Detection of long-term change in waterway health due to flow

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Key Points

- It has been more than a decade since Victoria began strategic sharing of water between consumptive uses and the environment and it is now appropriate to review whether this needs rebalancing.
- One part of this check is to determine whether waterway health has been declining.
- Statistical techniques can be applied to existing waterway health datasets to detect change, and to relate this change to changes in flow regime, but drawing conclusions about causality is difficult in the absence of a specifically designed monitoring program.
- Multiple lines of evidence will be needed to better ascribe changes in waterway health to flow changes.

Abstract

In 2005 Victoria legally designated an environmental water reserve as a start to strategically sharing water between consumptive use and the environment. The accumulation of environmental water and application of environmental flows has occurred in different systems along varying timelines. It is now important to determine whether this sharing of water has had the desired effect in arresting deterioration of waterway ecological health. This paper describes an assessment approach that was developed to account for the potential difficulties, including that: there was no monitoring program specifically designed and implemented for this assessment; existing data collected for other purposes must be used; defining ecological health is complex; each waterway functions uniquely; and, there are numerous non-flow factors affecting ecological health in waterways. Moreover, environmental water management was introduced relatively recently in most systems such that there may not yet be an impact on ecological health or any change may still be small. A hierarchical before-after regression model is recommended given the limitations of the data available. It is recognised that the issues may confound clear assessment and additional evidence will be needed to explain the quantitative findings. This evidence may come from relevant scientific literature, management documentation such as environmental flows studies or environmental water management plans, or short-term monitoring studies targeted specifically at the stream condition-flow connection, which may provide indicative results for understanding of predicting longer term change. The approach aims to be robust while accounting for the limitations, and is presented to stimulate collaborative discussion and obtain feedback.

Keywords

Assessment, water resources, waterway health, monitoring, environmental flows

Introduction

The concept and practice of water for the environment has resulted from a history of thought, study and trials which occurred across multiple places and fields of research (e.g. see the global review of environmental flows in rivers by Tharme 2003). In Victoria, it has long been recognised that consumptive use of water needed regulation to allow waterways to continue to flow (e.g. *Irrigation Act 1886*). However, it is only relatively recently that the environmental water concept formally entered Victorian policy, e.g. *Our Water Our Future 2004*, and legislation, e.g. *Water (Resource Management) Bill 2005* which amended the *Water Act*

1989 and defined the environmental water reserve (EWR) as water set aside to "*to preserve the environmental values and health of water ecosystems*". This amendment also introduced the Sustainable Water Strategies (SWSs) which were implemented across the state from 2006 to 2011, and set out long-term plans to manage water, including balancing the EWR with other uses. Practically, environmental entitlements have been issued (added to the EWR) in different systems at different times, as environmental water needs and availability have been identified. There have also been other incremental changes in water regulation, such as conditions on specific bulk entitlements and other water use to manage impacts to the EWR (e.g. allowing passing flows in a waterway before water is taken for other uses). Now, a decade after establishment of the EWR, the first SWSs are beginning to be reviewed, and as part of a long-term adaptive management approach, it is an appropriate time to try to assess whether the sharing between water uses applied during SWS implementation was balanced or if it needs to be adjusted.

Objective

To support one part of the water sharing assessment, this paper describes the development of an approach to assess whether the environmental values and health of water ecosystems have changed for reasons related to flow, before and after implementation of the SWSs. The approach aims to be robust while accounting for the limitations, and is presented to stimulate collaborative discussion and obtain feedback.

Scope

To ensure the outputs of the intended analysis are useful for policy, and the SWSs in particular, some relevant definitions and requirements are outlined below.

1. Waterways are defined to include: (a) rivers and streams, (b) wetlands and (c) estuaries.
2. Waterway health is defined as for the EWR, which includes "*their biodiversity, ecological functioning and quality of water and the other uses that depend on environmental condition*" (*Water Act 1989*).
3. Flow is defined to include its magnitude, duration, seasonality, frequency, and combinations thereof.
4. The relevant time scale is specifically looking at the impact of the EWR via the SWSs, i.e. before vs after application of water for the environment, which differs in timing and magnitude in different systems.
5. The relevant spatial scales of assessment are: (a) to be applicable state-wide, and (b) at a waterway system scale, to determine whether that system has been provided enough water to arrest health deterioration (or even improve it).

It should also be noted that this paper builds on related work linking flows to ecological health, from the long history of scientific research (e.g. Meyer 1997), to the more directly practical and system-specific FLOWS methodology studies which make recommendations for different flow components to meet the needs of specific waterway health objectives (DEPI 2013). Current work is examining how much the flow regime has changed with respect to ecologically important flow components, including recommended FLOWS components where such studies have occurred (Parker et al. in prep.).

Approach and considerations

The method described was developed in consultation with a technical advisory group, state government, representatives from catchment management authorities and water corporations, and independent waterway health and data analysis experts. This consultation highlighted several potential issues in detecting long-term deterioration of waterway health for flow-related reasons. There was particular concern regarding the lack of a monitoring program specifically designed to determine the field impacts of a large-scale intervention. Additionally, it was recognised that there are multiple complex dimensions to ecological health, there is no simple consensus definition, and there is no standardised monitoring. It was also emphasised that different types of waterway function differently, each waterway is influenced by flow uniquely, and there are many non-flow factors also affecting ecological health. The consultation process identified numerous ecological datasets that might be suitable for an analysis of condition trends, but also identified discrepancies in data availability for the three primary waterway types considered for analysis, with the most data available for rivers and streams, and fewer data available for wetlands and estuaries.

A final consideration was that although in some systems environmental water management has been in place for more than a decade, this is still a short period relative to the preceding years of altered flow regime, and it is also short in terms of ecological change, such that there may not yet be an impact on ecological health or that any change may still be too small to definitively detect. Furthermore, there are numerous systems where environmental water management has been in place for much less than a decade, and many systems where water has not been available to fulfil environmental water recommendations.

To address these issues, three pieces of work were undertaken:

1. A theoretical method development study which sets out a framework of logic examining methods of statistical analysis, their data requirements and implications for strength of inference to answer the question of interest (Sparrow & Bond 2018).

   1a. As a sub-piece to the theoretical method development, the logical framework was applied to the datasets available for rivers and streams, in order to identify which might be most suitable and to develop a test case (Sparrow & Bond 2018).

2. A review and assessment of the wetland data available to identify which might be suitable (Hale 2018).

3. A review and assessment of the estuarine data available to identify which might be suitable (Jenkins et al. 2018).

Proposed methods and data

As recognised earlier, lack of a targeted monitoring program has specific implications for the type of analysis possible, and the confidence that an analysis could provide in answering our objective. A before-after control-impact replicated model would be the most desirable approach (Downes et al. 2002), but is not possible in this case due to lack of appropriate "benchmark" data from before the EWR and SWSs. Such an approach would also require an explicitly designed intervention program with carefully selected control systems. Given these and other requirements to address confounding and limited replication of measurements (with reference to the datasets available), it is likely that a hierarchical before-after regression model (e.g. Webb & King 2009, Thomson et al. 2012) will be the most suitable method to determine if/how waterway health has changed in a particular system. A hierarchical regression can show whether changes in flow explain a statistically significant amount of the variation in waterway health, by first accounting for variation due to other variables. The confidence in the result will depend on data availability to address confounding factors and the magnitude of any change. More details on alternative approaches, and the implications for the proposed method are provided by Sparrow & Bond (2018).

For rivers (and streams) specifically, the datasets available at regional or larger spatial scale, the types and relevance of health indicators measured, the relationship of indicators to flow, and the temporal coverage, were compared to the requirements of the range of statistical approaches. The datasets considered are listed in Table 1, with a brief summary of relevant assessment criteria, suitability for the purpose of the LTWRA, and possible analytical model to be applied. The details of the assessment are described by Sparrow & Bond (2018). It was found that the Victorian Water Quality Monitoring Network and the Environment Protection Authority macroinvertebrate (and associated) datasets were most likely to meet the requirements. As mentioned in the Scope section (above), on-going work on change in ecologically important flow components over time (Parker et al. in prep.) will provide key data for this proposed statistical analysis to determine the relationship of river flow to waterway ecological health.

Table 1. Datasets assessed against analytical criteria.

Potential data source	General assessment notes	Suitability. Analytical model/s
Index of Stream Condition	Limited temporal resolution (three "snapshots", only once post-SWS).	Unsuitable. N/A.
RiverMAP Long Term Sites	Relatively high frequency of observations. Wide number of sites across state.	Suitable for further investigation. Hierarchical before-after regression model and trend analysis.
Victorian Water Quality Monitoring Network and Regional Water Monitoring Partnerships	Relatively high frequency of observations. Wide number of sites across state.	Suitable for further investigation. Hierarchical before-after regression model and trend analysis.
Aerial surveys of waterbirds in eastern Australia	Long-term but wetlands only and limited sites. Low ability to infer causality to flow/environmental water.	Unsuitable. N/A.
Wimmera Monitoring Program	Limited spatial scale (not state-wide). Low frequency especially post-SWS.	Unsuitable. N/A.
Victorian Environmental Flows Monitoring and Assessment Program	Possible change in monitoring over time.	May be combined with other fish datasets, further investigation needed. Trend analysis.
WaterWatch	Variable frequency, long-term and wide number of sites across state. However, would need significant quality assurance checking before use.	Unsuitable. N/A.
The Sustainable Rivers Audit and Southern Basins Project (combined)	2004-2017/18, i.e. limited data pre-SWS. Southern basins may have shorter timeframe.	Further investigation needed. Hierarchical before-after regression model and trend analysis.
Victorian instream woody habitat assessment	Only post-SWS data.	Unsuitable. N/A.
Wimmera bird monitoring project	Only pre-SWS data. Low ability to infer causality to flow.	Unsuitable. N/A.
Riparian Intervention Monitoring Project	Only post-SWS data.	Unsuitable. N/A.
Enhancing fish populations using instream woody habitat restoration: II. Quantifying environmental outcomes.	Only post-SWS data.	May be combined with other fish datasets, further investigation needed. Trend analysis.
Multiple projects assessing Macquarie Perch populations	Only post-SWS data.	May be combined with other fish datasets, further investigation needed. Trend analysis.
Native Fish Report Card	Only post-SWS data.	May be combined with other fish datasets, further investigation needed. Trend analysis.
Wetland summary: Index of Wetland Condition; The Living Murray; Wetland Monitoring and Assessment Program; individual studies; etc.	Datasets generally not long-term and often limited in spatial scale (one to a few wetlands only). Link between health and hydrology not as consistent.	Generally unsuitable. May be able to apply hierarchical before-after regression and trend analysis to individual wetlands as case studies.
Estuaries summary: Index of Estuary Condition; Estuarine Macrofauna; Estuaries Classification; Estuary Watch; (various) Estuary Water Quality Monitoring Programs; etc.	Datasets rarely long-term and often limited in spatial scale (one to a few estuaries only). Link between health and hydrology complicated by role of estuary mouth opening.	Generally unsuitable. May be able to apply hierarchical before-after regression and trend analysis to individual estuaries as case studies.

For wetlands, the review of the data available found that although there is considerable weight of evidence for the link between hydrological ('flow') regime and wetland health in the scientific literature, in Victoria there is a lack of reliably and consistently measured hydrology data on the temporal and spatial scales required (Hale 2018). This is a significant impediment to being able to quantitatively demonstrate a change in wetland health due to flow. Datasets relevant to wetland ecological health and their strengths and limitations are also reviewed. It is notable that given more than 35,000 mapped wetlands in Victoria, comprehensive monitoring is untenable. Lack of a consistent wetland dataset as well as the limited hydrological data, mean that wetland assessment is likely to be limited to a few case studies of systems with unusually detailed data.

Because of their connection to rivers, almost half of all major estuaries are likely to have some flow data from the Victorian stream-gauge network (Jenkins et al. 2018). However, as for wetlands, there is a lack of consistently measured ecological condition data suitable for tracking long-term trends. There are few data which are suitable for comparing pre- and post-SWS. Additionally, the understanding and evidence for the influence of flow on estuarine health is less developed than for rivers or wetlands. Again, a case study approach is likely to be required, and results are likely to only be indicative of change.

Discussion

The retrospective analysis of data collected for a range of purposes is unlikely to provide unequivocal detection of change in waterway health and determine how any change in health is related to changes in flow. As many studies have found, confounding among different possible influences (both natural and anthropogenic) is common and difficult to account for in highly variable environments. Water quality and macroinvertebrates have been studied relatively extensively, and only occasionally detect connections to flow (e.g. Hillman and Quinn 2002, Chessman et al. 2002). Mediation of the effect of environmental flows by life history triggers, habitat quality, and food web interactions may complicate measurement of the impact of flow on waterway health (e.g. Robson et al. 2017).

Recently however, more sophisticated attempts to account for confounding factors have begun to tease out possible flow impacts (e.g. Waite et al. 2014, Walsh & Webb 2016, Sardiña et al. 2016). The proposed approach for Victoria will examine the specific influence of individual flow components such as well-defined high flows, low flows, cease-to-flows, seasonality and variability, which has not commonly been attempted. Additionally, there are variations and developments in stepwise regression which may be applicable and will be tested in this case (e.g. Bayesian techniques, Webb et al. 2010). Despite these advancements, even where there is high confidence in any quantitative results, additional evidence will be needed to explain and contextualise the findings. For example, one important piece of context is that the application of water for the environment is commonly managed in coordination with complementary measures, such as riparian revegetation. Additional evidence may come from relevant scientific literature and management processes and documentation such as environmental flows studies or environmental water management plans. It is also intended that individual case study analysis will examine short-term monitoring targeted specifically at the ecology-flow connection, for example the Victorian Environmental Flow Monitoring and Assessment Program, which may provide indicative results for longer term change. This layered approach (see Figure 1) to answering the question of whether there has been deterioration in waterway health for reasons related to flow is consistent with approaches elsewhere with regard to complex real-world problems, where multiple lines of evidence are used to support decision-making. Additional investment in the existing short-term monitoring would strengthen overall assessment of change in ecological condition for reasons related to flow, including strengthening of causal inference and facilitation of modelling longer-term counterfactual scenarios, and supporting the role of science in decision-making and management of waterways (Hofler 2005, Stoffels et al. 2018).

Next steps

The proposed hierarchical before-after regression method is being tested against select sites within the currently identified datasets. The authors also invite discussion and feedback regarding:

i. Suggestions for additional datasets which might be suitable?

ii. Suggestions/ideas for additional analytical approaches which should be considered?

iii. Specific critique of the dataset assessment or matched approaches?

iv. Any potential issues with using the data and assessment approaches (statistical model) suggested?

A parallel piece of work is also exploring how best to communicate any quantitative results within the context of additional evidence.

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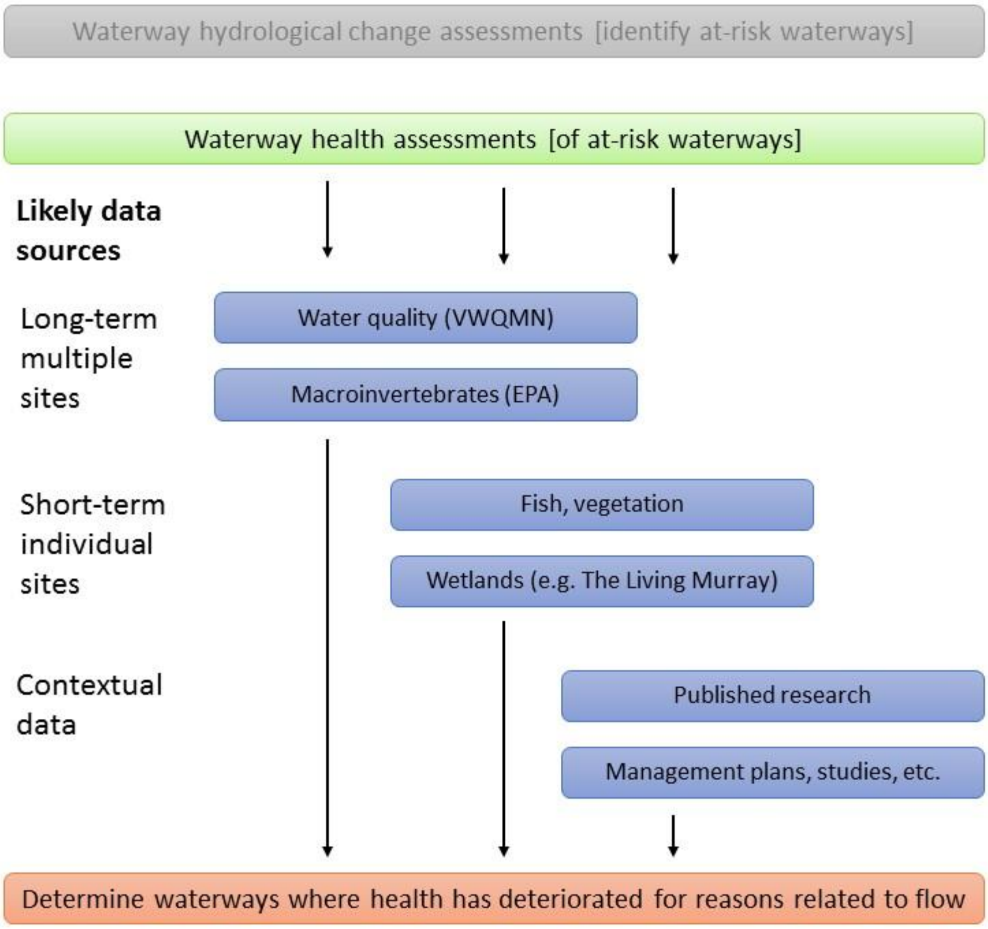

Figure 1. Multiple layers of evidence