Understanding the impact of climate change on water quality in South-East Australia

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Key Points

- We used the Millennium Drought as an historical proxy to understand the impact of prolonged dry periods on water quality at 135 sites across Victoria.
- Total nitrogen, total phosphorus, turbidity and dissolved oxygen decreased at most sites during drought periods, while electrical conductivity increased.
- Water quality was broadly explained by changes in flow conditions, though significant unexplained variability indicates poorly understood water quality processes associated with drought.
- Larger changes in water quality during drought conditions were seen in central and north-west Victoria.
- Further investigation of temporal and spatial drivers of water quality response to drought is required.

Abstract

As forecasts of future climate indicate reduced average rainfall in South East Australia, understanding the responses of water quality in freshwater ecosystems climate change is important. This study aims to understand the impact of climate change and variability on the behaviour of six water quality constituents (dissolved oxygen, total nitrogen, total; phosphorus, electrical conductivity, turbidity and pH) at 135 sites across Victoria, Australia.

A 27-year period of data that spans the Millennium Drought, used here as an historical proxy for prolonged dry conditions, was subdivided into drought and non-drought conditions. Observed concentrations, as well as results of statistical modelling using streamflow as an explanatory variable were compared between drought and non-drought conditions.

Results indicate that, in aggregate across Victoria, under drought conditions EC increases, while turbidity, TN, TP and DO decrease. This is largely explained by reduced streamflow during drought, and would be anticipated to occur during future dry periods under climate change. Increased EC and reduced DO are of particular ecological concern.

The impact of drought on water quality varies in space, with larger effects tending to occur towards central, northern and western regions of Victoria. further regionally explicit investigation is required to better understand this variability.

This research can inform future approaches to understanding, forecasting and managing water quality under climate change, and may aid in designing water quality improvement measures, including environmental watering programs.

Keywords

Water Quality, Climate Change, Drought, Pollution, Modelling

Introduction

Climate change is associated with many changes to the hydrological regime, including temperature, rainfall, evapotranspiration, and consequent changes to streamflow (e.g., Saft et al., 2015), as well as changes to land use (Anwar et al., 2013) and changing behavior of bushfires (Johnston & Maher, 2022). All these factors have the potential to influence water quality.

Across Victoria, prolonged extreme dry periods are likely to become more frequent (Rauniyar & Power, 2020) and intense (Delage & Power, 2020). Understanding the impact of extreme dry periods on water quality is vital for both understanding and managing the threats that climate change poses to the quality of waterways, and the human and ecological communities that rely on them.

Here we use the extreme dry conditions that occurred in south east Australia during the Millennium Drought as an historical proxy for the prolonged dry periods anticipated under climate change, to provide insight into possible changes to ambient water quality.

Methods

Analysis of water quality data included comparing water quality constituents during drought and non-drought periods, using measured water quality values, as well as the results of linear modelling that use flow and seasonality as independent variables. 135 stream monitoring sites across Victoria were selected for adequate coverage of daily streamflow data and monthly grab sampling for six water quality constituents (Electrical Conductivity (EC), Total Phosphorus (TP), Total Nitrogen (TN), Electrical Conductivity (EC), turbidity, dissolved oxygen (DO) and pH over a 27-year period (1995-2021 inclusive). The selected sites included catchments that drained varying proportions of native vegetation, agricultural and urban land uses.

A catchment-specific definition of drought based on rainfall anomaly was used to separate the water quality record into drought and non-drought periods, adapted from Saft et al., (2015).

At each site, Mann-Whitney U tests were used to test for significant differences in concentration between drought and non-drought periods. The percent change in median values at individual sites were also aggregated at the state level to assess the overall impact of the Millennium Drought on water quality within Victoria. A simple linear model that used flow and seasonality as independent explanatory variables was fit to each water quality constituent at each site:

$$C_t = f\big((Q_t)\big) \times \beta_Q + f(seasonality) \times \beta_{seasonality} \; + f(\varepsilon_C)$$

Where C_t and Q_t are concentration and flow respectively, seasonality is a sinusoidal function incorporating amplitude and phase shift, β_Q and $\beta_{seasonality}$ are coefficients, and $\mathcal{E}_c$ is an error term. The fitted coefficients for flow (β_Q) were then used to estimate the degree to which changes in flow during the Millennium Drought impacted water quality constituents, using observed changes in average flow during the two periods.

Results and Discussion

Distribution of drought periods

At all sites, a drought period was identified starting in the mid to late 1990s or early 2000s and finishing in 2009. At about half (71) the sites concentrated in the center and northwest of the state, a second drought period was identified, running approximately from 2012 to 2019 (Figure 1). The spatial patterns of identified drought periods should be noted when interpreting spatial distributions of water quality responses.

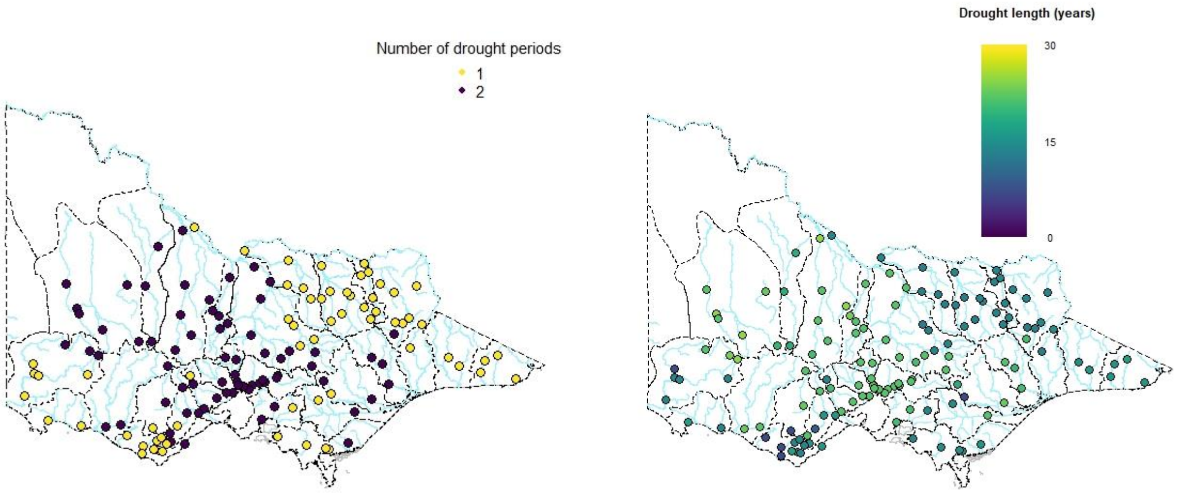

Figure 1. Number of distinct continuous drought periods (left) and total length of combined drought periods (right) identified during the study period.

Observed changes in water quality during extreme dry periods

During drought periods, more sites had significantly lower turbidity, TN, TP and DO concentrations, than sites that had higher concentrations of these constituents, or displayed no significant change (Table 1, Figure 2). EC was significantly higher across most sites during drought periods (Table 1), when compared with non-drought periods. Similar numbers of sites displayed higher, and lower pH during drought periods.

Larger proportional changes in EC were observed in central and western Victoria (Figure 3), which may relate to more intense hydrological responses to extended drought in these regions (i.e., a greater reduction in streamflow for a given reduction in rainfall) (Saft et al., 2015). Statewide increases in EC due to future extended drought periods may threaten ecological values, particularly in central and western Victoria, where several streams do not currently meet state environmental water quality objectives for EC (Commissioner for Environmental Sustainability Victoria, 2023).

Several sites displayed significantly increased turbidity, TN and TP during drought periods (Table 1), also concentrated in the central and western areas of the state. Some of these could be partially attributed to management actions. For example, a reduction in concentrations in the Broken basin can be attributed to the decommissioning of Lake Mokoan in 2009 (Stoffels and Weatherman 2014), which aligned with the end of the Millennium Drought, resulting in apparently high concentrations during defined drought periods.

At some sites in the west of the state, turbidity, TN and TP concentrations were significantly higher during drought periods. However, absolute turbidity values in these streams were often low (~5-15 NTU), so the proportionally higher turbidity during drought periods were not likely to be ecologically meaningful. Reductions in median turbidity (by as much as -72%) as well as TP and TN (by as much as -86% and -50%, respectively) during drought periods may significantly alter stream productivity.

Median DO concentrations were significantly lower during drought periods at 62 sites, indicating potential for ecological harm under conditions of long-term sustained drought. Note that only the difference in medians is presented here, and that difference for other ecologically important metrics (e.g., 5th percentiles for DO) are not reported, and will be further investigated in future.

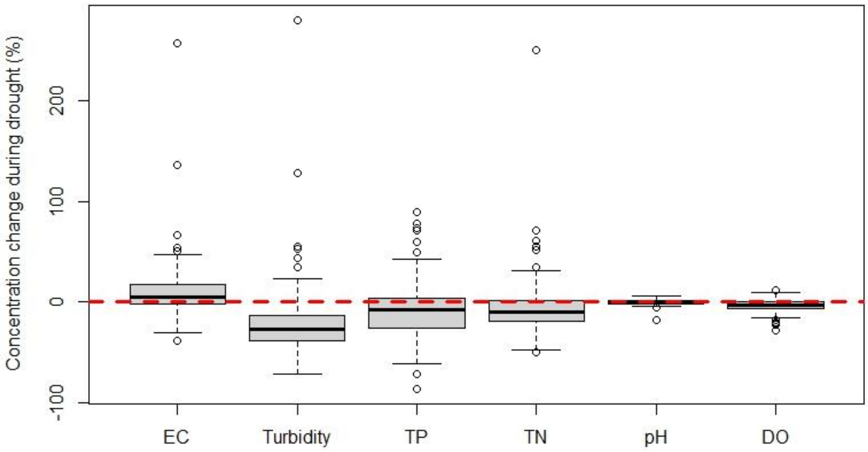

Figure 2. Percent change in median concentrations during drought periods, compared to non-drought periods at all 135 sites in Victoria 1995-2021 for Electrical Conductivity (µs/cm), turbidity (NTU), TN (mg/L), TP (mg/L), DO (mg/L), and pH. When aggregated across the state, the percent change in median concentrations differed significantly from 0 (1-sample Wilcoxon, p<0.05) for all constituents except pH, indicating a significant statewide shift to higher values (for EC), and lower values (for turbidity, TN, TP and DO) during drought conditions.

Table 1. Number of sites across Victoria exhibiting a significant (Mann-Whitney U, p<0.05) difference between drought and non-drought periods, displaying either higher, or lower values, or exhibiting no significant change during drought.

Water quality constituent	# sites higher during drought	# sites lower during drought	# sites no sig. change
EC	67	20	43
Turbidity	9	99	29
TP	18	60	54
TN	17	61	51
pH	46	49	40
DO	10	62	63

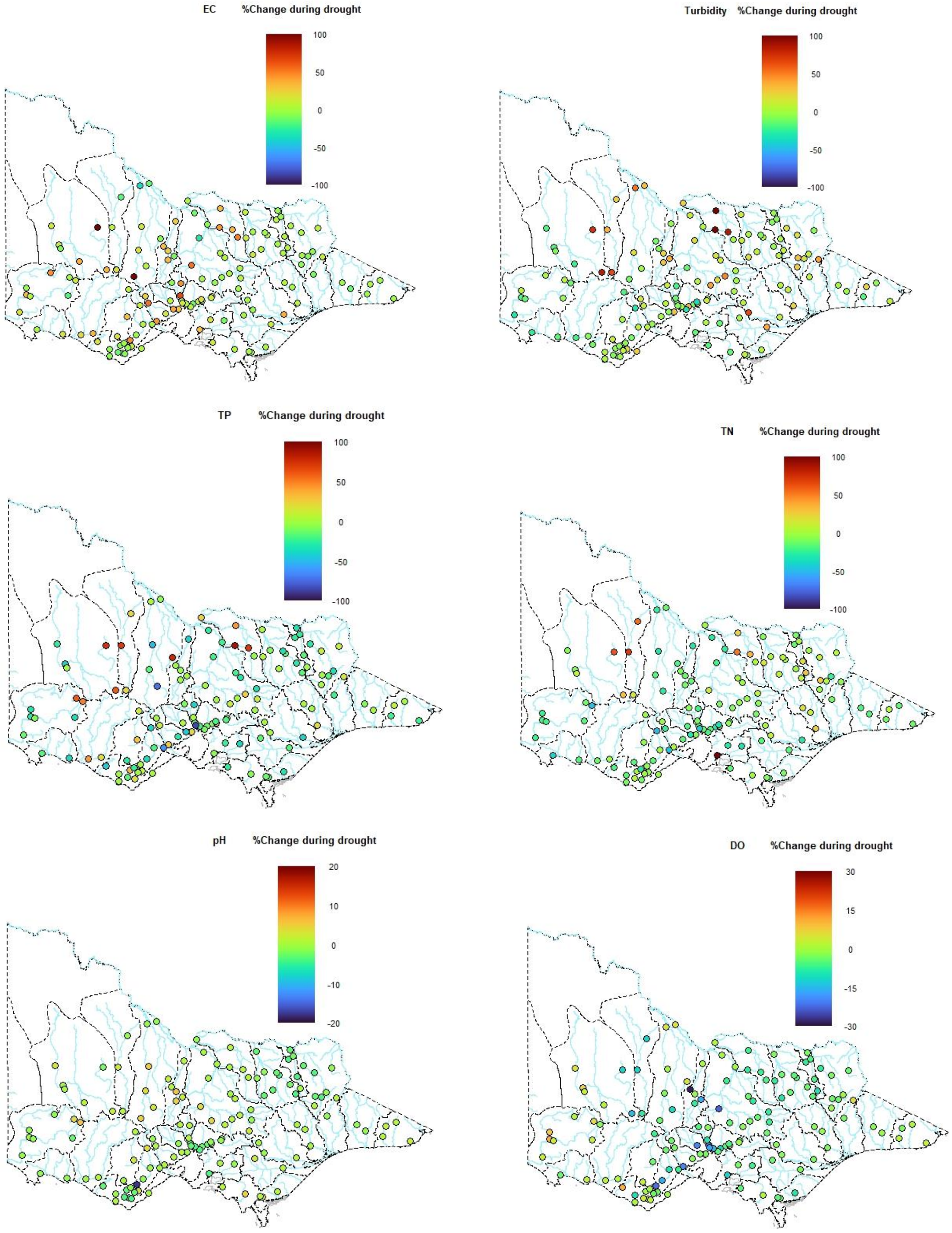

Figure 3. Change in median concentration (expresses as a %) during drought periods, compared to non-drought periods, at 135 sites. Results are presented for water quality constituents: Electrical conductivity (EC, µS/cm), turbidity (NTU), total phosphorus (TP, mg/L), total nitrogen (TN, mg/L), dissolved oxygen (DO, mg/L), and pH. Note the differing scales of the legends. For EC, turbidity and TN, values greater than 100% are plotted as 100% for display purposes.

Changes in concentration due to changes in flow during drought

Flow was a significant predictor of TN, TP, EC, turbidity, and pH, and generally explained the aggregated statewide trends towards higher EC, and lower turbidity, TN and TP during drought periods (Figure 4). This is broadly consistent with reduced erosion, mobilization and transport capacity of particulate pollutants during lower flow conditions. Higher EC is also consistent with reduced rainfall dilution, and enhanced evaporative concentration of total salts under drought conditions.

However, there is substantial variability in water quality (as seen in Figure 2) not explained by linear relationships with flow. Some variability is likely due to changes in rural and urban land and water management, including reservoir management, which were not controlled for in the site selection process. Further explicit examination of the mechanisms by which climate change alters water quality (e.g., bushfires, intense high rainfall events, changes in management of environmental flows) is required. Temporal variability associated with drought conditions but not related to flow, has also been identified within forested reference catchments in Victoria (Department of Energy, Environment and Climate Action, 2023), indicating that emerging processes associated with climate change may influence water quality.

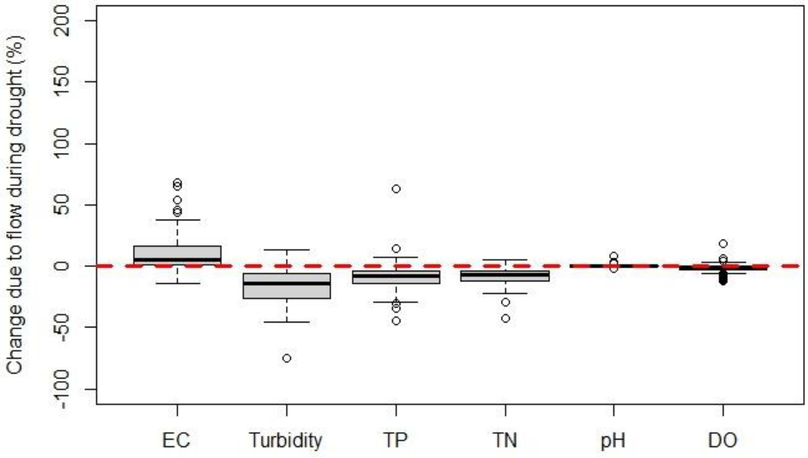

Figure 4. Change in concentration due to changes in flow during drought periods, when compared with non-drought periods, at all 135 sites in Victoria 1995-2021.

Conclusions

Broadly, dry conditions during the Millennium Drought coincided with significantly higher EC, and significantly lower turbidity, TN, TP, which were largely explained by changes in flow conditions. However, substantial variability in water quality responses exist. While the results were complicated somewhat by differing periods of drought observed across different parts of Victoria, as well as potential impacts of changing management, water quality changes during drought were not spatially uniform, with proportionally larger effects observed in central and western areas of Victoria, possibly associated with more intense hydrological responses to extended drought.

Regionally specific approaches to managing the effects of climate change on water quality will likely be required. While absolute increases in turbidity, TN and TP observed at some sites in this study during drought periods were not of particular ecological concern, the potential for increases during drought suggests that maintaining at-source approaches to controlling waterway sediment and nutrient pollution (e.g., riparian restoration, fertilizer budgeting) may aid in mitigating water quality risks, including the prevalence of cyanobacteria blooms under future climate change scenarios. Under a drier climate, increasing provision of environmental flows (where feasible) may be required to mitigate the negative ecological impacts of high EC and low DO. Potential emerging water quality processes associated with climate change, and their interrelation with changes to land management and land use intensity require further study.

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References

Anwar, M. R., Liu, D. L., Macadam, I., & Kelly, G. (2013). Adapting agriculture to climate change: a review. *Theoretical and applied climatology*, *113*, 225-245.

Delage, F. P., & Power, S. B. (2020). The impact of global warming and the El Niño-Southern Oscillation on seasonal precipitation extremes in Australia. *Climate Dynamics*, *54*, 4367-4377.

Johnston, S. G., & Maher, D. T. (2022). Drought, megafires and flood-climate extreme impacts on catchment-scale river water quality on Australia's east coast. *Water research*, *218*, 118510.

Rauniyar, S. P., & Power, S. B. (2020). The impact of anthropogenic forcing and natural processes on past, present, and future rainfall over Victoria, Australia. *Journal of Climate*, *33*(18), 8087-8106.

Saft, M., Western, A. W., Zhang, L., Peel, M. C., & Potter, N. J. (2015). The influence of multiyear drought on the annual rainfall-runoff relationship: An A ustralian perspective. *Water Resources Research*, *51*(4), 2444-2463.

Stoffels, R., and Weatherman, K. (2014) The decommissioning of Lake Mokoan: Effects on water quality and fishes of the Broken River. Final Report prepared for the Goulburn-Broken Catchment Management Authority by The Murray-Darling Freshwater Research Centre, MDFRC Publication 20/2014, June, 16pp.

Victorian State of the Environment 2023 Report: Scientific Assessments Volume 2 – Technical Report, Commissioner for Environmental Sustainability Victoria, 2023.

Victorian Water Quality Analysis 2023 – Technical Report, The State of Victoria Department of Energy, Environment and Climate Action, November 2023.