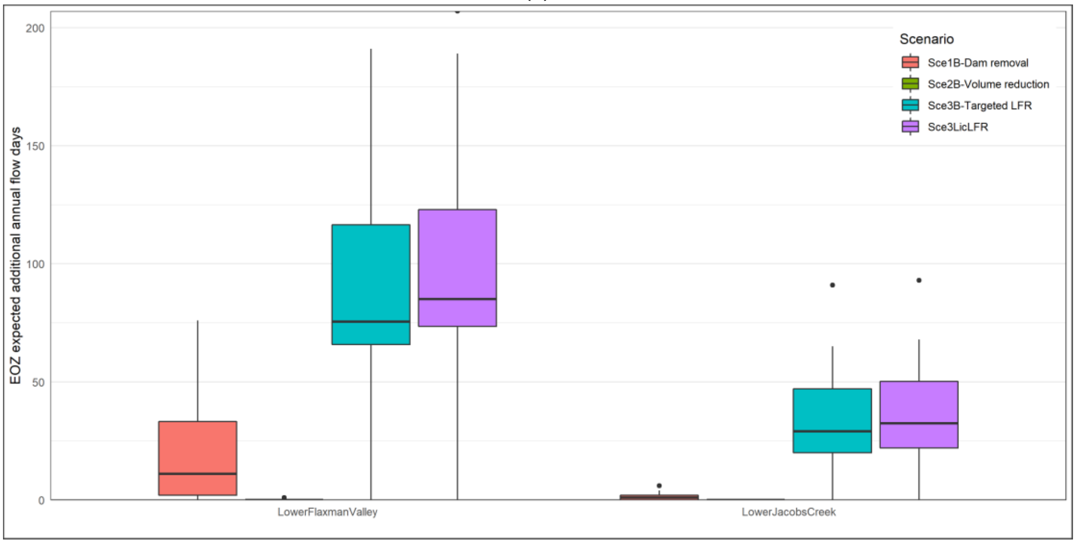


Figure 12. Summary of management zone flowing days: difference from 'Current', for receiving zones with (a) Scenario Set A (Category A), (b) Set B (Category A + B) and (c) Set C (Category A + B + C) targeted dams



(a)



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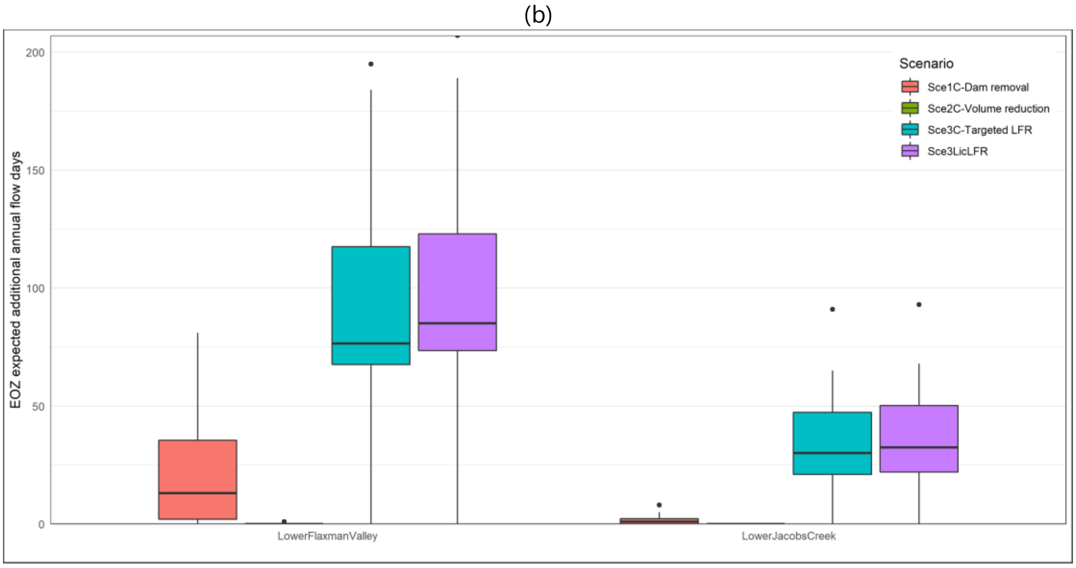

(c)

Figure 13. Summary of management zone flowing days: difference from 'Current', for receiving zones with targeted dams in upstream zones for (a) Scenario Set A (Category A), (b) Set B (Category A + B) and (c) Set C (Category A + B + C)

8 References

Jones-Gill A and Savadamuthu K. (2014). *Hydro-ecological investigations to inform the Barossa PWRA WAP review – Hydrology Report*. DEWNR Technical Report 2014/14, Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide

Department for Environment and Water (2022). *Modelling the impacts of water use, urban development and climate projections on surface water resources in the Barossa Prescribed Water Resources area*, DEW-TR-2022-13, Government of South Australia, Department for Environment and Water, Adelaide.

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