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Qualitative ecological assessment of risks and benefits to in-channel water quality from changes in flow related to the Reconnecting River Country Program

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Report to NSW Department of Planning and Environment

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Acknowledgement of Country

The authors acknowledge the Traditional Owners of the lands and waters of Australia, and in particular the Traditional Owners of the lands and waters of the Murray–Darling Basin. The river and its tributaries are known by many names including Millewa (Ngarrindjeri name for the main Murray channel in South Australia), Baarka (Barkindji; Darling River, inland New South Wales (NSW)), Warring (Taungurung; Goulburn River, Victoria), Kolety (Wamba Wamba; Edwards River, inland NSW), Kalari (Wiradjuri; Lachlan River, inland NSW), Murrumbidjeri (Wiradjuri; Murrumbidgee River, inland NSW) and Guwayda (Kamilaroi; Gwydir River, northern NSW), amongst others. While the European names are used in this report, the authors recognise the important associations and history of the Indigenous names for rivers and streams in the Basin. The authors express their respect for Elders, past and present, amongst the Nations of the Murray–Darling Basin.

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Document submission history

1 October 2021	V0.1	First draft for review of the approach. It does not include location specific analyses as the flow and inundation analyses required for that level of granularity will be incorporated into the next version of this document
18 October 2021	V0.2	First draft (V0.1) with comments and edits from the NSW DPIE reviewers
15 December 2021	V0.3	Expanded and modified in response to review comments
22 February 2022	V1.0	Expanded and modified in response to review comments, reflecting provision of updated flow statistics and assessment for the Murray. Blackwater risk likelihood assignment will be completed on provision of blackwater model results
23 March 2022	V1.1	Revised in response to review comments from DPE and improved the assessment of the flow scenarios. New sections on Murrumbidgee and inclusion of flow event statistics figures
19 April 2022	V2.0	Revised in response to review comments from DPE against v1.1; populated blackwater qualitative impact/likelihood tables for Murray & Murrumbidgee; added in flow event statistics for Hay as the representative gauge for d/s Murrumbidgee and subsequent risk assessment
6 May 2022	V2.1	Final in response to review comments against v2.0
19 August 2022	V2.2	Revision to Summary table to update mechanistic link to acid sulfate soils discussion
02 September 2022	V2.3	Final in response to review comments against v2.2

Important disclaimer

EXECUTIVE SUMMARY

In 2021, CSIRO was commissioned to undertake a ecological risk and benefits assessment of the impacts on water quality of raising flow limits for the delivery of water for the environment in the Murray River and Murrumbidgee River, as proposed under the NSW Government's Reconnecting River Country Program. The assessment was part of a larger project assessing other impacts such as the impact of changes in flow on river form and function, inundation of river floodplains, and impact on users of the river and its environs.

The 8 water quality issues of concern identified by the department as having potential links to relaxation of flow constraints were blackwater, eutrophication, blue-green algae blooms, salinity, turbidity, weir pool stratification/ destratification, acid sulfate soils and thermal pollution.

Constraint relaxation (modelled) flow scenarios were provided by the department, to be assessed for 3 areas of the Murray River (Hume to Yarrawonga; Yarrawonga to Wakool Junction, including the Edward/Kolety–Wakool system; Lower Murray from Wakool junction to Wentworth) and 2 in the Murrumbidgee River (downstream of Burrinjuck Dam to Hay; downstream of Hay to its junction with the Murray River).

METHOD

The assessment was to be qualitative, based on relevant literature and local expert knowledge (Chapter 3), and commensurate with the size and timeframe of the project. The assessment was confined to the flowing main channels in the assessment areas – floodplains and wetland habitats were not included in the assessment due to the high level of habitat heterogeneity and context dependency of water quality parameters within these habitats.

The first step was to develop a decision matrix to act as a filtering tool, with the first question '*Is there a mechanistic link between a given water quality issue and flow?*' acting as a stop/go. If no such link could be established, then a risk assessment for that issue was not undertaken. This is captured in Table 1.

Table 1 Summary of links to changes in flow magnitude for the water quality parameters being assessed. N/A indicates that a mechanistic link has not been established

WATER QUALITY PARAMETER	MECHANISTIC LINK TO INCREASED FLOW MAGNITUDE	POSITIVE, NEGATIVE OR BOTH	INCREASED RISK/BENEFIT WITH INCREASED FLOW MAGNITUDES
Blackwater	Yes	Both	Yes
Eutrophication	No	N/A	N/A
Blue-green algae blooms	Yes	Both	Yes
Salinity	Yes	Both	Yes
Turbidity	Yes	Negative	Not increased above current risk
Weir pool stratification/ destratification	Yes	Both	Not increased above current risk
Acid sulfate soils[1]	Yes	N/A	N/A
Thermal pollution	Yes	Negative	Not increased above current risk

[1] Acid sulfate soils are known to occur in the Edward Wakool system. Assigning risk requires combining mapping of these soils across the Edward Wakool system with an inundation mapping, information not available during preparation of this report. Determination of risk/benefit of water quality response from inundation of acid sulfate soils should be considered a key knowledge gap.

Where a mechanistic link existed and likelihood (from models if available, else expert opinion) occurred, risk impacts (from expert elicitation) were assigned at each of the flow thresholds used to characterise the set of constraint relaxation scenarios, noting that it was not always possible to discriminate change in risk and/or benefit between the flow thresholds.

The second step was to use these assignments of likelihood/impact/risk+benefit to assess whether the proposed constraint relaxation scenarios posed any more risk (or benefit) than current. For this purpose, the department provided flow event statistics that characterised the scenarios by the number of flow events of flow threshold magnitude over the >100 year scenarios modelling period. These data clearly showed a shift to winter watering of various magnitudes depending on the size of the relaxation of constraints as represented in the modelling of the scenarios.

MURRAY RIVER

Our overall assessment is that the 4 constraint relaxation scenarios do not increase the likelihood, and thus the risk, of adverse water quality events from current, and may increase the likelihood of benefit.

From a water quality perspective, and based on current knowledge, the constraint relaxation scenarios cannot be discriminated, that is they are not sufficiently different to each other that one scenario can be classed as ‘better’ than another. Season (water temperature) is a key driver for water quality parameters driven by metabolic processes (blackwater, blue-green algal blooms). Salinity represents a different situation as there are reach-based ecological processes that are affected, but also end-of basin targets that should be considered.

For example, reaches in the Hume to Yarrawonga project area are typically low in salt concentration, although the biota that inhabit these reaches are salt sensitive (see Shackleton et al., 2019). Thus, the likelihood of increasing the number and size of flow events causing salinity issues is unlikely, but the consequences are significant.

In the middle area (i.e. the Yarrawonga to Wakool Junction, including the Edward/Kolety-Wakool system), the greatest risk is associated with season (water temperature) and summer represents the greatest risk for water quality parameters driven by metabolic processes of microbes and algae. In this sense, timing and duration of flow events are the drivers. Temperature is the key predictor for hypoxic blackwater, but this also relates to the area of floodplain inundation, which will be affected by flow. In this respect, the risk doesn’t change, but the extent, or longevity of the effect is likely to increase as a consequence of greater extent of inundation.

In the Lower Murray, as with the upstream reaches, risk for blackwater and blue-green algal blooms are highest in summer. However, in this area, risk from blackwater is unlikely to come from incorporation of floodplain litter locally, rather from incorporation of carbon from upstream floodplains. In contrast to upper reaches, the Lower Murray is at greater risk from salinity (due primarily to saline groundwater), but biota in this region are better adapted to wide variations in salinity. Thus, while higher flows may increase the risk of salt mobilisation in the Lower Murray, there are strong benefits (e.g. contribution to the Basin Plan’s target of 2 million tonnes of salt exported from the Basin) that may outweigh negative impacts on biota.

MURRUMBIDGEE RIVER

Our overall assessment is that the 3 constraint relaxation scenarios do not increase the likelihood, and thus the risk, of adverse water quality events from current, and may increase the likelihood of benefit.

Similar to the Murray River project areas, and based on current knowledge, the constraint relaxation scenarios cannot be discriminated from a water quality perspective. As with the Murray River system, the greatest risk to water quality in the Murrumbidgee River upstream of Hay is associated with season (water temperature) and summer represents the greatest risk for water quality parameters driven by metabolic processes of microbes and algae. Thus, concordant with the Murray River assessment, it is the timing that is the driver in the Murrumbidgee River. Temperature is the key predictor for hypoxic blackwater, but this also relates to the area of floodplain inundation, which will be affected by flow. In this respect, the risk doesn’t change, but the extent, or longevity of the effect is likely to increase as a consequence of greater extent of inundation.

However, salinity is not influenced by temperature and the Murrumbidgee River downstream of Hay is assessed as being at lower risk to salinity impacts than the Murrumbidgee River upstream of Hay. This is not because it is less likely to occur, but because the impact is reduced as a consequence of organisms in this river segment being more tolerant of fluctuations in salt concentration.

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ABBREVIATIONS AND TERMS USED IN THIS REPORT

TERM	DESCRIPTION OF TERM AS USED IN THI REPORT
allochthonous	Used in this report in relation to carbon; signifying carbon that is generated from terrestrial sources (e.g. trees) rather than autochthonous carbon which is generated with aquatic ecosystems (e.g. algae)
benefit	an advantage or improvement, something of a positive nature
consequence	impact of an event, it can be negative or positive
decapod	a crustacean, e.g. yabbies, freshwater shrimp and prawns
disbenefit	a negative benefit
effect	a deviation from the expected – positive and/or negative (ISO 31000:2018)
Environmental water requirement (EWR)	The flow event/s required to support the completion of key known elements of a lifecycle of an organism or group of organisms (taxonomic or spatial), consistent with the objective/target, measured at the most appropriate gauge. EWRs can be met by various flows in a system including natural inflows, held environmental water, planned environmental water, essential supplies, conveyance water & consumptive orders.
event	Events refer to changed flow at specified Source model nodes that are either extended, raised or added in various flow scenarios
flow component	The classification of flow in a river defined by its magnitude (e.g., bank full BK).
flow limit	Constraint limit at various nodes (e.g. d/s Yarrawonga) aimed at different EWR in LTWPs. The term is used in this report to capture the notion that the model scenarios look to deliver larger flows than currently possible
hotspot	Locations in the landscape where activity is amplified
impact	Defined as the consequences, or effects of a risk event
issue	Eight water quality issues of concern were identified by NSW DPIE as having potential links to relaxation of flow constraints
likelihood	Probability of occurrence of an impact that affects the water quality issues (e.g., blackwater) (ISO definition 'the chance of something happening')
Long Term Water Plan (LTWP)	A requirement of the Basin Plan that gives effect to the Basin-Wide Watering Strategy for each river system & will guide the management of water over the longer term. DPIE is responsible for the development of nine plans for river catchments across NSW, with objectives for five, 10 & 20-year timeframes.
RiM-FIM	River Murray Floodplain Inundation Model
risk	the 'effect of uncertainty on (achieving) objectives'
risk level / level of risk	magnitude of a risk, usually expressed as a combination of consequences and the likelihoods of the consequences occurring. As different combinations of consequence and likelihood can result in the same risk level (e.g. 'high'), risk level is not sufficient for evaluating risk
water quality issue	Parameters identified by NSW DPIE as having potential links to relaxation of flow constraints
zone	RiM-FIM zones

1 INTRODUCTION

In 2021, CSIRO was commissioned by the Department of Planning and Environment[1] (the department) to undertake a qualitative risk and benefits assessment of the impacts on water quality of raising flow limits for the delivery of water for the environment as proposed under the NSW Government's Reconnecting River Country Program (the Program). It represents a collaboration between the department and CSIRO, with the flow and inundation modelling work being undertaken by the department and the water quality risk assessment being undertaken by CSIRO.

The risk assessment considers only the flowing main channels of rivers of the designated project areas. Floodplain and wetland habitats are not assessed due to the high level of habitat heterogeneity and context dependency of water quality parameters within these habitats.

The assessment has taken place in parallel with the development and provision of the flow time series and consequent inundation mapping for a range of constraint relaxation scenarios. As such, the development of the approach has been iterative and has benefited from feedback from the department as the detailed flow and inundation modelling progressed. This final report incorporates analysis of the flow event statistics provided by the department for the 5 water quality assessment areas used to inform the assessment.

1.1 Reconnecting River Country Program

As part of the Sustainable Diversion Limit Adjustment Mechanism, the NSW Government is implementing the Reconnecting River Country Program (formerly the NSW Constraints Measures Program) which includes 3 project areas in the southern-connected Murray–Darling Basin (the Basin):

- Murray River – Hume to Yarrawonga
- Murray River – Yarrawonga to Wakool
- Murrumbidgee River.

Within these 3 project areas, 5 water quality risk assessment areas have been identified:

- Murray River
  - Hume to Yarrawonga Weir
  - Yarrawonga Weir to Wakool Junction, including the Edward/Kolety–Wakool system
  - Lower Murray from Wakool Junction to Wentworth (Lock 10) (outside of Reconnecting River Country Program area but influenced by project area flows)
- Murrumbidgee River
  - Burrinjuck Dam to Hay
  - Hay to its junction with the Murray River.

The Reconnecting River Country Program aims to allow water for the environment to be delivered at higher river levels (above current operational limits) and, at times, for longer durations to provide connectivity of low-lying wetlands and floodplains, at ecologically appropriate times. The intent is to enhance the ecological outcomes for native fish, native vegetation, waterbirds, ecosystem functions and other native biota that can be

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[1] erstwhile the Department of Planning, Industry and Environment

achieved with water for the environment. The Program is investigating a range of flow limit options (flow regimes) and mitigation measure options for affected landholders in each project area.

The constraint relaxation scenarios to be assessed are identified by daily volumes at Yarrawonga and Doctors Point and are listed, together with their scenario ID, in Table 1.1. These are further described in Sections 4.1 and 5.1. The Lower Murray, which falls out of the Program's project area, is also being considered for downstream outcomes. Flow rates of 38 GL/day and 50 GL/day at Euston have been selected to represent bankfull and overbank events (DPIE 2020).

Table 1.1 Constraint relaxation scenarios to be assessed at each water quality assessment area

FLOW REGIME DEFINED BY FLOW LIMITS AT LOCATIONS	SCENARIO ID
Murray River	
Gauge for Hume–Yarrawonga: Doctors Point Gauge for Yarrawonga–Wakool Junction: Yarrawonga Gauge for Wakool Junction–Wentworth: Euston	
≤15 GL/day at Yarrawonga, ≤25 GL/day at Doctors Point (current)	Y15D25
≤25 GL/day at Yarrawonga, ≤25 GL/day at Doctors Point	Y25D25
≤30 GL/day at Yarrawonga, ≤30 GL/day at Doctors Point	Y30D30
≤40 GL/day at Yarrawonga, ≤40 GL/day at Doctors Point	Y40D40
≤45 GL/day at Yarrawonga, ≤40 GL/day at Doctors Point	Y45D40
Murrumbidgee River	
Gauge for upstream of Hay – Wagga Wagga Gauge for downstream of Hay - Hay	
≤22 GL/day at Wagga Wagga (current)	W22
≤32 GL/day at Wagga Wagga	W32
≤36 GL/day at Wagga Wagga	W36
≤40 GL/day at Wagga Wagga	W40

1.2 WATER QUALITY RISKS AND BENEFITS ASSESSMENT

Adverse water quality events occur intermittently in the Program project areas and are associated with widespread or localised death and mortality of native species. They can also impact on agricultural, domestic and recreational water users. Each type of event is caused by a sequence of antecedent hydrological conditions that interact with one or more physical or biological drivers. In many cases these are natural phenomena that occur more frequently under regulated flows.

The assessment identifies the mechanisms and likely ecological impacts of each type of event, in the context of managed water deliveries proposed by the Program's hydrological modelling (Table 1.1). These water deliveries and associated flow regimes (with corresponding frequency, timing, duration) are described via a set of flow options (scenarios), listed in Table 1.1. The assessment includes reference to critical knowledge gaps and mitigation strategies. The outcomes from the assessment will be used to:

- inform formal evaluation of RRCP flow limit and mitigation options (RRCP Options Evaluation Framework) for selecting the preferred project options (Strategic Business Case)
- address community and landholder concerns about spread of water quality risks under relaxed flow constraints
- develop appropriate mitigation measures.

In the following sections of this report, the adopted approach is described. This is followed by detailed description of each water quality issue, providing the evidence on which the risk assessment is based. This is then followed by assessment for each of the project areas.

2 ECOLOGICAL RISK/BENEFIT ASSESSMENT APPROACH

The risk assessment seeks to describe the current water quality risk in relation to the 8 water quality issues (listed below) identified by the department for the project areas. The resolution at which a qualitative ecological risk assessment can be made cannot match the resolution of the hydrological data provided by the department. This scale difference has been partially managed through the development of a two-step, two scale process – Step 1 at the finer scale of flow bands and Step 2 at the broader scale of flow regimes.

- Step 1 – assign the likelihood and impact (risk and benefit) of a water quality event occurring at a range of daily flow volumes (listed in Table 1.1) described within each of the constraint relaxation scenarios (also listed in Table 1.1). These flow volumes (flow bands) occur across all flow scenarios and the assignment of risk is independent of the flow scenarios in which they occur
- Step 2 – using the results from Step 1 and flow event details provided by the department for each of the constraint relaxation scenarios, assess the risks and benefits to water quality associated with each of the constraint relaxation scenarios such that the scenarios can be compared.

2.1 ASSIGNING RISK AND BENEFIT OF WATER QUALITY EVENTS, FOR FLOW CATEGORIES

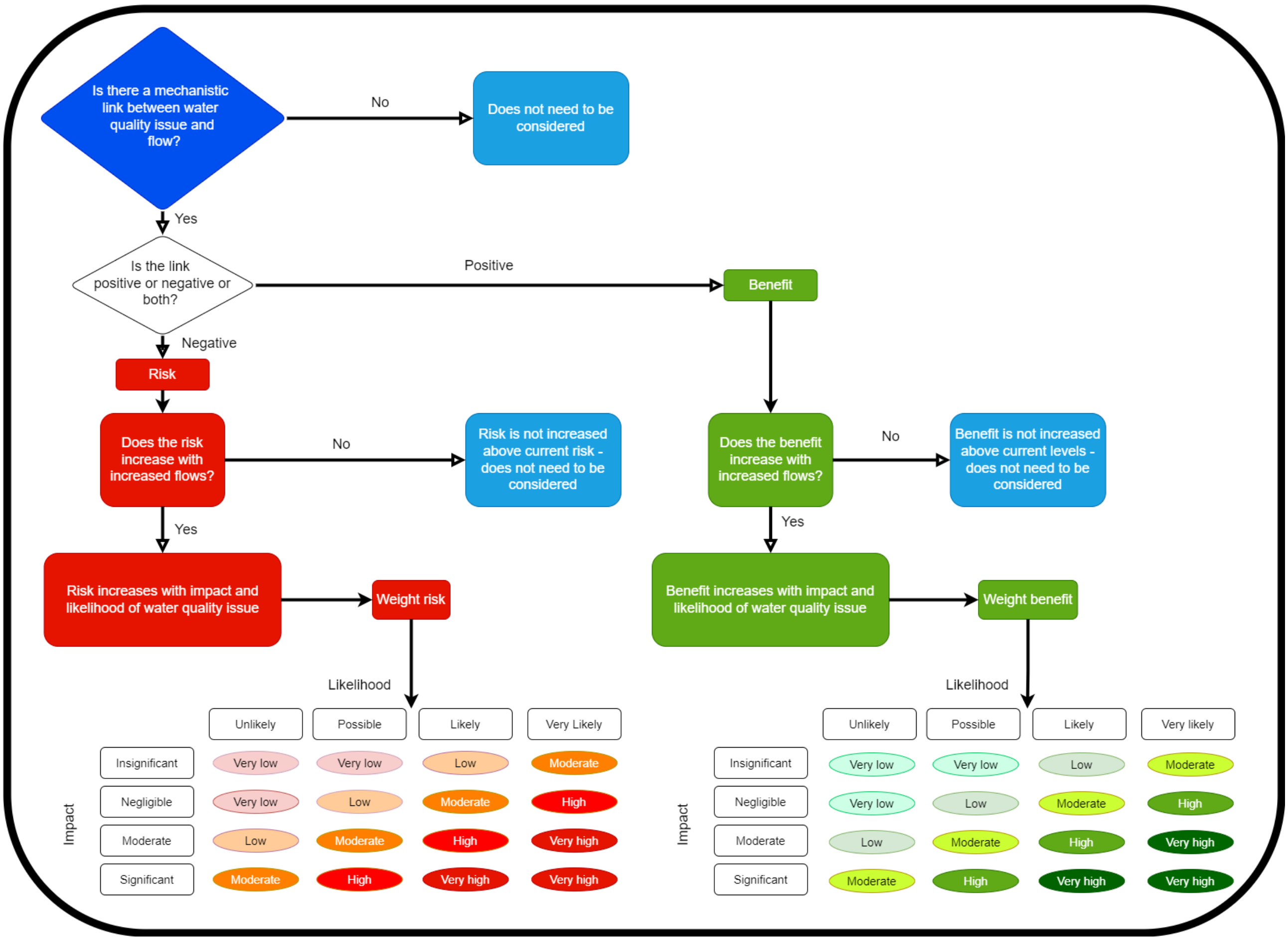
General descriptions of each issue are provided with supporting evidence from scientific literature. We establish a base-case scenario for understanding water quality issues under current operational flow limits in the Murray and Murrumbidgee rivers from expert knowledge and peer reviewed scientific literature generated within the Murray–Darling Basin. **It is important to note that this risk assessment considers only the flowing main channels of rivers of the designated project areas. Floodplain and wetland habitats are not assessed due to the high level of habitat heterogeneity and context dependency of water quality parameters within these habitats.** Where relevant, the role of connectivity between the main channel and its floodplain is included in the discussion. The 8 water quality issues of concern identified by the department as having potential links to relaxation of flow constraints:

- blackwater
- eutrophication
- blue-green algae ‘blooms’
- salinity
- turbidity
- weir pool stratification/ destratification
- acid sulfate soils
- thermal pollution.

While some of these water quality issues have clear mechanistic links to relaxation of flow constraints, others are less clear. Before analysing risks for increased flow limits (i.e. varying timing, duration and frequencies of different flow thresholds to get more water down the river with different timing and duration of flow size), we first need to determine if there is a mechanistic pathway from the risk level under the current flow regimes to changes to risk levels at the new proposed flow regimes (e.g. 25 GL/day at Yarrawonga, 25 GL/day at Doctors Point). We developed a decision matrix to guide this process (Figure 2.1).

After exploring current risks to water quality for each issue we then consider if mechanistic links between each issue and increases to flow magnitude exist (blue diamond, Figure 2.1). If the answer is NO, based off evidence from the literature, then we deem that this issue does not need to be considered further for risk assessment, i.e. although this is a water quality issue, **relaxing constraints does not change its risk** (light blue box, Figure 2.1).

If the answer is YES, we need to determine if the mechanistic link is positive, negative or both; if it is negative then risk is generated, if it is positive benefits are generated. If there is a linear relationship between increasing risks/benefits and increases in components of the flow regimes, risks/benefits can then be assessed by assigning impact and likelihood for each issue under each proposed flow limit (Figure 2.1).



	Unlikely	Possible	Likely	Very Likely
Insignificant	Very low	Very low	Low	Moderate
Negligible	Very low	Low	Moderate	High
Moderate	Low	Moderate	High	Very high
Significant	Moderate	High	Very high	Very high

	Unlikely	Possible	Likely	Very likely
Insignificant	Very low	Very low	Low	Moderate
Negligible	Very low	Low	Moderate	High
Moderate	Low	Moderate	High	Very high
Significant	Moderate	High	Very high	Very high

Figure 2.1 Step 1 decision flowchart for risk/benefit assignment to each flow category within a flow scenario

Although changes to maximum regulated flow volumes represent a fundamental component of proposed changes to flow regimes, it is envisaged that relaxation of flow constraints will allow water to be used in a more flexible manner and may alter the duration, frequency and seasonality (timing) of flows from current flow management – for example, using water to extend natural duration of flow events, increasing natural flow events and generating completely new events. Thus our risk assessment includes consideration of water quality outcomes under flows of different timing – autumn/winter (November to April), spring/summer (May to October) – and duration (< or >7 days) to assess the flow regimes related to a range of flow volumes considered within each of the constraint relaxation options.

Antecedent flow patterns and **frequency of flows** under each proposed flow scenario will also likely impact the risk of negative water quality outcomes for each project area. However, due to the substantial number of possible combinations, context dependency of each of these parameters and a lack of empirical evidence to support determination at this resolution, it is unrealistic to incorporate them into our risk assignment. Since antecedent flow patterns and frequency of flows under each of the proposed flow scenario will generally influence water quality issues in a consistent manner among each project area, we have instead included a table within each water quality issue section to indicate if these parameters will increase, decrease or not change risk (along with duration and seasonality which are also included in the risk assessment).

Risk and benefit assignments are made for each flow category for 3 of the water quality issues: blackwater, blue-green algae blooms and salinity. These are the output of Step 1, set out in tables structured as shown in Table 2.1.

Table 2.1 Example of reporting likelihoods, impacts and risks and benefits for each flow category within each water quality assessment area

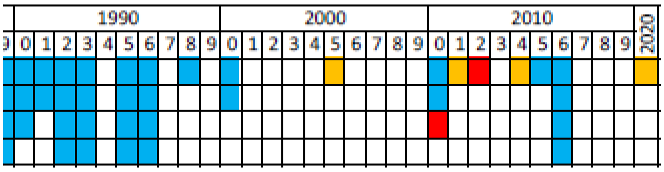
FLOW EVENT	FLOW EVENT TIMING (MONTH)	DURATION (DAYS)	RISK OF A WATER QUALITY EVENT			BENEFIT OF A WATER QUALITY EVENT		
			IMPACT	LIKELIHOOD	RISK	IMPACT	LIKELIHOOD	BENEFIT
>25 GL/day at Doctors Point	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate

There is an entry for each **flow category** within the constraint relaxation flow scenarios being considered for that project area.

- **Timing** differentiates between winter and summer temperatures.
- The **duration** breakpoint of 7 days for flows within a given flow band (e.g. 20,000 to 30,000 ML/day) has been chosen for practical reasons – it is a timeframe that is tangible and memorable to people who observe the river and its flows.
- **Impact** is the consequence if a water quality event did occur.
- **Likelihood** is an assessment of whether the impact will occur at all within this flow band/timing/duration.
- **Assessments** of risk and benefits are based on the impact/likelihood combinations encoded in Figure 2.1.

2.2 ASSIGNING RISK TO CONSTRAINT RELAXATION FLOW SCENARIOS

The department provided, for each water quality assessment area, the number of years (in their 120-year modelling period) in which flow events of >7 days duration, in summer and winter, occurred under current and the constraint relaxation scenarios. An example of these data is provided in Figure 2.2. These flow magnitudes (e.g. 20+ GL/day) match those used to assign risk in Step 1.



Total years		
Current constraints	Relaxed constraints	Difference
67	80	+13
45	47	+2
39	36	-3
36	35	-1

Figure 2.2 Example of the flow event information provided for the risk assessment

A blue cell on the left indicates that a flow event of >7 days occurred. Columns are years and rows are flow categories (e.g. 20+GL/day). Orange indicates where one or more events have been added in that year; red indicates where one or more events have been removed in that year. The total number of years in the full scenario modelling period (~120 years) under current and relaxed constraints are tabulated on the right. Difference is the number of events added less the number of events removed

A significant change and/or difference in the number of flow events in a flow category that has been deemed to have above a **moderate** likelihood of risk of a water quality event could indicate a heightened (or reduced) likelihood of an adverse (or beneficial) water quality event associated with that flow scenario.

Aggregation across water quality issues and flow categories to provide an overall rating for each scenario is best done through detailed water quality modelling which tracks likelihood of blackwater, blue-green algal blooms and salinity through time to provide likelihood distributions. A simple set of rules could be developed, based on the presumption that the risk levels for each water quality issue within flow categories do not change, i.e. the likelihood of a water quality event occurring and consequence of that event do not change; it is then that a significant change in the likelihood of the flow event itself that may increase or decrease the risk. However, it is difficult to develop a rule for aggregating risk and/or benefit across the flow categories, as regardless of change in pattern in the flow regimes (e.g. more flow events in the smaller flow range), expert opinion has assessed that the risk and benefit can accrue from just one event. In this report, we have chosen then to report change from current.

In addition to looking at the change in flow over the full simulation period, the assessment looks at the impact in a drought decade (2000–09) and a wet decade (2010–18 for the Murray, and 2010–20 for the Murrumbidgee). The intent of looking at these extremes, just for a decade, is to provide a finer level of granularity to the assessment.

3 WATER QUALITY ISSUES

This chapter discussed the 8 water quality issues in detail. Every effort has been made to reference the most relevant and up-to-date experimental and/or theoretical knowledge to inform and support our assignments of risk and benefit to flow bands (Step 1) and our assessments of likelihood and impact of changes in flow (as envisaged under the Reconnecting River Country Program) (Step 2) on the water quality issues.

3.1 BLACKWATER

'Blackwater' is the term used to describe occasions in water bodies when higher than usual concentrations of dissolved organic carbon (DOC) cause the water to darken in colour (Howitt et al., 2007). When blackwater is accompanied by reduced concentrations of dissolved oxygen (DO) in the water column this is described as a 'hypoxic blackwater' event (Whitworth et al., 2012). Hypoxic blackwater events can occur following natural or managed floods and are generally common in low gradient river systems with a high level of river-floodplain connection.

Plant litter accumulates on floodplains between floodplain inundation events, including within dry channels and anabranches (Whitworth et al., 2013). Following inundation, organic carbon compounds are leached from plant material, and when flood waters are returned to rivers (e.g. Wolfenden et al., 2018), contribute to elevated riverine DOC concentrations and provide an allochthonous source of carbon to support aquatic food webs (e.g. McInerney et al., 2017; Rees et al., 2020b; Whitworth et al., 2012). Temperature is a key limiting factor for the rate at which microbes metabolise DOC and consume oxygen and, if flooding occurs at optimal times for microbial activity, DOC metabolism can lead to widespread reductions in dissolved oxygen concentrations of water bodies, termed hypoxia. Very low dissolved oxygen concentrations (e.g. < 2 mg/L King et al., 2012) have led to widespread fish and decapod mortality events.

Thus, while floodplain inundation is an important mechanism for providing carbon for aquatic food webs and provides clear ecological benefits (e.g. see Junk et al., 1989), there is also a risk for negative outcomes from floodplain inundation.

The risk of hypoxic blackwater events occurring in rivers is increased if floodplain inundation occurs during warmer periods.

The type and amount of litter on a floodplain is also central to understanding the amount of bioavailable DOC that will be generated through floodplain inundation (Hladyz et al., 2011; Whitworth & Baldwin, 2016). When estimating the likelihood of hypoxic blackwater events occurring in river channels, time since last flood must be accounted for as a driver of litter loads (Whitworth and Baldwin, 2016). Lifting flow constraints is considered one mechanism by which floodplain litter build up can be controlled and mediated, and thus severity of risk of hypoxic blackwater events reduced.

Based on evidence from the scientific literature and following our decision matrix:

Blackwater has a mechanistic link to increased flow magnitude that can be both positive and negative and risks and benefits can increase with higher flows.

These relationships are described in Table 3.1.

Table 3.1 Blackwater links

Mechanistic link to increased flow magnitude?	Positive, negative or both	Do risk/benefits increase with higher flows?	Published evidence
Yes	Both	Yes	(Hladyz et al., 2011; Howitt et al., 2007; Junk et al., 1989; King et al., 2012; McInerney et al., 2017; Rees et al., 2020b; Whitworth & Baldwin, 2016; Whitworth et al., 2012; Whitworth et al., 2013; Wolfenden et al., 2018)
Additional flow parameters	**Influence on risk**		
Antecedent patterns	Extended periods of no floodplain inundation or extreme dry periods that stress trees may lead to a build-up of floodplain litter and increases the risk of hypoxic blackwater in subsequent flows		
Duration	Extended inundation duration may allow more time for leaching and may increase the risk of hypoxic blackwater		
Seasonality	If floodwater has very high DOC concentration risk of hypoxic blackwater is increased in summer due to increased rates of microbial activity		
Frequency	It is thought that increased frequency of flooding will reduce risk of blackwater by regulating litter build-up, however there is a lack of literature on this issue and more research is required		

The likelihood of blackwater events occurring in each assessment area has been validated against model outputs provided by the department (DPE, in prep) and the impact of blackwater events on water quality is derived from expert opinion and literature evidence. Together, Likelihood and Impact provide our final blackwater risk assessment, based on the assignment provided in Figure 2.1.

3.1.1 BLACKWATER RISK MITIGATION UNDER HIGHER FLOWS

Mitigation of the risk of blackwater causing hypoxic events due to higher flows can be achieved by carefully managing the timing of flows and by assessing antecedent patterns. Blackwater is far less likely to lead to hypoxic conditions if flows occur from May-October (e.g. Table 4.2, Table 4.6, Table 4.10). Risk increases in warmer months due to increased rates of microbial respiration consuming oxygen. Knowledge of litter loads within zones of potential inundation can provide accurate estimates of dissolved carbon concentration and expected patterns in dissolved oxygen rivers (e.g. BRAT), although litter estimation is time consuming and labour intensive. New approaches for remote assessment of litter standing stocks[2] and advances in modelling techniques offer promising improvements for mitigation of hypoxic events. The impact of extended (>7 days) hypoxic events is significant, leading to widespread aquatic biota mortality. Higher flows do not increase the risk of hypoxic blackwater above the risk of natural floods, but any managed flows need to carefully consider season and floodplain litter loads before proceeding.

3.2 EUTROPHICATION

Eutrophication is the process by which a water body becomes progressively more enriched with nutrients, commonly leading to excessive growth of algae. Eutrophication describes the biological effects of an increase in concentration of plant nutrients – usually nitrogen and phosphorus, but also silicon, potassium, calcium, iron or manganese – on aquatic ecosystems (Harper, 1992). Stratification and light penetration, not nutrient availability, are the primary triggers for algal blooms in regulated rivers of south eastern Australia, although nutrient exhaustion can limit the total biomass of blooms (Davis & Koop, 2006).

Higher flows (as a result of constraint relaxation) are unlikely to influence eutrophication since increased flows originate from the same source (such as Lake Hume and Burrinjuck Dam), and only the magnitude and timing of the flow are changing. Small increases in flows would lead to small increases in nutrient mobilisation. Higher flows (greater inundation) will mobilise more nutrients, but will then undergo a combination of consumption, dilution through increased flows and subsequent transport downstream. The final outcome could range from no, or very limited, short-lived increases in nutrients through to greater increases, though not persisting for long

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[2] (pers comm P McInerney) The research referred to is part of the Ecological Functions project (CSIRO and MDBA). The manuscript is in prep.

periods of time and the channel is not likely to become eutrophic (e.g. no consistent increase in riverine nutrient concentrations downstream of large areas of floodplain inundation, Rees et al., 2020a).

Based on evidence from the scientific literature and following our decision matrix:

Eutrophication has no mechanistic link to increased flow magnitude.

This relationship is described in Table 3.2.

Table 3.2 Eutrophication links

Mechanistic link to increased flow magnitude?	Positive, negative or both	Do risk/benefits increase with higher flows?	Published Evidence
No	N/A	N/A	(Davis & Koop, 2006; Harper, 1992; Rees et al., 2020a)
Additional flow parameters	**Influence on risk**		
Antecedent patterns	N/A		
Duration	N/A		
Seasonality	N/A		
Frequency	N/A		

3.3 BLUE-GREEN ALGAE BLOOMS

Blue-green algae, or cyanobacteria, comprise a group of photosynthetic prokaryotes that proliferate in warm, nutrient-rich, slow flowing or still waters. High concentrations of cyanobacteria (called blooms) can present significant risks to stock, domestic and recreational water users as toxic compounds are produced by some species (Baldwin, 2021). Blue-green algae blooms are common within the Basin, with primary causes attributed to eutrophication, warm summer and autumn water temperatures and continued low flows (Bowling et al., 2016). Within the River Murray, blooms can form in warm non-flowing surface waters of storages (e.g. Lakes Hume and Mulwala), which can then act as a net-exporter of cyanobacteria, influencing downstream phytoplankton community composition (e.g. Baldwin et al., 2010; Bowling et al., 2018). Blooms are more likely to occur in summer with elevated temperature and increased light intensity and duration, although they can potentially occur at any time of the year if conditions are suitable. Historically within the Murray River system blooms are more likely to occur when the water level in Lake Hume drops below 10% (Bowling et al., 2018).

In highly regulated river systems, such as the Murray and Murrumbidgee rivers, water passage via storages is unavoidable and will occur regardless of flow constraints. Thus, it is unlikely that higher flows will increase risks and benefits above those of base-flows. However, there are both potential positive and negative outcomes for blue-green algae blooms from relaxing constraints and they are related more to context specific timing of flows rather than flow magnitude. A potential positive outcome of increasing flows is that it can increase flexibility of river management and allow larger flows to help disperse blooms and increase water velocity above thresholds for bloom formation (e.g. ~0.05m/s - Mitrovic et al., 2003). A potential negative outcome is that larger flows may act to distribute blooms over a larger geographical area. The likelihood of either case occurring is highly context dependent and will be contingent on the species of phytoplankton and complex abiotic drivers such as meteorological patterns, water quality and antecedent conditions (e.g. Sherman et al., 1998).

Thus, for blue-green algae blooms we assess the general risk in relation to relaxation of constraints increasing the geographical distribution of blooms above baseline flows. We assess general benefits in relation to the capacity of increased flows providing an improved mechanism and more flexibility for dispersal of blooms, acknowledging that both benefits and risk are likely to be highly context dependent. For example, a very simple approach to avoid risks of spreading blooms is simply not to release environmental flows when cyanobacteria density is high within water storages. Both risks and benefits of any management intervention will need to be carefully considered for individual blooms, taking into account abiotic drivers at that time.

Based on evidence from the scientific literature and following our decision matrix:

Blue-green algae has a mechanistic link to increased flow magnitude that can be both positive and negative and risks and benefits can increase with increasing flows.

This relationship is described in Table 3.3.

Table 3.3 Blue-green algal bloom links

Mechanistic link to increased flow magnitude?	Positive, negative or both	Do risk/benefits increase with higher flows?	Published Evidence
Yes	Both	Yes	(Baldwin et al., 2010; Baldwin, 2021; Bowling et al., 2018; Bowling et al., 2016; Crawford et al., 2017; Mitrovic et al., 2003)
Additional flow parameters	**Influence on risk**		
Antecedent patterns	Long periods of no flow, or little flow are more suitable for blooms		
Duration	Longer flows may help disperse toxic blooms		
Seasonality	Blooms are more likely in summer when there are more daylight hours, higher light intensity and warmer temperatures		
Frequency	More frequent flows may help to disperse algae		

The impact and likelihood of blue-green algal bloom occurring in each project zone are derived from expert opinion and literature evidence. Together, Likelihood and Impact provide our final blue-green algal bloom risk assessment, based on the assignment provided in Figure 2.1.

3.3.1 BLUE-GREEN ALGAE BLOOM RISK MITIGATION UNDER HIGHER FLOWS

Mitigation of the risk of blue-green algae blooms being distributed over larger geographical scales than baseline flows by increasing flows is relatively easy to achieve. Risk can be mitigated by monitoring algal assemblages within the storages from which flows will be released (this monitoring already occurs in most storages). If harmful cyanobacteria concentrations are above desired thresholds (e.g. National Water Quality Management Strategy (NWQMS)) within storages, planned flow releases should be carefully reassessed, since increasing flows above base-flow requirements at this time could lead to a higher risk of increased bloom extent (e.g. Moderate to High, Table 4.3, Table 4.7, Table 4.11). However, increased flow flexibility also represents important benefits for riverine management. For example, increased flow velocity can be used to disperse cyanobacteria blooms in weir pools by disrupting thermal stratification and interrupting dominance of buoyant cyanobacteria over diatoms in highly illuminated surface waters (Sherman et al., 1998), highlighting the context dependency of the risk of flows for blue-green algae blooms.

3.4 SALINITY

The Basin is susceptible to elevated salt levels due to underlying saline groundwater (Hart et al., 2020). Since European colonisation in the 19th century removal of native vegetation for agriculture and the development of irrigation infrastructure in the Riverine Plains and Mallee regions have caused more water to enter groundwater systems, leading to mobilization of salt to the surface and to rivers (Hart et al., 2020). Though now largely under control in the main river channel due to salinity management actions that began in the 1980s, salinity requires ongoing active management to prevent further salinisation (Hart et al., 2020).

For aquatic organisms, variations in salinity can influence toxicity, ion regulation, reproductive success, and somatic growth of individuals, along with function, biodiversity, and community composition of ecosystems (Shackleton et al., 2019). Specific tolerance levels to salinity vary between species and geographic distribution (e.g. Kefford et al., 2007), though generally upland taxa are more sensitive changes in salt concentration. Salinity levels have remained above the World Health Organization's guideline for human consumption (800 µS/cm) at

Morgan in South Australia for prolonged periods during times of drought and low flow (Paul et al., 2018). Salinity in the lower Murray has decreased in the last 30 years from an average of 800 to about 400 µS/cm, due in part to government funded salinity mitigation strategies (Paul et al., 2018). The addition of environmental water allocations in rivers has had a major influence in reducing Basin salinity though export of salt, and in 2019–20 the only water to exit the barrages in South Australia was Commonwealth Environmental Water (CEW) which accounted for over 600,000 tonnes of salt export to the Southern Ocean (Ye et al., 2021). Thus, in 2019–20 the only contribution to the Basin Plan's 2 million tonne per annum salt export target for the Basin was from salt exported by CEW. Changes to natural flow patterns due to river regulation and a reduction in large 'flushing flows' has been linked to increased salinization of rivers, causing a gradual accumulation of salt over time and a gradual net increases in mean salt levels (Nielsen et al., 2003). There is strong evidence that reductions in flow can lead to decreased catchment flow inputs and increased influence of saline groundwater inputs, leading to elevated salinity, particularly in the lower Murray River and lakes (Mosley et al., 2012).

A potential perceived risk of relaxing flow constraints and increasing the magnitude of managed flows is salt mobilisation from floodplains and the raising of groundwater tables. Floodplain and wetland inundation from natural floods can lead to mobilisation of salt stored in floodplain environments into the Murray River and its tributaries, particularly in the lower reaches (Jolly et al., 2012). Such salt accessions can continue for several months after the recession of a flood which, when combined with the reduction in the river's dilution flows, may cause downstream increases in river salinity (Jolly et al., 2012). Short-term salt accessions (days to weeks) are thought to be caused by processes that include salt wash-off from the surface of floodplain soils, flushing of salt stored in the water columns and beds of permanent wetlands, and groundwater mixing processes within bank storage. Long-term salt recessions that can occur for many months after the flood peak are thought to be caused by inundation recharging saline groundwater beneath floodplains and wetlands, leading to slow displacement of saline groundwater to the river and its anabranches (Jolly, 1996; Overton et al., 2005). Floodplain salinisation is prevalent in the highly regulated lock/weir section of the lower Murray River, and though this region is not one of the project areas under evaluation in this project, downstream impacts of additional flows in project areas should be considered. The mid-Murray region and Loddon and Campaspe tributary catchments between Echuca and Swan Hill have historically suffered from groundwater driven salinity problems (though more recently improved due to groundwater recession from the Millennium Drought between 2000 and 2010, modernisation of the supply and farm irrigation systems, and water trade reducing the volume of water used across the region, pers comm Tim Shanahan, North Central Catchment Management Authority) and represent another potentially higher risk zone for riverine salinity accession.

However, given that proposed flow limit increases are far smaller (25–45 K ML/day) than natural flood peaks that occur ~5 years (>60 GL at SA border), it is also unlikely that managed flows will liberate large quantities of salt from floodplains. Relaxation of constraints also allows increased flexibility to manage flows to improve salinity. For example near Lock 6, salinization is driven by a lack of flooding and rising saline groundwater tables due to the effects of river regulation from Lock 6 and high inflows from regional groundwater levels increased by Lake Victoria (Overton et al., 2006). Regulation here has also led to reduced frequency and duration of the floods that leach salt from soils and supply plants with fresh water for transpiration. Overton et al. (2006) recommend that a combination of both lowering groundwater and increasing flooding frequency is likely to be required to conserve vegetation on the Chowilla floodplain.

Rises in the naturally saline groundwater level in the Lower Murray are due to the effects of river regulation and flow-control structures (Overton et al., 2006) and relaxation of flow constraints will improve the capacity and flexibility to inundate floodplains. However, given that natural flows are known to mobilise salt stored in floodplain environments into the Murray River and its tributaries there is a risk that salt accession to the river could be acerbated by increasing the size of managed flows.

Based on evidence from the scientific literature and following our decision matrix:

Salinity has a mechanistic link to increased flow magnitude that can be both positive and negative and risks and benefits can increase with higher flows.

This relationship is described in Table 3.4.

Table 3.4 Salinity links

Mechanistic link to increased flow magnitude?	Positive, negative or both	Do risk/benefits increase with higher flows?	Published Evidence
Yes	Both	Yes	(Hart et al., 2020; Jolly, 1996; Jolly et al., 2012; Kefford et al., 2016; Kefford et al., 2007; Mosley et al., 2012; Nielsen et al., 2003; Overton et al., 2005; Overton et al., 2006; Paul et al., 2018; Shackleton et al., 2019; Ye et al., 2021)
Additional flow parameters	**Influence on risk**		
Antecedent patterns	Long periods of no flow may allow salt to accumulate on floodplains		
Duration	N/A		
Seasonality	N/A		
Frequency	More frequent flows may help to export salt downstream		

The impact and likelihood of salinity issues occurring in each project zone are derived from expert opinion and literature evidence. Together, Likelihood and Impact provide our final salinity risk assessment, based on the assignment provided in Figure 2.1.

3.4.1 SALINITY RISK MITIGATION UNDER HIGHER FLOWS

Mitigation of the risk of salinity being negatively impacted by higher flows is difficult to achieve. However, mobilisation of salt by high flows is a natural function within Australian rivers, and the only mechanism by which salt can be exported from the Basin. Mobilisation of salt from saline habitats on floodplains is unavoidable and will occur if they are inundated. However, floodplain salinisation of the Murray and Murrumbidgee floodplains is restricted to the lower sections (downstream of Echuca and Hay), and within these areas many of the biota are well adapted to large fluctuations in salinity. Salinity is mobilised during periods of high flow, leading to dilution of salts in a larger volume of water, also decreasing severity of effects for biota. Risk of salinity being negatively associated with higher flows range from low to moderate (Table 4.4, Table 4.8, Table 4.12), and are not greater than the risk incurred by natural floods, but remain unavoidable nonetheless.

3.5 TURBIDITY

In Australia, anthropogenic activities have greatly increased the supply of sediment over the last 200 years, with primary sources including hillslope erosion, gully erosion and channel widening which have contributed to increased sediment storage in many of our rivers (Prosser et al., 2001). Rutherfurd et al. (2020) divide the Murray River's human sediment history into four periods; 1/ the aboriginal period (prior to 1840) that was characterized by clear water during summer low-flows in the Murray River and its southern tributaries 2/ the mining period where suspended sediment loads peaked in the 1870s and 1880s as valley floors were incised by gullies and gold sluicing flushed huge amounts of sludge into southern tributaries 3/ the ‘hiatus’ period between 1930–1960 where sediment supply from gullies and gold mining waned and low flow suspended solid concentrations returned to low levels and 4/ the regulation period from 1960 onwards where Murray River became disconnected from catchment derived sediment. Despite decoupling from catchment derived sediment, turbidity levels increased again during the latter period due to bank erosion from long duration summer irrigation flows, the invasion of introduced carp (*Cyprinus carpio*), wave erosion from boats and peak erosion rates switched from winter to summer (Rutherfurd et al., 2020).

‘Catastrophic widening’ is the term used to describe channel changes that have occurred during single high magnitude floods or a series of floods (Erskine & Bell, 1982). However studies that identify extreme floods as the primary cause of channel enlargement have focussed on rivers that eroded in the 1950s following an increase in the magnitude of high intensity floods (Prosser et al., 2001). Bank erosion and deposition are highly variable, both spatially and temporally, and managed environmental flows have little influence on bank erosion (e.g. Vietz et al., 2018). In southern Basin rivers regulated flow releases generally have low sediment loads because they are dominated by relatively clean water from dams and reservoirs and thus sediment transport is usually dominated by storm events (Olive & Olley, 1997). Since the proposed increased flows are relatively small (30–50 GL/day) in comparison to large natural flood events (e.g. flows at Doctors Point > 80 GL/day in 2016), it is unlikely that they will contribute to catastrophic channel widening or increased turbidity above those observed during natural flow spates or contribute to long term turbidity elevation. Turbidity naturally increases with increased flows in rivers, but primary drivers of elevated turbidity in the project area are high summer irrigation flows, invasive carp and wave erosion from boats.

Based on evidence from the scientific literature and following our decision matrix:

> Turbidity has a mechanistic link to increased flow magnitude that is not increased above current risk and risks and benefits do not increase with higher flows.

This relationship is described in Table 3.5.

Table 3.5 Turbidity links

Mechanistic link to increased flow magnitude?	Positive, negative or both	Do risk/benefits increase with higher flows?	Published Evidence
Yes	Not increased above current risk	No	(Erskine & Bell, 1982; Olive & Olley, 1997; Prosser et al., 2001; Rutherfurd et al., 2020; Vietz et al., 2018)
Additional flow parameters	**Influence on risk**		
Antecedent patterns	Extreme large natural flow event may mobilise large quantities of sediment		
Duration	N/A		
Seasonality	N/A		
Frequency	N/A		

3.6 WEIR POOL STRATIFICATION/DESTRATIFICATION

Weir pool thermal stratification describes the differential heating of surface water, which absorbs heat and becomes less dense, floating on dense cooler waters in weir bottoms (Baldwin, 2021; Boulton et al., 2014; Sheldon et al., 2021). The severity of weir pool stratification is controlled by the relative input of thermal energy from the sun and turbulence from flow or wind. Ongoing thermal stratification can lead to the separation of the surface waters from the bottom waters with a thermocline or area of rapid temperature change between the layers (Boulton et al., 2014). Surface waters are hotpots for phytoplankton primary production, since they have high light exposure and warmth and are therefore often well oxygenated during the day. In contrast, bottom waters are cool and dark, and can be dominated by heterotrophic consumption of carbon by sediment microbes, often leading to very low concentrations of dissolved oxygen.

Persistent thermal stratification in rivers does not generally occur because flow normally provides sufficient energy to prevent its establishment, however within weir pools stratification can occur during low and no-flow periods (Baldwin, 2021). When mixing occurs in weirs following extended periods of stratification, either via flows or changes to ambient air temperature, negative ecological outcomes can occur when waters with low dissolved oxygen and higher nutrients mix with well oxygenated surface waters. Depending on the extent of the reduced oxygen at depth, mixing can lead to reduced dissolved oxygen concentration in the entire waterbody, and in extreme cases hypoxic water that can cause large-scale fish mortality (e.g. Baldwin, 2019; Sheldon et al., 2021).

Ultimately there is a balance between the extent that deoxygenated waters extend at depth and the amount of water flowing through the weir. Despite flows having potentially negative ecological consequences for weir pool thermal stratification, this negative association is not determined by the size of the flow, and thus lifting flows above existing flow constraints does not increase the risk above current risk levels. Additionally, there is a reduced likelihood for flows to be released in peak summer periods.

Based on evidence from the scientific literature and following our decision matrix:

> Weir pool thermal stratification has a mechanistic link to increased flow magnitude that is not increased above current risk and risks and benefits do not increase with higher flows.

This relationship is described in Table 3.6.

Table 3.6 Weir pool stratification/destratification links

Mechanistic link to increased flow magnitude?	Positive, negative or both	Do risk/benefits increase with higher flows?	Published Evidence
Yes	Not increased above current risk	No	(Baldwin, 2019; Baldwin, 2021; Boulton et al., 2014; Sheldon et al., 2021)
Additional flow parameters	**Influence on risk**		
Antecedent patterns	Long periods of no flow increase the risk of stratification		
Duration	Longer periods with flow may help to prevent stratification		
Seasonality	Greater risks for stratification in summer when there higher when surface/bottom differential is higher		
Frequency	Increased flow frequency is likely to increase water mixing		

3.7 ACID SULFATE SOILS

Sulfidic sediments form when sulfate is reduced to sulfide by anoxic bacteria in the presence of organic carbon, and the sulfide that has been generated reacts with iron in clays and minerals in sediments to form iron sulfides (Hall et al., 2006; Rees et al., 2010). Due to their high carbon loading, anoxic conditions and prolonged periods of inundation wetlands that have any impact from salinity that contains sulfate can provide ideal conditions for formation of sulfidic sediments (Baldwin et al., 2007). When wetlands that contain sulfidic sediments dry, exposure of sediments to the atmosphere can lead to the oxidation of iron sulfides and the production of acid (Glover et al., 2011). Filling of some dry wetlands during floods has the potential to generate acidic conditions, particularly in more saline lowland regions, and although acidic water can be carried back to the main river channel via return flows, the dilution of acidic water by high flows will likely result in negligible effects on water quality. Acid sulfate soils occur in wetlands and in some channels higher on the floodplain of the Edward Wakool system, rather than the river channel. The pH of in-channel monitoring sites in the Edward Wakool system have been remarkably consistent since 2014 (Watts et al 2019) and there is no clear pathway between increasing in-channel flows of the Edward Wakool system above current constraints and changes to the risk or benefits to causing water quality responses from acid sulfate soils (acknowledging that flows were higher than proposed flow limits in both 2016 and 2021). Understanding any risk of higher flows leading to inundation of acid sulfate soils higher on the floodplain requires integration of maps showing extent and distribution of acid sulfate soils, with an accurate inundation model. These data were not in the scope of this report and should be considered an important knowledge gap for future risk evaluation.

Based on evidence from the scientific literature and following our decision matrix:

While there is a potential mechanistic link for the inundation of wetlands and channels that contain acid sulfate soils higher on the floodplain within the Edward–Wakool river system with increased flow magnitude, there is currently no evidence that changes to flow have yielded acid sulfate soil related impacts on in-channel water quality.

This relationship is described in Table 3.7.

Table 3.7 Acid sulfate soils links

Mechanistic link to increased flow magnitude?	Positive, negative or both	Do risk/benefits increase with higher flows?	Published Evidence
Yes	N/A	N/A[1]	(Baldwin et al., 2007; Glover et al., 2011; Hall et al., 2006; Rees et al., 2010, Watts et al., 2019)
Additional flow parameters	**Influence on risk**		
Antecedent patterns	Regular wetting and drying of wetlands may decrease risk		
Duration	Wetlands kept permanently full for long periods and then dried are at high risk		
Seasonality	N/A		
Frequency	Regular flooding may decrease risk		

1: Acid sulfate soils are known to occur in the Edward Wakool system. Assigning risk requires combining mapping of these soils across the Edward Wakool system with an inundation mapping, information not available during preparation of this report. Determination of risk/benefit of water quality response from inundation of acid sulfate soils should be considered a key knowledge gap.

3.8 THERMAL POLLUTION

Large dams are responsible for altering downstream riverine temperature dynamics, with subsequent consequences for biotic communities (e.g. the serial discontinuity concept, Ward & Stanford, 1983). Water in large dams becomes stratified into separate temperature layers during warmer months, with warm water near the surface and cooler waters near the bottom (Lugg & Copeland, 2014). Release of large and continued volumes of cold bottom-waters can suppress riverine summer river temperature, increase winter temperature, reduce annual temperature fluctuations, reduce daily thermal variation and delay seasonal temperature minima and maxima. Cold water withdrawn from near the base of the dam and released in summer is usually much colder than typical temperatures that prevail in rivers prior to dam construction and this effect has been termed both cold water pollution and thermal pollution (Lugg & Copeland, 2014).

Hume Dam is the major impoundment on the Murray River and its effect on downstream temperature is upwards of 200 km (NSW Cold Water Pollution Interagency Group, 2012; Sherman et al., 2007), occurring on a regular cycle with seasonal releases. Elsewhere, the effects of cold water pollution have extended up to 350 km downstream from the dam, depressing water temperature by up to 16°C (Parisi et al., 2020; Preece, 2004). The distance downstream of a dam where river temperatures are affected by cold water pollution can vary depending on the size, residence time, and discharge volumes of the reservoir (Gray et al., 2019). Cold water pollution within larger flow volumes persist further because the relatively greater volume of water is less responsive to ambient heating mechanisms and travels at a higher velocity (Preece & Jones, 2002). Under current flow constraints the thermal effects of Lake Hume on the Murray River are not likely to extend past Lake Mulwala (e.g. Walker, 1980), and relaxing constraints above current levels are unlikely to change this, since residence time in Lake Mulwala ameliorates cold water pollution. Cold water pollution can affect the waters downstream of large storages (from 100 to 350km) however, increasing the maximum volumes or durations of managed flows by the proposed amounts are unlikely to extend cold water pollution distance above current levels.

Based on evidence from the scientific literature and following our decision matrix:

Thermal pollution has a mechanistic link to increased flow magnitude that is not increased above current risk and risks and benefits do not increase with higher flows.

This relationship is described in Table 3.8.

Table 3.8 Thermal pollution links

Mechanistic link to increased flow magnitude?	**Positive, negative or both**	**Do risk/benefits increase with higher flows?**	**Published Evidence**
Yes	N/A	No	(Gray et al., 2019; Lugg & Copeland, 2014; NSW Cold Water Pollution Interagency Group, 2012; Parisi et al., 2020; Preece, 2004; Preece & Jones, 2002; Sherman et al., 2007; Walker, 1980; Ward & Stanford, 1983)
Additional flow parameters	**Influence on risk**		
Antecedent patterns	N/A		
Duration	N/A		
Seasonality	Effects of cold water pollution are highest in summer, when natural water temperatures should be higher		
Frequency	N/A		

4 MURRAY RIVER

The Murray River, with its connected floodplains and wetlands, has been subdivided into 3 water quality assessment areas which break the river into (from upstream) from (1) Hume Dam to Yarrawonga Weir, (2) Yarrawonga Weir to Wakool Junction (including the Edward/Kolety–Wakool system), (3) Wakool Junction to Wentworth (Lock 10) (Figure 4.1).

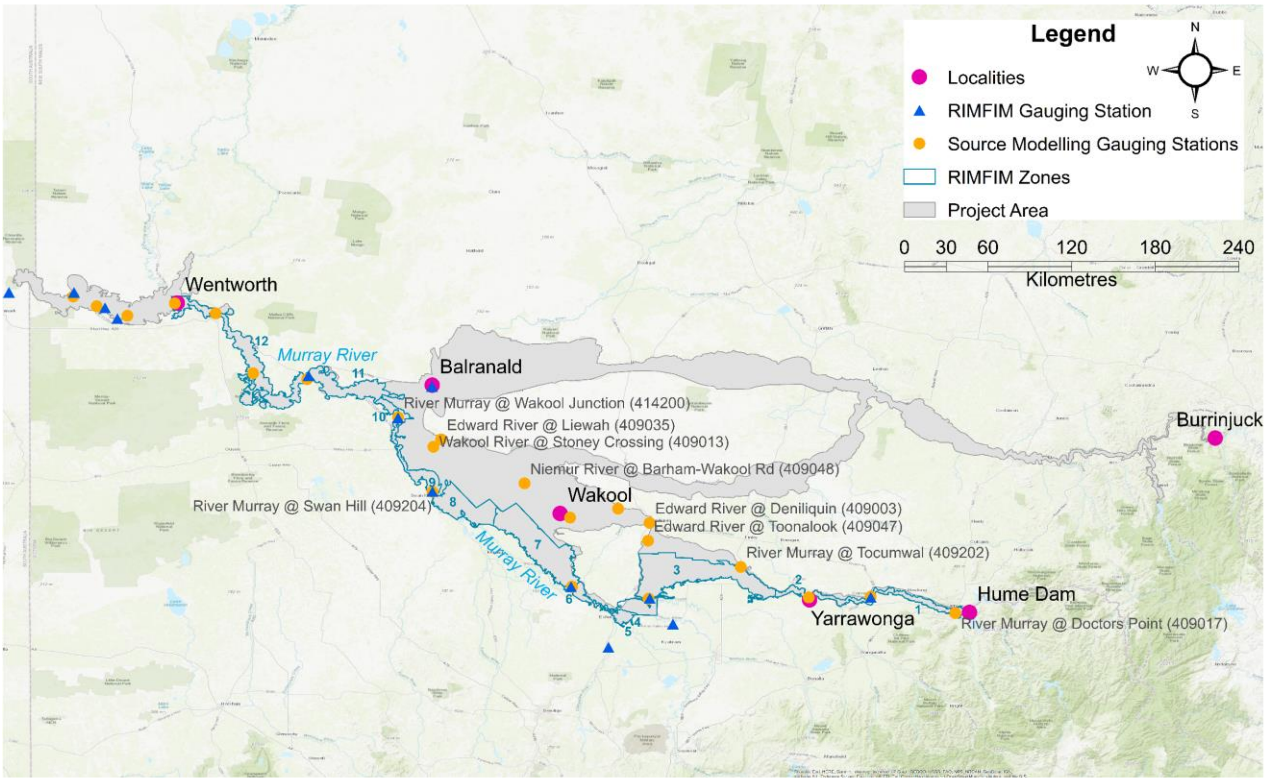

Figure 4.1 Map of the Murray River project areas – Hume Dam to Yarrawonga, Yarrawonga to Wakool Junction, Wakool Junction down to Wentworth (Lock 10); the 12 RiM-FIM[3] zones, and the river system modelling gauge locations

4.1 CONSTRAINT RELAXATION SCENARIOS FLOW EVENT ANALYSIS

Four constraint relaxation scenarios (plus current) have been created by the department to capture different configurations of relevant water plans:

- Y15D25 – ≤15 GL/day at Yarrawonga, ≤25 GL/day at Doctors Point (current)
- Y25D25 – ≤25 GL/day at Yarrawonga, ≤25 GL/day at Doctors Point
- Y30D30 – ≤30 GL/day at Yarrawonga, ≤30 GL/day at Doctors Point
- Y40D40 – ≤40 GL/day at Yarrawonga, ≤40 GL/day at Doctors Point
- Y45D40 – ≤45 GL/day at Yarrawonga, ≤40 GL/day at Doctors Point.

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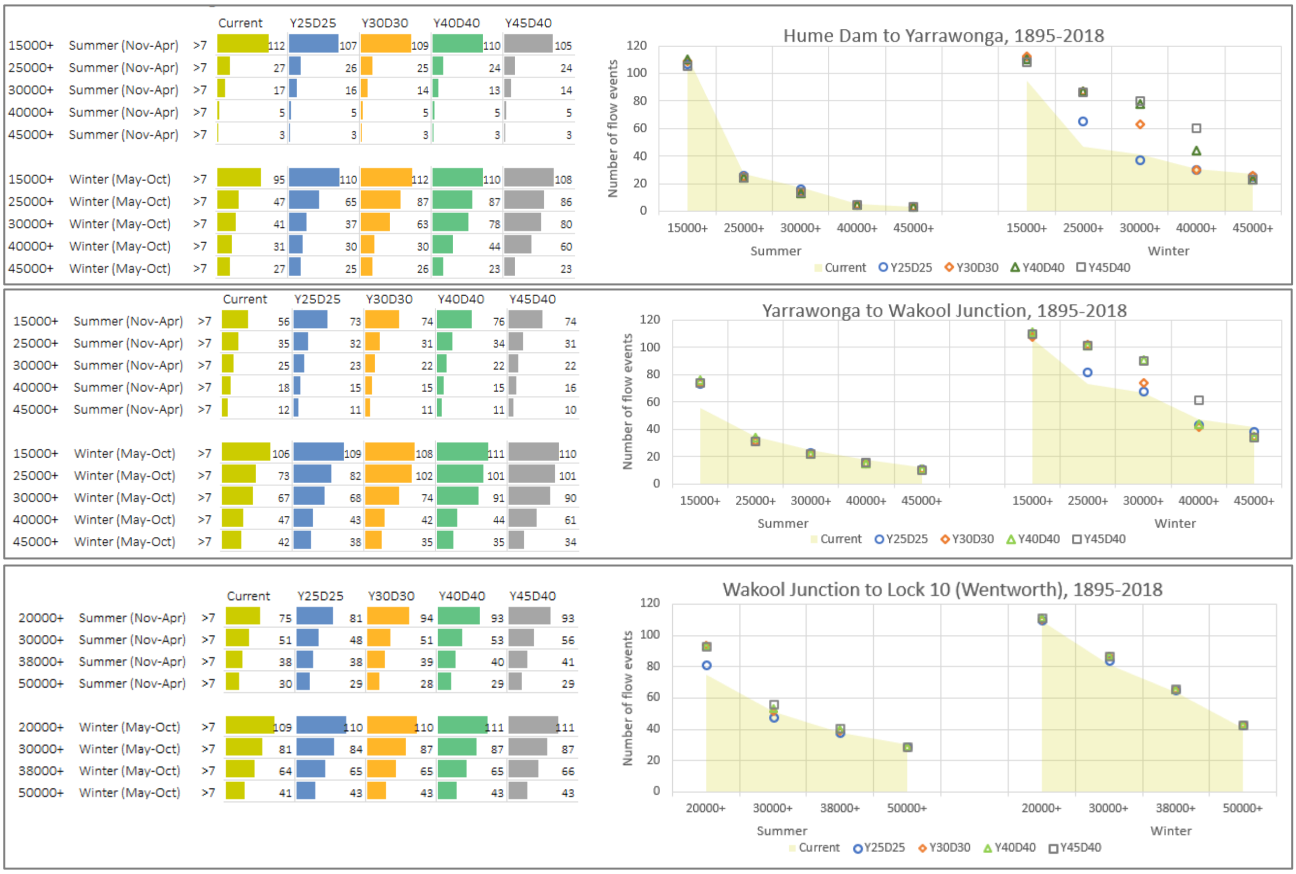
[3] The RiM-FIM zones have been used by the department to map the likely extent of floodplain/wetland inundation under the various flow scenarios. RiM-FiM is the River Murray Floodplain Inundation Model developed by CSIRO (Overton et al., 2006)

Simulated flows at (1) Doctors Point, (2) Yarrawonga and (3) Euston have been used to provide the flow event statistics for these scenarios. 20 GL/day represents a large fresh in the river at Euston and is the flow threshold for the flow event statistics provided by the department (DPIE 2020).



			Current	Y25D25	Y30D30	Y40D40	Y45D40
15000+	Summer (Nov-Apr)	>7	112	107	109	110	105
25000+	Summer (Nov-Apr)	>7	27	26	25	24	24
30000+	Summer (Nov-Apr)	>7	17	16	14	13	14
40000+	Summer (Nov-Apr)	>7	5	5	5	5	5
45000+	Summer (Nov-Apr)	>7	3	3	3	3	3
15000+	Winter (May-Oct)	>7	95	110	112	110	108
25000+	Winter (May-Oct)	>7	47	65	87	87	86
30000+	Winter (May-Oct)	>7	41	37	63	78	80
40000+	Winter (May-Oct)	>7	31	30	30	44	60
45000+	Winter (May-Oct)	>7	27	25	26	23	23

			Current	Y25D25	Y30D30	Y40D40	Y45D40
15000+	Summer (Nov-Apr)	>7	56	73	74	76	74
25000+	Summer (Nov-Apr)	>7	35	32	31	34	31
30000+	Summer (Nov-Apr)	>7	25	23	22	22	22
40000+	Summer (Nov-Apr)	>7	18	15	15	15	16
45000+	Summer (Nov-Apr)	>7	12	11	11	11	10
15000+	Winter (May-Oct)	>7	106	109	108	111	110
25000+	Winter (May-Oct)	>7	73	82	102	101	101
30000+	Winter (May-Oct)	>7	67	68	74	91	90
40000+	Winter (May-Oct)	>7	47	43	42	44	61
45000+	Winter (May-Oct)	>7	42	38	35	35	34

			Current	Y25D25	Y30D30	Y40D40	Y45D40
20000+	Summer (Nov-Apr)	>7	75	81	94	93	93
30000+	Summer (Nov-Apr)	>7	51	48	51	53	56
38000+	Summer (Nov-Apr)	>7	38	38	39	40	41
50000+	Summer (Nov-Apr)	>7	30	29	28	29	29
20000+	Winter (May-Oct)	>7	109	110	110	111	111
30000+	Winter (May-Oct)	>7	81	84	87	87	87
38000+	Winter (May-Oct)	>7	64	65	65	65	66
50000+	Winter (May-Oct)	>7	41	43	43	43	43

Figure 4.2 Flow event (>7 days) statistics for the 4 (plus current) constraint relaxation flow scenarios for the full simulation period (1895-2018) for the 3 water quality assessment areas of the Murray River; (top) Hume Dam to Yarrawonga, (middle) Yarrawonga to Wakool Junction, (bottom) Wakool Junction to Wentworth (Lock 10)

Figure 4.2 shows the changes in the number of flow events of >7 days duration in summer (November to April) and winter (May to October) over the 114 years of the simulation period (1895–2018). As can be seen from this figure, all the scenarios manage a small reduction (from current) in flow events of >7 days in summer, with the watering shifted to winter, together with an increase in larger volume flow events in in winter. There are some differences in the flow frequencies at which the flow events are delivered in the winter months; however, all scenarios follow a similar pattern. By the time the flow scenarios reach the Wakool Junction to Wentworth (Lock 10) assessment area, there is very little change in the number of flow events at the bankfull (38+ GL/day) and overbank (50+ GL/day) thresholds in the Murray River downstream of Euston. Subsets of these data to compare the scenarios under a dry decade (2000–09) and a wet decade (2010–18[4]) are provided in Figure 4.3 and Figure 4.4, respectively.

Table 4.1 shows the ratios (expressed as percentages of the total number of flow events) of the number of flow events (of any and all sizes) in summer and winter under each of the scenarios. This metric shows the shift from summer to winter in water ordering under all scenarios. (Number underpinning this metric are provided in 0).

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[4] Not quite a decade as the model results run from 1895 to 2018 only. As we are not comparing the number of follow events in the wet and dry decades, this is not considered an issue for the purposes of this reporting

Table 4.1 Overall ratio of number of flow events (of any and all sizes) in summer and winter (summer:winter) under each of the flow scenarios

WATER QUALITY ASSESSMENT AREA	CURRENT	Y25D25	Y30D30	Y40D40	Y45D40
Hume Dam to Yarrawonga	40:60	37:63	33:67	31:69	30:70
Yarrawonga to Wakool Junction	30:70	31:69	30:70	29:71	28:72
Wakool Junction to Lock 10 (Wentworth)	40:60	39:61	41:59	42:59	42:58

In the dry decade, the scenarios mimic the water delivery regimes under current – maintain a base flow throughout the summer months, with opportunity for an increase in higher volume flow events in the winter months. The wet decade provides more opportunity for how water (and thus flow events) are ordered. Particularly in the middle area (Yarrawonga to Wakool Junction), the changes in flow in the upstream area (Hume Dam to Yarrawonga) express as more flow events at the higher thresholds. This allows more water to enter the Edward/Kolety–Wakool system. As with the full period and dry decade, flow events in the lower area (Wakool Junction to Wentworth) are controlled by what happens upstream.

The likely impacts of these shifts on the likelihood of water quality events are discussed in Section 4.5.

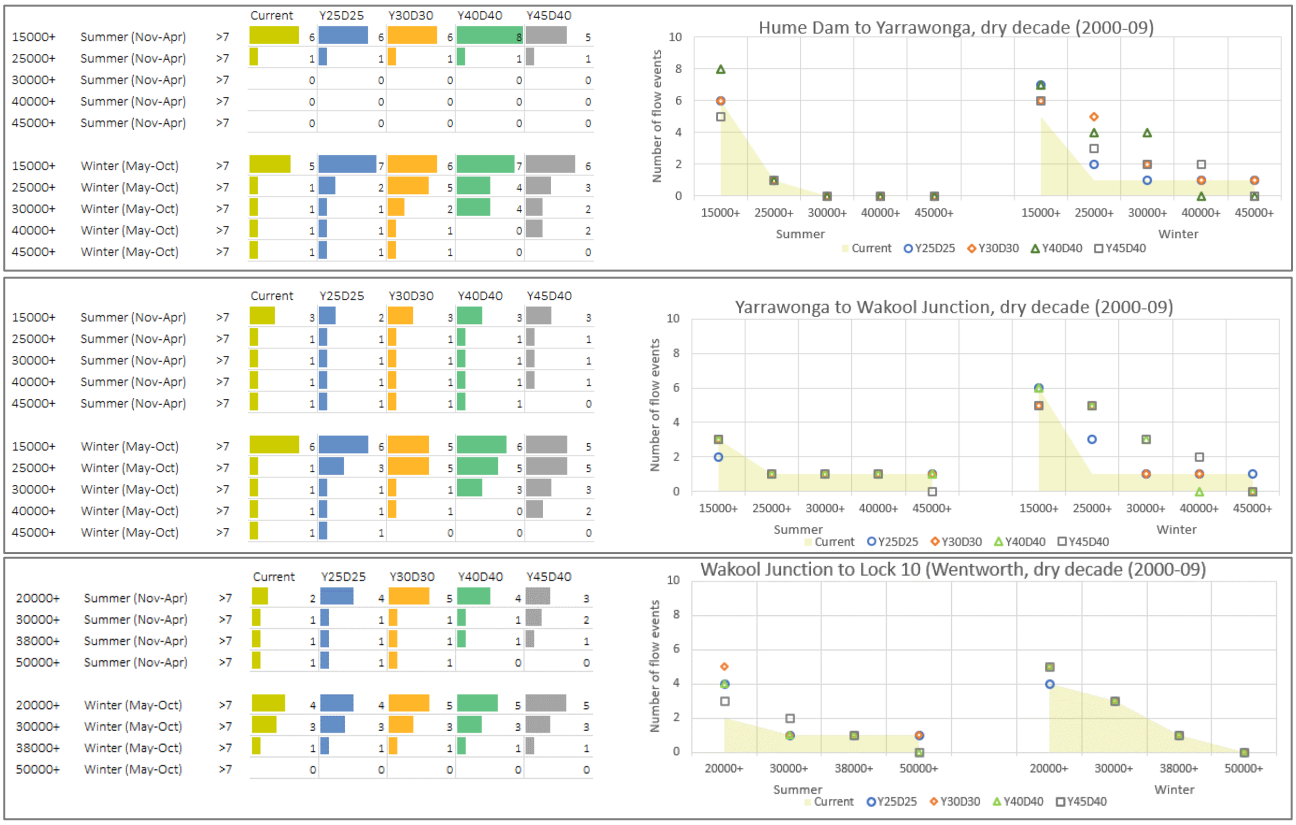


Figure 4.3 Flow event (>7 days) statistics for the 4 (plus current) constraint relaxation flow scenarios for a DRY decade (2000–09) for the 3 water quality assessment areas of the Murray River; (top) Hume Dam to Yarrawonga, (middle) Yarrawonga to Wakool Junction, (bottom) Wakool Junction to Wentworth (Lock 10)

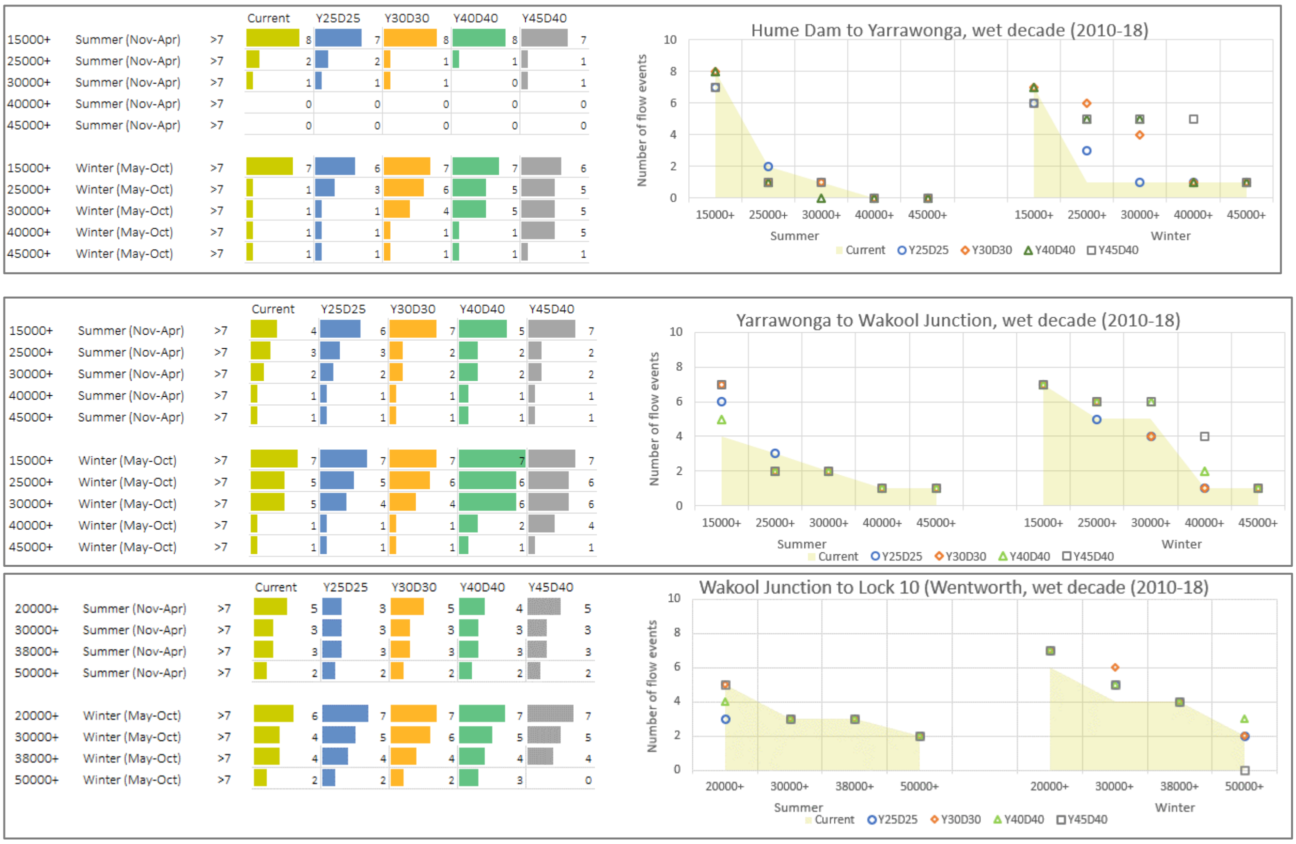


Figure 4.4 Flow event (>7 days) statistics for the 4 (plus current) constraint relaxation flow scenarios for a WET decade (2010–18) for the 3 water quality assessment areas of the Murray River; (top) Hume Dam to Yarrawonga, (middle) Yarrawonga to Wakool Junction, (bottom) Wakool Junction to Wentworth (Lock 10)

Further analyses of the flow event data are provided in 0.

4.2 Murray: Hume Dam to Yarrawonga

This section reports on our assessment of the risks and benefits for each of the threshold flow categories for blackwater, blue-green algal bloom and salinity water quality events (Table 4.2 to Table 4.4, respectively), for each of the flow threshold categories in this water quality assessment area. These assessments are then synthesised by flow category in Table 4.5. Flow categories relate to flows at Doctors Point.

4.2.1 Tables of risk and benefit assessments for 3 water quality issues by flow category

Table 4.2 Blackwater risk/benefit assignment Murray: Hume to Yarrawonga – likelihood and impact of a water quality event occurring in summer and winter in each flow category

Flow category	Flow event timing (Month)	Duration (days)	Risk of a water quality event			Benefit of a water quality event		
			Impact	Likelihood	Risk	Impact	Likelihood	Benefit
>25 GL/day at Doctors Point	Summer (Nov-Apr)	<7	Negligible	Possible	Low	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Possible	High	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>30 GL/day	Summer (Nov-Apr)	<7	Negligible	Possible	Low	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Possible	High	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High

Flow category	Flow event timing (Month)	Duration (days)	Risk of a water quality event			Benefit of a water quality event		
			Impact	Likelihood	Risk	Impact	Likelihood	Benefit
>40 GL/day	Summer (Nov-Apr)	<7	Negligible	Very likely	High	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Very likely	Very high	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>45 GL/day	Summer (Nov-Apr)	<7	Negligible	Very likely	High	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Very likely	Very high	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High

Table 4.3 Blue-green algal bloom risk/benefit assignment Murray: Hume to Yarrawonga – likelihood and impact of a water quality event occurring in summer and winter in each flow category

Flow category	Flow event timing (Month)	Duration (days)	Risk of a water quality event			Benefit of a water quality event		
			Impact	Likelihood	Risk	Impact	Likelihood	Benefit
>25 GL/day at Doctors Point	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate
>30 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate
>40 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate
>45 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate

Table 4.4 Salinity risk/benefit assignment* Murray: Hume to Yarrawonga – likelihood and impact of a water quality event occurring in summer and winter in each flow category

Flow category	Flow event timing (Month)	Duration (days)	Risk of a water quality event			Benefit of a water quality event		
			Impact	Likelihood	Risk	Impact	Likelihood	Benefit
>25 GL/day at Doctors Point	Summer (Nov-Apr)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>30 GL/day	Summer (Nov-Apr)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>40 GL/day	Summer (Nov-Apr)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High

Flow category	Flow event timing (month)	Duration (days)	Risk of a water quality event			Benefit of a water quality event		
			Impact	Likelihood	Risk	Impact	Likelihood	Benefit
>45 GL/day	Summer (Nov-Apr)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High

*For Risk, likelihood is based on having a negative effect on aquatic organisms, which is unlikely in this project area. Benefit is the benefit to salt transport, contributing to the Basin Plan's goals of 2m tonnes/salt exporting the Basin per year.

4.2.2 SYNTHESIS OF RISK AND BENEFIT ASSESSMENTS BY FLOW CATEGORY

The water quality issue risk and benefit assessments for blackwater (Table 4.2), blue-green algal bloom (Table 4.3) and salinity (Table 4.4) are collated for each flow threshold category in Table 4.5.

Table 4.5 Collation of water quality issue risk/benefit assessment by flow category for events of >7 days duration, Hume Dam to Yarrawonga

Flow category Hume to Yarrawonga	Flow event timing	Risk of a water quality event			Benefit of a water quality event		
		Blackwater	Blue-green algal bloom	Salinity	Blackwater	Blue-green algal bloom	Salinity
>25 GL/day	Summer	High	High	Moderate	High	High	High
	Winter	Moderate	Moderate	Moderate	High	Moderate	High
>30 GL/day	Summer	High	High	Moderate	High	High	High
	Winter	Moderate	Moderate	Moderate	High	Moderate	High
>40 GL/day	Summer	Very high	High	Moderate	High	High	High
	Winter	Moderate	Moderate	Moderate	High	Moderate	High
>45 GL/day	Summer	Very high	High	Moderate	High	High	High
	Winter	Moderate	Moderate	Moderate	High	Moderate	High

Blackwater, eutrophication, blue-green algae, salinity turbidity, weir pool stratification, acid-sulfate sediments and thermal pollution were identified as water quality issues that could have associated risk or benefits in response to different flow scenarios. An initial analysis of the issues determined that clear mechanistic links could be demonstrated between increased flow for blackwater, blue-green algae blooms and salinity. There is insufficient precision of knowledge on the response of these water quality parameters to be able to differentiate between flow scenarios as the same flow bands occur in all the scenarios. Consequently, the impacts and final assessment draw on qualitative understanding of the system.

From a water quality perspective, and based on current knowledge, the assessments for individual parameters are the same for the flow scenarios. Season (water temperature) is a key driver for water quality parameters driven metabolic processes (blackwater, blue-green algae). Salinity represents a different situation as there are reach-based ecological processes that are affected, but also end-of basin targets that should be considered. For example, upper catchments in the Murray River system are typically low in salt concentration, although the animals that inhabit these waters are salt sensitive (see Shackleton et al., 2019). Thus, the likelihood of increased flow magnitude causing salinity issues is unlikely, but the consequences are significant.

4.3 MURRAY: YARRAWONGA TO WAKOOL JUNCTION, INCLUDING THE EDWARD/KOLETY-WAKOOL SYSTEM

This section reports on our assessment of the risks of, and the benefits from, blackwater, blue-green algal bloom and salinity water quality events (Table 4.6 to Table 4.8, respectively), for each of the flow threshold categories in this water quality assessment area. These assessments are then synthesised by flow category in Table 4.9. Flow categories relate to flows at Yarrawonga.

4.3.1 Tables of risk and benefit assessments for 3 water quality issues by flow category

Table 4.6 Blackwater risk/benefit assignment Murray: Yarrawonga to Wakool Junction – likelihood and impact of a water quality event occurring in summer and winter in each flow category

Flow category	Flow event timing (Month)	Duration (days)	Risk of a water quality event			Benefit of a water quality event		
			Impact	Likelihood	Risk	Impact	Likelihood	Benefit
>15 GL/day	Summer (Nov-Apr)	<7	Negligible	Possible	Low	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Possible	High	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>25 GL/day	Summer (Nov-Apr)	<7	Negligible	Possible	Low	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Possible	High	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>30 GL/day	Summer (Nov-Apr)	<7	Negligible	Very likely	High	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Very likely	Very high	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>40 GL/day	Summer (Nov-Apr)	<7	Negligible	Very likely	High	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Very likely	Very high	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>45 GL/day	Summer (Nov-Apr)	<7	Negligible	Very likely	High	Significant	Likely	Very high
	Summer (Nov-Apr)	>7	Significant	Very likely	Very high	Significant	Likely	Very high
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Significant	Likely	Very high
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Likely	Very high

Table 4.7 Blue-green algal bloom risk/benefit assignment Murray: Yarrawonga to Wakool Junction – likelihood and impact of a water quality event occurring in summer and winter in each flow category

Flow category	Flow event timing (Month)	Duration (days)	Risk of a water quality event			Benefit of a water quality event		
			Impact	Likelihood	Risk	Impact	Likelihood	Benefit
>15 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate
>25 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate
>30 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate
>40 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate
>45 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate

Table 4.8 Salinity risk/benefit assignment* Murray: Yarrawonga to Wakool Junction – likelihood and impact of a water quality event occurring in summer and winter in each flow category

Flow category	Flow event timing (Month)	Duration (days)	Risk of a water quality event			Benefit of a water quality event		
			Impact	Likelihood	Risk	Impact	Likelihood	Benefit
>15 GL/day	Summer (Nov-Apr)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>25 GL/day	Summer (Nov-Apr)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>30 GL/day	Summer (Nov-Apr)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>40 GL/day	Summer (Nov-Apr)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>45 GL/day	Summer (Nov-Apr)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High

* For Risk, likelihood is based on having a negative effect on aquatic organisms, which is unlikely in this project area. Benefit is the benefit to salt transport, contributing to the Basin Plan's goals of 2m tonnes/salt exporting the Basin per year.

4.3.1 SYNTHESIS OF RISK AND BENEFIT ASSESSMENTS BY FLOW CATEGORY

The water quality issue risk and benefit assessments for blackwater (Table 4.6), blue-green algal bloom (Table 4.7) and salinity (Table 4.8) are collated for each flow threshold category in Table 4.9.

Table 4.9 Collation of water quality issue risk/benefit assessment by flow category for events of >7 days duration, Yarrawonga to Wakool Junction

Flow category Yarrawonga to Wakool Junction	Flow event timing	Risk of a water quality event			Benefit of a water quality event		
		Blackwater	Blue-green algal bloom	Salinity	Blackwater	Blue-green algal bloom	Salinity
>15 GL/day	Summer	High	High	Moderate	High	High	High
	Winter	Moderate	Moderate	Moderate	High	Moderate	High
>25 GL/day	Summer	High	High	Moderate	High	High	High
	Winter	Moderate	Moderate	Moderate	High	Moderate	High
>30 GL/day	Summer	Very high	High	Moderate	High	High	High
	Winter	Moderate	Moderate	Moderate	High	Moderate	High
>40 GL/day	Summer	Very high	High	Moderate	High	High	High
	Winter	Moderate	Moderate	Moderate	High	Moderate	High
>45 GL/day	Summer	Very high	High	Moderate	High	High	High
	Winter	Moderate	Moderate	Moderate	High	Moderate	High

As with the Hume to Yarrawonga reach, greatest risk is associated with season (water temperature) and summer represents the greatest risk for water quality parameters driven by metabolic processes of microbes and algae. In this sense, it is reasonable to argue that, though the risk assessment is driven by flow band, it is the timing that is the driver. Temperature is the key predictor for hypoxic blackwater, but this also relates to the area of floodplain inundation, which will be affected by flow. In this respect, the risk doesn't change, but the extent, or longevity of the effect is likely to increase as a consequence of greater extent of inundation.

4.4 Lower Murray: Wakool Junction to Wentworth

This section reports on our assessment of the risks of, and the benefits from, blackwater, blue-green algal bloom and salinity water quality events (Table 4.10 to Table 4.12, respectively), for each of the flow threshold categories in this water quality assessment area. These assessments are then synthesised by flow category in Table 4.13. Flow categories relate to flows at Euston.

4.4.1 Tables of risk and benefit assessments for 3 water quality issues by flow category

Table 4.10 Blackwater risk/benefit assignment Lower Murray: Wakool Junction to Wentworth – likelihood and impact of a water quality event occurring in summer and winter in each flow category

Flow category	Flow event timing (Month)	Duration (days)	Risk of a water quality event			Benefit of a water quality event		
			Impact	Likelihood	Risk	Impact	Likelihood	Benefit
>20 GL/day	Summer (Nov-Apr)	<7	Negligible	Possible	Low	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Possible	High	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>38 GL/day	Summer (Nov-Apr)	<7	Negligible	Very likely	High	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Very likely	Very High	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very Low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>50 GL/day	Summer (Nov-Apr)	<7	Negligible	Very likely	High	Significant	Likely	Very high
	Summer (Nov-Apr)	>7	Significant	Very likely	Very High	Significant	Likely	Very high
	Winter (May-Oct)	<7	Negligible	Unlikely	Very Low	Significant	Likely	Very high
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Likely	Very high

Table 4.11 Blue-green algal bloom risk/benefit assignment Lower Murray: Wakool Junction to Wentworth – likelihood and impact of a water quality event occurring in summer and winter in each flow category

Flow category	Flow event timing (Month)	Duration (days)	Risk of a water quality event			Benefit of a water quality event		
			Impact	Likelihood	Risk	Impact	Likelihood	Benefit
>20 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate
>38 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate
>50 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate

Table 4.12 Salinity risk/benefit assignment* Lower Murray: Wakool Junction to Wentworth – likelihood and impact of a water quality event occurring in summer and winter in each flow category

FLOW CATEGORY	FLOW EVENT TIMING (MONTH)	DURATION (DAYS)	RISK OF A WATER QUALITY EVENT			BENEFIT OF A WATER QUALITY EVENT		
			IMPACT	LIKELIHOOD	RISK	IMPACT	LIKELIHOOD	BENEFIT
>20 GL/day	Summer (Nov-Apr)	<7	Moderate	Unlikely	Low	Significant	Likely	Very high
	Summer (Nov-Apr)	>7	Moderate	Unlikely	Low	Significant	Likely	Very high
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Significant	Likely	Very high
	Winter (May-Oct)	>7	Moderate	Unlikely	Low	Significant	Likely	Very high
>38 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Significant	Likely	Very high
	Summer (Nov-Apr)	>7	Moderate	Possible	Moderate	Significant	Likely	Very high
	Winter (May-Oct)	<7	Moderate	Possible	Moderate	Significant	Likely	Very high
	Winter (May-Oct)	>7	Moderate	Possible	Moderate	Significant	Likely	Very high
>50 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Significant	Likely	Very high
	Summer (Nov-Apr)	>7	Moderate	Possible	Moderate	Significant	Likely	Very high
	Winter (May-Oct)	<7	Moderate	Possible	Moderate	Significant	Likely	Very high
	Winter (May-Oct)	>7	Moderate	Possible	Moderate	Significant	Likely	Very high

* The base case ecological condition has a different starting point to the upstream project areas, i.e. the organisms are more salt-tolerant. For this reason, the likelihood of risk is reduced compared to that for upstream. The likelihood of benefit is likely as there is always a benefit.

4.4.1 SYNTHESIS OF RISK AND BENEFIT ASSESSMENTS BY FLOW CATEGORY

The water quality issue risk and benefit assessments for blackwater (Table 4.10), blue-green algal bloom (Table 4.11) and salinity (Table 4.12) are collated for each flow threshold category in Table 4.13. Three flow threshold categories were selected to assess water quality outcomes in the lower Murray in response to relaxed flow constraints upstream at Doctors Point and Yarrawonga Weir – 20 GL/day (large fresh), 38 GL/day (bankfull) and 50 GL/day (small overbank) in the Murray downstream of Euston, based on environmental water requirements for the lower Murray River published in the Long Term Water Plan for the NSW Murray-Lower Darling (DPIE, 2020).

Table 4.13 Collation of water quality issue risk/benefit assessment by flow category for events of >7 days duration, Wakool Junction to Wentworth (Lock 10). Flow categories relate to large fresh, bankfull and overbank flows in the Murray River downstream Euston (414203) as described in DPIE (2020)

FLOW CATEGORY D/S EUSTON	FLOW EVENT TIMING	RISK OF A WATER QUALITY EVENT			BENEFIT OF A WATER QUALITY EVENT		
		BLACKWATER	BLUE-GREEN ALGAL BLOOM	SALINITY	BLACKWATER	BLUE-GREEN ALGAL BLOOM	SALINITY
>20 GL/day	Summer	High	High	Low	High	High	Very high
	Winter	Moderate	Moderate	Low	High	Moderate	Very high
>38 GL/day	Summer	Very high	High	Moderate	High	High	Very high
	Winter	Moderate	Moderate	Moderate	High	Moderate	Very high
>50 GL/day	Summer	Very high	High	Moderate	Very high	High	Very high
	Winter	Moderate	Moderate	Moderate	Very high	Moderate	Very high

As with other reaches, risk for blackwater and blue-green algae blooms are highest in summer. However in this region, risk from blackwater is unlikely to come from incorporation of floodplain litter locally, rather from incorporation of carbon from upstream floodplains. In contrast to upper reaches, the Lower Murray is at greater risk from salinity (due primarily to saline groundwater), but biota in this region are better adapted to wide variations in salinity. Thus, while higher flows may increase the risk of salt mobilisation in the lower Murray, there are strong benefits (such as contribution to the Basin Plan's target of 2 million tonnes of salt exported from the Basin) that may outweigh negative impacts on biota.

4.5 RISK AND BENEFIT ASSESSMENT OF CONSTRAINT RELAXATION SCENARIOS ACROSS THE 3 MURRAY RIVER WATER QUALITY ASSESSMENT AREAS

This section brings together the flow event frequency statistics reported in Section 4.1 with the collated water quality event risk/benefit assessments for each water quality assessment area (Table 4.5, Table 4.9, Table 4.13, respectively) to provide an overall risk/benefit assessment of each of the 4 constraint relaxation scenarios across the 3 Murray River water quality assessment areas.

Relaxation of flow constraints that result in an increase in the number of flow events that occur for >7 days may affect the impact of a given water quality issue e.g., if the number of times a hypoxic blackwater event occurs for more than 7 days during a given period increases, we expect that blackwater risk will be higher.

An assessment is provided for each scenario (Sections 4.5.1 to 4.5.4), with a summary of the assessments provided in Table 4.5 in Section 4.5.5.

Risk mitigation strategies for blackwater, blue-green algal blooms and salinity due to change in the frequency, timing and/or duration of flow events at thresholds are provided in Sections 3.1.1, 3.3.1 and 3.4.1.

4.5.1 Y25D25 CONSTRAINT RELAXATION SCENARIO

The risk of adverse impacts from individual water quality events is ‘Moderate’ to ‘Very high’ in summer across all flow thresholds and this remains so under this scenario. The slight increase in >15 GL/day flow events in the Yarrawonga to Wakool Junction assessment area reflects the additional flow that can be contained with the river under the constraint relaxation – any increase in the likelihood (due to increase in frequency) of an adverse water quality event (while most unlikely) would be offset by a reduction in its impact, resulting in status quo risk assessment.

The likelihood of adverse impacts for individual water quality events in winter is ‘Unlikely’ and the impact of even one water quality event is ‘Significant’. Thus the additional and larger flow events in winter do not change the risk assessment of ‘Moderate’; however the likelihood of a benefit of these larger and more frequent flow events may improve from ‘Moderate’ to ‘High’, giving an overall net gain.

There is a modest shift in the summer:winter flow event ratio in the upper assessment area (Hume Dam to Yarrawonga). At the downstream assessment area between Wakool Junction and Wentworth (Lock 10), the slight increase in >20 GL/day >7-day flow events is balanced by a decrease in >30 GL/day >7 day flow events with no change in risk assessment from ‘Moderate’.

The shift in flow events from summer to winter downgrades the risk of a water quality event under the Y25D25 scenario to ‘Moderate’ across all water quality issues. The likelihood of a water quality event in winter is ‘Unlikely’ – however the impact is ‘Significant’, maintaining the residual risk rating at ‘Moderate’.

The shift in flow events from summer to winter is positive, which may shift the likelihood of a benefit of Unlikely to Possible for blue-green algal bloom, resulting in an overall residual benefit rating of ‘High’.

Overall, the Y25D25 scenario is most similar to current.

4.5.2 Y30D30 CONSTRAINT RELAXATION SCENARIO

As with the Y25D25 scenario, the Y30D30 scenario has reduced the number of flow events overall in summer compared to current. It has increased the number of flow events in winter in the 20–40 GL/day range. However, the increased relaxation allows for a significant shift in the summer:winter ratio from current (33:67 from 40:60, respectively) in the upstream assessment area (Hume Dam to Yarrawonga). At the downstream assessment area, this scenario is very similar to current.

The shift in flow events from summer to winter downgrades the risk of a water quality event under the Y30D30 scenario to 'Moderate' across all water quality issues. The likelihood of a water quality event in winter is 'Unlikely' – however the impact is 'Significant', maintaining the residual risk rating at 'Moderate'.

The shift in flow events from summer to winter is positive, which may shift the likelihood of a benefit of 'Unlikely' to 'Possible' for blue-green algal bloom, resulting in an overall residual benefit rating of 'High'.

4.5.3 Y40D40 CONSTRAINT RELAXATION SCENARIO

As with the previous scenarios, the Y40D40 scenario has made minor adjustments to reduce the number of flow events in summer compared to current. It has increased flow events in winter in the 20–40 GL/day range by more than 5%; and has achieved an overall shift in the summer:winter ratio (31:69 compared to 40:60 under current) in the upper assessment area (Hume Dam to Yarrawonga). At the downstream assessment area, this scenario is very similar to current.

The shift in the number of flow events from summer to winter downgrades the risk of a water quality event under the Y40D40 scenario to Moderate across all water quality issues. The likelihood of a water quality event in winter is Unlikely – however the impact is Significant, maintaining the residual risk rating at Moderate.

The shift in flow events from summer to winter is positive, which may shift the likelihood of a benefit of Unlikely to Possible for blue-green algal bloom, resulting in an overall residual benefit rating of High.

4.5.4 Y45D40 CONSTRAINT RELAXATION SCENARIO

As with the previous scenarios, the Y45D40 scenario has made minor adjustments to reduce flow events in summer compared to current, with the summer:winter ratio changing from 40:60 under current to 30:70 in the upper assessment area (Hume Dam to Yarrawonga). It has increased flow events in winter in the 20 –40 GL/day range. At the downstream assessment area, this scenario is very similar to current, and in fact shows a small increase in the summer:winter flow event ratio (ref Table 4.1).

The shift in flow events from summer to winter in both upstream assessment areas (Hume Dam to Wakool Junction) downgrades the risk of a water quality event under the Y45D40 scenario to Moderate across all water quality issues. The likelihood of a water quality event in winter is Unlikely – however the impact is Significant, maintaining the residual risk rating at Moderate.

The shift in flow events from summer to winter is positive, which may shift the likelihood of a benefit of Unlikely to Possible for blue-green algal bloom, resulting in an overall residual benefit rating of High.

4.5.5 COMPARISON OF CONSTRAINT RELAXATION SCENARIOS

The changes in number of flow events in the selected dry (2000–09) and wet (2010–20) decades under all scenarios are modest, as would be expected. All scenarios maintain a base flow through summer and winter in these decades, with shift of flow events to winter secured in all scenarios.

All scenarios mitigate against the most significant driver of adverse water quality events, which is high temperatures associated with summer. As evident from Figure 4.2, all scenarios deliver increased flow events in winter, at different threshold levels. Any increase in larger size flow events (>45 GL/day) brings significant benefit, potentially moving the benefit level from 'High' to 'Very High'. This is due to the potential flushing effect of these flow events for mitigating against blackwater, and through transport of salt down through the system.

However, from a qualitative risk assessment perspective, none of these differences in pattern are sufficient to discriminate between the relaxation constraint scenarios or from current.

> Our overall assessment is that the 4 constraint relaxation scenarios do not increase the likelihood, and thus the risk, of adverse water quality events from current. They all have the potential to increase the likelihood of realising a benefit of an improvement in water quality.

The assessments made in this section are summarised in Table 4.14.

Table 4.14 Overarching risk/benefit assessment of constraint relaxation scenarios for the Murray River

CONSTRAINT RELAXATION SCENARIO	CHANGE IN RISK RATING FROM CURRENT	RISK RATING	CHANGE IN BENEFIT RATING FROM CURRENT	BENEFIT RATING
Y25D25	No change	Moderate	Moderate -> High	High
Y30D30	No change	Moderate	Moderate -> High	High
Y40D40	No change	Moderate	Moderate -> High	High
Y45D40	No change	Moderate	Moderate -> High	High

5 MURRUMBIDGEE RIVER

The Murrumbidgee River, with its connected floodplains and wetlands, has been subdivided into 2 water quality assessment areas – (1) Burrinjuck Dam to Hay and (2) Hay to the junction with the Murray River (Figure 5.1).

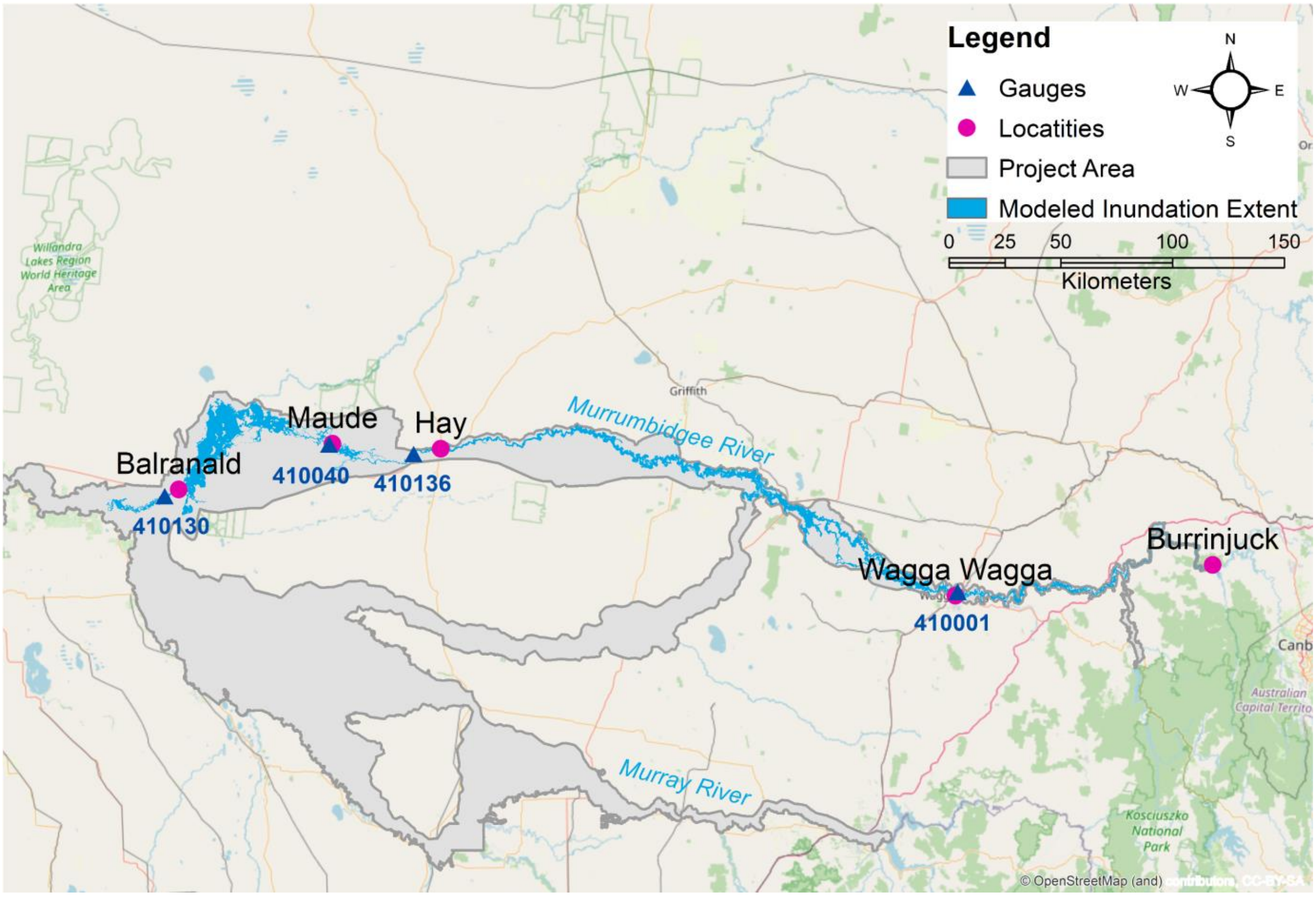


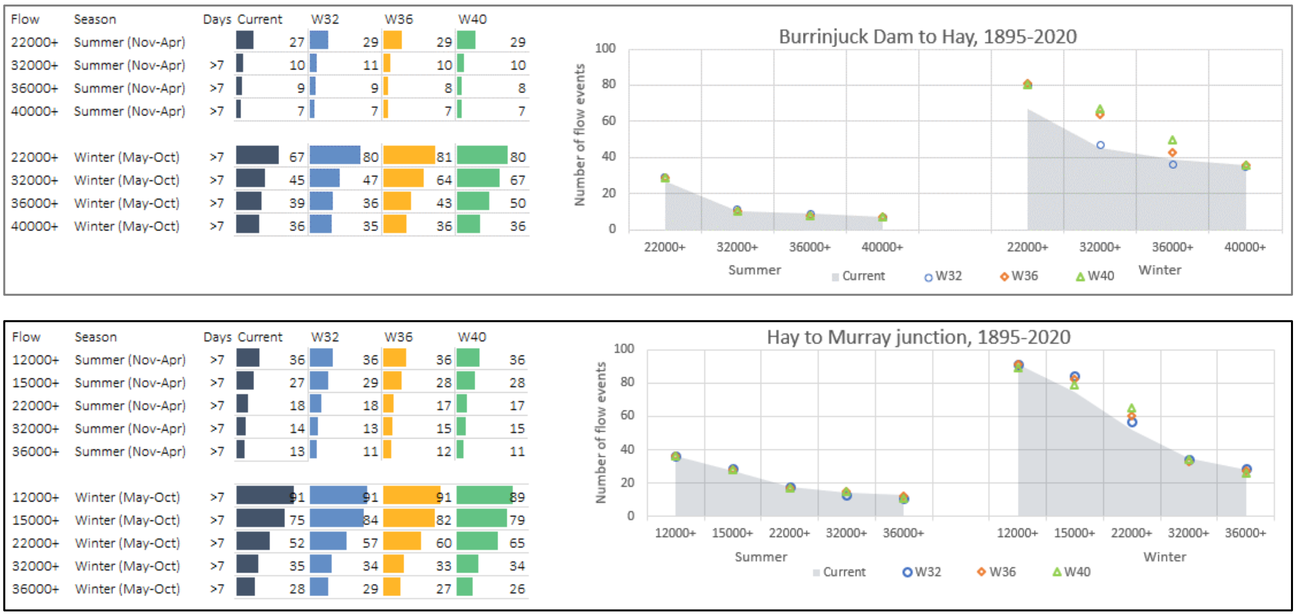
Figure 5.1 Map of the Murrumbidgee project area showing modelled inundation extent for water quality project for constraint relaxation scenarios and gauges used for the Source modelling. Not refined for land holder negotiations.

5.1 CONSTRAINT RELAXATION SCENARIOS FLOW EVENT ANALYSIS

Three constraint relaxation scenarios (plus current) have been created by the department to capture different configurations of relevant water plans:

- W22 – ≤22 GL/day at Wagga Wagga (current)
- W32 – ≤32 GL/day at Wagga Wagga
- W36 – ≤36 GL/day at Wagga Wagga
- W40 – ≤40 GL/day at Wagga Wagga.

Simulated flows at Wagga Wagga have been used to provide flow event statistics for the water quality assessment area from Burrinjuck Dam to Hay, and simulated flows at Hay for the assessment area from Hay to the junction of the Murrumbidgee with the Murray River. Smaller sized flow events of ≥12,000 GL/day and ≥15,000 GL/day have been provided for the Lower Murrumbidgee (downstream of Hay) to provide more context for the effect of relaxation of constraints on the smaller sized flow event through that section of the Murrumbidgee River.



Flow	Season	Days	Current	W32	W36	W40
22000+	Summer (Nov-Apr)		27	29	29	29
32000+	Summer (Nov-Apr)	>7	10	11	10	10
36000+	Summer (Nov-Apr)	>7	9	9	8	8
40000+	Summer (Nov-Apr)	>7	7	7	7	7
22000+	Winter (May-Oct)	>7	67	80	81	80
32000+	Winter (May-Oct)	>7	45	47	64	67
36000+	Winter (May-Oct)	>7	39	36	43	50
40000+	Winter (May-Oct)	>7	36	35	36	36

Flow	Season	Days	Current	W32	W36	W40
12000+	Summer (Nov-Apr)	>7	36	36	36	36
15000+	Summer (Nov-Apr)	>7	27	29	28	28
22000+	Summer (Nov-Apr)	>7	18	18	17	17
32000+	Summer (Nov-Apr)	>7	14	13	15	15
36000+	Summer (Nov-Apr)	>7	13	11	12	11
12000+	Winter (May-Oct)	>7	91	91	91	89
15000+	Winter (May-Oct)	>7	75	84	82	79
22000+	Winter (May-Oct)	>7	52	57	60	65
32000+	Winter (May-Oct)	>7	35	34	33	34
36000+	Winter (May-Oct)	>7	28	29	27	26

Figure 5.2 Flow event (>7 days) statistics for the 3 (plus current) constraint relaxation flow scenarios for the full simulation period (1895-2020) for the 2 water quality assessment areas of the Murrumbidgee River; (top) Burrinjuck Dam to Hay, (bottom) Hay to junction with the Murray River

Figure 5.2 shows that, in the Upper Murrumbidgee, all 3 scenarios have a small increase in the number of flow events > 7 days in summer (over the simulation period) at the lower flow thresholds. More flow events have been achieved in winter, under all scenarios, with the W36 and W40 scenarios providing a substantial increase (~48%, +19 and +22 respectively) in flow events above the 32 GL/day threshold (32000+).

In the Lower Murrumbidgee (downstream of Hay), all 3 scenarios show a small decrease in flow events of >36 GL/day in summer. More flow events have been achieved in winter, with all scenarios providing a substantial increase (10% –20%, +5 to +13) in flow events above the 22 GL/day threshold (22000+) and maintaining winter flows at the lower end of the flow thresholds. This reflects a preferential shift to ordering of water in winter and the flow time series (and number of flow events) in the scenarios show that this can be achieved.

The shift from summer to winter is captured as percentages in Table 5.2. Refer to 0 for detailed calculation.

Table 5.1 Shift in flow events from summer to winter (summer:winter)

WATER QUALITY ASSESSMENT AREA	CURRENT	W32	W36	W40
Burrinjuck Dam to Hay	22:78	22:78	19:81	19:81
Hay to Murray River Junction	28:72	27:73	27:73	27:73

Subsets of these data to compare the scenarios under a dry decade (2000–09) and a wet decade (2010–20[5]) are provided in Figure 5.3 and Figure 5.4, respectively.

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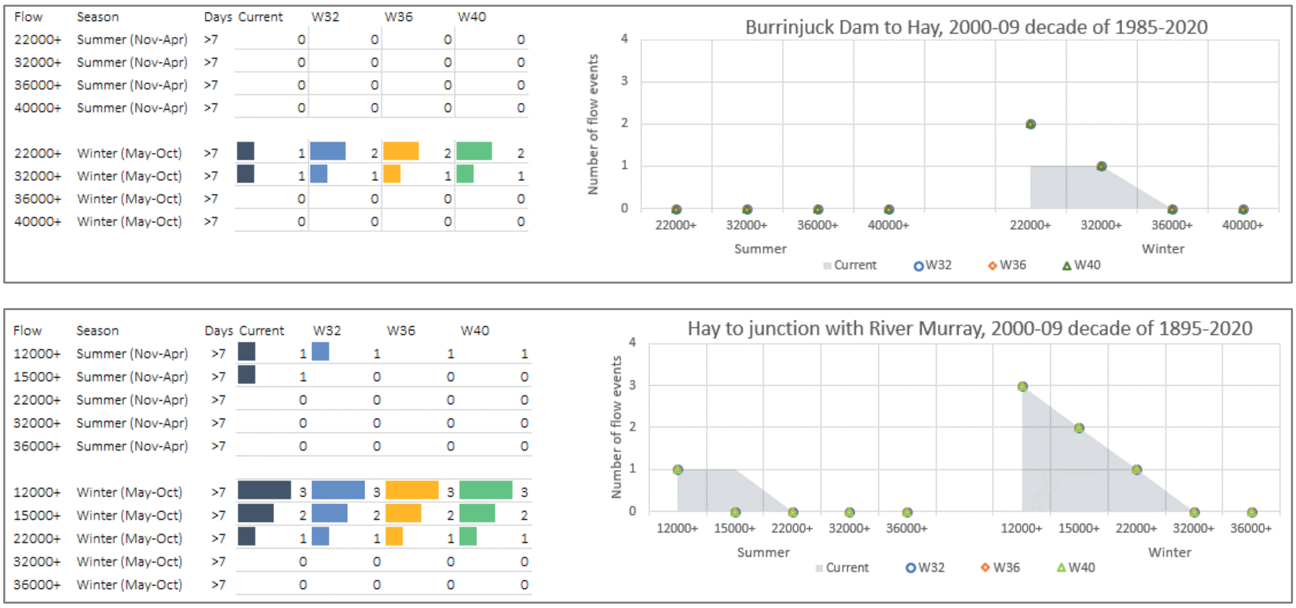
[5] 11 years as the Murrumbidgee Source model runs from 1895 to 2020. As we are not comparing the number of flow events in the wet and dry decades, this is not considered an issue for the purpose of this reporting

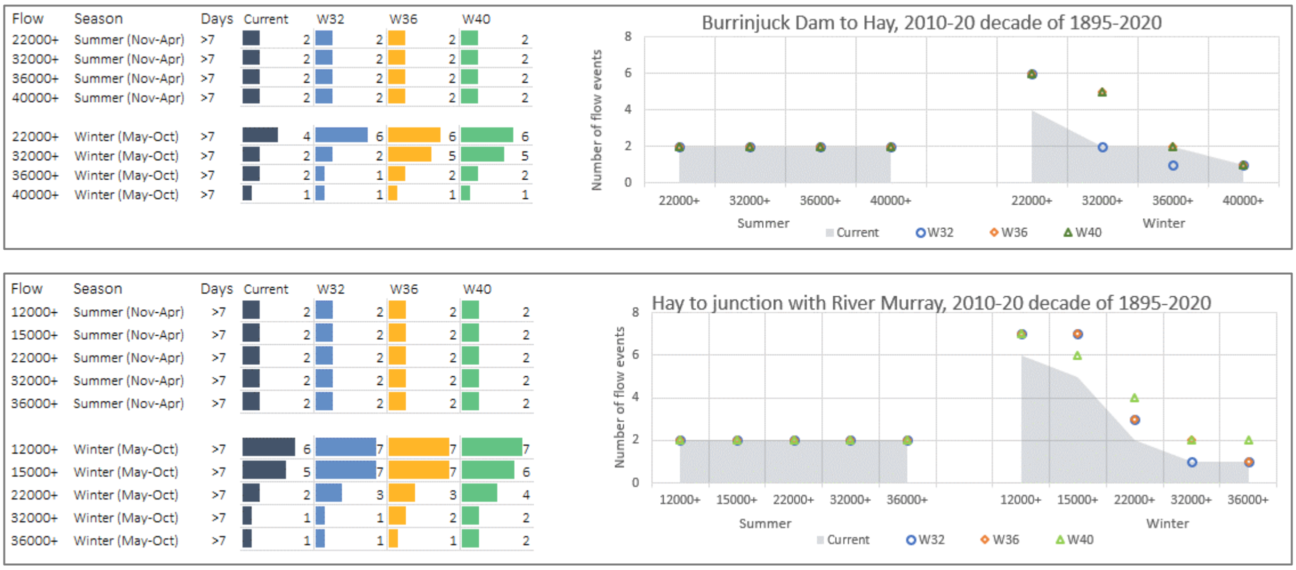


Flow	Season	Days	Current	W32	W36	W40
22000+	Summer (Nov-Apr)	>7	0	0	0	0
32000+	Summer (Nov-Apr)	>7	0	0	0	0
36000+	Summer (Nov-Apr)	>7	0	0	0	0
40000+	Summer (Nov-Apr)	>7	0	0	0	0
22000+	Winter (May-Oct)	>7	1	2	2	2
32000+	Winter (May-Oct)	>7	1	1	1	1
36000+	Winter (May-Oct)	>7	0	0	0	0
40000+	Winter (May-Oct)	>7	0	0	0	0

Flow	Season	Days	Current	W32	W36	W40
12000+	Summer (Nov-Apr)	>7	1	1	1	1
15000+	Summer (Nov-Apr)	>7	1	0	0	0
22000+	Summer (Nov-Apr)	>7	0	0	0	0
32000+	Summer (Nov-Apr)	>7	0	0	0	0
36000+	Summer (Nov-Apr)	>7	0	0	0	0
12000+	Winter (May-Oct)	>7	3	3	3	3
15000+	Winter (May-Oct)	>7	2	2	2	2
22000+	Winter (May-Oct)	>7	1	1	1	1
32000+	Winter (May-Oct)	>7	0	0	0	0
36000+	Winter (May-Oct)	>7	0	0	0	0

Figure 5.3 Flow event (>7 days) statistics for the 3 (plus current) constraint relaxation flow scenarios for a DRY decade (2000–09) for the 2 water quality assessment areas of the Murrumbidgee River; (top) Burrinjuck Dam to Hay, (bottom) Hay to junction with the Murray River

In the dry decade, the scenarios reflect the inability of the system to deliver flow events of >22 GL/day for a period of >7 days in summer. The number of years with >7-day flow events >22 GL/day in winter increases under all scenarios upstream of Hay; however it is only in one additional year, and no flows >36 GL/day are achieved in any year or any season. A similar pattern is seen in the lower Murrumbidgee with scenarios removing flow events in summer and maintaining winter flow events as per current.



Flow	Season	Days	Current	W32	W36	W40
22000+	Summer (Nov-Apr)	>7	2	2	2	2
32000+	Summer (Nov-Apr)	>7	2	2	2	2
36000+	Summer (Nov-Apr)	>7	2	2	2	2
40000+	Summer (Nov-Apr)	>7	2	2	2	2
22000+	Winter (May-Oct)	>7	4	6	6	6
32000+	Winter (May-Oct)	>7	2	2	5	5
36000+	Winter (May-Oct)	>7	2	1	2	2
40000+	Winter (May-Oct)	>7	1	1	1	1

Flow	Season	Days	Current	W32	W36	W40
12000+	Summer (Nov-Apr)	>7	2	2	2	2
15000+	Summer (Nov-Apr)	>7	2	2	2	2
22000+	Summer (Nov-Apr)	>7	2	2	2	2
32000+	Summer (Nov-Apr)	>7	2	2	2	2
36000+	Summer (Nov-Apr)	>7	2	2	2	2
12000+	Winter (May-Oct)	>7	6	7	7	7
15000+	Winter (May-Oct)	>7	5	7	7	6
22000+	Winter (May-Oct)	>7	2	3	3	4
32000+	Winter (May-Oct)	>7	1	1	2	2
36000+	Winter (May-Oct)	>7	1	1	1	2

Figure 5.4 Flow event (>7 days) statistics for the 3 (plus current) constraint relaxation flow scenarios for a WET decade (2010–20) for the 2 water quality assessment areas of the Murrumbidgee River; (top) Burrinjuck Dam to Hay, (bottom) Hay to junction with the Murray River

The relatively wet decade of 2010–2020 provides more opportunity for understanding how water and flow events are ordered. Summer flow events are maintained at current levels throughout the period. The relaxation of constraints provides opportunity for a few more >7-day flow events in winter, in both areas of the Murrumbidgee, above the 22 GL/day threshold.

The likely impacts of these shifts on the occurrence of water quality events are discussed in Section 5.4.

5.2 Murrumbidgee – upstream of Hay

This section reports on our assessment of the risks of, and the benefits from, blackwater, blue-green algal bloom and salinity water quality events (Table 5.2 to Table 5.4, respectively), for each of the flow threshold categories in this water quality assessment area. These assessments are then synthesised by flow category in Table 5.5. Flow categories relate to flows at Wagga Wagga.

5.2.1 Tables of risk and benefit assessments for 3 water quality issues by flow category

Table 5.2 Blackwater risk/benefit assignment Murrumbidgee upstream of Hay – likelihood and impact of a water quality event occurring in summer and winter in each flow category

Flow category	Flow event timing (Month)	Duration (days)	Risk of a water quality event			Benefit of a water quality event		
			Impact	Likelihood	Risk	Impact	Likelihood	Benefit
>22 GL/day at Wagga Wagga	Summer (Nov-Apr)	<7	Negligible	Possible	Low	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Possible	High	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>32 GL/day	Summer (Nov-Apr)	<7	Negligible	Possible	Low	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Possible	High	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>36 GL/day	Summer (Nov-Apr)	<7	Negligible	Very likely	High	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Very likely	Very high	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>40 GL/day	Summer (Nov-Apr)	<7	Negligible	Very likely	High	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Very likely	Very high	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High

Table 5.3 Blue-green algal bloom risk/benefit assignment Murrumbidgee upstream of Hay – likelihood and impact of a water quality event occurring in summer and winter in each flow category

Flow category	Flow event timing (Month)	Duration (days)	Risk of a water quality event			Benefit of a water quality event		
			Impact	Likelihood	Risk	Impact	Likelihood	Benefit
>22 GL/day at Wagga Wagga	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate
>32 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate
>36 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate
>40 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate

Table 5.4 Salinity risk/benefit assignment Murrumbidgee upstream of Hay – likelihood and impact of a water quality event occurring in summer and winter in each flow category

Flow category	Flow event timing (Month)	Duration (days)	Risk of a water quality event			Benefit of a water quality event		
			Impact	Likelihood	Risk	Impact	Likelihood	Benefit
>22 GL/day (current)	Summer (Nov-Apr)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>32 GL/day	Summer (Nov-Apr)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>36 GL/day	Summer (Nov-Apr)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>40 GL/day	Summer (Nov-Apr)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	<7	Significant	Unlikely	Moderate	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High

5.2.1 SYNTHESIS OF RISK AND BENEFIT ASSESSMENTS BY FLOW CATEGORY

The water quality issue risk and benefit assessments are collated for each flow threshold category in Table 5.5.

Table 5.5 Collation of water quality issue risk/benefit assessment by flow category for events of >7 days duration, Burrinjuck Dam to Hay

Flow category upstream of Hay	Flow event timing	Risk of a water quality event			Benefit of a water quality event		
		Blackwater	Blue-green algal bloom	Salinity	Blackwater	Blue-green algal bloom	Salinity
>22 GL/day	Summer	High	High	Moderate	High	High	High
	Winter	Moderate	Moderate	Moderate	High	Moderate	High
>32 GL/day	Summer	High	High	Moderate	High	High	High
	Winter	Moderate	Moderate	Moderate	High	Moderate	High
>36 GL/day	Summer	Very high	High	Moderate	High	High	High
	Winter	Moderate	Moderate	Moderate	High	Moderate	High
>40 GL/day	Summer	Very high	High	Moderate	High	High	High
	Winter	Moderate	Moderate	Moderate	High	Moderate	High

As with the Murray River system, the greatest risk to water quality in the Murrumbidgee River upstream of Hay is associated with season (water temperature and increased light) and summer represents the greatest risk for water quality parameters driven by metabolic processes of microbes and algae. Thus, concordant with the Murray River assessment, though the risk assessment is driven by flow category, it is the timing that is the primary driver of water quality risks in the Murrumbidgee River. Interrogation of long-term dissolved oxygen records in the Murrumbidgee indicate that riverine hypoxia does not occur during winter. Although temperature is a key predictor for the occurrence of hypoxic blackwater events in rivers, the area of floodplain inundated (and thus the magnitude of the flow) and the litter load on the floodplain are also important drivers, particularly during high-risk warmer months. In this respect, the risk doesn't change, but the extent, or longevity of the effect is likely to increase as a consequence of greater extent of inundation.

5.3 Murrumbidgee – downstream of Hay

This section reports on our assessment of the risks of, and the benefits from, blackwater, blue-green algal bloom and salinity water quality events (Table 5.6 to Table 5.8, respectively), for each of the flow threshold categories in this water quality assessment area. These assessments are then synthesised by flow category in Table 5.9. Flow categories relate to flows at Hay.

5.3.1 Tables of risk and benefit assessments for 3 water quality issues by flow category

Table 5.6 Blackwater risk/benefit assignment Murrumbidgee downstream of Hay – likelihood and impact of a water quality event occurring in summer and winter in each flow category

Flow category	Flow event timing (Month)	Duration (days)	Risk of a water quality event			Benefit of a water quality event		
			Impact	Likelihood	Risk	Impact	Likelihood	Benefit
>22 GL/day	Summer (Nov-Apr)	<7	Negligible	Possible	Low	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Possible	High	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>32 GL/day	Summer (Nov-Apr)	<7	Negligible	Possible	Low	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Possible	High	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>36 GL/day	Summer (Nov-Apr)	<7	Negligible	Very likely	High	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Very likely	Very high	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very Low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High
>40 GL/day	Summer (Nov-Apr)	<7	Negligible	Very likely	High	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Significant	Very likely	Very high	Moderate	Likely	High
	Winter (May-Oct)	<7	Negligible	Unlikely	Very low	Moderate	Likely	High
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Moderate	Likely	High

Table 5.7 Blue-green algae risk/benefit assignment Murrumbidgee downstream of Hay – likelihood and impact of a water quality event occurring in summer and winter in each flow category

Flow category	Flow event timing (Month)	Duration (days)	Risk of a water quality event			Benefit of a water quality event		
			Impact	Likelihood	Risk	Impact	Likelihood	Benefit
>22 GL/day at Wagga Wagga	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate
>32 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate
>36 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate
>40 GL/day	Summer (Nov-Apr)	<7	Moderate	Possible	Moderate	Moderate	Possible	Moderate
	Summer (Nov-Apr)	>7	Significant	Possible	High	Significant	Possible	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Unlikely	Low
	Winter (May-Oct)	>7	Significant	Unlikely	Moderate	Significant	Unlikely	Moderate

Table 5.8 Salinity risk/benefit assignment Murrumbidgee downstream of Hay – likelihood and impact of a water quality event occurring in summer and winter in each flow category

Flow category	Flow event timing (Month)	Duration (days)	Risk of a water quality event			Benefit of a water quality event		
			Impact	Likelihood	Risk	Impact	Likelihood	Benefit
>22 GL/day at Wagga	Summer (Nov-Apr)	<7	Moderate	Unlikely	Low	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Moderate	Unlikely	Low	Moderate	Likely	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Likely	High
	Winter (May-Oct)	>7	Moderate	Unlikely	Low	Moderate	Likely	High
>32 GL/day	Summer (Nov-Apr)	<7	Moderate	Unlikely	Low	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Moderate	Unlikely	Low	Moderate	Likely	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Likely	High
	Winter (May-Oct)	>7	Moderate	Unlikely	Low	Moderate	Likely	High
>36 GL/day	Summer (Nov-Apr)	<7	Moderate	Unlikely	Low	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Moderate	Unlikely	Low	Moderate	Likely	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Likely	High
	Winter (May-Oct)	>7	Moderate	Unlikely	Low	Moderate	Likely	High
>40 GL/day	Summer (Nov-Apr)	<7	Moderate	Unlikely	Low	Moderate	Likely	High
	Summer (Nov-Apr)	>7	Moderate	Unlikely	Low	Moderate	Likely	High
	Winter (May-Oct)	<7	Moderate	Unlikely	Low	Moderate	Likely	High
	Winter (May-Oct)	>7	Moderate	Unlikely	Low	Moderate	Likely	High

5.3.1 SYNTHESIS OF RISK AND BENEFIT ASSESSMENTS BY FLOW CATEGORY

The water quality issue risk and benefit assessments are collated for each flow threshold category in Table 5.9.

Table 5.9 Collation of water quality issue risk/benefit assessment by flow category for events of >7 days duration, downstream of Hay. Flow categories relate to large fresh, bankfull and overbank flows in the Murrumbidgee River downstream of Wagga Wagga

Flow category D/s Hay	Flow event timing	Risk of a water quality event			Benefit of a water quality event		
		Blackwater	Blue-green algal bloom	Salinity	Blackwater	Blue-green algal bloom	Salinity
>22 GL/day	Summer	High	High	Low	High	High	High
	Winter	Moderate	Moderate	Low	High	Moderate	High
>32 GL/day	Summer	High	High	Low	High	High	High
	Winter	Moderate	Moderate	Low	High	Moderate	High
>36 GL/day	Summer	Very high	High	Low	High	High	High
	Winter	Moderate	Moderate	Low	High	Moderate	High
>40 GL/day	Summer	Very high	High	Low	High	High	High
	Winter	Moderate	Moderate	Low	High	Moderate	High

As with the Murrumbidgee River upstream of Hay, the greatest risk to water quality in the Murrumbidgee River downstream of Hay is associated with season (water temperature) and summer represents the greatest risk for water quality parameters driven by metabolic processes of microbes and algae. Thus, concordant with the Murrumbidgee River upstream of Hay assessment, though the risk assessment is driven by flow category, it is seasonal timing that is the primary driver of adverse water quality risks in the Murrumbidgee River. Salinity is not influenced by temperature however, and the Murrumbidgee River downstream of Hay is assessed as being at lower risk than the Murrumbidgee River upstream of Hay. This is not because it is less likely to occur, but because the impact is reduced as a consequence of animals in this river segment being better adapted to fluctuations in salt concentration (Table 5.8).

5.4 RISK AND BENEFIT ASSESSMENT OF CONSTRAINT RELAXATION SCENARIOS ACROSS THE 2 MURRUMBIDGEE RIVER WATER QUALITY ASSESSMENT AREAS

This section brings together the flow event statistics reported in Section 5.1 with the collated water quality event risk/benefit assessments for each water quality assessment area (Table 5.5 and Table 5.9, respectively) to provide a risk/benefit assessment of each of the 3 constraint relaxation scenarios.

Relaxation of flow constraints that result in an increase in the number of flow events that occur for >7 days may affect the impact of a given water quality issue e.g., if the number of times a hypoxic blackwater event occurs for more than 7 days during a given period increases, we expect that blackwater risk will be higher.

Risk mitigation strategies for blackwater, blue-green algal blooms and salinity due to change in the frequency, timing and/or duration of flow events at thresholds are provided in Sections 3.1.1, 3.3.1 and 3.4.1.

5.4.1 W32 CONSTRAINT RELAXATION SCENARIO

The modest change in flow events achieved under this scenario across all of the flow categories is not sufficient to change the assessment of the likelihood of water quality events, or of their significance should they occur. The likelihood of the occurrence of adverse water quality events in summer remains as ranging from 'Possible' to 'Very likely' for blackwater, 'Possible' for blue-green algal bloom, and 'Unlikely' for salinity across all flow thresholds; with the impact of a salinity water quality event reducing from 'Significant' to 'Moderate' downstream of Hay. The slight increase in flow events above 22 GL/day in summer reflects the additional flow that can be sent down the river under the constraint relaxation. The summer:winter flow event ratio is the same as for current (22:78).

Our assessment is that there is no change in risk level under the W32 scenario from current and it remains 'Moderate' to 'Very high' for blackwater, 'Moderate' to 'High' for blue-green algal blooms, and 'Moderate' to 'Low' for salinity from upstream of Hay to downstream of Hay, winter and summer respectively. The increase in winter flow events is positive but probably insufficient to shift the likelihood of a benefit above 'Possible'.

5.4.2 W36 CONSTRAINT RELAXATION SCENARIO

As with the W32 scenario, the W36 scenario shows little difference to current in the summer months. It has increased flow events in winter, particularly in the lower flow range. The summer:winter ratio is the same overall as for the W32 scenario and only slightly different to current (27:73 versus 28:72 for current).

Our assessment is that there is no change in risk level under the W36 scenario from current and it remains 'Moderate' for blackwater in winter, and 'High' to 'Very high' for blackwater in summer; 'Moderate' to 'High' for blue-green algal blooms in winter and summer, respectively, and 'Moderate' to 'Low' for salinity from upstream of Hay to downstream of Hay. The increase in winter flow events is positive but probably insufficient to shift the likelihood of a benefit occurring above 'Possible'.

5.4.3 W40 CONSTRAINT RELAXATION SCENARIO

The shift in summer to winter flow events is evident in the upstream area (Burrinjuck Dam to Hay) with change in summer:winter ratio moving from 22:78 under current to 19:81 under this scenario. The scenario provides for a greater number of years with flow events above 36 GL/day in winter (than any of the other scenarios).

However the risk assessment for flow events of this size is the same as for smaller sized flow events. While this may be seen as an improvement in terms of flow in the river, it does not change the risk assessment.

Our assessment is that there is no change in risk level under the W40 scenario from current. It remains ‘Moderate’ for blackwater in winter and ‘High’ to ‘Very high’ in summer; ‘Moderate’ to ‘High’ for blue-green algal blooms in winter and summer, respectively, and ‘Moderate’ to ‘Low’ for salinity from upstream of Hay to downstream of Hay. The increase in winter flow events is positive but probably insufficient to shift the likelihood of a benefit above ‘Possible’.

5.4.4 COMPARISON OF CONSTRAINT RELAXATION SCENARIOS

Changes in the number of flow events in the selected dry (2000–09) and wet (2010–20) decades under all scenarios are modest (Figure 5.3 and Figure 5.4, respectively). The dry decade is indeed very dry; nevertheless a small increase in the number of flow events is achieved in the winter, and none in the summer.

All scenarios mitigate against the most significant driver of adverse water quality events, which is high temperatures associated with summer. As evident from Figure 5.2, all scenarios deliver increased flow events in winter, at different threshold levels.

However, from a qualitative risk assessment perspective, none of these differences in annual pattern are sufficient to discriminate between the relaxation constraint scenarios or discriminate them from current.

Our overall assessment is that these 3 constraint relaxation scenarios do not increase the likelihood of adverse water quality events from current and may increase the likelihood of benefit.

The assessments made in this section are synthesised in Table 5.10. These tables reflect an attempt to give a single risk rating that weights each water quality issue equally and is based on expert opinion.

Table 5.10 Overarching risk/benefit assessment of constraint relaxation scenarios for the Murrumbidgee River

CONSTRAINT RELAXATION SCENARIO	CHANGE IN RISK RATING FROM CURRENT	RESIDUAL RISK RATING	CHANGE IN BENEFIT RATING FROM CURRENT	RESIDUAL BENEFIT RATING
W32	No change	Moderate	Moderate -> High	High
W36	No change	Moderate	Moderate -> High	High
W40	No change	Moderate	Moderate -> High	High

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DATA RECEIVED

REF:	DATE RECEIVED	DESCRIPTION / TITLE	MEDIA TYPE
Murray TS flow	10/09/2021	Murray - 5 flow time series (see README_naming_convention.txt for how to decipher the scenario)	zip file
Spatial datasets	13/09/2021	Locations of Source nodes, habitat classification, project areas	zip file
Inundation extents	29/09/2021	Spatial layers of inundation extents - contains 4 zip files	zip file
Flow design	29/09/2021	Presentation on types of constraint relaxation flows	.pptx
Murray project areas	19/10/2021	Spatial datasets; Murray RRCP project areas, made by merging respective RIM-FIM zones	.gdb
Murrumbidgee project areas	21/10/2021	Details the Bidgee project areas (including some of the Murray)	.shp
PGM-CMP potential survey areas	21/10/2021	Generated to broadly capture potential inundation for asset capture work	.pdf
Murray TS flow	28/1/2022	A set of files containing model output of daily flows for Murray gauges for each flow scenario	.csv
Murrumbidgee TS flow	28/1/2022	Preliminary daily flow data for Murrumbidgee gauges	.csv
Mid-bidgee	28/1/2022	Bidgee CARM inundation model – raster dataset containing CTF thresholds relative to the gauged flow at Wagga Wagga (4100001), Burrinjuck Dam to Hay weir, in GL/day	GIS, pdf, etc
DNA) frequency exceedance charts	Various over period 1-18/3/2022	Exceedance charts showing all years, and identifying years in which flow thresholds exceeded at least once (ie at least one event of ≥ that magnitude in the year)	pdfs

Appendix A DETAILED FLOW EVENT ANALYSIS

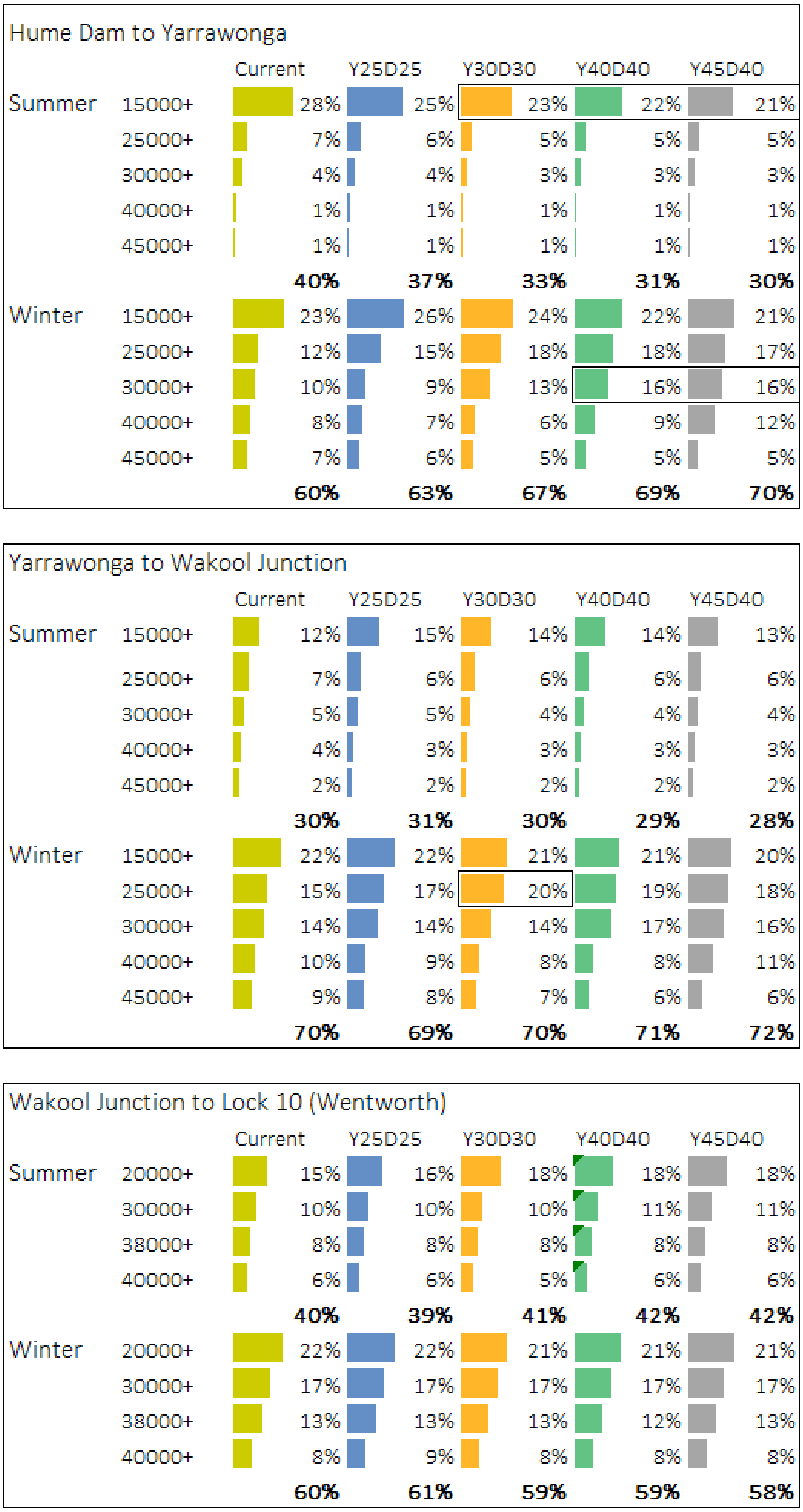
A.1 MURRAY RIVER

ApxTable 0.1 Change from current in the number of years with ≥1 flow event >7 days in each scenario, Murray River

	SUMMER				WINTER			
	Y25D25	Y30D30	Y40D40	Y45D40	Y25D25	Y30D30	Y40D40	Y45D40
Hume Dam to Yarrawonga								
15000+	-5	-3	-2	-7	15	17	15	13
25000+	-1	-2	-3	-3	18	40	40	39
30000+	-1	-3	-4	-3	-4	22	37	20
40000+	0	0	0	0	-1	-1	13	20
45000+	0	0	0	0	-2	-1	-4	-4
Yarrawonga to Wakool Junction								
15000+	17	18	20	18	3	2	5	4
25000+	-3	-4	-1	-4	9	29	28	28
30000+	-2	-3	-3	-3	1	7	24	23
40000+	-3	-3	-3	-2	-4	-5	-3	14
45000+	-1	-1	-1	-2	-4	-7	-7	-8
Wakool Junction to Lock 10 (Wentworth)								
20000+	0	0	0	0	0	0	0	0
30000+	0	0	0	0	0	0	0	0
38000+	0	1	2	3	1	1	1	2
50000+	-1	-2	-1	-1	2	2	2	2

We derived a ratio metric to show the shift in summer to winter ordering in the flow scenarios. The department's frequency statistics provided the number of years with events in each flow category (used to calculate the changes reported in ApxTable 0.1 and ApxTable 0.2). The number of flow events in each category are expressed as a percentage of the number of flow events over the year (summer plus winter). For example, in the Current scenario, Hume Dam to Yarrawonga assessment area, 15000+ flow events of >7 days duration occur in 112 years in summer (Figure 4.2) and in 95 years in winter (Figure 4.2). Using the ratio metric, these are expressed as 28% (summer) and 23% (winter) of the flow regime described by the scenario.

This is a somewhat artificial metric and is only intended to demonstrate that the flow scenarios have all achieved a shift in their overall flow regime pattern to winter (ApxFigure 0.1, ApxFigure 0.2). As can be seen from these figures, each scenario has achieved this in a slightly different way, using a different internal pattern (e.g. in ApxFigure 0.1, Y25D25 scenario has more smaller flows than Y30D30).



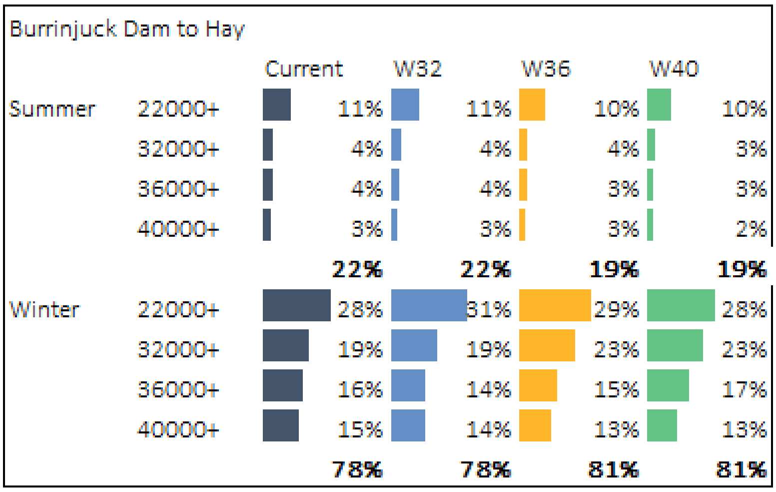
Boxed outline identifies percentage change from current of >= 5%

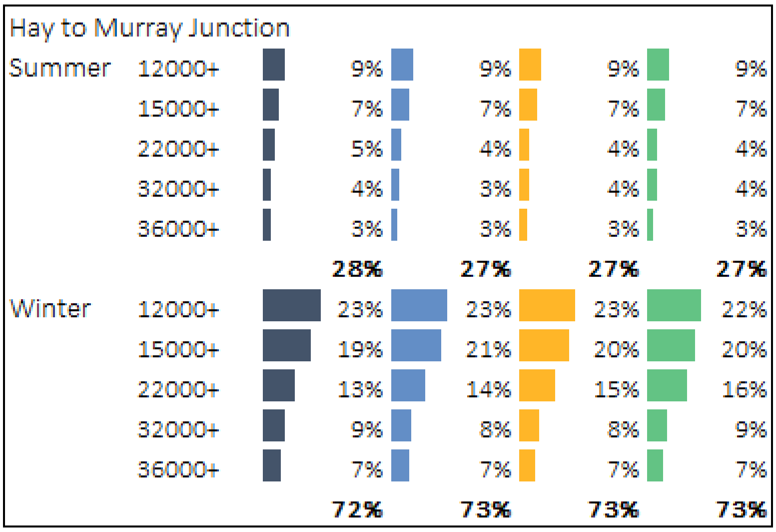
ApxFigure 0.1 Proportion of years with ≥1 flow event of ≥7 days by flow category, across summer and winter, Murray River

A.2 MURRUMBIDGEE RIVER

ApxTable 0.2 Change from current in number of years with at least 1 flow event >7 days in each scenario, Murrumbidgee River

	SUMMER			WINTER		
	W32	W36	W40	W32	W36	W40
Upstream Hay						
22000+	2	2	2	**13**	14	13
32000+	1	0	0	2	**19**	**22**
36000+	0	-1	-1	-3	4	11
40000+	0	0	0	-1	0	0
Downstream Hay						
12000+	0	0	0	0	0	-2
15000+	2	1	1	9	7	4
22000+	0	-1	-1	5	8	13
32000+	-1	1	1	-1	-2	-1
36000+	-2	-1	-2	1	-1	-2





ApxFigure 0.2 Proportion of years with ≥1 flow event of ≥7 days by flow category, Murrumbidgee River. Proportions used to weight categories within scenarios

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Contact us

1300 363 400
+61 3 9545 2176
csiroenquiries@csiro.au
csiro.au

For further information

Land & Water
Dr Paul McInerney
+61 2 6051 9837
+61 400 949 079
Paul.Mcinerney@csiro.au
csiro.au/en/about/people/business-units/Land-and-Water

Land and Water
Susan Cuddy
+61 2 6246 5705
+61 477 714 466
Susan.cuddy@csiro.au
csiro.au/en/about/people/business-units/Land-and-Water