SURFACE WATER SCIENCE

Evaluating cease to pump rules in the unregulated tributaries of the Murrumbidgee and Tumut rivers

Murrumbidgee Unregulated and Alluvial Water
Sources Water Sharing Plan 2012

January 2022

NSW Department of Planning and Environment | dpie.nsw.gov.au

Published by NSW Department of Planning and Environment

dpie.nsw.gov.au

Title: Evaluating cease to pump rules in the unregulated tributaries of the Murrumbidgee and Tumut rivers

First published: January 2022

ISBN/ISSN: 978-1-76058-539-6

Department reference number: PUB21/820

Acknowledgements

Citation: Wood, B., Coleman, D., and Brooks A., (2022) Evaluating cease to pump rules in the unregulated tributaries of the Murrumbidgee and Tumut rivers. The Surface Water Science group within NSW Department of Planning and Environment

Cover image: Adelong Creek, Andrew Brooks

Acknowledgment of Country

The Department of Planning and Environment acknowledges the Traditional Owners and Custodians of the land on which we live and work and pays respect to Elders past, present and future.

Contents

Summary

Restrictions to water extraction that protect low flows have been established through the NSW *Water Management Act 2000* and NSW's water sharing plans (WSPs) in order to balance water needs for environmental, cultural, social and economic purposes. A primary objective of water sharing plans is to protect river flows and the aquatic ecosystems dependent on them. Cease to pump (CtP) rules are a key management strategy within these plans and aim to reduce the ecological impact of over extraction during low flow periods.

This report evaluates the influence of CtP rules on low flow regimes in seven unregulated rivers (water sources) within the Murrumbidgee Unregulated and Alluvial Water Sources Water Sharing Plan 2012.

In most rivers the implementation of the CtP protected the low flow regime based on one or more low flow metrics. All sites achieved a greater number of days with flow, except the Goodradigbee River which never ceased to flow either with or without the CtP rule implemented.

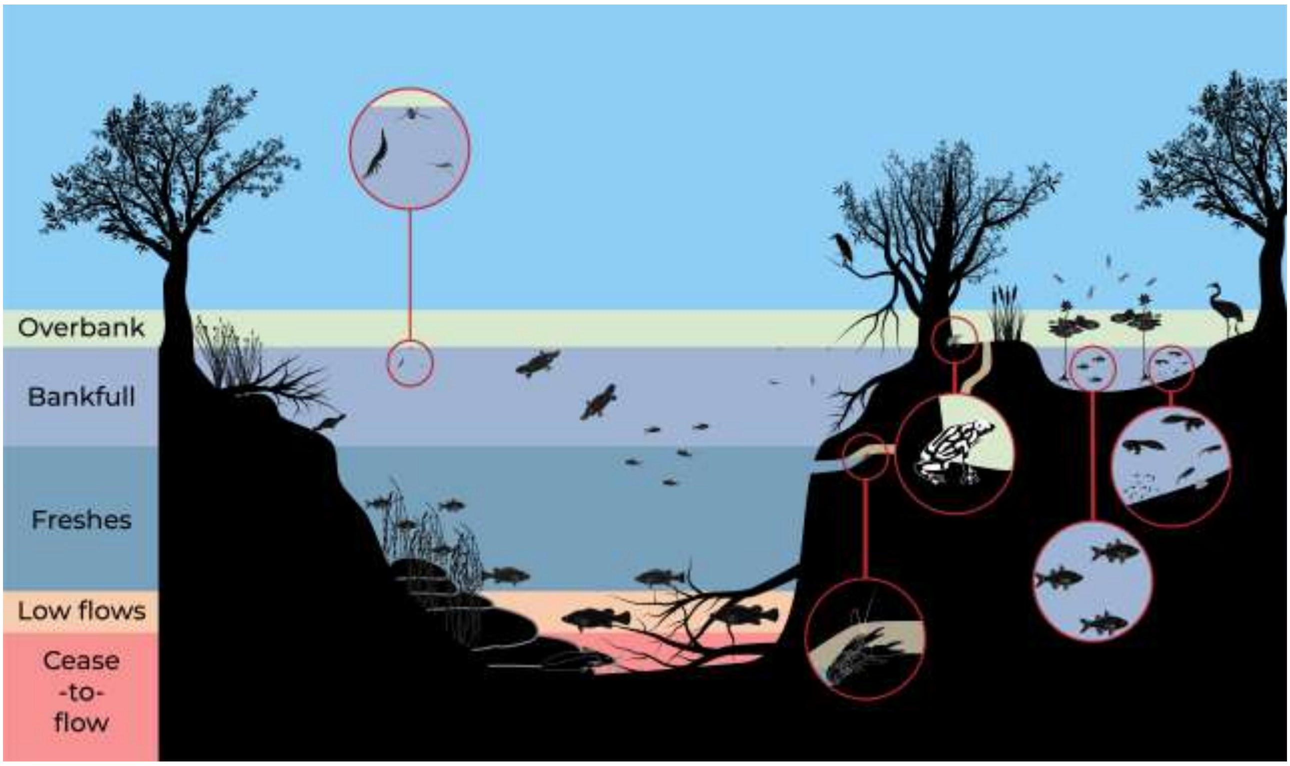

Figure 1. Diagram summarising the various components of river flow. This report focuses on the influence of Cease to pump rules on the low and cease-to-flow components.

Background

Flow is an important driver of physical, chemical and biological processes in rivers and changes to the natural flow regime of rivers can have negative impacts on flow dependent ecosystems (Boulton and Brock, 1999; Chessman et al., 2006; Rolls et al., 2017). Water extraction in unregulated rivers can exacerbate the ecological impacts of drying and low flows by decreasing the natural wetting regime and creating artificial droughts (Finn et al., 2009; McKay and King, 2006; Watts et al., 2018). Water resource development has impacted flows in several unregulated tributaries of the Murrumbidgee and Tumut Rivers (Hardwick et al., 2012). There has been an increase in the average period between flows and a reduction in annual flooding volumes, which is likely to impact on water dependent environments downstream (CSIRO, 2008).

Flows in unregulated rivers are not controlled by dams and users rely on natural flow regimes for access to water. In unregulated river systems, WSPs can provide fixed environmental flow rules such as CtP rules, which prevent water extraction when river flows fall below a certain threshold level (Driver et al., 2013). These rules aim to protect low flows and to maintain critical flows for the benefit of basic landholder right water users and the environment (Brooks et al., 2011; McKay and King, 2006). Management decisions in the upper Murrumbidgee unregulated system have the potential to impact flows downstream with consequences for both water quality and ecological function (Dye, 2010).

Study purpose and approach

The department has a responsibility under the Water Management Act 2000 to review and amend water sharing plans if the provisions within the plan are not achieving the desired outcomes. The Murrumbidgee unregulated WSP has specific environmental objectives established to protect, and where possible enhance environmental outcomes for water dependent ecosystems. The purpose of this report is to assess the effectiveness of CtP rules at protecting low flows and maintaining natural flow regimes in unregulated rivers within the Murrumbidgee Unregulated and Alluvial Water Sources WSP 2012.

A simple assessment of the performance of the plan against the environmental objectives can be measured through changes in flow regime and key low flow metrics such as number of cease-to-flow days, low flow spell duration and minimum daily flows. We compared these metrics under two modelled flow scenarios – with the CtP rules implemented and without the CtP rules.

Figure 2. Goobarragandra River in the Murrumbidgee Unregulated and Alluvial Water Sources WSP area

Main findings

- Low flow metrics showed an improvement in most rivers from the CtP rule implementation
- Minimum daily flow increased with the implementation of the CtP rule at all sites, except Molonglo which remained unchanged
- The CtP rules reduced periods of low flows caused by extraction in the Upper Yass and Adelong rivers.
- The number of cease-to-flow days were reduced by the CtP rule in all rivers, except the Goodradigbee which did not cease to flow during the period of record
- Adelong Creek and Goobarragandra Creek were prevented from ever completely drying out through the implementation of the CtP rule.

What this means for water management

Protecting low and base flows using CtP rules in unregulated rivers is an important strategy for protecting and enhancing the ecological condition of unregulated rivers. Overall, the CtP rule is effective at reducing the artificial low flow periods caused by over extraction. Without the policy in place these rivers would be placed under increased drying and ecological stress associated with cease-to-flow and low flow conditions (Coleman and Brooks, 2020; Growns et al., 2017).

Project details

Study Sites

This study was carried out in seven unregulated rivers within the area of the Murrumbidgee Unregulated and Alluvial Water Sources Water Sharing Plan 2012 (Figure 3). Five sites flow directly into the Murrumbidgee River; 3 above and 2 below Burrunjuck Dam, and the other 2 sites flow into the Tumut River below Blowering Dam, a tributary of the Murrumbidgee River (Figure 3).

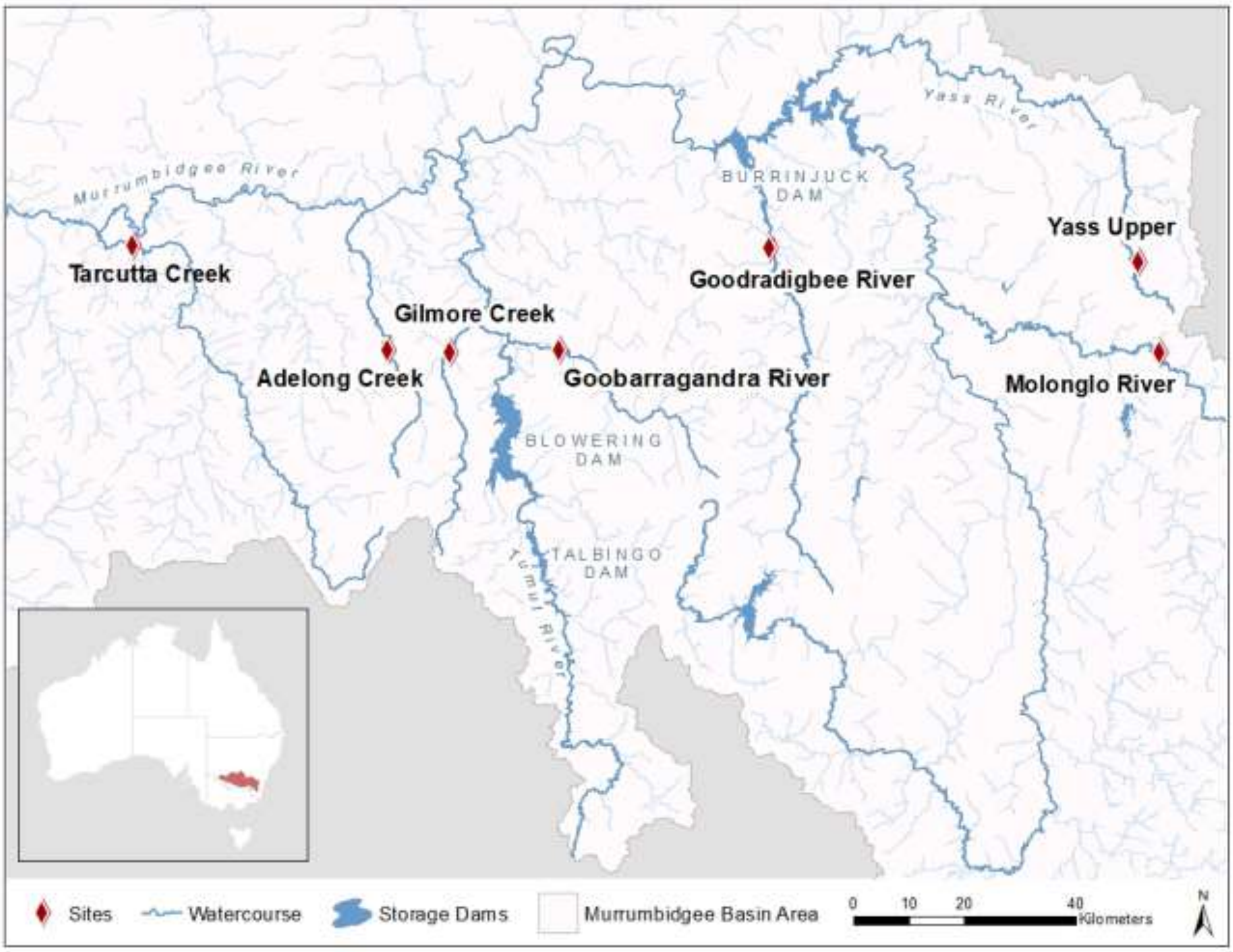

Figure 3. Map of the seven study sites within the Murrumbidgee Basin Area.

Statistical analysis

We undertook two analyses of the low flow hydrology of the focus rivers. First, hydrological data measured at gauges within each river were analysed in order to evaluate the effectiveness of CtP rule implementation in protecting low flows (Gauge sites listed in Table 2). Secondly, average daily flows were modelled using Integrated Quantity-Quality Model (IQQM) a hydrologic modelling tool developed by the NSW Government for use in water resource management policy planning and evaluation (DIPNR, 2005; Simons et al., 1996). Two modelled CtP scenarios were considered for each river: a) with CtP rule implemented and b) without the CtP implemented. Six different metrics which measure specific characteristics of low flow hydrology were calculated at each site using the modelled hydrological data (Table 1).

Table 1. Metrics used to evaluate the effect of the CtP rule implementation in each of the rivers using modelled hydrological data. All metrics were calculated on an annual basis for each year within the period of record that triggered the CTP rule (Table 2).

Metric	Unit
1. Minimum mean daily flow	Megalitres per day (ML/d)
2. Number of low flow spells	Count
3. Length of the longest low flow spell (duration)	Days
4. Total duration of low flow spells (cumulative duration)	Days
5. 10th percentile of mean daily flows	Megalitres per day (ML/d)
6. Number of cease to flow days	Count

The modelled flow data was analysed using the River Analysis Package (Marsh et al., 2003) software to calculate each of the low flow metrics listed in Table 1 on an annual basis for each year of record. Two-sided T-tests were carried out using only data in years where the CtP threshold was reached in the no CtP scenario to test if there was a significant difference in the medians of each metric value between the two scenarios, with CtP rule implemented and without CtP rule. Normality of the data was checked with a Shapiro-Wilk test and if data were not normally distributed then an alternative Wilcoxon signed-rank test was used. Low flow was defined as flow below 10 % of mean daily gauged flow calculated at each site using the whole record period from Water NSW gauge data (see Table 2 for low flow thresholds for each site). Flow duration curve (FDC) plots were computed on the whole period of record mean daily discharge data. Graphical and statistical analysis was carried out using RStudio for R and the packages: tidyverse, hydrostats, and scales.

Results

How often was CtP rule triggered throughout the study period?

We compared the CtP threshold values and the number and proportion of years in each record period triggering CtP conditions at each of the seven sites (Table 2). At two of the sites, Molonglo and Yass Upper, the CtP conditions were triggered in all years of the record. In contrast, Goodradigbee and Goobarragandra only triggered the CtP in 20% and 24% of the years in the record period (Table 2).

Table 2. Cease to pump (CtP) thresholds for the seven rivers and the number of years where flow was less than or equal to the CtP at that site for the whole period of gauged record. CtP thresholds identified in the NSW Water Sharing Plan for the Murrumbidgee Unregulated and Alluvial Water Sources 2012.

Sites	CtP threshold (ML)	Number of years CTP triggered (n)	Number of years in record	Period of Record	% of years in record CtP triggered	10 % flow (ML)
Adelong Creek (410061)	12	30	63	1948-2010	48	13.0
Gilmore Creek (410059)	10	33	64	1947-2010	52	10.8
Goobarragandra River (410057)	63	16	66	1945-2010	24	120.4
Goodradigbee River (410024)	45	19	96	1915-2010	20	102.2
Molonglo River (410705)	1.6	3	3	2013-2015	100	0.173
Tarcutta Creek (410047)	12	53	73	1938-2010	66	18.0
Yass Upper (410851)	1	95	95	1916-2010	100	0

Effect of CtP rule on low flow component of flow duration curves

The predicted flow regime was altered by the implementation of CtP rule at each of the seven sites (Figure 4). The flow duration curves shown in Figure 4, demonstrate that low flows are more common under the CtP rule implemented scenario (blue curve) compared to without the CtP (red curve). This preservation of low flows under the CtP rule scenario is most apparent in the flow duration curves for the Adelong Creek, Gilmore Creek, Molonglo River, Tarcutta Creek and Yass upper sites (Figure 4).

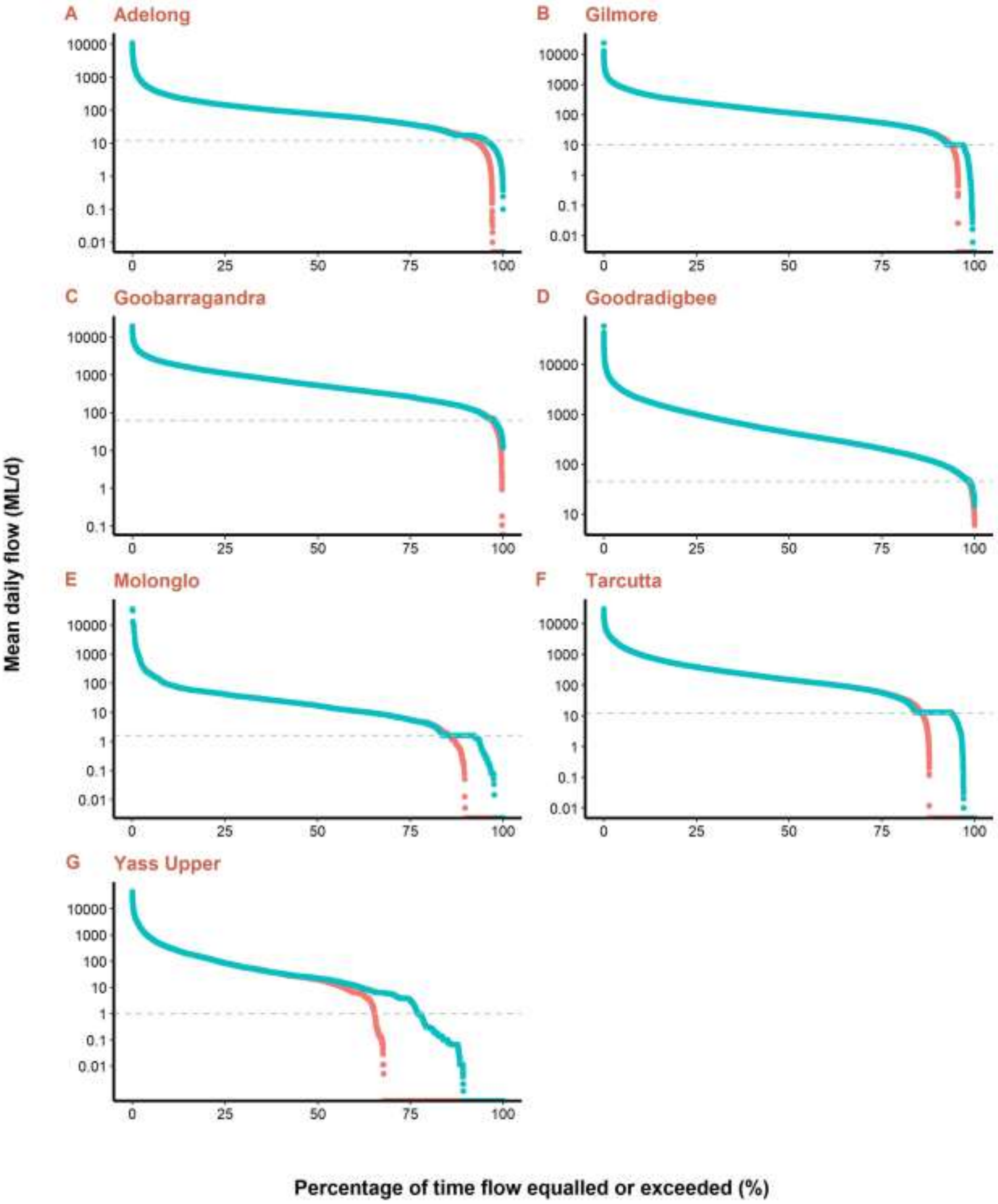

Figure 4. Flow duration curves showing the effect of the Cease to pump (CtP) (blue) compared to without the CtP rule (red) at the following sites: A) Adelong Creek, B) Gilmore Creek, C) Goobarragandra River, D) Goodradigbee River, E) Molonglo River, F) Tarcutta Creek and G) Yass Upper. The grey dashed lines are the CTP threshold levels for each site.

Benefits of CtP rule to minimum daily discharge

The benefits of the CtP rule during years when the CtP was triggered were apparent when comparing the minimum mean daily flow (ML/d) values between the two scenarios (Figure 5 & Table 3). The positive effect of CtP implementation on the minimum mean daily flow was statistically significant for six out of the seven sites ($p < 0.05$, Table 3). With the implementation of the CtP rule the hydrological models predicted an increase in minimum mean daily flow at all sites, except Molonglo where the increase was insignificant (Figure 5, Table 3, $p>0.05$). The largest change in magnitude of flows was at Goobarragandra, with an increase in minimum mean daily flow of 18 ML/d (43%). Adelong, Gilmore and Tarcutta sites also saw significant increases in minimum mean daily flow of 70%, 75%, and 88% respectively (Table 3). Without CtP rule the average minimum mean daily flow was zero at Yass Upper, this increased to 0.8 (ML/d) with the CtP implemented (Table 3).

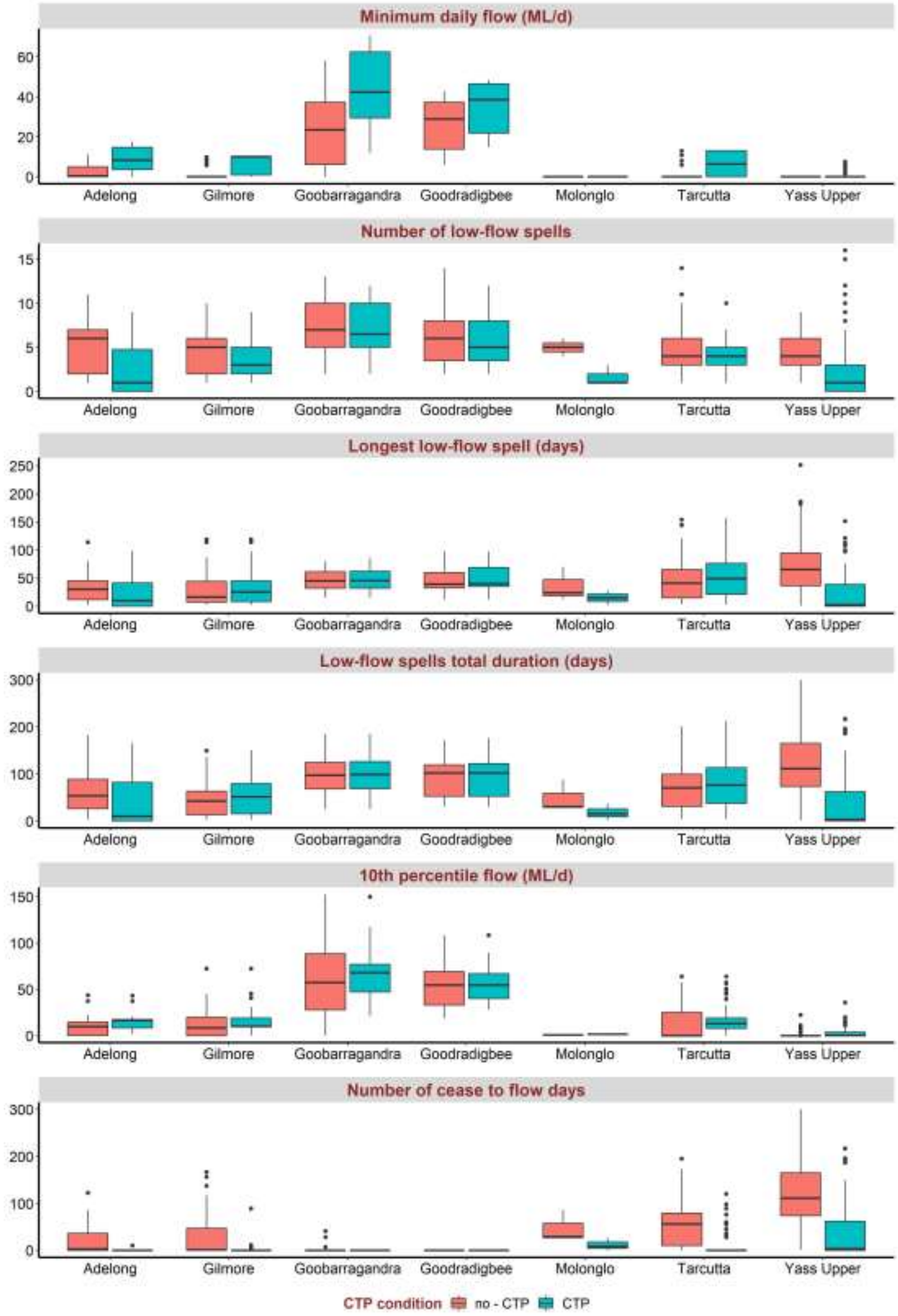

Figure 5. Differences in each hydrology metric across rivers in the Murrumbidgee with the CtP rule implemented (blue = CTP) and without the CtP rule (red = no-CTP). Only data for years where the CTP was reached was included to show the effect of CtP implementation.

Table 3. Mean (± SE) annual values of calculated hydrology metrics under each scenario; with the CtP rule (CtP) and without the CtP (No CtP) and results of paired t-tests to assess effect of the two scenarios. * indicates statistical significance ($p < 0.05$). Only data for years where the CTP was reached was included to show the effect of CtP implementation (n = number of CtP years, Table 2).

Minimum mean daily flow (ML/d)

	No CtP	CtP	Difference	% Change	p-value
Adelong	2.63 (0.67)	8.73 (1.10)	6.10	70	<0.001*
Gilmore	1.57 (0.55)	6.39 (0.78)	4.82	75	<0.001*
Goobarragandra	24.62 (4.88)	42.96 (4.89)	18.34	43	<0.001*
Goodradigbee	26.01 (3.00)	34.69 (2.81)	8.68	25	<0.001*
Molonglo	0.00 (0.00)	0.05 (0.05)	0.05	100	1
Tarcutta	0.82 (0.37)	6.94 (0.78)	6.12	88	<0.001*
Yass Upper	0.00 (0.00)	0.79 (0.19)	0.79	100	<0.001*

Number of low flow spells

	No CtP	CtP	Difference	% Change	p-value
Adelong	5.27 (0.56)	2.57 (0.52)	-2.70	-105	<0.001*
Gilmore	4.36 (0.42)	3.70 (0.38)	-0.67	-18	0.012*
Goobarragandra	7.19 (0.84)	7.00 (0.82)	-0.19	-3	0.149
Goodradigbee	6.05 (0.78)	5.84 (0.71)	-0.21	-4	0.174
Molonglo	5.00 (0.58)	1.67 (0.67)	-3.33	-200	0.174
Tarcutta	4.93 (0.37)	4.19 (0.24)	-0.74	-18	0.003*
Yass Upper	4.59 (0.19)	2.37 (0.34)	-2.22	-94	<0.001*

Length of the longest low flow spell (days)

	No CtP	CtP	Difference	% Change	p-value
Adelong	33.90 (4.96)	22.50 (4.79)	-11.4	-51	<0.001*
Gilmore	30.18 (5.48)	35.94 (5.85)	5.76	16	<0.001*
Goobarragandra	45.31 (4.90)	47.56 (5.51)	2.25	5	0.098
Goodradigbee	47.26 (5.59)	48.89 (5.62)	1.63	3	0.181
Molonglo	35.67 (17.46)	15.00 (7.51)	-20.67	-138	0.193
Tarcutta	47.58 (5.54)	54.23 (5.70)	6.65	12	<0.001*
Yass Upper	73.75 (5.32)	23.18 (3.55)	-50.57	-218	<0.001*

Table 3. Continued

Total duration of low flow spells (days)

	No CtP	CtP	Difference	% Change	p-value
Adelong	64.47 (8.92)	39.10 (8.80)	-25.37	-65	<0.001*
Gilmore	47.12 (6.99)	53.79 (7.56)	6.67	12	<0.001*
Goobarragandra	98.31 (11.11)	99.31 (11.25)	1.00	1	0.003*
Goodradigbee	95.79 (9.54)	96.37 (9.70)	0.58	1	0.181
Molonglo	48.33 (19.86)	17.67 (9.91)	-30.66	-174	0.109
Tarcutta	76.40 (7.58)	83.21 (8.03)	6.81	8	<0.001*
Yass Upper	119.00 (6.95)	39.63 (6.08)	-79.37	-200	<0.001*

10 % of mean daily flows (ML/d)

	No CtP	CtP	Difference	% Change	p-value
Adelong	10.23 (1.99)	14.59 (1.62)	4.36	30	<0.001*
Gilmore	13.21 (2.84)	15.64 (2.55)	2.43	16	0.006*
Goobarragandra	61.91 (10.66)	68.87 (8.43)	6.96	10	0.045*
Goodradigbee	54.14 (5.68)	56.37 (4.84)	2.23	4	0.117
Molonglo	0.47 (0.23)	1.12 (0.47)	0.65	58	0.250
Tarcutta	13.22 (2.72)	17.59 (2.38)	4.37	25	<0.001*
Yass Upper	1.06 (0.33)	3.53 (0.64)	2.47	70	<0.001*

Number of cease-to-flow days

	No CtP	CtP	Difference	% Change	p-value
Adelong	22.33 (5.87)	0.33 (0.33)	-22.00	-6,600	0.001*
Gilmore	31.48 (8.86)	3.27 (2.71)	-28.21	-862	<0.001*
Goobarragandra	4.75 (3.00)	0.00 (0.00)	-4.75	-	0.181
Goodradigbee	0.00 (0.00)	0.00 (0.00)	0.00	-	-
Molonglo	46.67 (19.70)	11.67 (8.01)	-35.00	-300	0.101
Tarcutta	60.66 (7.56)	14.75 (4.05)	-45.91	-311	<0.001*
Yass Upper	119.00 (6.95)	39.63 (6.08)	-79.37	-200	<0.001*

Note: the values in this table have been rounded, difference and % change have been calculated on unrounded values

Low flow spells analysis

Under the CtP rule implemented scenario all sites had a reduced number of low flow spells (Figure 5 & Table 3). The reduction in the number of low flow spells during CtP years was statistically significant (p<0.05) in 4 out of 7 sites: Adelong, Gilmore, Tarcutta and Yass Upper (Table 3). None of the sites saw an increase in the number of low flow spells with CtP rule implementation, however the length of the longest low flow spell and total duration of low flow spells varied between the sites (Table 3). The length of the longest low flow spell was significantly reduced at Yass Upper and Adelong sites, with a reduction of 51 and 11 days respectively (p<0.05). At the remaining sites, the change in the length of the longest low flow spell varied from a reduction of 21 days at Molonglo to an increase of 7 days at Tarcutta River (Table 3). The total duration of low flow spells was significantly reduced at two sites: Adelong Creek and Yass Upper, with 25 and 79 fewer low flow days at respectively ($p<0.05$, Table 3). Whereas there were slight increases in the total duration of low flow days at Gilmore Creek and Tarcutta River (both increased 7 days, $p<0.05$, Table 3).

All rivers saw an increase in the magnitude of the 10 $^{\%}$ of mean daily flows (ML/d) under the CtP rule implemented scenario. The lowest 10 % flow metric is the threshold at which the lowest proportion of river flows fall under, an increase to this threshold means an improvement to low flow conditions. These benefits were statistically significant at 5 out of 7 sites: Adelong, Gilmore, Goobarragandra, Tarcutta and Yass Upper ($p<0.05$, Table 3).

Cease-to-flow conditions

The number of days where a river ceased-to-flow was significantly reduced under the CtP rule implemented scenario (Figure 5 & Table 3). All sites achieved a greater number of days with flow, except Goodradigbee which never ceased to flow either with or without the CtP rule implemented. Adelong Creek and Goobarragandra River also achieved zero cease to flow days under the CtP rule, whereas without the CtP implemented flow ceased at these sites for 22 days and 5 days respectively. The greatest reduction in cease-to-flow days occurred in the Tarcutta Creek with 45 fewer cease to flow days and at the Upper Yass site with 79 less days where flow ceased (both significant $p < 0.05$) (Table 3).

Conclusions

This study found that the CtP rules protected natural low flows in all 7 unregulated rivers of the Murrumbidgee WSP area. There was an improvement in all six key low flow metrics tested by the predictive models with the CtP implemented scenario compared to without the CtP implemented. The CtP rule resulted in higher low flow thresholds (10 % mean daily flow) at all sites and increased minimum daily flows at all but one site, which was unchanged, indicating that the CtP rule is effective at protecting low flows in these rivers.

The CtP rule improved the outlook of low flow spells in most rivers. In 5 out of 7 rivers there were significantly fewer low flow spells with the CtP rule implemented. There were also improvements to the length of the longest low flow spell and the total duration of low flow spells at some sites. There was a reduction of cease to flow conditions in all but one site, which did not cease to flow under either CtP scenario. Adelong Creek and Goobarragandra River were prevented from ever completely drying out through the implementation of the CtP rule. Without the CtP in place these rivers would be placed under increased drying and ecological stress associated with cease to flow conditions.

Overall, the CtP rule is effective at reducing the effects of over extraction during low flow periods, as demonstrated by improvements in six key metrics under the CtP implemented hydrological model. Whilst the ecological benefits of reducing cease to flow periods or increasing the duration and frequency of low and very low flow periods are well understood (Poff and Zimmerman, 2010), further research could focus on linking the outcomes of CtP rule with ecological benefits and long-term outcomes in unregulated rivers.

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