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Understanding risks of hypoxic blackwater and low dissolved oxygen events under climate change

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Acknowledgments

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The authors pay respect to the Traditional Owners and their Nations of the Murray−Darling Basin. We acknowledge their deep cultural, social, environmental, spiritual and economic connection to their lands and waters.

Executive summary

Climate change projections indicate that the Murray-Darling Basin will become warmer, and rainfall is likely to decline. The impacts on the hydrological regime of climate change will include lower mean annual runoff, fewer high flow days and longer periods of low flow. The hydrological regime influences water quality in the MDB and therefore climate change is expected to impact water quality outcomes. This study investigates the consequences of climate change for the hydrological conditions that lead to hypoxic blackwater and low dissolved oxygen events. Using simulated streamflow at more than 150 stream gauges from across the Basin, the historical and future frequency and duration of (a) low-flow, high-temperature events that are related to low levels of dissolved oxygen in water ways and (b) to floodplain inundation events related to hypoxic blackwater is assessed.

We find that the frequency and duration of low-flow, high-temperature events are expected to increase by between 50% and 200% under the projected future climates, suggesting that number and duration low dissolved oxygen events are likely to increase. The increases in frequency and duration of these events occurs across the MDB but are likely to be most evident in the northern parts of the Basin where the historical frequency of events is highest. We also find that the period between flows that inundate floodplains, here specified as the 99th percentile historical streamflow, increases under future drier climates and hence the frequency of floodplain inundation will decrease. The consequence of this finding for blackwater events is that while there is expected to be fewer future floodplain inundation events, when they do occur it is expected the chance of a blackwater event occurring when the floodplain is inundated there will be greater as a longer inter-event period will lead to a greater accumulation of organic matter on the floodplain. Geographically, the regions where the risk are likely to increase the most are in the lower reaches of the MBD where flows are highly regulated and the frequency of flow exceeding the 99th percentile historical streamflow tend to be low.

Our results indicate that under future climates, the risk of water quality events related to hypoxic blackwater, and low dissolved oxygen levels is likely to be higher. Management interventions can mitigate these risks to some extent, both locally and at a river system scale. Therefore, the adaptation of water management plans to consider climate change should reflect impacts on water quality as well as water quantity.

1 Introduction

Climate change projections indicate that the Murray-Darling Basin (MDB) is almost certain to get warmer and likely to get drier. The direct impacts of these climate changes on runoff characteristics have been assessed showing that mean annual runoff is expected to decrease (Chiew et al., 2018; Chiew et al., 2022; Zheng et al., 2024) and as a result less water will be available to all users in the future. It is also expected that the frequency of high flow events will reduce and the duration of drought and low flow events will increase (Zheng et al., 2024).

Climate change and the consequent changes to runoff characteristics in the Basin are also likely to impact on water quality (Baldwin, 2021). There are numerous water quality issues within the Basin that are likely to be impacted by climate change including the levels of salinity, dissolved oxygen, nutrients and sediment in the Basin's water ways (Baldwin, 2021). Water quality issues are not observable for much of the time, but tend to become apparent during acute events, such as algal blooms, blackwater events and fish deaths. Acute water quality related events often precipitated by multiple conditions to occurring simultaneously, for example algal blooms require an initial algal population, an abundant nutrient supply and hydrologic conditions, including flow velocity and water temperatures.

In many instances, the impacts of acute water quality related events can be mitigated through active management. For example, regulated releases of water from dams can increase dissolved oxygen concentrations, dilute high river salinities, or increase streamflow sufficiently to break up algal blooms. More local interventions, such as installing aerators or adding chemical ameliorants (Baldwin, 2021), can also be used to mitigate the impacts of acute water quality events. These management interventions all require resources, either water or financial resources. Therefore, it is important to understand how the occurrence of acute water quality related events may change in the future to better understand the need for management intervention and hence water and financial resources to support mitigation activities.

Predicting the severity and duration of acute water quality events is highly challenging. Modelling methods used to predict water quality tend to simulate bio-geo-chemical processes that are formulated to require datasets that are collected either sparsely on a routine basis (e.g. water temperature and dissolved oxygen concentrations) or only intermittently (e.g. floodplain litter loads) to support their parameterisation and initialisation (Whitworth and Baldwin, 2016; Whitworth et al., 2012). Therefore, using these modelling methods for understanding the frequency and severity of events under future climate across the Basin will require either the collection of comprehensive datasets for the entire Basin, or future projections will contain very large uncertainties. An alternative strategy to understand the impacts of future climate change on the water quality events is to characterise the conditions conducive to water quality events and assess the how the frequency and severity of these conditions are likely to change.

In this report, we summarise an investigation into the likely impacts of future climate change on blackwater and low dissolved oxygen events in the MDB. We assess the historical frequency and duration of conditions that are conducive to both blackwater and low dissolved oxygen events and assess the extent to which these change under projected future climates.

2 Methods

We assess changes in the hydrological factors that influence low dissolved oxygen and blackwater events under a changing climate using streamflow simulations generated by the Integrated River System Modelling Framework (IRSMF) and SILO temperature analysis. We first introduce the streamflow and climate data used for the analysis and then describe the analysis methods.

2.1 Data

For the IRSMF simulations we use historical and projected future streamflow simulations generated as a part of the Outlook Modelling investigation (Gao et al., 2023). Simulations used in the analysis represent the fully implemented Basin Plan under four climate scenarios: Historical, “Warmer and wetter” (termed Future Wet in this report), “Hotter and drier” (Future Mid) and “Much hotter and much drier” (Future Dry). IRSMF simulations for the three future climate scenarios were generated by scaling climate and inflow forcing data using change factors, that broadly represent the range and midpoint of possible future climate changes in the MDB at 2060 (Table 1). Details on the methods to generated the scaling factors are contained in Gao et al. (2023).

Table 1 Summary of change factors for the three future climate scenarios. Change factors for temperature are additive, while all other variables are multipliers to be applied to the historical timeseries.

Variable	Region	Scenario		
		Warmer and wetter	Hotter and drier	Much hotter and much drier
Rainfall	Northern MDB	1.12	0.97	0.89
	Southern MDB	1.05	0.97	0.88
Temperature	Northern MDB	2.1	2.9	3.9
	Southern MDB	1.9	2.6	3.4
PET	Northern MDB	1.05	1.07	1.11
	Southern MDB	1.05	1.07	1.11
Runoff	Northern MDB	1.35	0.86	0.66
	Southern MDB	1.03	0.78	0.61

Daily simulated streamflow data were extracted for 154 stream gauge locations for analysis. The locations of the sites used in the analysis and properties of streamflow simulations are presented in Figure 1.

Daily timeseries of maximum temperature were extracted for each of the 154 stream gauge locations from the gridded SILO climate analysis (Jeffrey et al., 2001). To illustrate the variability of daily maximum temperature we plot the average number of days the maximum temperature exceeds 35° C (Figure 2).

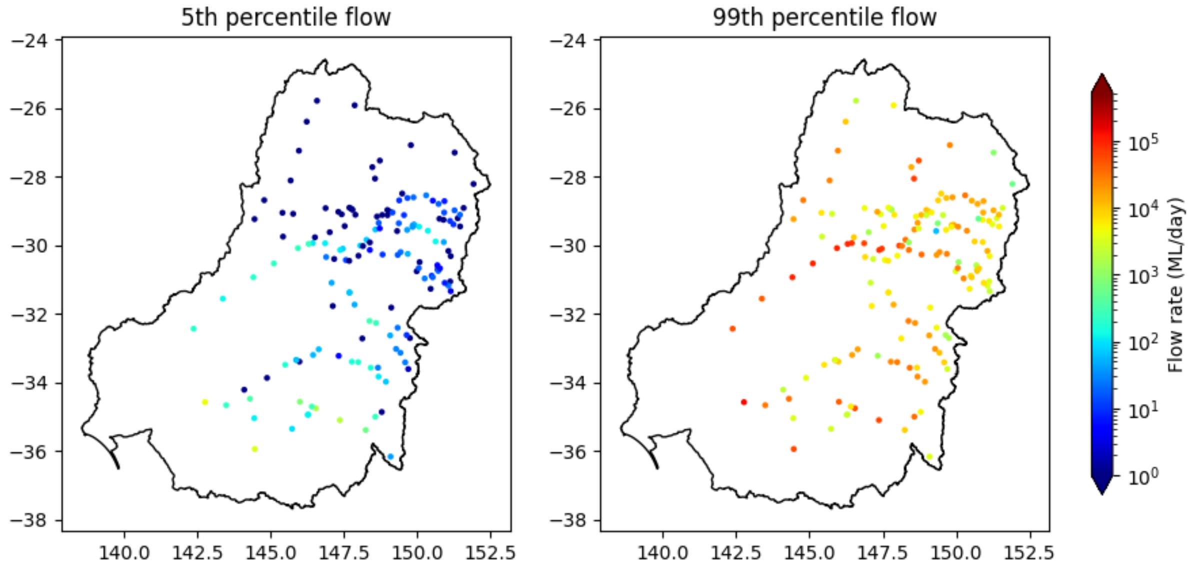

Figure 1 Stream gauges used in the for analysis showing the historical 5th (left) and 95th (right) percentile streamflow.

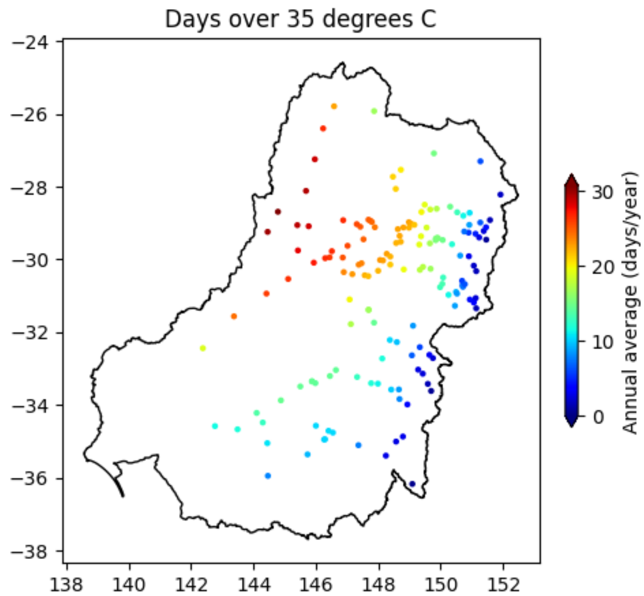

Figure 2 Summary of daily maximum temperatures at the stream gauges used in the analysis.

2.2 Analysis

2.2.1 Risk of hypoxic blackwater events

The occurrence of hypoxic blackwater events is precipitated by large quantities of organic material entering rivers from the floodplain. The organic material releases tannins, dissolved organic carbon, and nutrients causing water to take on a black appearance. Microorganisms subsequently metabolise the organic carbon and, in the process, consume oxygen from the water column. If the rate of oxygen consumption by microorganisms outstrips the rate of oxygen replenishment, then hypoxic (low oxygen) conditions can occur. Reoxygenation of hypoxic water is promoted by turbulent water movement, encouraged by water flow and wind, and also the release of oxygen from aquatic plants, so stagnant and slow flowing water is more susceptible to hypoxic conditions (Baldwin, 2021; Whitworth and Baldwin, 2016). Hypoxic conditions can lead to the death of native aquatic life that are sensitive to low oxygen levels and enable more tolerant alien species to succeed.

The level of oxygen in a water column is strongly influenced by temperature. The oxygen holding capacity of water decreases with increasing water temperature. Microbial metabolism is also accelerated by higher temperatures, which can increase the rate of oxygen consumption. The combination of these factors will mean that higher water temperatures are likely to result in hypoxic conditions occurring more rapidly.

The severity of hypoxic blackwater events will also be dependent on the supply of organic matter. Organic matter enters streams when high streamflow events inundate floodplains. The amount of material that can enter a stream is dependent on the amount accumulated on the floodplain. Organic material progressively accumulates on floodplains between flood events. Longer durations between flood events therefore result in greater organic material accumulation and the greater potential for hypoxic blackwater events following a subsequent flood.

Climate change projections indicated that increases in temperature are virtually certain across the Murray-Darling Basin. Therefore, the temperature related risks to future blackwater events are unlikely to be limiting. Rather, we assume that the supply of organic matter into the river network is more likely to limiting and analyse the duration between flood inundation events as an indicator of organic matter accumulation, and hence potential supply to water ways during flood events.

Using the river system model output we define a flow threshold for each gauge which is assumed to be related to the inundation of the floodplain. The actual flow threshold that leads to inundation of the floodplain is not known for all gauges analysed and therefore we adopt the 99th percentile daily flow. We assume when streamflow exceeds the 99th percentile daily flow organic matter on the floodplain will be transported into waterways and then reset the accumulation of floodplain organic matter. Therefore, the amount of organic matter accumulated on the floodplain can be characterised by the duration of periods between streamflow events that are greater than or equal to the 99th percentile daily flow.

We undertake a spell analysis for periods between the simulated streamflow exceeding the 99th percentile. Using the spell analysis, we assess the number and duration of periods between flow exceeding the 99th percentile as a measure of the potential frequency and severity of blackwater events. Longer periods between 99th percentile streamflow events will allow greater amounts of organic matter to accumulate on the floodplain, leading to a greater likelihood of a blackwater event occurring when an inundation flow (exceeding the 99th percentile) subsequently occurs.

Using the river system model output under the historical and future climate conditions we summarise changes in the mean duration between 99th percentile streamflow events and the number of events where the duration exceeds 1, 5 and 10 years.

2.2.2 Risk of low dissolved oxygen events

Low dissolved oxygen events are not necessarily related to flooding but occur when river flow is slow and temperature is high. We undertake a spell analysis of the joint occurrence of low flow and high temperature and assess changes in key summary statistics.

We adopt the 5th percentile daily flow as an indicator of slow flow conditions. A flow velocity criterion would be a preferable indicator of slow flow conditions, however only a very small number of the gauges used for analysis had the necessary combination of rating tables and cross-sections required to estimate the average flow velocity from available streamflow data.

Riverine water temperatures are only sparsely monitored across the MDB (Joehnk et al., 2020). While models are available to relate air temperature and flow data to riverine water temperatures, insufficient data were available to adequately calibrate them. Therefore, we assumed that high water temperature conditions could be approximated from maximum daily air temperatures. For the results presented in this report we used a maximum daily air temperature exceeding 35°C as the threshold for high temperature conditions for all analysis gauges. However, we also assessed the sensitivity of results to higher thresholds (40°C and 45°C) finding broadly similar results.

Using the river system model output under the historical and future climate conditions we summarise changes in the mean duration events where flow was less than the historical 5th percentile and temperatures were greater than 35°C and the average annual frequency of events exceeding 1 and, 5 days duration.

3 Results

We firstly demonstrate the analysis undertaken for a single stream gauge and then summarise results for 154 gauges across the MDB.

3.1 Demonstration of analysis

We demonstrate the analysis approach for gauge 422203A: Balonne River at Barrackdale. Figure 3 depicts time series of maximum daily temperature and simulated daily streamflow. The colouring of the points in Figure 3 illustrates analysis of the joint occurrence of temperature exceeding 35 degrees and streamflow being lower than the 5th percentile. The maximum temperature data show a strong seasonal cycle, with many days exceeding 35 degrees each year. In contrast, the simulated streamflow time series shows that there are long periods when streamflow remains above the 5th percentile, and that seasonal patterns are relatively weak. The dark blue points, showing the days of low flow and high temperature when streamflow is lower than the 5th percentile and temperatures exceed 35 degrees C.

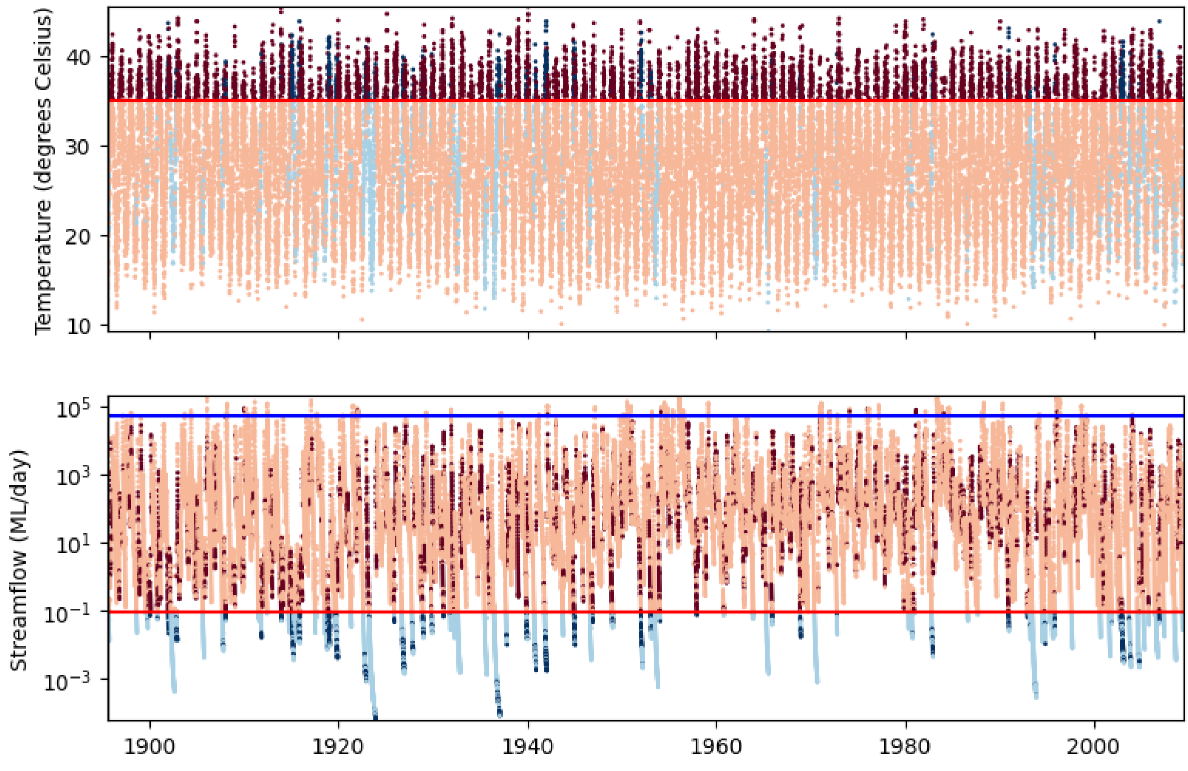

Figure 3 Timeseries of historical maximum daily air temperature and simulation streamflow for gauge 422203A. Blue colours are the days where streamflow is lower than the 5th percentile and red colours are days where streamflow exceeds the 5th percentile. Dark colours are days when the temperature exceeds 35°C, while pale colours are days when temperatures are lower than 35°C. The horizontal red lines shows the temperature and flow thresholds for analysis of hot and low flow conditions while the horizontal blue line shows the 99th percentile streamflow.

Figure 4 shows an alternative view of the same data, just showing the days when streamflow and temperature thresholds are exceeded. The seasonal cycle of temperature is more evident with no days exceeding 35 degrees between mid-April (day of year = 110) and early September (day of year = 250). In contrast, there are many years where extended periods of low flow occur between April and September. In the 114-year simulation record, there is a total of 364 low flow and high temperature days (Table 2) many of the occurring as multi-day events.

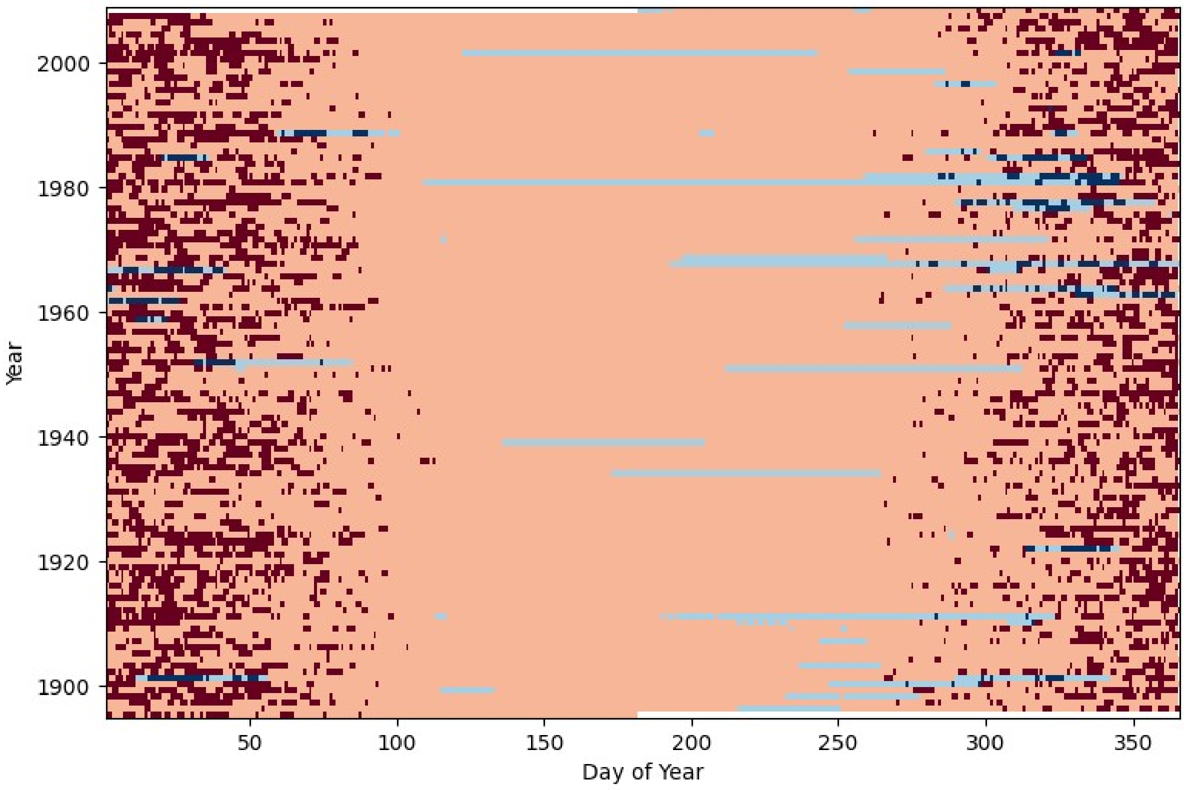

Figure 4 Spell analysis of historical air temperature exceeding 35°C and streamflow exceeds the 5th percentile daily streamflow. Colour scheme is identical to that shown in Figure 1.

Table 2 Summary of the number of days in the historical time series where flow falls below the low flow threshold and temperature exceeds 35 °C

		Flow		
		> 5th percentile	<= 5th percentile	All
Air Temperature	<35 °C	33850	1718	35568
	≥35 °C	5706	364	6070
	All	39556	2082	41638

The risk of low dissolved oxygen events increases with the duration of low-flow, high-temperature events. We therefore assess the distribution of low-flow, high-temperature events durations (Figure 5) for historical and future climate scenarios. Under the historical climate scenario there are a total of 96 low-flow, high-temperature events in the simulation record, which is equivalent to events occurring in approximately 4 out of 5 years on average (Table 3). Of these low-flow, high-temperature events 27 exceed 5 days in length, or on average one event every 4 years. The average duration of low-flow, high-temperature events close to 4 days.

Under all the future climate scenarios, the total number of low-flow, high-temperature events increases in the simulation record and the duration of events also increases. The increases in the number of events and duration are greater for drier future climate scenarios than wetter scenarios. The frequency of any event increases such that on average there is at least one event per year, and the average frequency of an event exceeding 5 days in length nearly doubles to an average of one event every 2 years under the future dry scenario. The mean event length increases by between 20% and 55% with average duration under the Future Mid scenario being slightly longer than 5 days.

These results indicate that the conditions conducive to the occurrence of low dissolved oxygen conditions will become more frequent under future climates and, when they do occur, persist for longer periods.

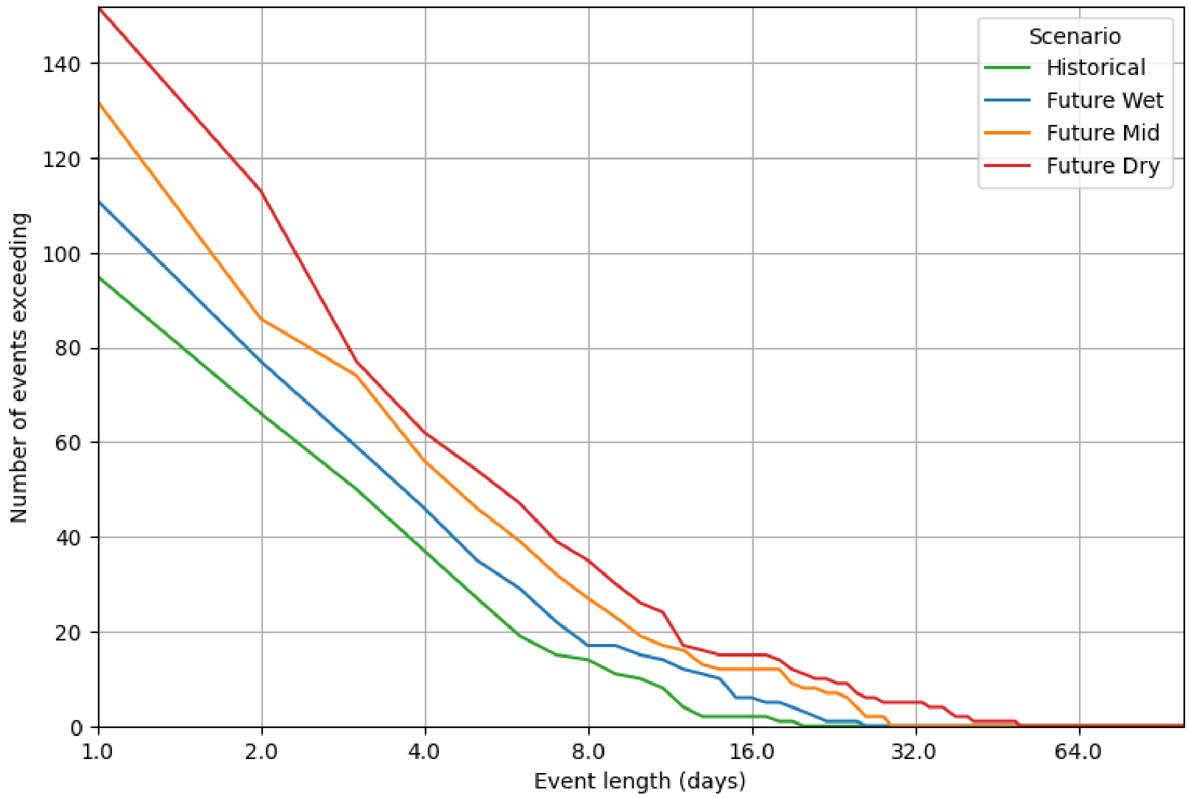

Figure 5 Frequency of the length of low-flow, high-temperature events under historical and future climate scenarios for gauge 422203A.

Table 3 Summary statistics for the length and frequency of low flow and high temperature events under historical and future climate scenarios for gauge 422203A.

Climate scenario	Mean event length (days)	Frequency of 1-day event occurrence (events per year)	Frequency of 5-day event occurrence (events per year)
Historical	3.87	0.83	0.23
Future Wet	4.59	0.97	0.31
Future Mid	5.26	1.16	0.40
Future Dry	5.96	1.33	0.47

The risk of blackwater events is assumed to be related to the accumulation of organic matter on the floodplain. We use the length of spells between 99th percentile flow events as a measure for the duration over which organic matter accumulates on the floodplain and the frequency distribution of spell lengths is analysed under historic and future climates (Figure 6). The length of spells between 99th percentile flow events is highly variable, extending from a few days to many years. For the simulation generated using the historical climate scenario, there are 30 spells that exceed one year, 7 that exceed 5 years and only one that exceeds 10 years, with a mean spell length of 1.6 years (Table 4).

Under the future climate scenarios, changes in the distribution of spell lengths follow the changes in the runoff characteristics relative to the historical climate scenario. The Future Wet scenario, where the runoff scaling factor is greater than 1.0, produces more shorter (<2 year) spells and fewer longer (>2-year spells) that the historical climate scenario. The Future Mid and Future Dry scenarios, that have runoff scaling factors less than 1.0, have fewer spells that are less than 3 years and more spells that are longer than 6 years than the historical climate scenarios, with similar numbers of spells in the range of 3-6 years. The mean length of the spell between 99th percentile flow events decreases slightly under the Future Wet scenario, but nearly doubles under the Future Dry scenario.

These results indicate that at this stream gauge, under a drying climate, there will an increasing number of long spells between flow events that potentially inundate the floodplain. This means that there are likely to be fewer occasions when the floodplain is inundated, however, when it is inundated, there will be greater chance of sufficient organic matter to have accumulated for a blackwater event to occur.

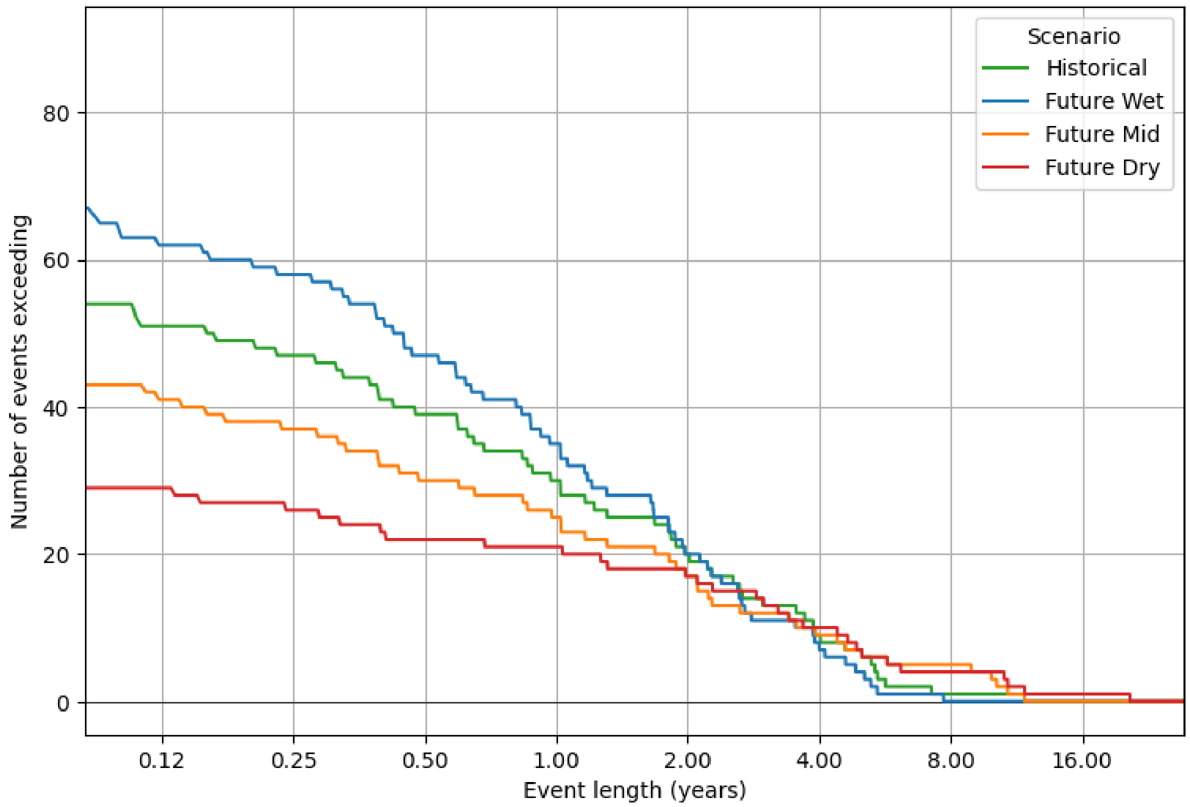

Figure 6 Frequency of the length of spells between 99th percentile flow events under historical and future climate scenarios for gauge 422203A.

Table 4 Summary statistics for the length of spells between 99th percentile flow events under historical and future climate scenarios for gauge 422203A.

Climate scenario	Mean event length (years)	Number of 1-year events in simulation	Number of 5-year events in simulation	Number of 10-year events in simulation
Historical	1.63	30	7	1
Future Wet	1.23	35	4	0
Future Mid	2.21	25	7	3
Future Dry	3.24	21	7	4

3.2 Basin-wide of risk of low dissolved oxygen events

The frequency of low-flow, high-temperature events varies across the Basin (Figure 7, Figure 9). Under the historical climate scenario, low-flow, high-temperature events occur most frequently in the northern MDB, reaching up to an average of 14 events per year that persist for more than one day and an average of 4 events per year that persist for more than 5 days. The average number of days above 35° C is the highest in the northern MDB (Figure 2), which is partially driving the greater numbers of low-flow, high-temperature events than the remainder of the Basin.

Under future climates, the frequency of low-flow, high-temperature events is generally projected to increase across the Basin, particularly under the Future Mid and Future Dry scenarios (Figure 8, Figure 10). Increases in the frequency of low-flow, high-temperature events are greatest in the northern MDB. The average number of events that persist for one or more days increases by up to 4.5 events per year, while the events that persist for 5 or more days increases by up to 3.5 events per year. Under the Future Wet scenario there are a small number of gauges where the frequency of low-flow, high-temperature events decreases, but these decreases are very small compared to the increases across the majority of gauges. These results suggest that the frequency of low dissolved oxygen events is likely to increase in the future over large parts of the Basin, particularly in the northern MDB.

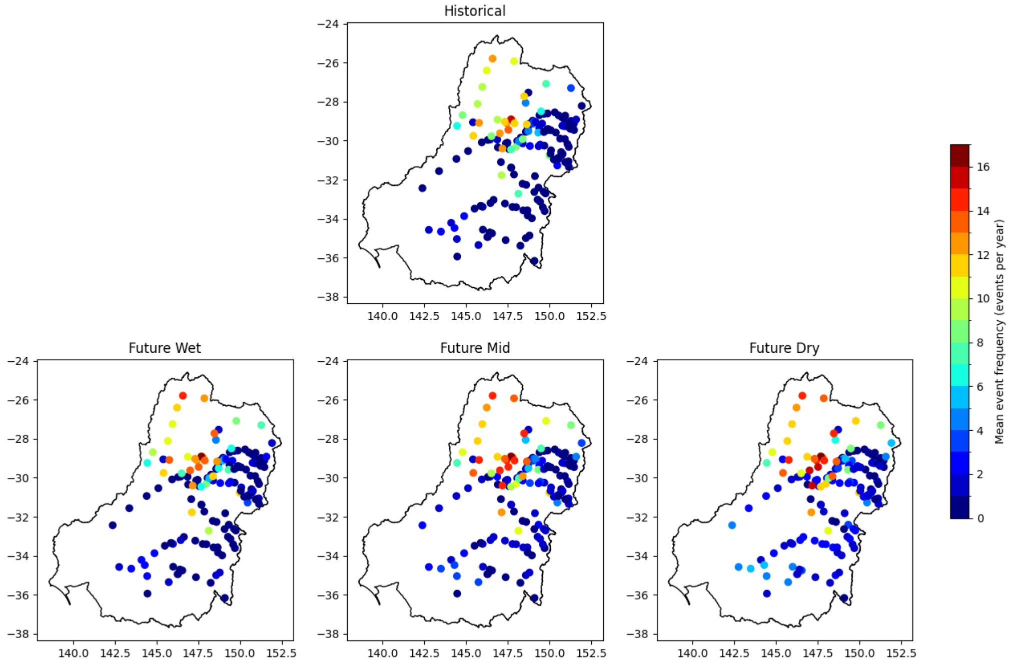

Figure 7 Annual frequency of low-flow, high temperature events of at least one day in length under historical and future climates.

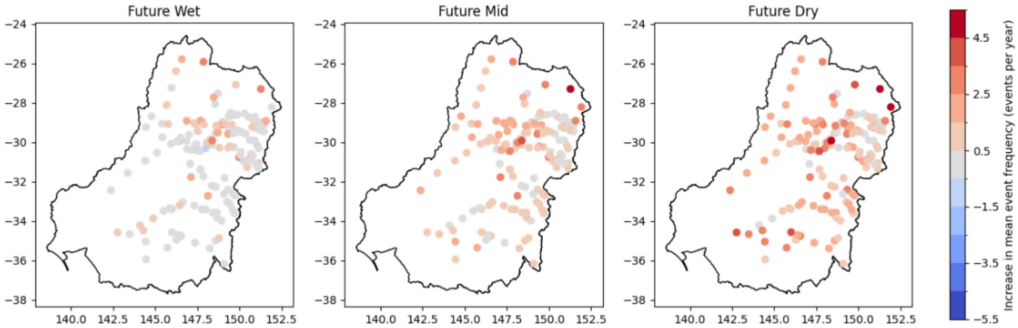

Figure 8 Projected change in average annual frequency of low-flow, high temperature events of at least one day in length.

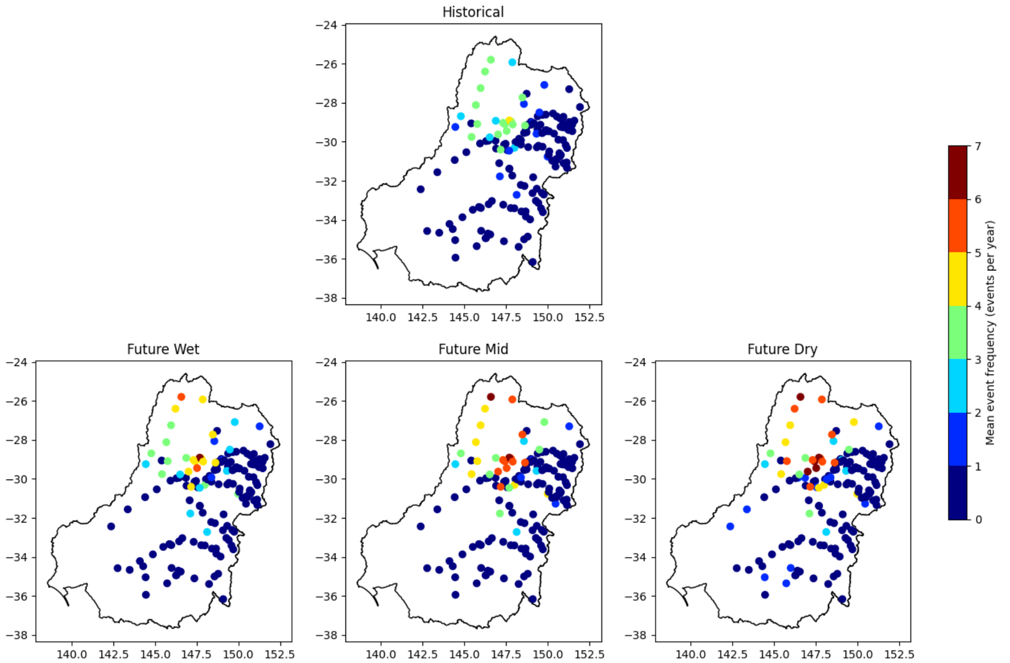

Figure 9 Average annual frequency of low-flow, high temperature events of at least five days in length under historical and future climates.

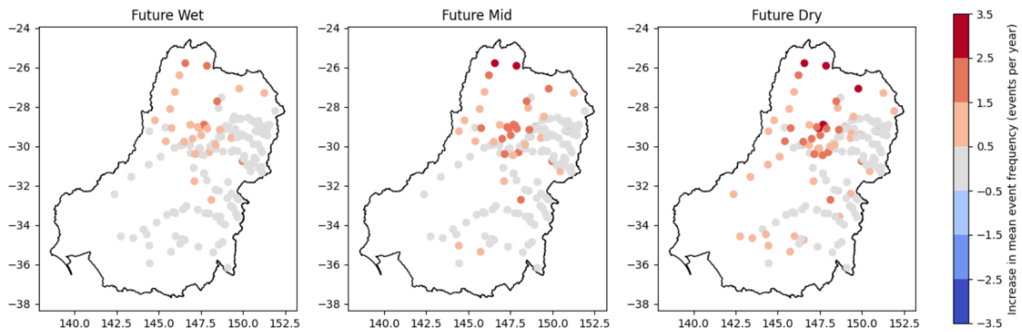

Figure 10 Projected change in average annual frequency of low-flow, high temperature events of at least five days in length.

The average duration of low-flow, high-temperature events is also variable across the Basin under the historical and future climate scenarios. Under the historical climate scenario, the mean event duration exceeds four days in the northern MDB but tends to be less than 2 days for much of the southern and eastern Basin (Figure 11). The average duration of the low-flow, high-temperature events is projected to increase under all future climate scenarios for most gauges (Figure 12). Under the Future Wet scenario, increases in the average duration of low-flow, high-temperature events tend to occur primarily in the north of the Basin, while under the Future Dry scenario increases in the average duration tend to be distributed across the Basin. These results indicate that when conditions for low dissolved oxygen do occur then the events are likely to be longer and under the Future Mid scenario the durations are approximately 50% longer that the historical climate scenario.

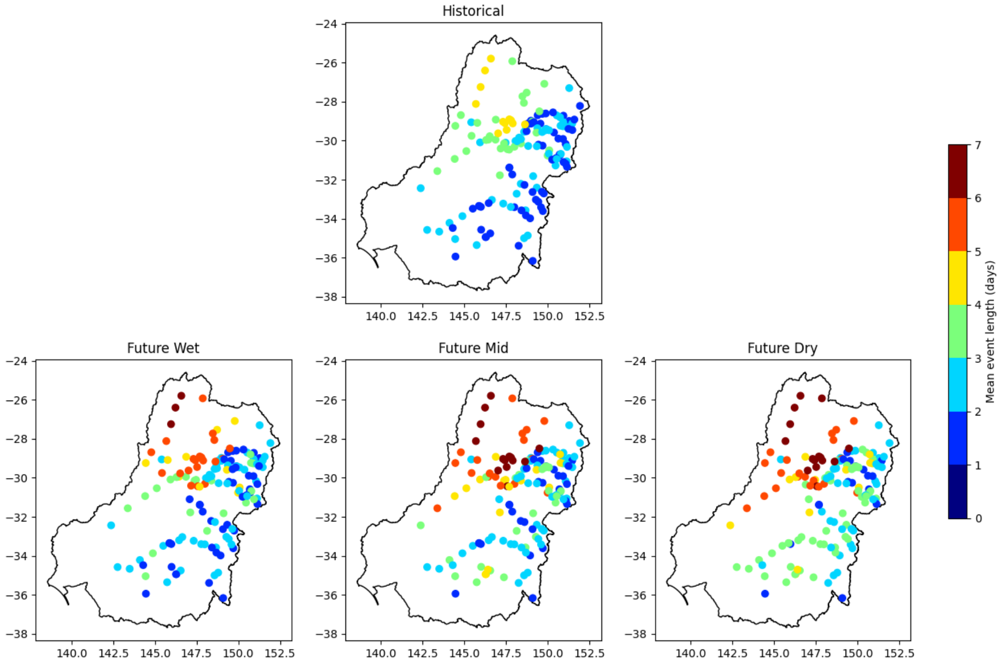

Figure 11 Average duration of low-flow, high-temperature events under historical and future climate conditions.

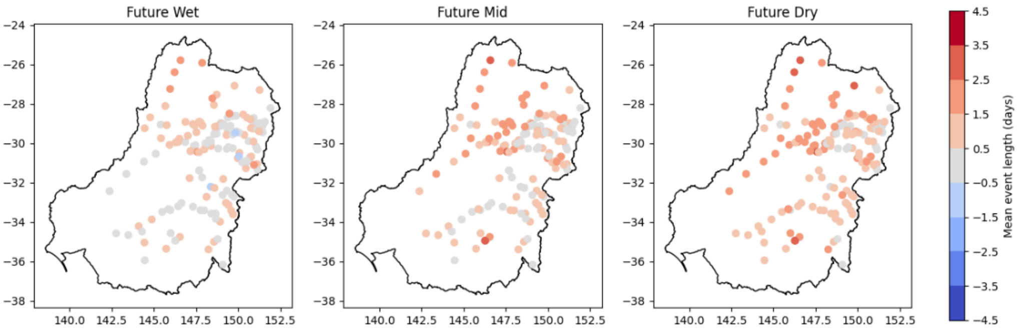

Figure 12 Projected change in average duration of low-flow, high temperature events.

3.3 Basin-wide risk of Blackwater events

The average number of years between events exceeding the 99^{th} percentile daily flow tends to be larger in the southern MDB and particularly for gauges with larger catchment areas and are more heavily influenced by river regulation (Figure 13). Under the historical climate, the average number of years between events exceeding the 99^{th} percentile daily flow for gauges in the lower reaches of the Basin is greater than 8-10 years suggesting that there currently substantial periods of time for organic matter to accumulate on floodplains. However, in the upper reaches of the basin, on average there is an event that exceeds the 99^{th} percentile daily flow every 1-2 years which means that there is little time for organic matter to accumulate on floodplains.

Under the future climate scenarios, the spatial patterns in the average number of years between 99^{th} percentile streamflow events remain similar to the historical spatial patterns (Figure 13), with longer periods between events in the lower reaches of the Basin. Changes in the average number of years between 99^{th} percentile streamflow events are broadly aligned with the corresponding inflow scaling factors (Figure 14). The Future Wet scenario produces little change in the average number of years between 99^{th} percentile daily flow events for most stream gauges and small reductions at gauges along the Darling River. The Future Mid and Future Dry scenarios produce increases in the average number of years between 99^{th} percentile daily flow events. These results suggest that the hydrological conditions leading to blackwater events are likely to occur less frequently, that is periods between events that inundate floodplains become longer. The direct consequence of less frequent floodplain inundation is that it means that the period for organic matter to accumulate on the floodplain will be longer and as a result, when floodplains are inundated, there will be a greater chance of there being sufficient organic matter to induce blackwater events.

Under the Future Dry scenario our results show there are a small number of stream gauges in the lower reaches of the Basin where fewer than 2 events exceed the 99^{th} percentile daily flow in the simulated record, and the average inter-event period is greater than 32 years. With so few events in the simulated record, the sequence of wet and dry periods will have an impact on frequency of events and therefore the numbers need to be treated with caution. However, the broad implication is that under a much drier future climate there will be many fewer events that inundate floodplains in the regulated parts of the Basin and therefore when floodplains are inundated there will be a greater chance of blackwater events occurring.

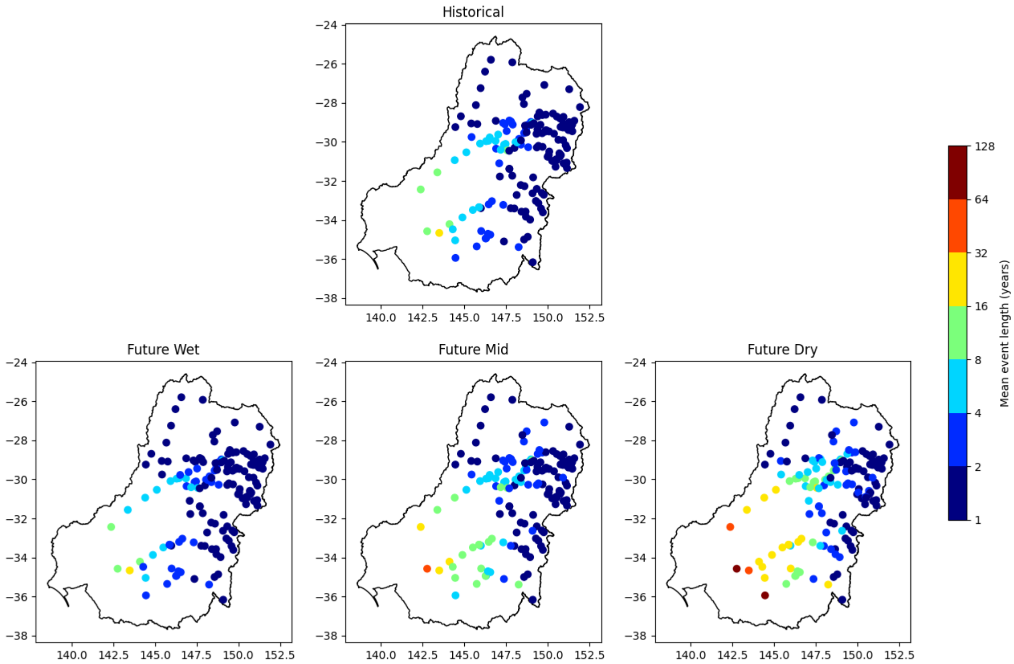

Figure 13 Average number of years between flow events exceeding the 99th percentile daily flow under historical and projected future climate conditions.

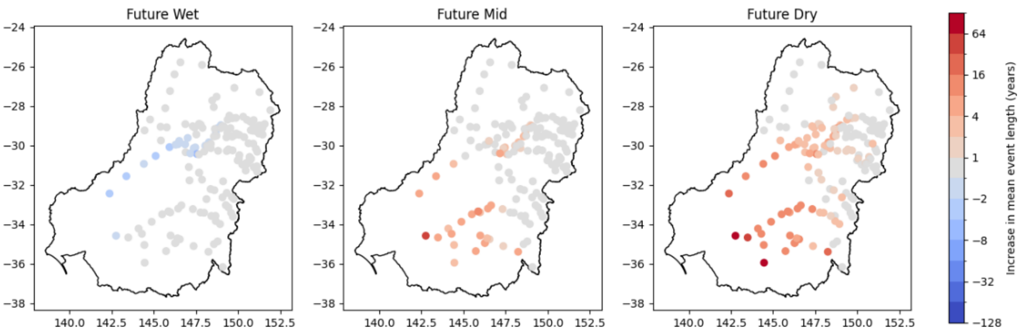

Figure 14 Projected future changes in the average number of years between flow events exceeding the 99th percentile daily flow.

4 Discussion

This study has assessed the future changes in hydroclimate conditions contributing to the occurrence of blackwater and low dissolved oxygen events. The results indicate that under future warmer and drier climates the hydroclimate risks of both blackwater and low dissolved oxygen events will increase. The frequency and average duration of low-flow, high-temperature events that support the occurrence of low dissolved oxygen events approximately doubles under the highest impact future projections while it increases by 50% under the most moderate scenario investigated.

The duration between events that inundate the floodplain, as represented by the 99th percentile flow in this study, is expected to increase under future drier climates over large parts of the Basin. This will mean that there will be longer periods for organic matter to accumulate on the floodplains between inundation events. Therefore, when floodplains are inundated, there will be a greater chance of a blackwater event occurring as more organic matter will be washed into the rivers and waterholes. However, these inundation events are likely to occur less often. Therefore, conditions conducive to blackwater events may be expected to occur less frequently but be more likely to result in a blackwater event occurring.

The analysis reported here has adopted thresholds to define low-flow, high-temperature events, and floodplain inundation events. The conclusions from the analysis could potentially be impacted by the thresholds chosen to define these events. We assessed the sensitivity of conclusion to the adopted thresholds by investigating a wide range of flow and temperature thresholds to characterise low-flow, high-temperature events, and flow thresholds to identify floodplain inundation events. While the baseline frequency and duration of events vary with the threshold that is adopted, the direction of projected changes and the relativities between the Future Wet, Future Mid and Future Dry climate scenarios is consistent with the results presented here.

Quantile-based thresholds on high and low flows were adopted to define events, meaning that the flow thresholds were different for each gauge. The use of quantile-based thresholds was a convenient assumption made to allow consistent analysis, and hence interpretation, across all analysed gauges. However, at each gauge the characteristics of river cross-section will define the flow at which the floodplain is inundated, and the flow at which the stream velocity reduces to levels where there is insufficient turbulence to support water column reoxygenation. Initially we sought to define high and low flow thresholds at each gauge using a combination of river cross-sections and rating curves. However, we found river cross-sections are only available for a small proportion of the analysed gauges. In addition, where cross-sections were available, discrepancies existed between the reference levels in the cross-sections and rating curves which limited the ability to reliably estimate flow velocity and floodplain inundation thresholds. Consistent low and high flow thresholds across all gauges could be used as an alternative to quantile-based thresholds and have been implemented operationally to assess the risk of fish deaths (e.g. https://water-monitoring.information.qld.gov.au/). A limitation of using consistent thresholds across all gauges is that the exceedance probability of these thresholds would be different at each gauge and interpretation of results would require consideration of the underlying flow frequency.

The simulated streamflow for historical and future climates used in the analysis presented here was generated using the Integrated River System Modelling Framework. The simulations for future climates generated using the IRSMF relies on the scaling of historical river system inflows. Scaling of inflows is a simple but practical method of generating future projections of river system outcomes. However, there are also potential limitations of scaling inflows rather than explicitly modelling the hydrological process responses to changes in climate forcing for the analysis reported here. The annual inflow scaling used to generate the simulations used in this study assumes that hydrographs will translate linearly in response to climate change. Actual streamflow responses to changes in climate forcing, particularly those associated with high and low stream flows evaluated in this study, are highly likely to be non-linear. Under a warmer and drier climate, non-linearities in streamflow responses to climate change are likely produce longer periods of low streamflow as catchments tend to become drier. This means that the analysis here may underestimate the increase in frequency and severity of hydrological conditions related to low dissolved oxygen events under drying climates. Resolving the limitations with inflow scaling would require the generation of inflows using rainfall-runoff models that capture the non-linearities in streamflow responses to climate change using projected climates. However, such analysis was not possible within the constraints of this study.

The analysis undertaken in this study was only possible for stream gauges in New South Wales and Queensland. The hydroclimate indicators analysed were derived from daily streamflow simulations. Within the IRSMF models for NSW and Queensland catchment run at daily time steps, while models for Victoria run at monthly time steps. Methods to disaggregate monthly simulations to daily values are available, however their robustness under changed hydroclimate conditions has not been established. As a result, analysis was limited to regions where daily simulations were readily available. It is expected that future versions of river systems models for Victoria will produce daily simulations, and therefore analysis of risks of low dissolved oxygen and blackwater events will be possible for Victoria, when these simulations are available.

5 Conclusions

Climate change projections indicate that the Murray-Darling Basin will become warmer, and rainfall is likely to decline. This is expected to translate into lower mean annual runoff and changes in the hydrological regime that manifest as fewer high flow days and longer periods of low flow. These changes to the hydrological regime are also expected to have impacts on water quality in the MDB. This study investigated how climate change is expected to impact on the hydrological conditions that lead to hypoxic blackwater and low dissolved oxygen events. Using simulated streamflow at more than 150 stream gauges from across the NSW and Queensland we assessed the historical and future frequency and duration of (a) low-flow, high-temperature events that are related to low levels of dissolved oxygen in water ways and (b) to floodplain inundation events.

We find that the frequency and duration of low-flow, high-temperature events are expected to increase by between 50% and 200% under the projected future climates, suggesting that number and duration low dissolved oxygen events are likely to increase. The increases in frequency and duration of these events occurs across the MDB but are likely to be most evident in the northern parts of the Basin where the historical frequency of events is highest. We also find that the period between flows that inundate floodplains, here specified as the 99^{th} percentile historical streamflow, increases under future drier climates and hence the frequency of floodplain inundation will decrease. The consequence of this finding for blackwater events is that there is expected to be fewer future floodplain inundation events and as a result few events where organic matter can enter river channels from the floodplain. However, when floodplain inundation does occur it is expected that chance of a blackwater event occurring will be greater as longer periods between inundation events will lead to a greater accumulation of organic matter on the floodplain. Geographically, the regions where the risk is likely to increase the most are in the lower reaches of the MBD where flows are highly regulated and the frequency of flow exceeding the 99^{th} percentile historical streamflow tend to be low.

Our results indicate that under future climates, the risk of acute water quality events related to hypoxic blackwater, and low dissolved oxygen events is likely to be higher. Practical management strategies can address these some of these risks, both locally and at a river system scale, but future water management plans need to address the climate change impacts on water quality as well water quantity.

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