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Implementing dead storage representation in the Barwon-Darling Source model to improve low flow and cease to flow behaviour

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Abstract: Under an increasingly variable climate, water resources are expected to become less reliable, especially in unregulated valleys with non-perennial/intermittent water courses. River System Planning models need to represent these varying conditions in the low flow regime, including cease-to-flow (CTF) and resumption to flow, to inform water management decisions to improve outcomes for stakeholders such as water users and the environment. The existing river systems (hydrological) models representing the Barwon-Darling Valley have been limited in achieving such objectives. This paper proposes to improve these metrics by implementing a representation of 'dead storage' within the main river's channel in the modelling, which conceptualises various refuge pools and other standing water when the river is in its CTF regime. Dead storage improves modelled behaviour by introducing antecedent conditions (memory), which will change losses based on each flow event.

The true challenge of this work is in its implementation, i.e. how to size these dead storages to represent a physical value and model effectively. Various data have been explored and analysed, including remote sensing data to track identified 'water bodies' within the channel and bathymetric data to understand the sizing of refuge pools and other standing water during CTF conditions. This work identified that a combination of data sources with calibration is required to effectively size and emulate observed behaviour (such as CTF events), in lieu of the identified data not being fit for direct usage in the model. The resulting modelled outputs from this methodology showed that CTF behaviour can be matched and simulated low flow losses are far more realistic than previously modelled.

Keywords: Climate Change, Hydrological modelling, Barwon-Darling, Dead Storage, Cease to flow

1. INTRODUCTION

River System Models are used for various planning functions and are critical for water management. Simplistically, these models are a representation of a valley's water balance and track various components of the hydrological cycle, including flows, extractions and losses under the existing water sharing rules and water management infrastructures. Throughout the years, various attempts have been made to improve these models and dial on specific components of the water balance, which require detailed representation to robustly inform planning decisions. One such focus has been to improve the low flow and cease to flow behaviour. These representations are critical in the understanding of drought conditions, ecological impacts and required mitigations to minimise impacts to various stakeholders.

The Barwon-Darling River System Model is currently being developed using eWater Source modelling platform, and part of its desired outcomes is to have improved low flow behaviour. A key challenge of this work is that the valley is unregulated and has highly variable flow, resultingly, no single cease-to-flow (CTF) event is truly the same, causing calibration with a traditional piece-wise-linear (PWL) loss model to be not fit for purpose. What a model would require is an antecedent memory, allowing for losses to be variable at the CTF regime.

Channel 'dead storage' is one mechanism which is hypothesised to solve this issue. The theory is that during the CTF regime there is a significant volume of ponded surface water (shown in Figure 1.1) that is trapped throughout the river's reach. With no additional inflow, these ponded areas begin to evaporate and seep into the alluvium below, drying out the riverbed and depleting refuge pools. When the first flush comes down the system, a proportion (if not all) of it is required to fill the dead storage, before any flows can be passed down the system. System losses will vary depending on the length and climate factors of the drying event during the CTF regime. Naturally, the hydrological representation of these processes is simplified here, where in reality, additional processes would occur, such as soil moisture depletion in the alluvium (Kim et al., 2025). Our purpose is to represent the dominating mechanism (surface water) and hence the surface water-ground water interaction is not incorporated.

The true challenge of this work is in its implementation, i.e. how to size these dead storages to represent a physical value and model losses effectively. Data is limited and can be highly uncertain (described in Section 2). This research describes how key parameters of the dead storage were selected and implemented within the Barwon-Darling Source Model.

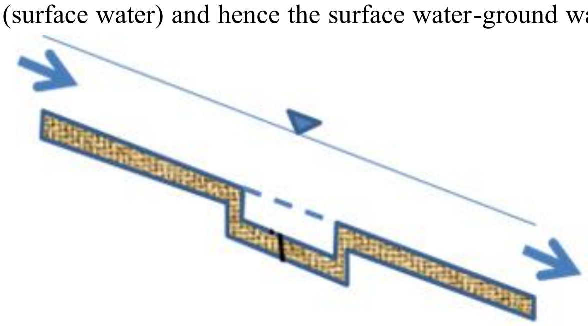


Figure 1.1 A conceptual diagram of longitudinal section of a river reach showing dead storage (eWater, 2019). When the river stops flowing, there is ponded water trapped within the river's bed, this dead storage dries out and needs to be filled by the following event before streamflow can resume.

1.1. Objective

The following three objectives have been derived from various peer reviews of the existing Barwon-Darling IQQM model.

1. Improve loss representation to incorporate antecedent conditions.
2. Improve modelled representation of low flow and cease to flow events
3. Broaden model functionality for multiple low flow objectives

2. DATA AND METHODOLOGY

2.1. Evidence of dead storage and depletion during the Tinderbox Drought

Figure 2.1 shows an aerial image of Louth (425004), the lower reaches of the Barwon-Darling Water Management Zone. The top panel shows the mapped refuge pools (red polygons) that have a persistent surface water component. The split lower panel shows a section of this river (black hatched box) during the start (left) and end (right) of the CTF event during the Tinderbox Drought. The drying of dead storage in the river is obvious in the former panel, where pools of water can be spotted in several locations. Interestingly, there appears to be a greater area of surface water present than that identified in the mapped refugia 2015 study, possibly indicating that there is additional storage which is present, however, not as deep. The lower right panels clearly highlights that sections of the river become completely dried out and for flow to resume, these dead storages are required to be filled.

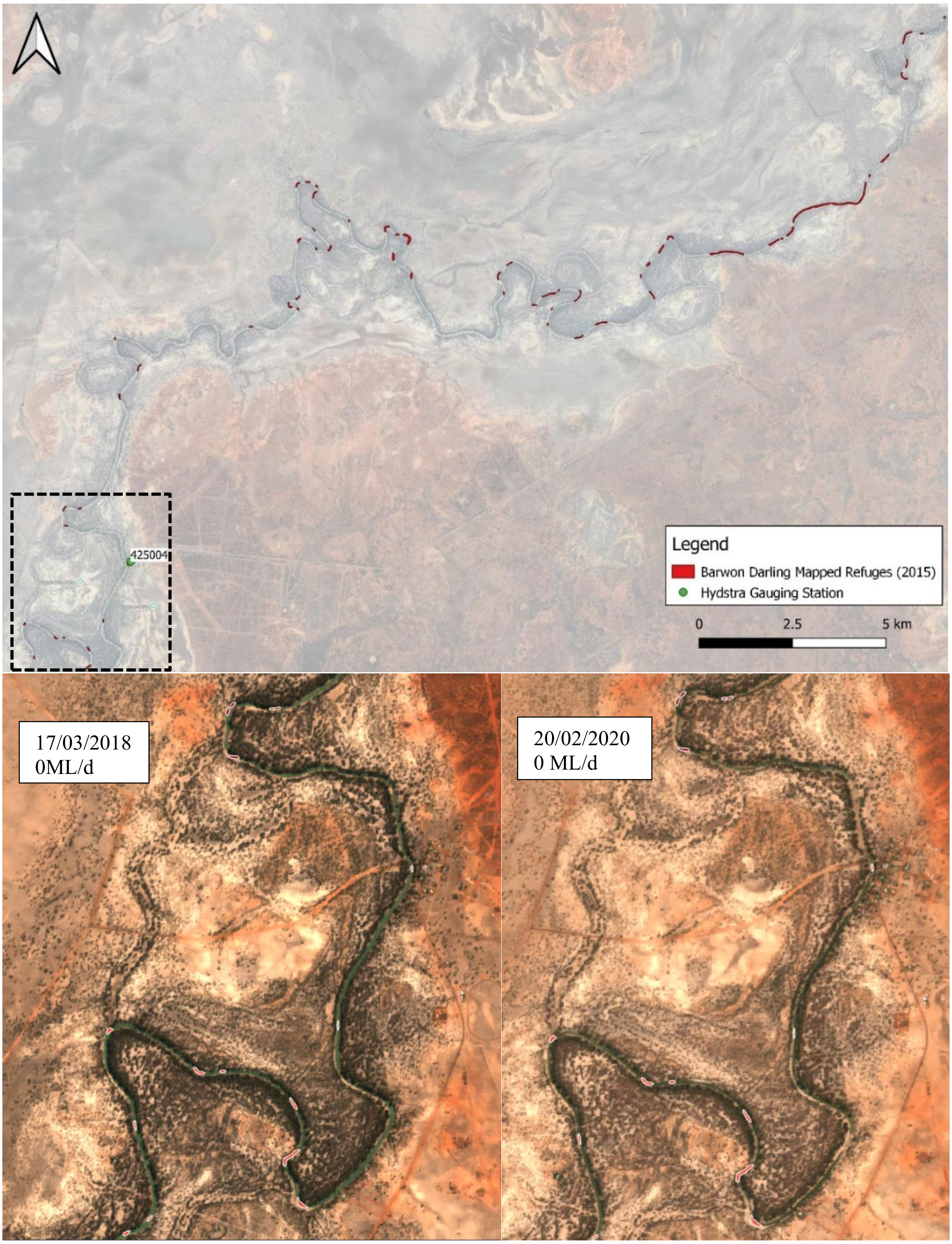


Figure 2.1. Dead Storage illustration at Louth (425004) Satellite comparing mapped refuges (red polygons) to water observations during the start (17th march 2018) and peak (18th February 2020) of the Tinderbox Drought. Dead storages are observed to dry significantly, which is notable along the straight north of Louth drying out completely and pools declining in extent. Images courtesy of Geoscience Australia from the Sentinel-2 Satellite and Google Earth imagery.

2.2. Data Review

Under no constraints the dead storage of each reach within the Barwon-Darling could be mapped through an extensive bathymetric and LIDAR study when the river is at its CTF regime. This would resultingly provide the required volumes, area and respective level-volume-area (LVA) relationships required to represent dead storage. This approach is unrealistic from several facets, including cost, timing (mapping during a CTF event for the whole river), and the fact that the river is ever evolving from a geomorphological perspective. In lieu of these constraints we must explore other data sources to inform our choice of dead storage parameters.

2.2.1. Bathymetry

Bathymetric data is the closest point of truth to estimating dead storage parameters. We have received a mapped section of refuges along the Barwon-Darling which was undertaken by Fisheries NSW in 2015. Fisheries NSW have converted Sonar data to polygons of the refuges which have an area and an average depth (depth data available Mungindi to Walgett). Whilst this data is beneficial to our work, it's limited in the fact that it is a lower bound estimate, in the sense that these refuges are well below the CTF level in a river and in reality, there is a significant area and volume of water surrounding these refuges. Figure 2.1 illustrates this, as even during the peak of the Tinderbox Drought, there is more surface water within the channel than that captured by the refuge pool extent.

2.2.2. Remote Sensing

Another key piece of data is remote sensing. There are several satellites which track various data including water observations. Digital Earth Australia (DEA) have their 'waterbodies' product which tracks changes in the wet surface area of waterbodies over time. This can be used to identify when waterbodies are increasing or decreasing in wet surface area. Along the Barwon-Darling there are several waterbodies representing the river's channel. The polygons mapped as waterbodies are based on if the cell is considered wet for at least 10% of the time, which is the case for the Barwon-Darling. The tool has a cell resolution of approximately 30m, which is its key limitation for representing dead storage, as often the river width is less than 30m especially during the CTF regime. Attempts to utilise DEA waterbodies to inform dead storage parameters has ultimately been unsuccessful due to these uncertainties in the data.

Higher resolution satellites such as Sentinel-2 (5m cell resolution) provide greater insight into these dead storage areas, however, are still limited from both a spatial and temporal resolution, with most water related observations only being available post 2020. Still as illustrated by Figures 2.1, the imagery provides a solid insight into the extent of drying of these dead storages, however, are not in a fit for purpose condition to be utilised directly in this research. We have still found the data to be beneficial in informing our research that the area of the dead storages far exceed that of what was recorded in the 2015 refuge mapping project.

2.3. Methodology

Dead storage data within the Barwon-Darling is quite limited and uncertain based on the data review undertaken (section 2.2). What we do know is that the true dead storage area lies somewhere between the extent of the DEA waterbodies and the 2015 refuge pools. The volume and respective LVA curves remaining mostly unknown, apart from the fact that it will exceed the volume represented in the 2015 mapping study. Parameter calibration is required given the constraints on data. The following steps have been identified as part of the works methodology of parameter estimation.

1. Use DEA waterbodies 'channel storage' as the identified maximum area for dead storage. Then apply a depth assumption as a first pass estimate.
2. Trial the sensitivity of different area-volume relationships on key metrics.
3. Calibrate dead storage to improve the low flow and CTF modelled results.

- Variables of **area**, **volume** and **LVA** shape. Seepage will remain a constant to follow the Department's methodology.

2.3.1. Estimated Lower and Upper Bounds of Dead Storage

Table 2.3.1. Dead Storage Parameter Estimation for the Barwon-Darling

Reach (US -DS gauge)	Lower Bound Area	Upper Bound Area	Lower Bound Volume	Upper Bound Volume[1]
1 (416001 - 416050)	1.5 Ha	79.7 Ha	41.0 ML	398.7 ML

[1] Assumed 0.5m average depth

2 (416050 - 422004)	1.9 Ha	227.1 Ha	53.1 ML	1135.4 ML
3 (422004 - 422003)	23.1 Ha	322.7 Ha	839.6 ML	1613.7 ML
4 (422003 - 422025)	7.2 Ha	302.8 Ha	231.1 ML	1514.2 ML
5 (422025 - 422001)	9.7 Ha	458.5 Ha	306.4 ML	2292.3 ML
6 (422001 - 422026)	15.0 Ha	645.8 Ha	510.2 ML	3229.2 ML
7 (422026 - 422027)	1.7 Ha	271.5 Ha	56.7 ML	1357.7 ML
8 (422027 - 422002)	34.5 Ha	588.5 Ha	1172.7 ML	2942.6 ML
9 (422002 - 422028)	14.1 Ha	710.5 Ha	479.3 ML	3552.3 ML
10 (422028 - 425039)	2.3 Ha	143.2 Ha	77.0 ML	716.0 ML
11 (425039 - 425003)	37.8 Ha	864.3 Ha	1283.1 ML	4321.3 ML
12 (425003 - 425038)	13.8 Ha	30.1 Ha	469.7 ML	150.3 ML[2]
13 (425038 - 425037)	4.3 Ha	298.6 Ha	147.1 ML	1493.1 ML
14 (425037 - 425036)	1.1 Ha	44.7 Ha	37.3 ML	223.7 ML
15 (425036 - 425035)	2.8 Ha	150.8 Ha	96.4 ML	754.2 ML
16 (425035 - 425004)	75.8 Ha	1050.7 Ha	2572.5 ML	5253.3 ML
17 (425004 - 425900)	60.8 Ha	1242.5 Ha	2064.4 ML	6212.7 ML
18 (425900 - 425008)	61.6 Ha	1610.5 Ha	2089.9 ML	8052.3 ML

3. RESULTS

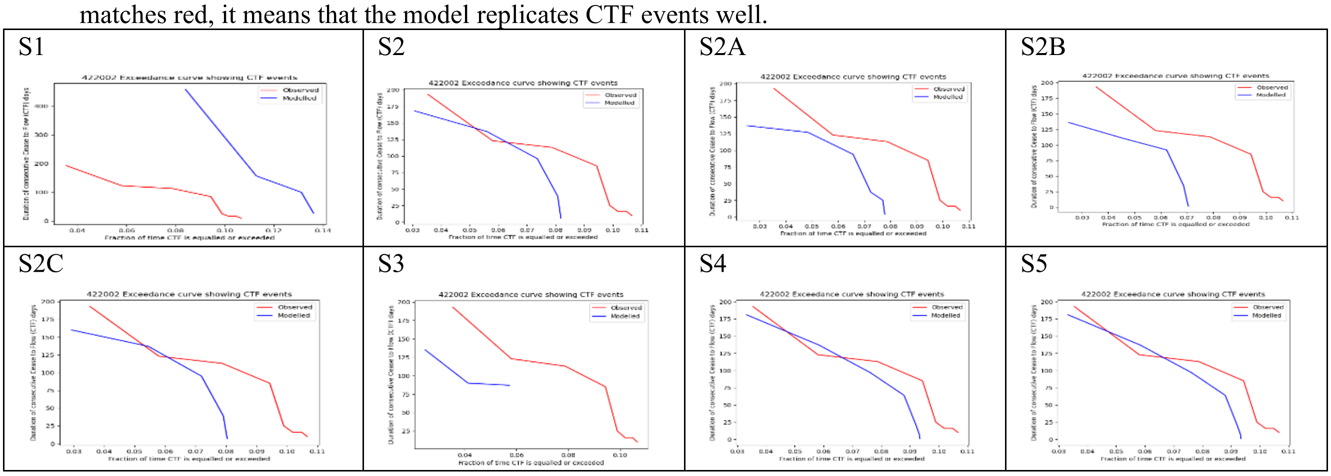
3.1. Sensitivity analysis

A sensitivity analysis was undertaken to understand how dead storage parameters influence modelled results relating to CTF behaviour. The case study looked at reach 2 (Presbury to Mogil Mogil) and reach 8 (Geera to Brewarrina) within the Barwon-Darling Source Model. We show the sensitivity results from reach 8 as it highlights the sensitivity more than what we noticed in reach 2. Table 3.1. shows that having no dead storage resulted in an under estimation of CTF events, using the full DEA area to be an overestimate and the choice of LVA to be minimally sensitive to matching observed CTF. The shape of the CTF exceedance curve could only be minimally altered by changing the ratio of area to volume. Dead storage area was found to be the key parameter which was sensitive to changing CTF metrics. Volume only becomes sensitive if the dead storage runs completely dry (which is unrealistic based on remote sensing observations). Effectively dead storage can be calibrated to match the CTF metric by altering area.

Table 3.1.1.Dead Storage Parameter Sensitivity Analysis for reach 8 (Geera to Brewarrina).

Scenario	Description	Modelled CTF (%)	CTF Bias (%)
S1	Use estimated area and volume from remote sensing and DEM analysis	13.6	27.7 (10.6)
S2	Half volume and area	8.2	-23.2 (10.6)
S2 a	Linear LVA	7.8	-27.0 (10.6)
S2 b	Exponential LVA (greater volume than area growth)	7.1	-33.9 (10.6)
S2 c	Logarithmic LVA (greater volume than area growth)	8.0	-24.6 (10.6)
S3	No dead storage	5.7	-46.3 (10.6)
S4	S2, but Increase area 20% (reducing effective depth)	8.5	-20.7 (10.6)
S5	S2, but Increase volume 20% (increasing effective depth)	9.3	-12.4 (10.6)

Figure 3.1.1. Dead Storage Parameter Sensitivity Analysis CTF Exceedance curves. Refer to Figure 3.2.1. for full description of the plot. The x-axis is exceedance and y-axis is duration of CTF event. If the blue line matches red, it means that the model replicates CTF events well.



[2] Reach 12 upper bound estimate is likely incorrect due to the depth assumption

3.2. Calibration Results

Dead Storage was calibrated by scaling down the maximum extent (from DEA waterbodies). The LVA curve was based on representative cross-section (minimal focus was placed here given the insensitivity of the LVA shape parameter). This work has generated additional statistics for matching CTF behaviour, the CTF exceedance curve (Figure 3.2.1) and the CTF Annual Bar chart (Figure 3.2.2). The plots show how well the model matched the frequency and duration of CTF events. Figure 3.2.3 shows the part of Department's Model report card, which displays various model performance metrics. Figure 3.2.3. shows that the low flow and percent of events where streamflow less than 1ML/d (effectively CTF) were able to be matched near perfectly, the flow exceedance curves also match very well. Figure 3.2.2. shows that the model generally represents CTF conditions well on an annual scale, however, may not always get the timing of these events perfectly. Finally, Figure 3.2.1 shows that the model matched the CTF exceedance well (shown by the right tails aligning) and matched the longest CTF spell extremely well, however, the model generally fell short in matching the frequency of longer CTF events (shown by there being a slight divergence between the red and blue lines).

Reach 2

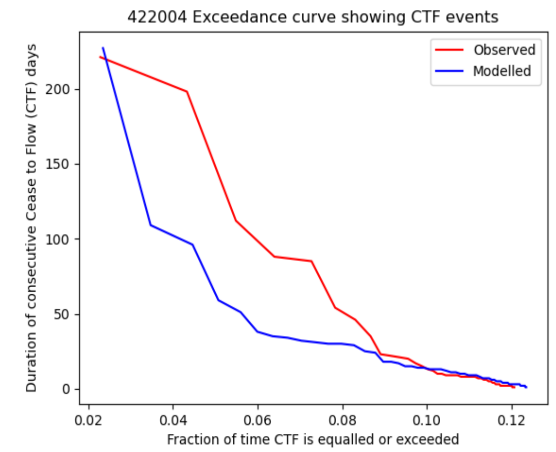


Figure 3.2.1a. Reach 2 CTF Exceedance Curve Plot

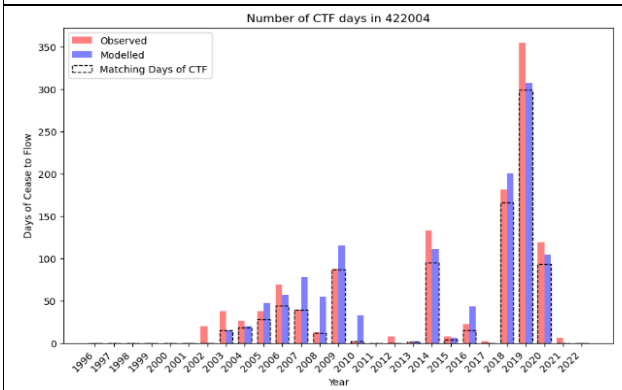
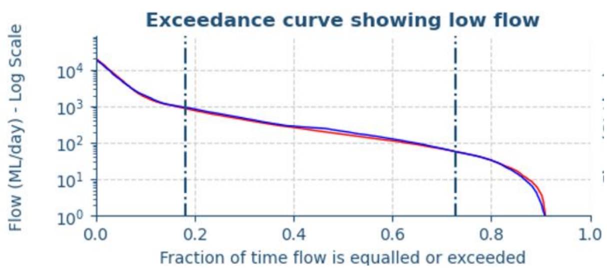


Figure 3.2.2a. Reach 2 Annual CTF bar chart



Reach 8

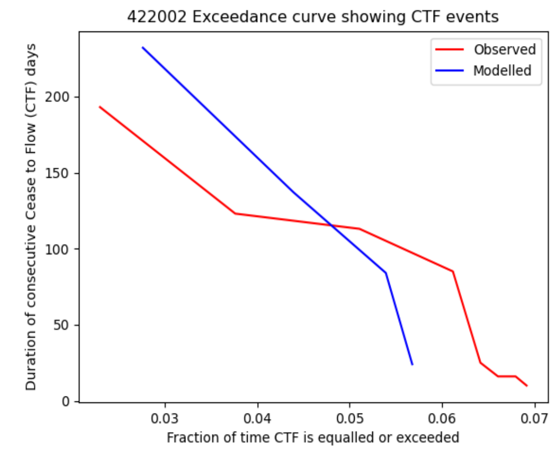


Figure 3.2.1b. Reach 8 CTF Exceedance Curve Plot (5ML/d filter due to gauging uncertainty)

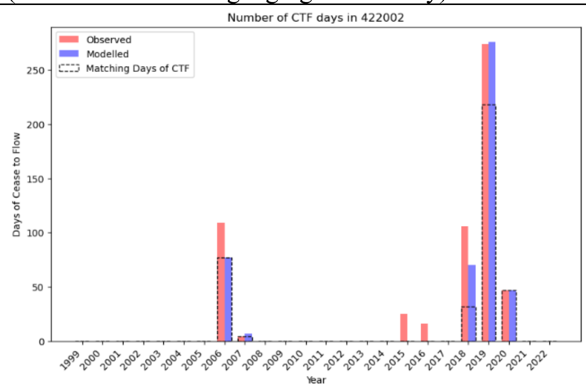
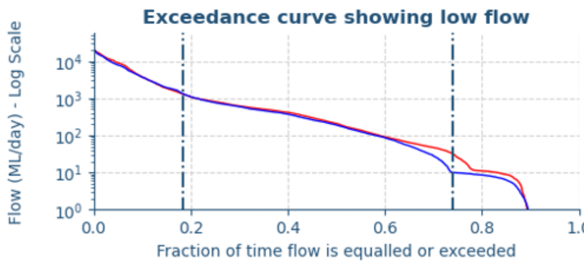


Figure 3.2.2b. Reach 8 Annual CTF bar chart



Univariate Statistic	Observed	Modelled	Bias (%)
Mean Flow (ML/day)	989.9	989.4	-0.1
Mean Flow in Low Range (ML/day)	18.8	18.5	-1.7
Mean Flow in Middle Flow Range (ML/day)	279.3	309.6	10.9
Mean Flow in High Flow Range (ML/day)	4575.3	4481.6	-2.0
Driest 3 Year Mean (ML/d)	269.0	254.2	-5.5
Wettest 3 Year Mean (ML/d)	2720.9	5689.1	109.1
% of Days less than 1 ML/day	9.0	8.9	-1.3
Standard Deviation (ML/day)	2700.0	2618.7	-3.0

Bivarite Statistic	Value
Nash-Sutcliffe Efficiency (NSE)	0.9

Figure 3.2.3a. Log Flow Exceedance and Key Statistics

Univariate Statistic	Observed	Modelled	Bias (%)
Mean Flow (ML/day)	1364.9	1284.0	-5.9
Mean Flow in Low Range (ML/day)	7.1	4.3	-39.1
Mean Flow in Middle Flow Range (ML/day)	366.4	342.7	-6.5
Mean Flow in High Flow Range (ML/day)	6265.4	5902.9	-5.8
Driest 3 Year Mean (ML/d)	300.1	293.7	-2.1
Wettest 3 Year Mean (ML/d)	3989.7	7978.1	100.0
% of Days less than 1 ML/day	10.7	10.5	-1.7
Standard Deviation (ML/day)	3170.1	2990.9	-5.7

Bivarite Statistic	Value
Nash-Sutcliffe Efficiency (NSE)	0.96

Figure 3.2.3b. Log Flow Exceedance and Key Statistics.

4. DISCUSSION AND CONCLUSION

Does dead storage improve modelled results? Dead storage improves model performance in the key metrics of matching CTF days, low flow bias and resumption of flow. This case study showed that when using dead storage in a Source model, the length of CTF can be matched, the mean flow in the low range is within 2% of observations and the intensity of CTF events are replicated to a good extent (i.e., being able to represent average annual behaviour and fluctuations). When compared to a base case (without dead storage), these improvements demonstrate that dead storage does improve model results.

Creating a more robust model? By implementing channel dead storage, the Source Model has an antecedent memory creating variable system losses. When compared to a traditional PWL relationship this allows for there to be a better fit across various CTF events and will likely result in an improved representation of more severe (longer and drier) CTF events as there is capacity for the model to further draw down on dead storage. Overall, with losses being driven by climatic factors instead of being purely calibrated, the Barwon-Darling Source Model is more robust than its counterparts to both historic and future extreme climates when accessing the low flow and CTF regime.

5. CONCLUSION

River system models play a critical role in the development of policy for water management. The Barwon-Darling Source Model is currently being developed and has implemented channel dead storage to improve the representation of the low flow and cease-to-flow regime. This work found that dead storage improves model performance significantly at the low flow and CTF regime, allows for the removal of static piece wise linear loss nodes, hence introducing an antecedent memory to the model. Parameter choice was a key challenge in this work, with there being a significant limitation in available data to directly inform dead storage parameters. It was determined that parameter calibration is required, however, initial estimates can be informed by bounds from remote sensing and bathymetric data.

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