MID-TERM REVIEW

Healthy Waterways Strategy 2018-2028
Port Phillip & Westernport, Victoria

Macroinvertebrates

A Technical Report to inform the Healthy Waterways Strategy Mid-term Review

This Technical Report has been developed for Melbourne Water as part of the Healthy Waterways Strategy Mid-term Review through a collective effort with many organisations and individuals. In particular, Melbourne Water thanks:

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Dr. Yung en Chee (Melb Uni) provided initial feedback on scope and information on Habitat Suitability Models.

Vincent Pettigrove (RMIT) and Claudette Keller (RMIT) provided data and expert opinion on water, sediment and pollutant studies across the region and specific input for several of the targeted sites.

Edward Tsyrlin provided advice and information regarding Dandenong Ranges Amphipod in Lyrebird Gully Creek as well as technical reports on threatened macroinvertebrate species across the region presented in Tsyrlin and Carew (2022) and Tsyrlin *et al* (2022).

Tiana Preston provided advice and input from the Environmental Water Resources team at Melbourne Water, especially on issues related to unregulated catchments.

Tim Donovan provided data on diversion licenses, restrictions and bans for Lyrebird Gully and Cockatoo Creeks.

Alison Kemp provided water quality data.

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Front page image credit: Eddie Tsyrlin and John Gooderham (Stonefly nymph)

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Glossary of terms and abbreviations

AOO	Area of occupancy is the smallest area essential at any stage to the survival of existing populations of a taxon. (Atlas of Living Australia)
BAUF	Business as usual future (for 2068)
CURR	Current, 2018 baseline
CRSWS	Central Region Sustainable Water Strategy
eDNA	Environmental DNA
EOO	Extent of occurrence [EOO] is defined as the area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon, excluding cases of vagrancy. (Atlas of Living Australia)
HSM	Habitat Suitability Models
HWS	Healthy Waterways Strategy 2018
KEQ	Key Evaluation Question
LTWRA	Long-term Water Resource Assessment
LUMaR	Land Use Macroinvertebrate Response index
MEP	Monitoring and Evaluation Plan
SIGNAL2	Stream Invertebrate Grade Number – Average Level
Strategy	refers in this instance as the Healthy Waterways Strategy 2018

Acknowledgement of Traditional Owners

The rivers, wetlands and estuaries of the Port Phillip and Westernport region are part of Country belonging to the Bunurong, Gunaikurnai, Taungurung, Wadawurrung and Wurundjeri Woi-wurrung peoples. These Traditional Owners have lived in and been connected to the land, water, plants and animals of this area for many thousands of years, and we offer our respect to their Elders past and present.

Overall Summary

Melbourne Water's long-term macroinvertebrate monitoring program is considered one of the most comprehensive environmental datasets in Australia, stretching back to the early 1990s. While an earlier review of some of the data was conducted in the mid 2000's (Webb and King, 2006, Webb and King, 2009) and the data has been used for a range of other purposes (e.g. development of habitat suitability models, setting water policy objectives) and for specific studies (e.g. Little Stringybark Creek intervention monitoring), this is the first analysis over the full time period.

This report is one of several background reports feeding into the Healthy Waterways Strategy (HWS) mid-term review Science Inquiry (Melbourne Water, 2023a). The extent to which this technical report has evaluated each key evaluation question (KEQ), and their sub-KEQs, with respect to macroinvertebrates as a value is summarised in Table 1.

Table 1. Summary of the mid-term evaluation KEQs and the extent to which they are presented in this report.

KEQ	Sub-KEQ	Relevance to this report and overview
1 – To what extent have the performance objectives of the Strategy been achieved?	1a. To what extent has collaboration and co-delivery contributed to achieving the Performance Objective targets so far?	This will be answered through the Evaluation of Collaboration and Co-delivery which is part of the Implementation Inquiry (Melbourne Water, *in prep*).
	1b. To what extent is strategy delivery on track to achieve the Performance Objective targets by 2028?	An overview of progress towards performance objectives is provided in the Implementation Inquiry report (Melbourne Water, *in prep*).
3 – What is the state of waterway values?	3a. To what extent are key values on the target trajectory?	This question is evaluated for macroinvertebrates at a site scale in this report. An analysis at sub-catchment scale is provided in the HWS Science Inquiry Report (Melbourne Water, 2023a) with a combination of site scale trend analysis and re-run HSM models.
	3b. What other spatial and temporal trends and patterns for key values are of significance for implementation?	This question was evaluated at site scale using trend analysis and is presented in this report.
2 – To what extent has progress been made towards the longer-term environmental condition targets for	2a. What environmental conditions (e.g. Water quality) and external conditions (e.g. policy) help explain current key value trends?	This question is investigated (but not answered) for macroinvertebrates at site scale under Results. Sites that were declining or improving with high confidence in the trend were highlighted for investigation of changes to conditions over time.

rivers, wetlands and estuaries?	2b. To what extent have projected known and emerging future threats changed from 2018? Have any assumptions about impacts to key values changed?	Evaluation of how threats have changed since 2018 is presented in the Threats Technical Report (Melbourne Water, 2023b)
4 -To what extent have the delivery methods of the Strategy been appropriate, effective, and efficient?	4a. To what extent are interventions appropriate and effective for achieving outcomes?	A stocktake of common interventions used across the region is presented in the Interventions report (Melbourne Water, 2023c)
	4b. What are the key remaining knowledge gaps that need to be addressed in the next 5 years to improve strategy delivery or prepare for the next HWS?	Identification of Knowledge Gaps is presented in Part F of the Science Inquiry Report (Melbourne Water, 2023a)
	4c. How can collaborative governance enable effective and efficient delivery of the Strategy?	This will be addressed in the Implementation Inquiry Report (Melbourne Water, *in prep*).

The analysis presented in this report assessed trends at the individual site scale that help to answer KEQ3b. In later work – see the HWS Science Inquiry Report (Melbourne Water, 2023a) - we have integrated the site scale assessment with an analysis conducted at the sub-catchment scale using Habitat Suitability Models (HSMs) where models were updated to represent the HWS works undertaken to 2022 as well as urbanisation in stormwater priority areas that has occurred since 2018. A rubric combining the site scale trend assessment with the sub-catchment outputs of the updated models is presented in the Synthesis Methods document (Melbourne Water, 2023d) and this answers KEQ3a.

We were able to assess trends in LUMaR at site scale at the majority (77) of the 132 long-term monitoring sites (Table 2). While there are fewer sites with declining macroinvertebrate trends in the recent period (i.e. last 10 years) compared to the historical period (i.e. the entire dataset), this does not mean that sites have greatly improved. In fact, no sites with declining macroinvertebrate trends over the historical period have been categorised as improving. However, it is worth highlighting that 14 additional sites were classified as having a stable macroinvertebrate trajectory in recent times compared the historical period, with many of these sites recently transitioning from declining to stable.

Table 2. The number of sites categorised as stable, improving, or declining over recent (last 10 years) and historical trends (full record) time periods.

Time period	Stable	Improving	Declining	Couldn't be assessed
Historical trend[1]	37	14	20	65
Recent trend[2]	51	12	15	54

[1] Historical trend: the change in the LUMaR index trend line since the start of data collection (1992 – 2022),
[2] Recent trend: the change in LUMaR index trend line in the past 10 years (2012 – 2022).

Although LUMaR was the index used to determine changes in trend over time, other macro indices such as SIGNAL2 are also presented alongside for comparison in the Results section.

All catchments, except for Werribee, had more than 50% of sites with enough data for trend assessment. In the Werribee Catchment, trends could only be assessed for 30% of the sites.

Of the 77 sites with trends, we focused our attention on 15. These 15 sites had either improving or declining macroinvertebrate trends with a good to moderate level of confidence in each trend. Sites where the confidence in trends was low were not considered worthy of focus until further data is collected that improved the confidence in the trend. Also, sites that were considered stable were not deemed to be a focus under the logic that these sites do not require a change in strategy implementation. The 15 sites were the focus of our evaluation against KEQ 3b. The key findings from the analysis of these sites include:

- LUMaR identified key trends in the macroinvertebrate communities, but more detailed information on specific taxa and functional feeding groups helped uncover potential mechanisms underlying the changes observed. SIGNAL2 and EPT families were also useful and enabled a more holistic picture of site trends compared with using only LUMaR or any single indicator on its own.
- While in many cases it was challenging to confidently explain causal factors for observed trends using empirical data, there was sufficient evidence using multiple environmental conditions data sets, in combination with knowledge of mechanisms from published literature, to draw inferences regarding the likely major drivers of trends
- The impacts of the millennium drought were not necessarily very clear or dominant in the LUMaR or SIGNAL2 trend data and the recovery that we expected to see was not detected. This may be due to continued flow stress in many areas of the region or it may be that the indices are not designed for this purpose.
- Sites with predominately urban catchments were in moderate to poor LUMaR and SIGNAL2 ranges, while sites in forested catchments were high.
- The range of SIGNAL2 scores across the region is smaller than the newer LUMaR index , which can better differentiate across the region. However, neither index works well for ephemeral streams.
- There were limited flow gauges in the upper parts of most catchments.
- Declines were generally associated with sites that had an initial high or very high LUMaR rating. Improvements were generally associated with sites that are improving from Low and Very Low.

A summary of the sites which were declining includes:

- The concerning trend of 9 sites declining from a ‘high’ or ‘very high’ LUMaR score to more moderate levels. These tend to be sites along the mainstem of major streams and rivers with mostly rural catchments and, in most cases, increasing levels of urbanisation. While it has been difficult to attribute casual factors to these trends using the data available in the analysis time frame, it is worth investigating further whether altered flow regimes caused by urbanisation and climate change are driving much of this decline.

A summary of the sites which were increasing includes:

- Improving LUMaR scores in the middle and lower Dandenong Creek sites (DNG-23690-8 and DNG-31881-3) were unexpected due to the extent of historical and on-going urbanisation in the catchment. While promising, further investigation is required to better understand the drivers of this improved trend. It is considered unlikely that health will improve beyond moderate condition because the significant extent of urban and industrial catchment land-use would require long time frames and significant investment in urban renewal to continue to improve condition.
- While further analysis is required, there was only one site which showed a response that could be relatable to the millennium drought and improved flow management (Lyrebird Gully Creek LYR-722-3) .

Table 3 below provides a summary of the key findings for each site where trends were further investigated.

Table 3. Summary of key findings for the 15 sites monitoring site selected for further analysis where trend was assessed to be of moderate or high confidence. Red = declining trend and green = improving trend.

Catchment	Site	Summary of findings
Yarra	LYR-722-3: Lyrebird Gully Creek (Olinda Creek sub-catchment)	Trends in LUMaR are increasing but there has been a reported decline in listed vulnerable amphipod species. It is possible that the increase in LUMaR is due to the rise of other species that occupy the same niche and improvement in flow regime after the drought.
	DIY-5232-7: Diamond Creek (Tributary of Yarra) (Diamond Creek (Rural) sub-catchment)	Reasonable evidence to suggest this decline is related to reduced stream flows.
	CCK-1538-8 Cockatoo Creek (Woori Yallock Creek sub-catchment)	The increase in shredders and scrapers potentially indicates greater coarse particulate organic matter (CPOM; leaves, twigs, etc) in the stream. Causal factors are not entirely clear but may be related to improvements in water regime and water quality relating to changes in agriculture in the catchment.
	YAR-275352-4 Yarra River (Yarra River Lower sub-catchment)	The declining trend reflects a gradual loss of a range of macroinvertebrate families. Causal factors are not clear but are likely associated with a combination of reduced stream flows and urban development.
Dandenong	DBS-363-4 Dobsons Creek (Dandenong Creek Upper sub-catchment)	The reduction in variability in LUMaR scores are considered due to significant stormwater intervention in the catchment.
	DNG-23690-8 Dandenong Creek (Dandenong Creek Middle sub-catchment) and DNG-31881-3 (Dandenong Creek Lower sub-catchment)	Increasing trends are driven by an increase in filter feeders and filtering collectors and an increase in sensitive taxa. Improving water quality, possibly linked to large stormwater treatment wetlands, is a potential contributing factor.
Westernport	LNG-16294-3 Lang Lang River (Lang Lang River sub-catchment)	Declining trends are due to a general reduction in macroinvertebrate families, including some sensitive families. It is not certain what environmental factors are causing this trend. Historical erosion impacts could still be contributing to current decline.

Catchment	Site	Summary of findings
	TOO-4334-2 Toomuc Creek (Cardinia, Toomuc, Deep and Ararat Creeks sub-catchment)	There is a sustained decline in the presence of sensitive taxa which is reflective of the increasing levels of urbanisation in the catchment since the 90's.
Werribee	WER-35204-8 Werribee River (Werribee River Middle sub-catchment)	Declining trend is moderately uncertain. Recent samples lack a number of sensitive families. Causal factors are not clear but are likely associated with a combination of reduced stream flows and urban development.
	KRT-26894-4 Kororoit Creek (Kororoit Creek Lower sub-catchment)	The increasing trend is unusual, given high levels of existing and increasing urbanisation and requires further monitoring.
Maribyrnong	BAR-1063-1 Baringo Creek (Jacksons Creek sub-catchment)	The absence of sensitive families in recent surveys is concerning but requires additional samples to confirm this trend.
	DPW-28678-1 Deep Creek (Deep Creek Upper sub-catchment)	A small recent declining trend is associated with the absence of macroinvertebrate families from a variety of functional feeding groups. Declining stream flow is likely to be contributing to this trend.
	MRB-130320-1 and MRB-134012-8 Maribyrnong River (Maribyrnong River sub-catchment)	There is a consistent yet subtle decline over time. Causal factors are not clear but are likely associated with reduced stream flows and urban development.

Recommendations for consideration in the Science Inquiry

While there are site scale recommendations within relevant sections, the following recommendations more broadly include:

- Investigate nominated sites in order to better understand causal factors, prioritising declining sites.
- Ensure annual data collection for uncertain sites and review trends by 2025, and if confidence in the trends increases,, add to the list of sites to investigate causal factors.
- To protect priority reaches and threatened species, improve monitoring and available management options (e.g. location of flow gauges and proactive management of sleeper licences as well as site scale interventions such as tanks).
- Consider management options for threatened species recovery following disturbance events (e.g. translocation of species into recovered habitats).
- Install long-term flow gauges in upper catchment reaches (perennial and non-perennial) to better understand the impacts of climate change on flow regimes, including monitoring of water quality changes.
- Prioritise acquisition of impervious surface mapping across the region, including historical data, in order to track urban development, ensuring infill development is captured.

1. Introduction

The HWS Mid-Term Evaluation Plan (Whitewater Consultancy, 2022) sets out the KEQs relevant for the macroinvertebrate key value. This interim report presents findings based on two of the KEQs (KEQ3b – trends and patterns of significance and KEQ2a – drivers of these trends and patterns). Other work that has been undertaken in parallel to answer other KEQ's is available in Table 1.

Combining Habitat Suitability Models (HSMs) with our long-term monitoring sites (used to answer KEQ3a – are values on the target trajectory) increases our ability to understand this key value and to assess the effectiveness of works and changes to short- and long-term threats such as urbanisation and climate change. The models allow us to run climate, threat and management scenarios at a reach scale, while the surveillance monitoring sites tell us how the site has changed over time. While there are over 25,000 km's of waterways in our region, the HSMs at present apply to 8,400 km's of waterways as they exclude headwaters and there are 132 surveillance monitoring sites across the region which are sampled annually.

During the HWS development phase in 2018, HSMs were developed for macroinvertebrates, fish and platypus that predicted the likelihood of occupancy based on management scenarios or environmental change (Appendix 2). These model outputs were used to communicate the effect of long-term climate change and the impact of urbanisation that was planned for the region with the co-design participants. Feedback from the community and the model outputs were combined to develop a set of 50-year targets for each value and the known supporting environmental condition. Targets for the HWS were set at the sub-catchment scale (there are 69) by averaging HSM results. More information on the summary of macroinvertebrate targets and the assumptions used is in Appendix 3

As a general principal, due to strong community desire to protect and improve waterways across the region, the long-term target set in the HWS is for no decline in macroinvertebrates anywhere and improvement in some key areas.

Several indexes have been developed for integrating and interpreting macroinvertebrate data in the Australian context. SIGNAL2 (Chessman, 1995, 2003) and LUMaR (Walsh and Webb, 2013) are two which have been found to be useful in the Australian context. LUMaR is considered to be more sensitive to urbanisation and therefore more appropriate for use in the Melbourne region. It has been the basis of the macroinvertebrate HSM development. In this report, trends over time in both LUMaR and SIGNAL2 have been analysed and are presented at the site scale in the Results section. The HSMs have been re-run with new information on the works that have been undertaken between 2018 and 2022 as well as the degree of un-mitigated urban development that has occurred in stormwater priority areas since 2018. Additionally, a range of new climate change models have been explored to develop new predictions, that depict the impact to in-stream values and the change in our understanding since 2018. The HSM derived information have been combined with site trend data to help evaluate whether we are on-track or not to achieving the long-term targets (KEQ 3a). Further discussion on the approach for target setting and the rubric which will be used for this evaluation can be found in Appendix 3.

The analysis of trend data from the surveillance monitoring sites presented in this interim report will be useful when evaluating the target trajectories. It is important to note that the surveillance monitoring sites are not typically representative of the entire sub-catchment, which is also why the HSMs are needed to evaluate progress towards target attainment.

The 132 fixed monitoring sites across the region are designed to reflect the range of environmental gradients and threats across the region along with the location of key interventions for stormwater and revegetation works. Of the 132 sites, there are currently 78 that have been sampled enough over time for a trend line of relevant metrics (LUMaR and SIGAL2) to be produced. The number of sites for which a trend line can be produced will increase over time. Trends have been categorised into stable, increasing, decreasing or uncertain. The evaluation then focuses on increasing and decreasing trends as it is assumed that stable trends are not a major concern at present.

It is important to note that the observed trends are long-term – that is, within the last ten years and up to 20 years for some sites (Figure 3. Distribution of sites and sample frequency of macroinvertebrate sites across the MW region (Source: macroinvertebrate database https://tools.thewerg.unimelb.edu.au/mwbugs/). As such, actions or threats observed since 2018 cannot be attributed to the trend data. Instead, we are attempting to understand the trajectory of the key value and what may be driving this. Given our long-term targets (at sub-catchment scale) are to either prevent decline, maintain current key value status or to increase the value in some areas, it is important to focus attention on areas which are declining, as these areas are likely to require greater levels of investment to address persistent threats. Additionally, it is as important to highlight sites that have improved over time so we can understand the effectiveness of interventions or changes to threats/conditions that have led to the improvement.

To help understand what is driving particular trends observed in the site monitoring data, we draw on the conceptual models which were refined during the development of the HWS (Figure 1).

These static models tell us about the environmental conditions that support macroinvertebrates. Our analysis has applied a multiple-lines-of-evidence approach using data and observations around each of the environmental conditions where it was available, to help explain observed trends in the macroinvertebrate communities. This in-turn provides insights into the types of management interventions needed - we have captured whether or not there are suitable performance objectives (management outputs) for the relevant sub-catchment in the HWS mid-term evaluation Threats technical report (Melbourne Water, 2023b).

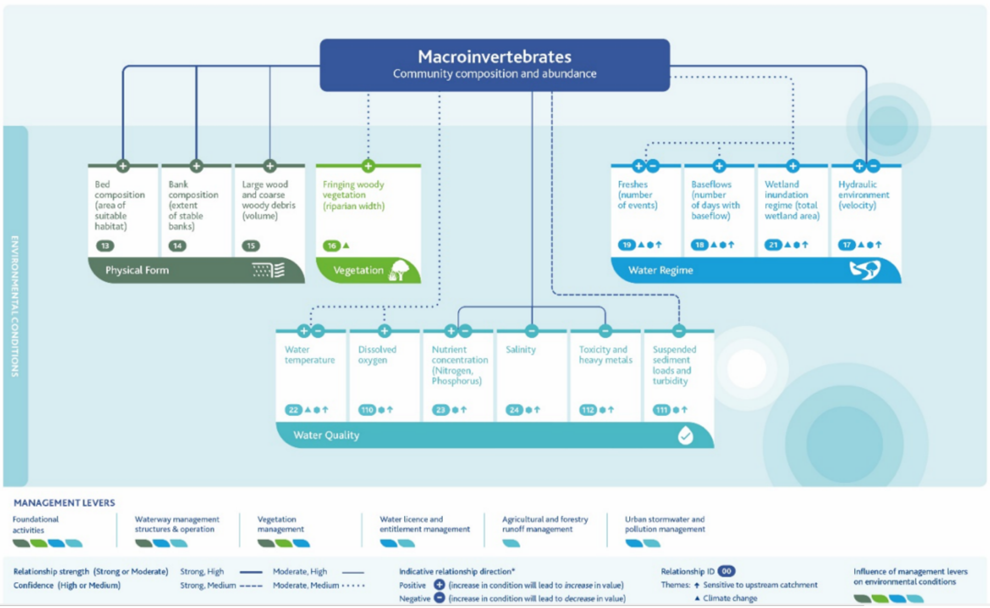

Figure 1. Static conceptual model of showing the connection between environmental conditions and macroinvertebrates community composition and abundance.

2. Methods

Long-term stream macroinvertebrate monitoring and reporting

Macroinvertebrates are the primary focus of Melbourne Water's long-term broad-scale stream health monitoring surveillance program. This is because macroinvertebrates are "the only instream key value that is clearly linked to and has sufficient granularity to permit reliable inference of stream health and function" (WERG Technical Report 19.7 Chee et al 2020). The monitoring program is adaptive and has evolved from 120 sites at the beginning of the HWS to 132 in the most recent program update (Walsh, 2022).

Briefly, long-term monitoring sites have been selected in a systematic manner to encompass variation in the primary environmental gradients (attenuated imperviousness, attenuated forest cover, and mean annual discharge) that are thought to be driving responses in macroinvertebrate communities across the Melbourne region. Existing and/or new sites were also selected to test hypotheses and resulting targets of the HWS for macroinvertebrate assemblages in response to climate change (warmer, drier conditions), revegetation, conventional urban growth, and urban growth under integrated water management designed for stream protection. This approach effectively combines a broad scale surveillance with a long-term intervention monitoring program. Where possible, sites are sampled at least annually using standard collection methods.

A description the monitoring objectives is available in the Rivers Monitoring and Evaluation Plan (MEP) (2020) while a detailed description of the macroinvertebrate monitoring program is available in the latest Melbourne Waterway Research-Practice Partnership Technical Report (Walsh, 2022).

Macroinvertebrate indices

A major challenge for biotic monitoring programs is determining how to best represent complex ecological patterns and changes in simple, but representative, ways. Biotic indices are often used to meet this challenge. Macroinvertebrate communities are particularly complex, with hundreds of families representing taxa with different ecological roles (e.g. predators, filter feeders, leaf shredders). A number of indices exist to describe this complexity. Some indices adopted, and often used nationally, include SIGNAL, SIGNAL2, and AUSRIVAS. A common index used globally is the EPT index, which is a tally of the number of families within three orders (Ephemeroptera, Plechoptera, Trochoptera) that are sensitive to waterway degradation. Many of these indices, particularly SIGNAL and SIGNAL2, "distinguish cool, chemically dilute streams from warm, chemically enriched streams" (Chessman, 2003). However, they can be relatively insensitive to low and moderate levels of degradation resulting from natural variation within regions and over time at single sites.

An index known as LUMaR (Land Use Macroinvertebrate and Response index) was developed for the Melbourne region and used in the HWS for setting the long-term targets. LUMaR combines an Observed/Expected ratio of macroinvertebrate families with taxon-sensitivity weightings. Further explanation of the derivation of the index can be found in "LUMaR: a sensitive macroinvertebrate index of stream condition combining observed:expected ratios and sensitivity weightings" by Walsh (in prep). LUMaR is a more applicable measure of stream condition than previously used indexes such as SIGNAL, SIGNAL2 and AUSRIVAS as it has greater sensitivity to moderate levels of degradation and better accounts for the variation in expected taxa across this region (e.g. there is significant differences in expected taxa between the west and east rivers due to rainfall patterns). The LUMaR score can be calculated for monitoring data and is also an output of the HSMs.

We also investigated the use of a new macroinvertebrate community index called Australian Macroinvertebrate Flow Index (AMFI) (Chessman et al, 2022), as it potentially enhances our ability to investigate the impacts of flow regime variability on macroinvertebrates. However, the calculation of this index relies on taxon abundance and, as the MW macroinvertebrate data is sub-sampled, we do not (yet) have reliable abundance data. The LUMaR index does not rely on taxon abundance for its calculation.

LUMaR index trend investigation

Each data point in the LUMaR index assessment is the average of two samples; Edge/Riffle or Edge/Edge and in most years data was collected in both Spring and Autumn so two data points for the year exist. To assess stream health trajectory at a site, a non-linear trend line is plotted using LUMaR index values (Appendix 4).

A trend line is included for sites that contain suitable data to present a reliable trend. We consider site data suitable for the plotting of a trend line if sites contain six or more LUMaR values and there are no large or unexpected changes in LUMaR values over time. Trend lines are fitted using the 'loess' scatter plot smoothing function with the following function arguments in R statistical software (R Core Development Team, 2018): family='gaussian'; span=1; degree=1. 'loess' is considered the most appropriate method as it robustly fits a smoothed curve without prior assumptions about the shape or form of the curve (Cleveland et al, 1992).

The stream health trajectory at a site was assessed at two temporal scales (see Figure 2 below):

- Historical trend: the change in the LUMaR index trend line since the start of data collection (1992 – 2022), and;
- Recent trend: the change in LUMaR index trend line in the past 10 years (2012 – 2022).

Assessing changes in stream health trajectory at multiple temporal scales can help uncover the underlying reasons for any major changes in stream health. For example, if a site is showing a recent stable trend for stream health but a historical trend for decreasing stream health, then this may suggest that a long-term disturbance, such as urbanization, has recently stabilised.

Assigning a change trajectory to LUMaR index trend lines is difficult because of the non-linear nature of the trends and the subjective nature of what constitutes a change over a defined timeframe. To make the process of assigning change trajectories as objective as possible, we followed a process which involved assigning LUMaR index trajectories ('declining', 'stable', 'improving, or 'variable') based on the degree of LUMaR change over defined timeframes.

> **Historical trends.** For historical trends, a negative or positive change equal to, or greater than, 0.15 LUMaR for the period post 1992 was used to assign 'decreasing' and 'improving' rating categories. A change of less than 0.15 LUMaR was categorised as 'stable'. If the historical trend was erratic or highly variable over time, we assigned this as a 'variable' trajectory.
>
> **Recent trends.** For recent trends, a negative or positive change equal to, or greater than, 0.1 LUMaR for the period post 2012 was used to assign 'decreasing' and 'increasing' rating categories. A change of less than 0.1 LUMaR was categorised as 'stable'. If the historical trend was erratic or highly variable over time, we assigned this as a 'variable' trajectory.

For each LUMaR index trajectory, we also assigned a level of confidence (low, moderate, or high) in that trajectory based on its 95% confidence interval (CI), with low confidence (i.e. a higher uncertainty) in the trajectory of LUMaR index trend lines with wider CIs, long timeframe of no data collection, and lower number of LUMaR index values. Assigning a level of confidence in each LUMaR index trajectory assisted in determining which sites should be the focus of a detailed investigation to unravel the likely causal factors for the observed change. Confidence ratings were determined as follows:

- High confidence = tight (≤0.1 LUMaR) CI with potentially a high number of values (>9) within an existing rating category.
- Moderate confidence = CIs intervals ranging between 0.2 LUMaR and/or few LUMaR index values (6-8) and/or long timeframe of no data collection.
- Low confidence: large range in CI (>0.2 LUMaR) and/or few LUMaR index values (6-8) and/or big gap.

The macroinvertebrate monitoring sites were also categorised according to their dominant land-use and land-cover: forested, rural, urban, and urbanising. This classification was broad and performed by the Waterways and Biodiversity Team staff using empirical data on forest cover and imperviousness cover as well as aerial imagery showing urban areas, forest cover and other relevant land use cover.

The categories may not describe the entire complexity of land-use or land-cover that exist in the catchment of each site. For example, sites classified as urbanising may still have a substantial rural land-use. Nonetheless, these categories are not used for quantitative statistical purposes and are only used to help describe some of the key patterns we observe in each broad land-use and land-cover category.

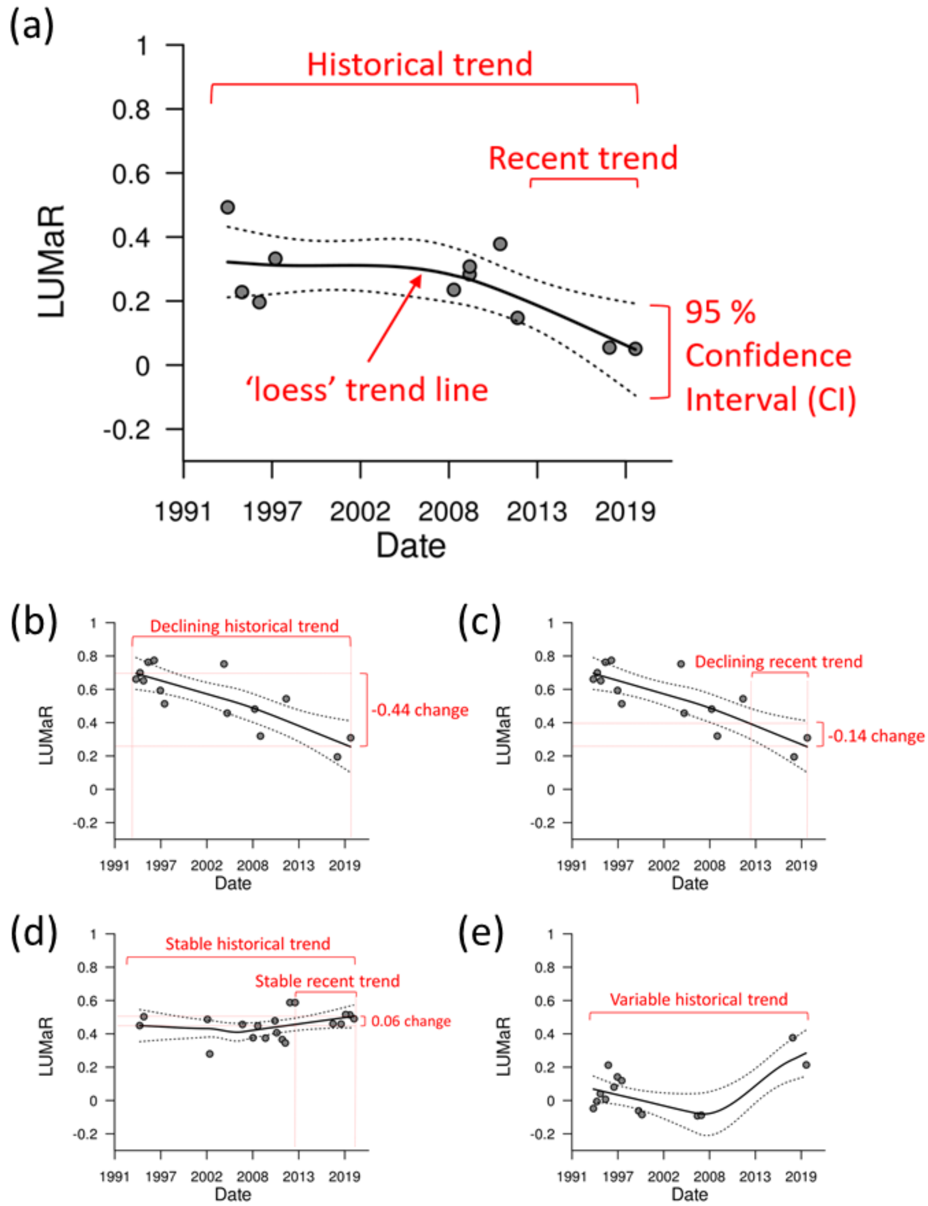

Figure 2. Illustration of how we assessed non-linear trend lines to determine sites requiring further reporting. Plot (a) shows the 'loess' trend line and its 95% confidence interval (CI) as well as the timeframe considered for historical and recent trends; (b) shows a declining historical trend; (c) shows a declining recent trend; (d) shows stable historical and recent trends; (e) shows a variable historical trend.

Habitat Suitability Models

Habitat Suitability Models (HSMs) for macroinvertebrate families have been re-run to assist in understanding whether macroinvertebrate targets are on-track or not (i.e. KEQ3a). Data on new urban development that has occurred since 2018 in stormwater priority areas, as well as interventions such as revegetation that has been implemented since 2018 and stormwater mitigation projects that have been planned or implemented since 2018, were used to update the model predictions to help to assess whether we are on track towards the long-term targets. The outputs of the updated macroinvertebrate HSMs are presented in Chee et al. (2023). Appendix 2 presents a brief overview of the models and the approach used in evaluation and in examining the effectiveness of management actions to date in Chee et al. (2023). The site-scale analysis presented in this report and the outputs of the updated HSMs were combined to categorise sub-catchments where macroinvertebrates values are declining or stable in order to answer KEQ 3a. This work is covered in more detail, including the results for KEQ 3a in HWS Science Inquiry Report (Melbourne Water, 2023a). An overview of the site and HSM assessment can be found in Appendix 3.

For the HWS in 2018 climate change was acknowledged to be a significant threat to the region alongside urbanisation. Climate change was represented relatively simplistically in the HSMs. Warming was represented by a 1.5^{0}C increase in mean annual temperature from 2016 values, capped at a maximum of 15.8^{0}C. Drying was represented by a reduction in mean annual runoff depth (equivalent to a 25% reduction in long-term mean annual discharge at the mouth of the Yarra River). These options were chosen to be broadly consistent with DELWP (2016).

Since 2018 our understanding of climate change as an increasing threat both globally and regionally has progressed significantly. The way climate change is represented in the HSMs has also improved substantially. More information on this can be found in the Habitat Suitability Model-Climate Change Technical Report (Chee et al., 2023b). Six global climate models have been utilised to explore the variety of plausible futures and these have been downscaled progressively to represent the Melbourne region.

For the Mid-term Review, two of the six models were chosen to represent the best and worst case plausible futures under two emission scenarios; medium (RCP4.5) and high (RCP8.5). The two models were ACCESS-1.0 developed by CSIRO and BoM (a hot dry model for the south of Vic) and HadGEM2-CC (a hot dry model for the majority of Victoria).

New species distribution models were run for the two models x 2 emission scenarios and the outputs of this work are presented in Habitat Suitability Model-Climate Change Technical Report (Chee et al., 2023b).

To be conservative, the macroinvertebrate model outputs for the worst case model and emission scenario (HadGEM2-CC RCP 8.5) were then used to identify sub-catchments across the region that were either most susceptible to climate change (climate change vulnerable) or were most resilient to climate change (climate change stronghold). These areas were considered important to highlight for the mid-term review and results of this analysis are presented in HWS Science Inquiry Report (Melbourne Water, 2023a). In short, however, macroinvertebrate models did not significantly change under this climate change scenario (compared with the Business-as-Usual Future, BAUF) used in 2018.

Supporting Environmental Condition data

This section describes the approach used to explain both the increasing and decreasing macroinvertebrate trends identified. It is focused on KEQ 2a. *What environmental conditions (e.g. Water quality) and external factors (e.g. policy) help explain current key value trends?*

The process for identifying and deciding on the most appropriate data sets to help explain the key value trends has evolved following analysis of the macroinvertebrate trends.

Table 4 below provides a summary of the qualitative and quantitative data used where available to help understand the macroinvertebrate trends.

Table 4. Environmental condition data, identified in the Macroinvertebrates conceptual model (Alluvium, 2017,) that have been used to help explain macroinvertebrate trends. Note: this conceptual model was produced based on published studies reporting general changes in aquatic macroinvertebrate community composition and abundance and the relationships are not specific for LUMaR.

Environmental conditions	Associated threats	Quantitative data	Qualitative data
Water quality	Urbanisation, Climate change, land clearing, ag practices, Industrial practices	Water Quality Index*, individual WQ parameters, any available sediment or toxicant data available from research programs	Expert opinion
Water regime	Over-allocation Unlicensed stock and domestic Urbanisation Climate Change	Long Term Water Resources Assessment (LTWRA), diversions data, published journal articles, flow gauge data#	Field observations (expert opinion, or from reports), map imagery imperviousness changes Existence of Stream Flow Management Plans and Environmental Water Action Plans
Vegetation	Land clearing Climate change Stock access Ag practices Bushfire Pest plants	Spatial query 6-km upstream# Attenuated forest cover 2006 and 2016**	Field observation, map imagery time series
Physical form	Stock access Land clearing Urbanisation Climate change Pest animals	Industry reports, such as from geomorphological studies	Field observations

** A measure of the amount of forest cover alongside as well as upstream of the stream segment in 2006. Laterally, attenuated forest cover is calculated as exponentially weighted overland with a half-decay distance of 35 m from the stream AND exponentially weighted upstream with a half-decay distance of 1000 m. Range = 0–1.

results of flow gauge data and spatial queries of vegetation cover was not available in time for this draft report

* The Water Quality Index (WQI), developed by EPAV, assesses key indicators of water quality against Victorian environmental quality objectives for relevant indicators in the Environment Reference Standard (2021). These are combined to calculate an overall water quality index score (WQI), corresponding to a rating of Very Poor to Very Good.

Table 5. Water Quality Index scoring categories

Water quality index score	Rating	Description
8–10	Very Good	High quality waterbodies generally not impacted by pollution
6–8	Good	Meets Victorian water quality objectives
4–6	Fair	Some evidence of stress
2–4	Poor	Under considerable stress
0–2	Very Poor	Under severe stress

The water quality indicators that make up the WQI are: dissolved oxygen, metals, nutrients (total nitrogen and total phosphorous), pH, salinity (not at estuarine sites) and turbidity. Data presented as graphs in Appendix 6 includes *E.coli* which is not part of the overall WQI and is not mentioned in the analysis as it is a recreational water quality indicator primarily.

Alongside water quality monitoring data, sediment quality and pollutant data and ecotoxicology studies have been used where data is available. Sediments in the stream form part of the habitat for macroinvertebrates they accumulate pollutants that are present in the water column. Sediment pollutants can be toxic to macroinvertebrates and, therefore, can be part of explaining the population present at a site.

In addition to environmental condition data, a summary of overall catchment changes for each site is provided. This provides an understanding of land-use changes such as urbanisation, significant disturbance events such as bushfires and drought along with any other relevant contextual information.

Evaluation process

For each site, we followed a structured process to evaluate (a) trends in the macroinvertebrate community and (b) the environmental conditions and external factors that help explain these trends.

1. For sites with enough data, we plotted 'loess' trend lines using the LUMaR index values. We also plotted 'loess' trend lines for SIGNAL2 scores.
2. Categorised both historical and recent trends as either 'stable', 'declining', 'improving, ''variable' or not assessable (Table 6).
    a. Sites that were 'declining' or 'improving and with a high or moderate level of confidence in the trend over historical timescales were selected for further investigation in this document.
    b. Sites with trend lines that were 'declining', 'improving or 'variable', but which had a low confidence in trend, were flagged as sites to 'watch'.
    c. NOTE: In the Results, trends were generally described with reference to the historical trends.

Table 6. Rubric for assessing 3b – assigning trend and determining sites to analyse further.

Status trajectory	Performance criteria / evidence
Improving – for further investigation	Improvement in LUMaR index over the historical record of >0.15 AND confidence in trend is Moderate or High
Stable	Decline or improvement in LUMaR index over the historical record of <0.15 and confidence is Moderate or High
Variable	LUMaR index is highly variable over the historical record where confidence in Low
Declining – for further investigation	Decline in LUMaR index over the historical record of >0.15 *AND* Confidence in trend is Moderate or High
Not assessable	Insufficient data for a trend line

3. For the sites selected for further investigation, we used a range of data sources to assist in a multiple-lines-of-evidence approach to uncover possible reasons for the observed trends. This approach utilised the following information:
    a. Overall catchment change - a general understanding of overarching and/or significant changes such as catchment land use or urbanisation that have occurred upstream of the site or within its upstream catchment;
    b. Family level macroinvertebrate data, as well as genus and species where available, with a particular focus on functional feeding groups. Functional feeding groups highlight the key ecological roles of taxa and can help focus attention on key environmental changes (e.g. increase in shredding macroinvertebrates may indicate

an increase of in-stream particulate organic matter in the stream and ultimately riparian vegetation);

c. Supporting environmental data, identified in the Macroinvertebrates conceptual model (Alluvium, 2017); i.e. water quality, water regime (including urbanisation), physical form, and vegetation;
d. Summarised findings into conclusions and recommendations at the site scale;
e. Considered the inferential strength and potential broader application of the findings e.g. common threats across the sites and similarities or differences for different land uses.

Limitations and uncertainties

This investigation is limited in its ability to stand alone as an assessment against the KEQ's used during the HWS mid-term review. It is an analysis of the long-term macroinvertebrate data and provides a perspective on changes over time at site scale. It is intended to be used alongside other information derived from HSMs (works and urban growth to 2022 and updated climate-change predictions) to help assess the trajectory of macroinvertebrates across the region.

The analysis draws on a blend of inductive and deductive reasoning and includes correlative / observational data, manipulative experimental data (laboratory, field), expert opinion derived through elicitation and multiple lines and levels of evidence, combining some or all of the above. Where we are not confident in the relationship, we have stated so.

We recognise that, as with any investigation, there are limitations and uncertainties related to the methods that we used and the findings we uncovered. Below, we raise these limitations and uncertainties.

LUMaR trend trajectory assessment

Biotic community trends over time are often non-linear and metrics that account for this non-linearity are therefore most appropriate for visualising trends. However, the non-linear nature of the 'loess' trend line, and the subjective nature of what constitutes a change over a defined timeframe, makes assigning trajectories for each LUMaR site trend problematic. As opposed to simple linear regression, we cannot use 'loess' regression to test whether trends are increasing or decreasing. However, to make the process of assigning change trajectories as objective as possible, we followed a structured decision-making process, as outlined in detail above, with defined LUMaR change values that specify historical and recent trends.

Spatial and temporal gaps in macroinvertebrate data

There are large periods of time in many macroinvertebrate monitoring sites where little or no data was collected. This is especially the case for a critical period during the Millennium Drought (1997-2009). It is not known why data gaps exist during the Millennium Drought period, but these gaps could exist due to no sampling because of a lack of surface water. Information on the reasons for no data collection is not systematically collated in the current database.

The recent re-evaluation of the macroinvertebrate monitoring surveillance program (Walsh, 2022) means that we have only recently taken steps to improve spatial bias and fill monitoring gaps (Figure 3).

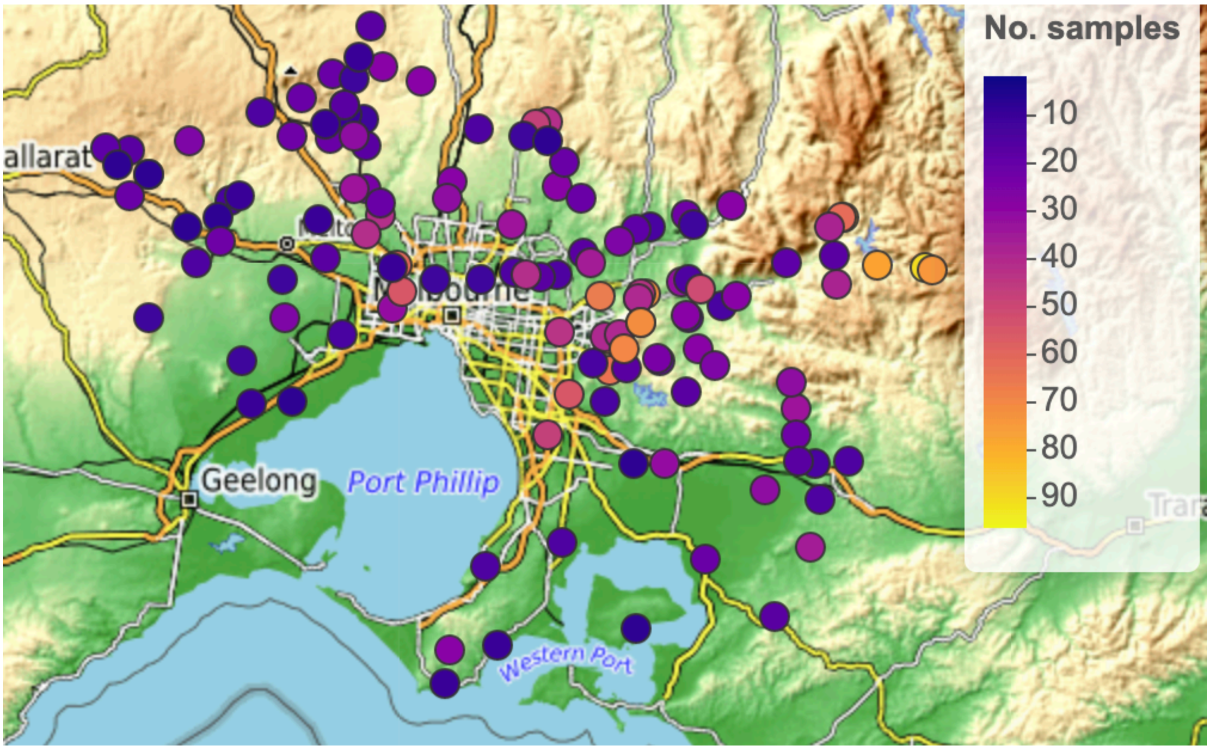

Figure 3. Distribution of sites and sample frequency of macroinvertebrate sites across the MW region (Source: macroinvertebrate database https://tools.thewerg.unimelb.edu.au/mwbugs/).

There is a noticeable spatial and sample frequency bias in the macroinvertebrate monitoring sites. In particular, sites have been sampled less frequently in western Melbourne. The reasons for this are likely diverse, but include:

- A strong precipitation gradient, leading to more intermittent surface flow in western Melbourne. This may have reduced monitoring frequency in many western sites due to a lack of surface water.
- A greater focus on intervention and other research macroinvertebrate programs, such as for Little Stringybark and Dobsons Creeks, in eastern Melbourne.
- Melbourne Water did not take over managing the Werribee (and some of the Westernport) catchment until 2007.

Scale and purpose of measurement

The macroinvertebrate monitoring surveillance program was designed to collect macroinvertebrate data to investigate responses in macroinvertebrate communities to changes in environmental gradients over long time scales (Walsh, 2022). Further, the macroinvertebrate community data was intended to complement the habitat suitability modelling. As such, we highlight that we are using the macroinvertebrate monitoring surveillance program data at a site scale and lean on general conceptual patterns, where possible, that can be transferred to other sites and larger scales.

Non-perennial flow regimes

We acknowledge that a major gap in this investigation, and of the macroinvertebrate monitoring surveillance program in general, is the poor representation of macroinvertebrate communities from sites experiencing non-perennial flow regimes. The LUMaR index, and many other macroinvertebrate metrics, do not perform well in systems that cease to flow and tend to assign lower scores in undisturbed intermittent systems compared to undisturbed perennial systems (Walsh et al, 2001).

Environmental condition and threat data limitations

The environmental condition and contextual threat data has several limitations that has prevented a more quantitative and robust approach to understanding drivers of macroinvertebrate communities. These can be summarised as:

Water quality data

Not all macroinvertebrate sites highlighted in this analysis had a nearby water quality monitoring site. The Water Quality Index works well at reporting against overall compliance with the Environmental Reference Standards (previously SEPP) it is probably not designed or well suited to detecting smaller changes over time. This is for several reasons; a) it up-weights indicator components that are significantly under-performing compared with the Environmental Reference Standards with the outcome of highlighting where significant problems occur and b) there are sub-indices within the overall index that combine similar parameters i.e. all metals are combined into a sub-index and TN and TP are also combined and sub-indices are weighted according to whether one of the subcomponents is significantly above the standards. So improvements are not likely to be detected in the overall index unless there are consistent changes across multiple parameters. This issue of an overall index masking changes in its components over time is common and simply requires that the index is used alongside all of the component data rather than as the sole source of water quality information.

Flow data

Due to limited time, the available flow gauge data was not utilised to make a more quantitative assessment of flow conditions and changes over time. For the analysis presented here, some evidence for declining flow conditions has been drawn from the Long Term Water Resources Assessment data on water availability at a catchment scale (Government of Victoria, 2020). Where possible, we also drew draw on information within Streamflow Management Plans, Local Management Rules and Environmental Watering Actions Plans. Stream flow Management Plans and Local Management Rules were generally assessed as being stronger mechanisms for managing flows because firm rules are described that triggers bans and restrictions coming into play. The Environmental Watering Action Plans generally did not provide clear indication on when firm mechanisms like bans and restrictions are triggered.

There was limited data on changes to urbanisation such as historical impervious mapping. This is being addressed with the acquisition of new data from NearMap that will soon be providing impervious mapping for 2022, 2018, 2014 data for some of the regions for 2012. Moving forward this data will be updated every 4 years.

Vegetation data

An assessment of changes to vegetation over time was very limited due to a lack of cohesive data. Available data on vegetation quality is currently based on expert opinion and does not provide a robust assessment of change over time. A new field-based method for vegetation quality has recently been deployed however data was not available in time for this assessment. Methods are also being refined for quantifying vegetation extent and a historical time series of reach scale data will be available for 2022, 2018, 2014 data for some of the regions for 2012. The current evaluation was limited to 2 time periods of data 2006 and 2016.

Physical habitat data

Qualitative assessment of the physical form at some sites was made by drawing on geomorphological studies. Often it was based on the broader catchment rather than specific site conditions. New physical form monitoring program should help to provide a more useful region-wide data set by the end-of-strategy review.

3. Results

Overview of site LUMaR trends within catchments

A total of 77 long-term monitoring sites had sufficient data (≥ 6 points in time) to investigate LUMaR trends through time (Table 15, Appendix 5).

LUMaR index trends in 70% of sites within the Werribee catchment could not yet be assessed due to limited data availability. In contrast, LUMaR index trends could be investigated at more than 55% of sites within all other catchments.

For the entire time period (historical trend 1992 - 2022), the LUMaR index for 37 of the sites had a 'stable' trend line, 6 sites had a 'variable' trend line, 14 had an 'increasing' trend line, and 20 were classified as having a 'declining' trend line (Table 15, Appendix 5). One of the 55 sites classified as 'not assessable' did, in fact, have enough data for a trend line, but all the sample points were collected in the last decade, and only recent trends were evaluated.

A greater number of sites (51) were classified as 'stable' when only recent (last 10 years) LUMaR index data was assessed (Table 16, Appendix 5). For this recent assessment, 12 sites were classified as 'increasing', 15 as 'declining' and 54 as 'not assessable'.

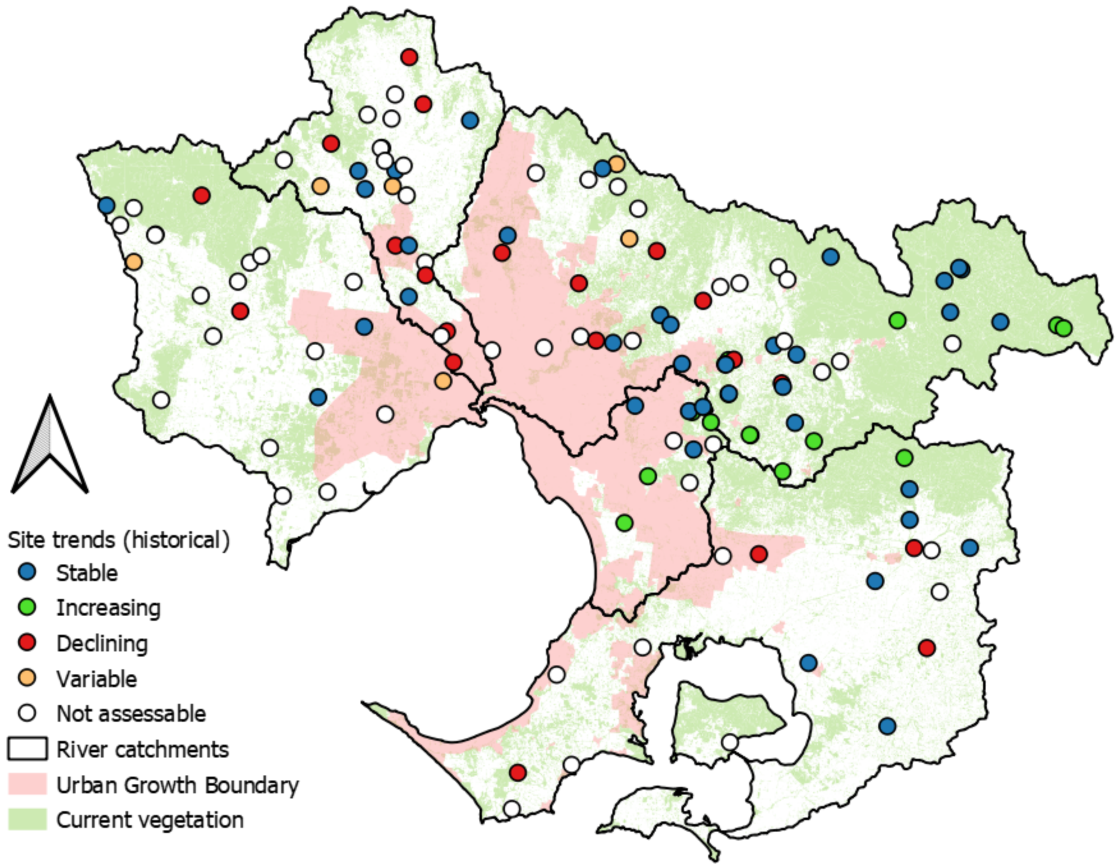

Figure 4. Map of distribution of macroinvertebrate monitoring sites and their corresponding trend assessment. Assessable sites in each catchment over the historical period: Werribee 7, Maribyrnong 15, Yarra 37, Dandenong 7, Westernport 11.

Yarra catchment

75% of assessable sites within the Yarra catchment were ‘stable’ or ‘increasing’, with seven ‘declining’ and two with a ‘variable’ trend (Figure 5, Table 15, Appendix 5).

The relatively large proportion of ‘stable’ or ‘improving’ trends may be because the Yarra catchment has the largest number of monitoring sites located in largely forested and rural catchments (Figure 5). Only 14 sites are regarded as being within largely urban or urbanising areas (Figure 5). Four of the five mainstem Yarra River monitoring sites had ‘stable’ or ‘declining’ LUMaR trends. The only mainstem Yarra River monitoring site that has an ‘‘improving’ LUMaR trend is the most upstream site that is unimpacted by urbanisation.

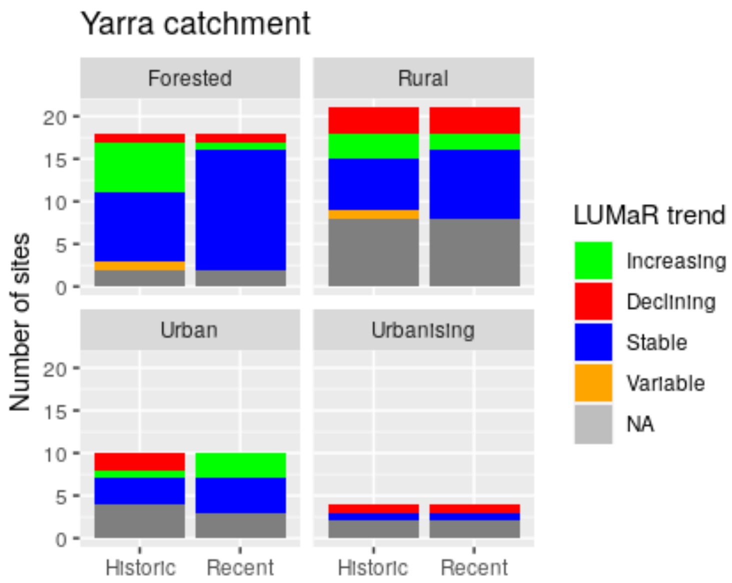

Figure 5. Number of macroinvertebrate sites in the Yarra catchment in each historical and recent trend category (increasing, declining, stable, variable, NA=not assessable) within broadly defined land-use and land-cover categories.

Dandenong catchment

Of the sites that could be assessed, LUMaR index trends at all sites within the Dandenong were either classified as ‘stable’ or ‘increasing’ (Figure 6). Except for one largely forested site, all sites that could be assessed were situated in largely urban parts of the Dandenong catchment (Figure 6). Most of these urban sites, particularly in the middle and lower parts of the catchment, were rated as having a ‘Very low’ or ‘Low’ macroinvertebrate score at the start of the HWS due to high levels of urbanisation and channel modification, which has impacted many of the environmental conditions. All mainstem Dandenong Creek monitoring sites had ‘stable’ or ‘increasing’ LUMaR trends.

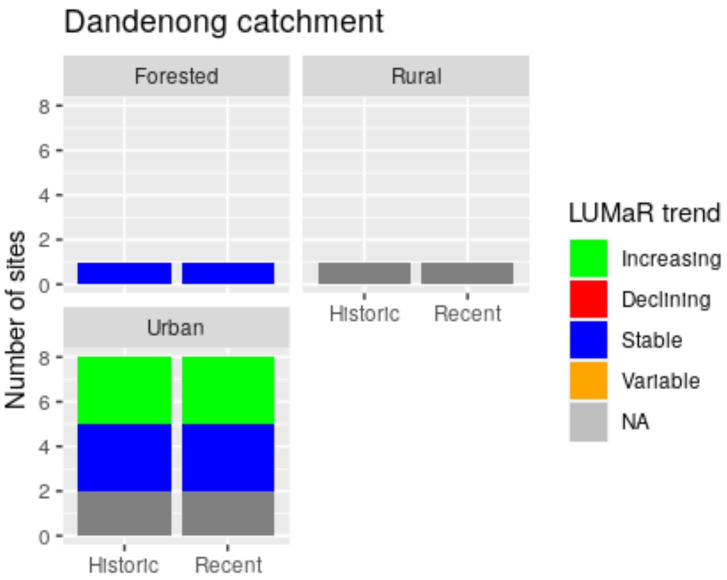

Figure 6. Number of macroinvertebrate sites in the Dandenong catchment in each historical and recent trend category (increasing, declining, stable, variable, NA=not assessable) within broadly defined land-use and land-cover categories.

Westernport catchment

In the Westernport catchment, most assessable sites had LUMaR index trends classified as 'stable', with one site having an 'increasing' trend and four sites classified as 'declining' (Figure 7). Most sites in the Westernport catchment are in largely rural areas, with only one site within a forested area (Figure 7). Of the three sites within urban and urbanising parts of the Westernport catchment, only one site could be assessed and was categorised as 'declining' over the historical time scale (Figure 7). Mainstem Bunyip River sites had 'stable' or 'declining' LUMaR trends over historical timescales. All assessable mainstem Lang Lang River and Tarago River sites had 'stable' or 'declining' LUMaR trends over historical timescales.

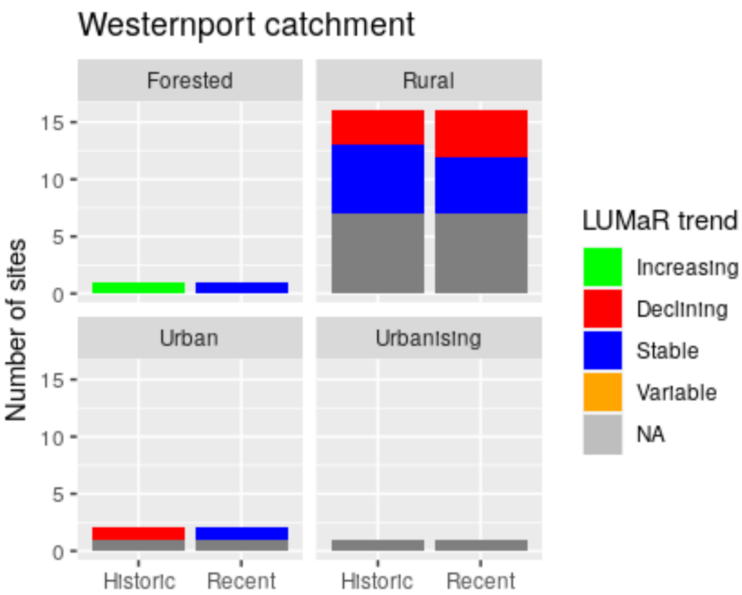

Figure 7. Number of macroinvertebrate sites in the Westernport catchment in each historical and recent trend category (increasing, declining, stable, variable, NA=not assessable) within broadly defined land-use and land-cover categories.

Werribee catchment

No sites within the Werribee catchment had sites where LUMaR index historical trends were classified as ‘increasing’ (Figure 8). The urban and urbanising sites that could be assessed had stable or variable trends (Figure 8). One forested site and one rural site had ‘declining’ trends (Figure 8). No mainstem Werribee River, Lerderderg River, or Kororoit Creek sites had LUMaR trends that were ‘increasing’ on historical timescales.

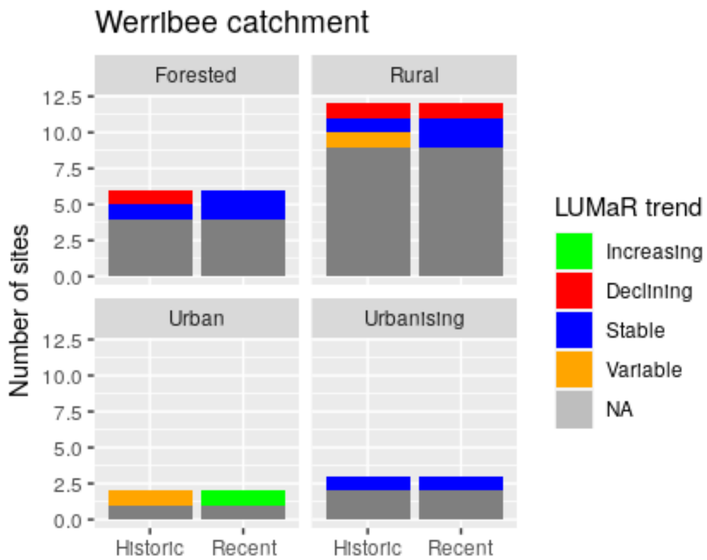

Figure 8. Number of macroinvertebrate sites in the Werribee catchment in each historical and recent trend category (increasing, declining, stable, variable, NA=not assessable) within broadly defined land-use and land-cover categories.

Maribyrnong catchment

No sites within the Maribyrnong catchment had sites where historical LUMaR trends were classified as ‘increasing’ (Figure 9). One largely forested site, four urbanising, and two urban sites were classified as ‘declining’ (Figure 9). All mainstem Maribyrnong River and Deep Creek sites had ‘declining’ LUMaR trends over the historical time period.

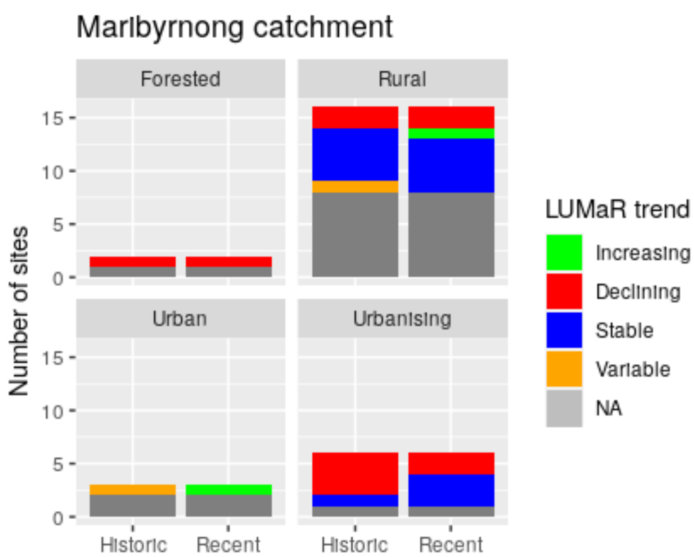

Figure 9. Number of macroinvertebrate sites in the Maribyrnong catchment in each historical and recent trend category (increasing, declining, stable, variable, NA=not assessable) within broadly defined land-use and land-cover categories.

Sites for detailed investigation

Fifteen sites were selected for detailed investigation based on criteria outlined in Figure 10. As described above (in Methods - Evaluation process), these sites were selected because they had ‘declining’ or ‘increasing’ LUMaR trends for which there was a high or moderate level of confidence associated with the trend over the historical time scale.

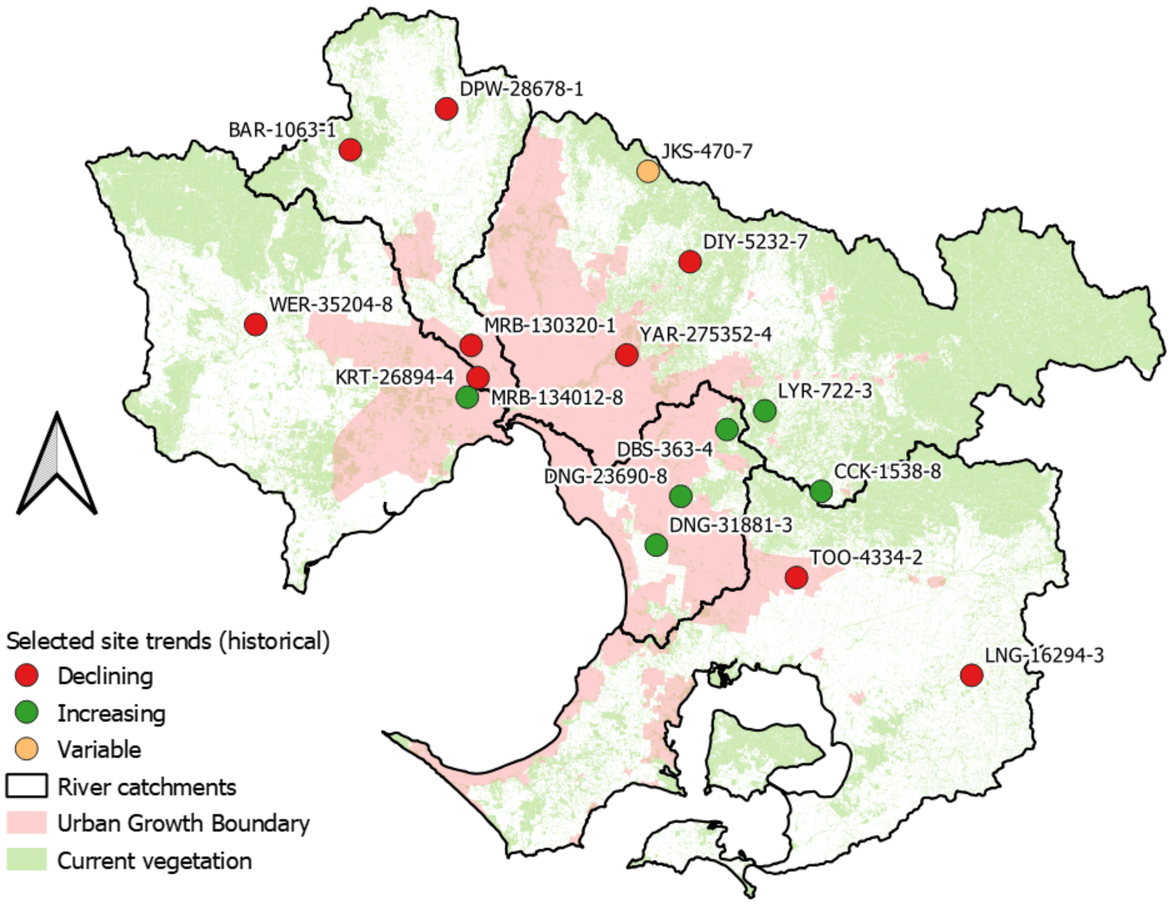

Figure 10. Macroinvertebrate sites which contained moderate or high confidence LUMaR trends that were selected for investigation into casual factors to explain trends (ie KEQ2a).

Yarra

LYR-722-3: Lyrebird Gully Creek (Olinda Creek sub-catchment)

Site description

Lyrebird Gully Creek is located downstream of Olinda Road, Olinda, and was first sampled for macroinvertebrates in 1994. It is located in a forested catchment of the Dandenong Ranges, though there is some urbanisation upstream of this site. The creek is a tributary of Olinda Creek and is not impacted by the Silvan Reservoir. This location is known habitat for Dandenong Ranges Amphipod, listed as threatened under the Flora and Fauna Guarantee Act (1988).

Figure 11. Aerial image of location of LYR-722-3 Lyrebird Gully Creek macroinvertebrate sampling location and its upstream catchment area. Headwaters are shown in white, tributaries in teal.

Photo 1. Photo of LYR-722-3: Lyrebird Gully Creek (Olinda Creek subcatchment)/

Site trend and indicators of change

The LUMaR index at Lyrebird Gully Creek has steadily increased since monitoring began in the early 90's. The stream was severely affected by the Millenium Drought (1997-2009), with records of complete surface-flow cessation in 2007, 2008, and 2009. While LUMaR index values did drop during the drought, this did not affect the long-term positive site trajectory. In 2012, the Olinda Golf Course, which held a significant diversion license, was closed. It is possible that water regime and potentially water quality improvements since the golf course closure may have supported the recovery of macroinvertebrate conditions following the end of the drought. The SIGNAL2 score trend shows lower values during and toward the end of the Millenium Drought but a weak positive trend from 2010 onward.

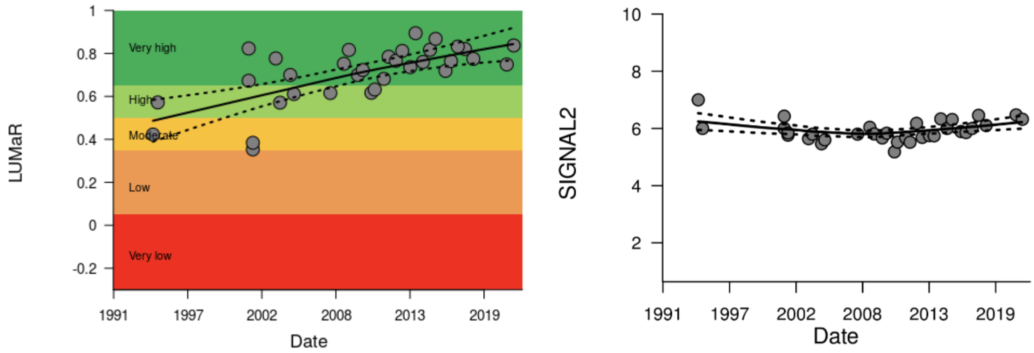

Figure 12. The (left) LUMaR index values (grey dots) and (right) SIGNAL2 scores (grey dots) for Lyrebird Gully (LYR-722-3). The trend line (solid line) and 95 % confidence intervals of the trend line (dashed line) are also displayed.

Overall catchment changes

This is one of the forested sites in the macroinvertebrate network and no significant changes in the upstream catchment have occurred in either forest cover or urbanisation over the period of record. Directly Connected Imperviousness (DCI) is recorded as 0 for this catchment and is not expected to increase in the future. The Millennium drought is likely to have impacted this site as streamflow is spring-fed and irrigation licenses exist. The Olinda Golf Course closed in 2012 which reduced water take from the creek for irrigation until 2018 when the license was transferred to Parks Victoria and proportionally reduced overall. Parks Victoria has not been recorded to have used much of their allocation since 2018, so overall, the pressure from extraction is currently low.

Macroinvertebrate community

The overall improvement in LUMaR at Lyrebird Gully Creek, while encouraging, potentially oversimplifies some of the complexities of drought impacts and recovery.

During the drought, two species of amphipods completely disappeared from this site following complete surficial drying of the stream. *Paramoera fontana (*Pontogeneiidae*)* returned to the stream 12 months after flow resumed. However, *Austrogammarus australis* (Paramelitidae) - Dandenong Ranges amphipod*,* a species listed as vulnerable in the Flora and Fauna Guarantee Act (1988), has not yet returned to the stream, despite being present in upstream environments. Previously this species is recorded as being distributed across this area of the catchment (Papas and Crowther, 2007, Figure 13).

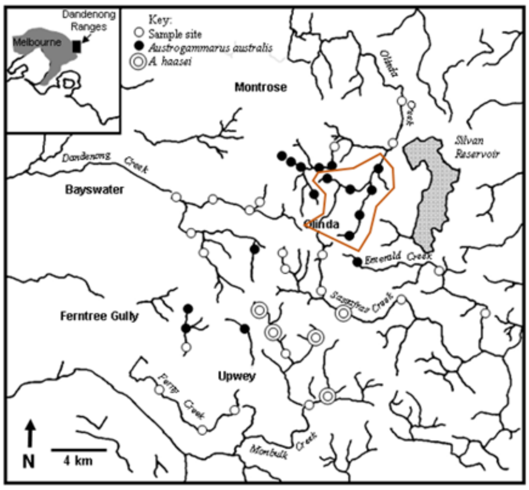

Figure 13. Map of historic distribution of vulnerable amphipod species taken from Papas and Crowther, 2007. Polygon shows area of the map corresponding to the catchment upstream of LYR-722-3.

It is possible that the decrease in amphipod abundance created niche space for other species to occupy. Supporting this theory is an increase in the abundance and continued presence of other shredder and scraper taxa, including from the families Ptiloactylidae, Psephenidae, and Ceratopogonidae. The continued presence of taxa from these families may be one of the reasons for sustained high LUMaR scores post-drought. Though no specific study has been done to date, it is thought that the Dandenong Ranges amphipod is unlikely to disperse easily, so re-establishing this species in this catchment via translocation intervention undertaken in non-drought years may be a potential management option *(Tsyrlin, pers comm).* A recent study on *Austrogammarus sp.* distribution by Tsyrlin and Carew (2022) did not appear to resample this site but does generally conclude that *Austrogammarus australis* distribution has not changed substantially across the Dandenong Ranges.

Water regime

A supra-seasonal drought affected Lyrebird Gully Creek, like many other catchments in the region, between 2001 and 2009. This drought resulted in reduced flows and, unusually for this normally perennial stream draining wet eucalypt forest, culminated in the complete surficial drying of the streambed in the early autumns of 2007, 2008, and 2009 (Imberger et al. 2016).

Stream flow in the Olinda Creek was not monitored consistently until 2004, some years into the drought period. Melbourne Water set out specific restriction levels for the Olinda catchment as a part of its Drought Response Plan review in 2004. Bans were triggered when flows dropped below 6ML/day (winter) and 4.5ML/day (summer) at a gauge significantly downstream of the macroinvertebrate site, in Mount Evelyn. The first Olinda Creek Water Supply Protection Area Stream Flow Management Plan (Olinda Creek SFMP, Melbourne Water, 2007) was approved in 2007 that detailed a range of restrictions as well as the bans listed above. As part of a regular review process, the Olinda Creek SFMP was reviewed and amended in 2018 to incorporate new information (Melbourne Water, 2018).

Estimates of the water use by licenced diverters since 2007 indicate a large proportion of licences in the catchment are inactive. If, through trade or changing circumstances, these licences become active, there will potentially be more water diversion pressure on the creek.

Hydrological models were created in 2013 to model how much the flows in Olinda Creek differed from the natural flow regime. The model suggests that current flows are similar to the natural flow regime, and for most of the time, current water harvesting practices have little if any effect on flow in the upper reaches of Olinda Creek. However, an analysis of low flows shows that flows less than 5 ML/day do occur more frequently in the summer months (December to March) under current conditions compared to natural conditions (SKM, 2013).

Historically, two irrigation licenses existed in this catchment totalling 18ML for the Olinda Golf Course and the Parks Victoria Rhododendron Gardens. Examination of the metered data taken by these licenses indicates that there was harvesting from the creek during the drought years on record, though the cap was never reached. Despite restrictions coming into play during this time, harvesting is likely to have put significant pressure on creek flow that contributed to the contraction of the amphipod species range.

The Olinda Golf Course closed in 2012 and data suggests that it stopped using its irrigation allocation in 2009. In 2018, the Golf Course license was traded to Parks Victoria and reduced overall by 20% so the new upper allocation for this catchment area is now 16.6 ML. The unlicensed forms of water harvesting for stock and domestic use and farm dams may also have contributed to local pressures during that drought period that particularly impacted amphipods.

The recently updated Environmental Water Action Plan (EWAP, Melbourne Water, 2021) for Olinda Creek identifies actions to address the potential impact of water extraction on the observed decline in threatened species and acknowledges that the current bans and restrictions in place may not be sufficiently protective.

Investigate impacts of surface water extractions on flow in Lyrebird Creek and determine if bans on extractions could be developed that would prevent cease to flows under dry conditions. Determine if restriction and ban rules in the Olinda Creek SFMP will also protect flows in Lyrebird Creek.

Additionally, there are performance objectives in the HWS for this sub-catchment relating to the protection of the low flow water regime

Identify and implement opportunities to reduce the key threat of summer low flow stress by addressing causal factors such as water for domestic and stock uses, climate change, diversions or urbanisation.

In summary, there appear to be actions in place to protect low flows in the upstream portion of the Olinda Creek catchment for the protection of threatened species. However, until a better understanding of how to protect Lyrebird Gully Creek is developed, the full license allocation, coupled with potential unlicensed stock and domestic use in this area of the catchment is a potential threat.

Vegetation

Aerial time series data (1984-2020, data not shown) shows no evidence of significant clearing occurring anywhere in the areas depicted in Figure 14.

Vegetation quality is rated as high along this reach (level 4 Vegetation Visions), although confidence in the score is low. Attenuated forest cover along this reach was 98.8% in 2006 and 2016.

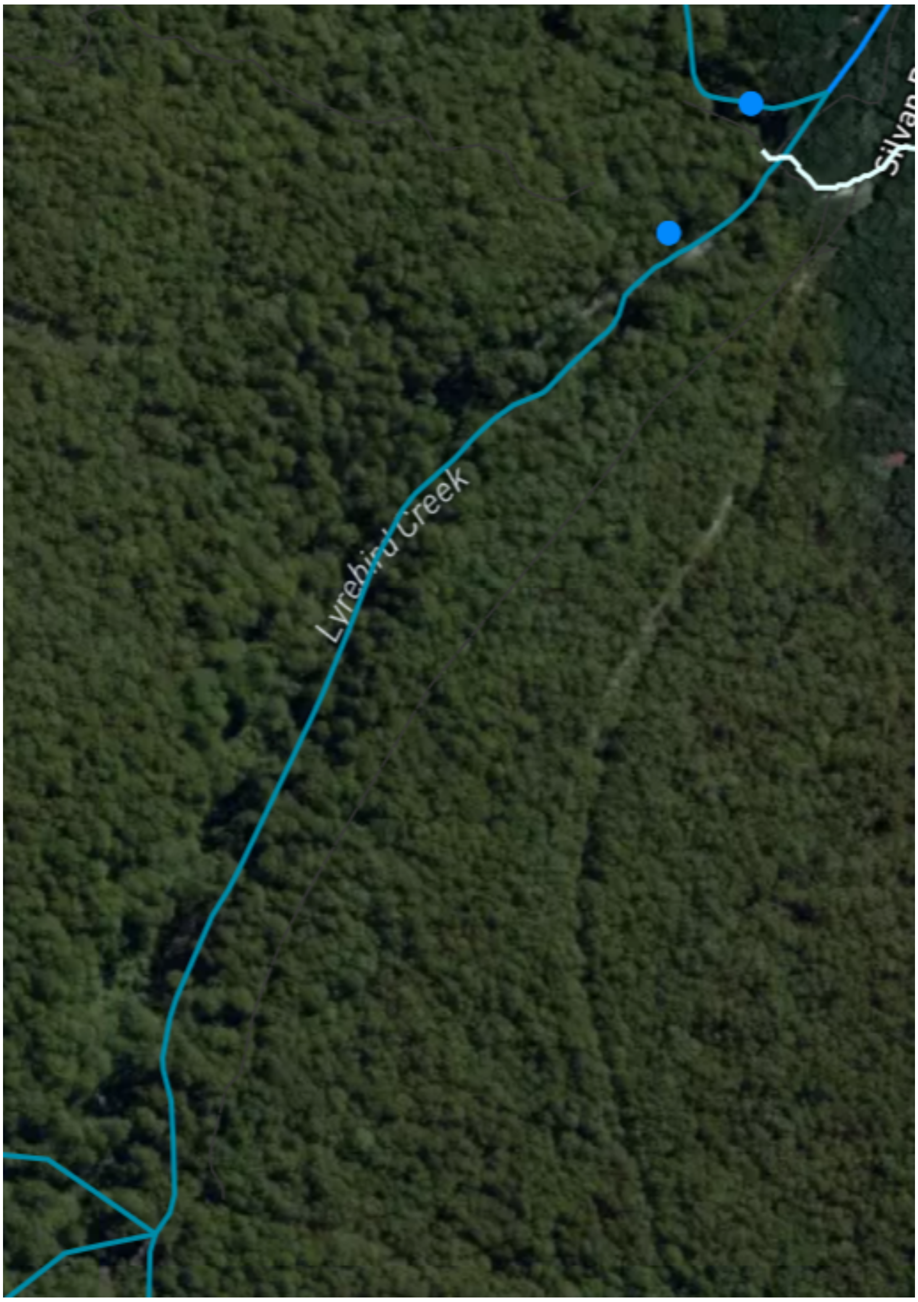

Figure 14. Macroinvertebrate monitoring site location and upstream reach (aerial image is from OpenStreetMap 2021).

Water Quality

No water or sediment quality data is available for this location from the Melbourne Water monitoring programs. Generally, similar sites in the Dandenong Ranges have elevated total nitrogen and total phosphorus compared with Environmental Reference Standards and, moderate to good dissolved oxygen (DO), low salinity, and generally low turbidity.

There are potential sources of nutrients in the catchment near Olinda township due to the presence of septic tanks, grey water discharges and local stormwater. Similarly, there may have been some improvement in water quality (nutrient and pesticides) since the closure of the Olinda Golf Course in 2012. However these statements are purely speculative without actual data but do indicate that water quality investigations may be required at this location.

Aerial time series data (1984-2020, data not shown) shows no evidence of significant development that would indicate the potential for bifenthrin to be of concern. Bifenthrin is toxic to amphipods at low levels (Pettigrove, *pers comm*). This location could be further investigated to rule out the presence of very low level pesticides as a barrier to the recolonization of Dandenong Ranges amphipod. No sediment quality data has been collected in the nearby catchment to assist with our analysis.

Physical form

Information about the physical form of the creek was not available at the time of this evaluation.

Conclusion and recommendations

There has been an overall increase in LUMaR and SIGNAL2 at this site despite the decline of listed vulnerable amphipod species, possibly due to the rise of other species that occupy the same niche.

Recommendations for consideration:

- Installation of a gauge in the upstream part of the catchment – for Implementation Inquiry Report
- Prioritise this area for investigation by A3P for evidence of very low level pesticide pollutants – for Implementation Inquiry Report
- Prioritise the actions in the EWAP outlined above to consider whether the Olinda Creek SFMP bans and restrictions are sufficient to protect the Lyrebird Gully Creek catchment. This would be good to do now to inform future drought years.
- Investigate the potential for re-establishing the Dandenong Ranges amphipod population by translocation. This could be considered in the broader context of considering the potential of translocation as a management tool to be used after significant disruptions such as drought and bushfire.
- Develop a threatened species monitoring program, acknowledging that indexes don't always tell the story of particular species

DIY-5232-7: Diamond Creek (Tributary of Yarra) (Diamond Creek (Rural) sub-catchment)

Site description

The Diamond Creek site is located at the end of Marriot Lane, St. Andrews, within the Diamond Creek (Rural) sub-catchment, and was first sampled for macroinvertebrates in 1994. This sub-catchment is considered to be mostly rural with forested headwaters and some minor urban influence (Figure 15).

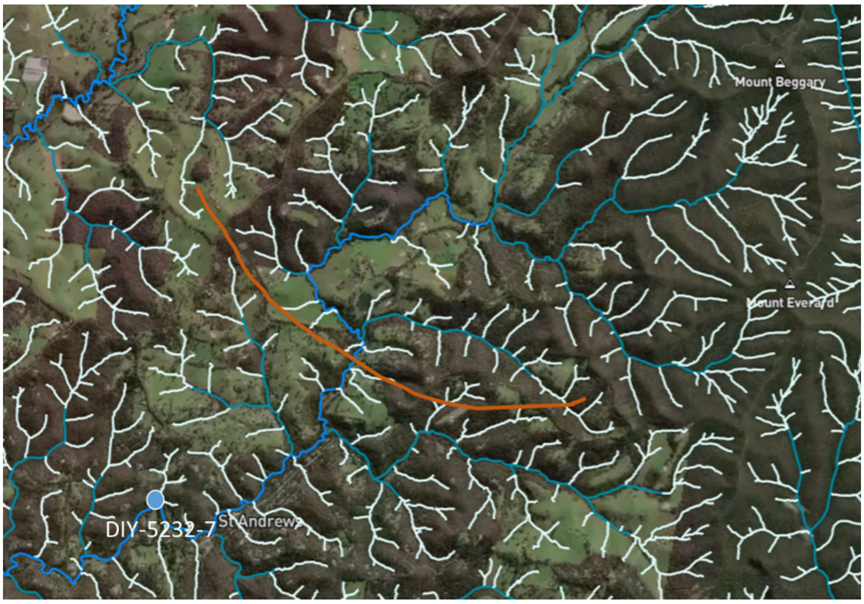

Figure 15. Aerial image of location of DIY-5232-7 Diamond Creek macroinvertebrate sampling location and its upstream catchment area. The approximate position of the fire front is shown in orange. Headwaters are shown in white, tributaries in teal and main creek in blue.

Photo 2. Photo of DIY-5232-7: Diamond Creek (Tributary of Yarra) (Diamond Creek (Rural) sub-catchment).

Site trend and indicators of change

The LUMaR score at Diamond Creek has seen a steady decline since monitoring began in 1992. However, there is some uncertainty in this negative trend, with only seven monitoring occasions, relatively few samples collected in recent years and large 95% confidence intervals associated with the last decade. While the SIGNAL2 trend line is less variable over time, there is a decline in SIGNAL2 score from ~5 to ~3 over a three-decade period (Figure 16).

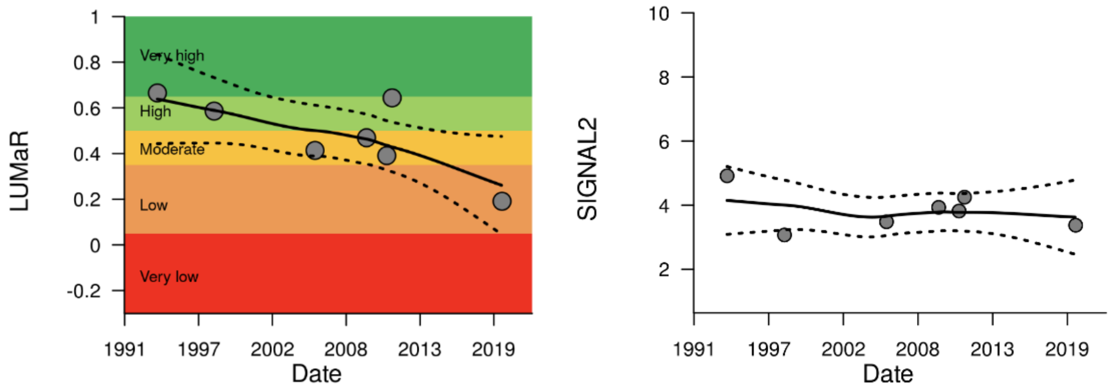

Figure 16. The (left) LUMaR index values (grey dots) and (right) SIGNAL2 scores (grey dots) for Diamond Creek (DIY-5232-7). The trend line (solid line) and 95 % confidence intervals of the trend line (dashed line) are also displayed.

Overall catchment changes

The upstream headwaters of the Diamond Creek were impacted significantly by the bushfires in 2009 and the fire front came within a few kilometres of the sampling point (see Figure 15Figure). The catchment land use does not appear to have changed significantly.

Directly Connected Imperviousness is recorded as 0% and is not expected to increase.

Macroinvertebrate community

Overall, there is no consistent patterns in the loss of macroinvertebrate taxa at Diamond Creek. The negative LUMaR index trend is likely driven by a general loss of macroinvertebrate taxa and not related to changes in specific families or representative groups. For instance, while some EPT families were absent in the most recent sample, and are partly responsible for this low LUMaR score, many of these EPT families have also been absent in previous samples.

Water regime

No detailed data on flow has been examined for this location. However other forms of published evidence on the existing flow regime in Diamond Creek have been used to develop an understanding of the condition over the macro trend time frame.

The Long-term Water Resource Assessment (LTWRA) (Victorian Government, 2020) mentions that management of waterways that do not have environmental entitlements, such as the Diamond Creek, have actually declined in their provision of environmental flow components over time, even with the protections of the Central Region Sustainable Water Strategy (CRSWS) and the Diamond Creek Local Management Plan (2016) in place (Figure 17).

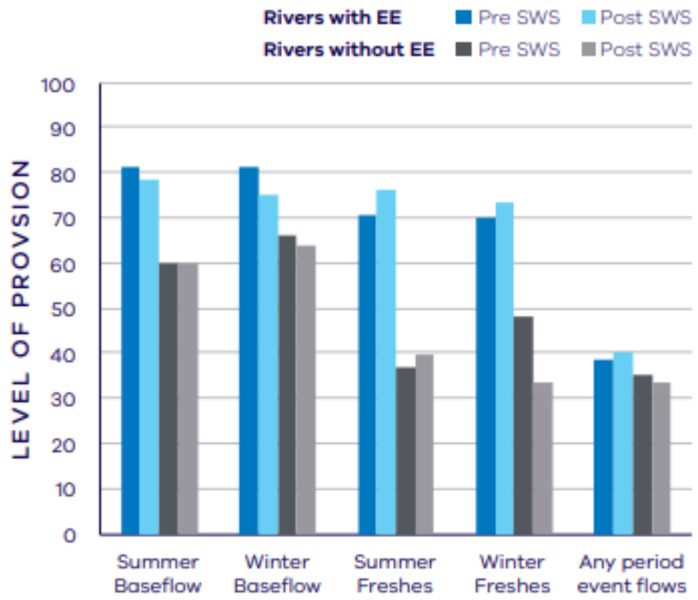

Figure 17. Average change in provision of ecologically important flow components in rivers with environmental entitlements (EE) and without pre SWS (1975 – 2006) and post SWS (2007 – 2018) (graph sourced from LTWRA). Y axis is % provision of the flow component.

The Diamond Creek Local Management Plan (Melbourne Water, 2016) outlines the following:

A range of diversions including surface water extractions, domestic and stock use, groundwater bores and water harvested from farm dams can reduce streamflows. Melbourne Water's assessment has shown that diversions have changed the hydrology in the catchment in the following ways:

1. The long-term statistics indicate that the development of water resources within the catchment has decreased the median flow of Diamond Creek by between 44% and 64%.

2. Water resources development within the catchment has had the most profound effect on the median daily flows during the low flow season. The median daily flow has been reduced by up to 50% between January and April but the median daily flow has only been reduced by 10% over the winter months (Wealands et al, 2009).

It also quotes studies conducted in the catchment to estimate the impact of unlicensed farm dams:

- *The total volume of domestic and stock dams (un-licensed in 2013) is approximately 2,693 ML. This represents a significant increase (264%) over the last decade as a previous estimate found the volume of water held in stock and domestic dams to be 740 ML in the year 2000 (RMCG, 2013)*
- *It is estimated that farm dam use is more than 100% of the sustainable diversion limit in the majority of the catchment.*
- *Dam storages account for 12% of runoff in this sub-catchment*.

Performance objectives in the HWS are in place to try to protect the natural flow regime in the creek, and the environmental values:

- *Identify and implement opportunities to maintain or improve flow regime in refuge reaches to support in stream values and platypus populations. Reduce key threat of summer low flow stress* *by addressing causal factors such as water for domestic and stock uses, climate change, diversions and urbanisation.*

Regrowth in the upstream catchment that occurred after the 2009 bushfires could also be contributing to the reduction in stream flows, and in combination with increased farm dams and climate change, it seems plausible that reduced stream flows could be a significant factor that has contributed to the decline in macroinvertebrates in Diamond Creek.

Vegetation

An examination of time-lapse imagery over the period 1984-2020 (data not shown) does not show a detectable change in land clearing or revegetation (other than what is likely to be natural post-bushfire regeneration).

Vegetation quality along this reach is medium (i.e. level 3 vegetation vision score). There has been no change to the extent of vegetation with attenuated forest cover along this reach at 69.8% in 2006 and 2016.

Figure 18. Macroinvertebrate monitoring site location and upstream reach (aerial image is from OpenStreetMap 2021).

Water quality

There are no long-term water quality monitoring location in the immediate vicinity, but there is a location downstream in Cottles Bridge (Figure 19).

Figure 19. Map showing relative location of Macroinvertebrate site DIY-5232-7 (in blue) and water quality monitoring site YADIA0068 (in purple).

Water quality data collected here since 2000 shows poor overall compliance with the Environmental Reference Standards (Figure 20), most of which is driven by low dissolved oxygen and high turbidity (Figure 21).

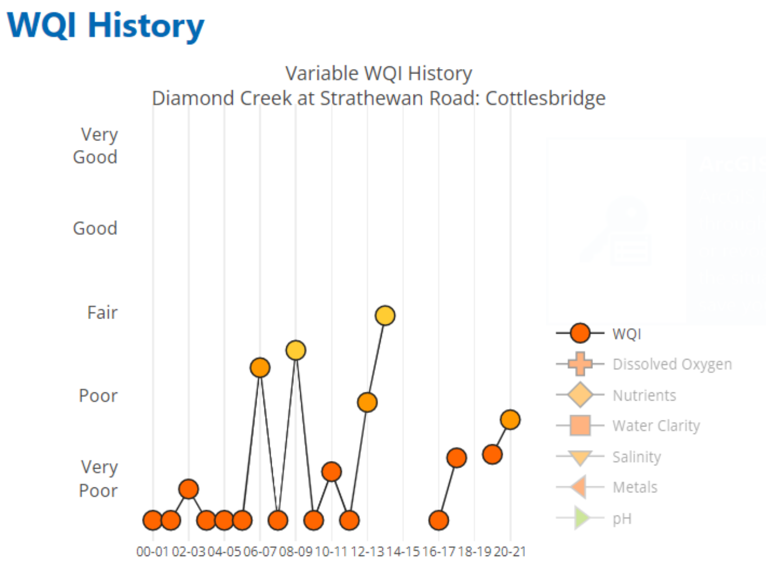

Figure 20. Graph of Water Quality Index (WQI) for YADIA0068 Diamond Creek at Strathewan Rd Cottles Bridge between 2000 and 2021 showing overall compliance is poor to very poor. No significant decline over time is detected.

High turbidity was frequently recorded in the 18 months immediately after the 2009 bushfires as the groundcover in the upstream catchment was regenerating and erosion run-off was high (Figure 21). Dissolved oxygen levels are poor at this location, probably as an overall indication of low flow conditions prevailing for significant periods each year (Figure 21). Generally speaking, other water quality parameters are average for rural areas of the catchment; elevated nutrients and relatively good metals scores. Notably, there was a period in 2005 when chromium and cadmium levels were quite high at this site (data shown in Site 1, Appendix 6).

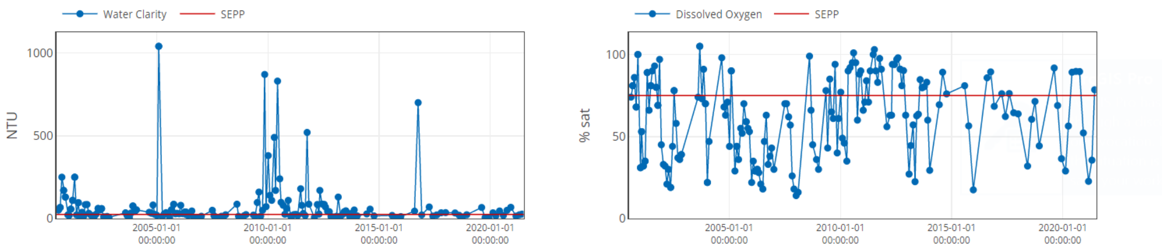

Figure 21. Water clarity and Dissolved Oxygen data for YADIA0068 showing poor compliance with Environmental Reference Standards and particularly poor turbidity for the period in the 18 months after the fires in 2009. Red line indicates the Environmental Reference Standard for this area of the catchment.

Recent sediment quality and pollutant investigations in St Andrews detected low levels of metals, the pesticides atrazine and simazine at low levels and paracetamol was commonly detected indicating septic tank impacts (Keller and Pettigrove, *pers comm*). On balance there were not a lot of additional pollutants detected in quantities high enough to be impacting macroinvertebrates significantly.

Overall water quality at this location has been consistently poor and has demonstrated no significant decline of the period corresponding to macroinvertebrate decline.

Physical form

Information about the physical form of the creek was not available at the time of this evaluation.

Conclusion and recommendations

In summary, the strongest lines of evidence to explain the decline in macroinvertebrates over time in Diamond Creek are likely to be related to changes in the flow regime. The median flow of Diamond Creek has decreased by between 44% and 64% and is likely related to increased water resource development in the catchment. Increased farm dams, over allocation in the catchment, regrowth of the upstream forested areas since the 2009 bushfires and climate change are all likely to be contributing to the change. Water quality data is consistently poor further downstream, particularly for turbidity and dissolved oxygen and this is likely to also be impacting macroinvertebrate communities. However, water quality does not show a particular decline over the timeframe since 2000.

Recommendations for consideration: Investigate the decline in macroinvertebrates over time in Diamond Creek and the relationship to changes in the flow regime. Investigate the relative pressures coming from increased farm dams, over allocation in the catchment, regrowth of the upstream forested areas since the 2009 bushfires and climate change as likely contributions to decline. We recommend issues regarding diversions and farm dams in the Diamond Creek catchment be a priority area addressed in more detail as part of the Implementation Inquiry.

CCK-1538-8 Cockatoo Creek (Woori Yallock Creek sub-catchment)

Site description

Cockatoo Creek downstream of Brisbane Road bridge in Cockatoo was first sampled for macroinvertebrates in 1994. Its catchment is predominately rural (Figure 22).

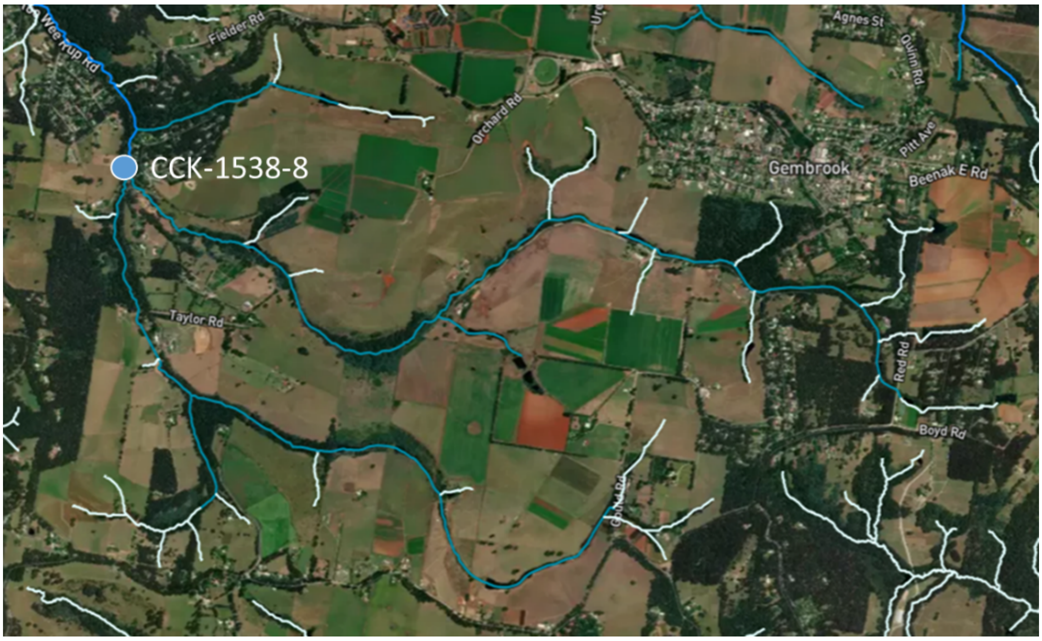

Figure 22. Aerial image of location of CCK-1538-8 Cockatoo Creek macroinvertebrate sampling location and its upstream catchment area. Headwaters are shown in white, tributaries in teal.

Photo 3. Photo of CCK-1538-8 (Woori Yallock Creek sub-catchment).

Site trend and indicators of change

The LUMaR index trend line and the SIGNAL2 trend line at Cockatoo Creek show a positive trend over time (Figure 23). The survey points are clustered in time, with the first four points having a lower LUMaR score than the more recent two samples –the positive trend line is driven by these two recent points. There is a high degree of uncertainty associated with this positive trend line due to the small number of points (6) and a large gap in time of no sampling (1997 – 2012).

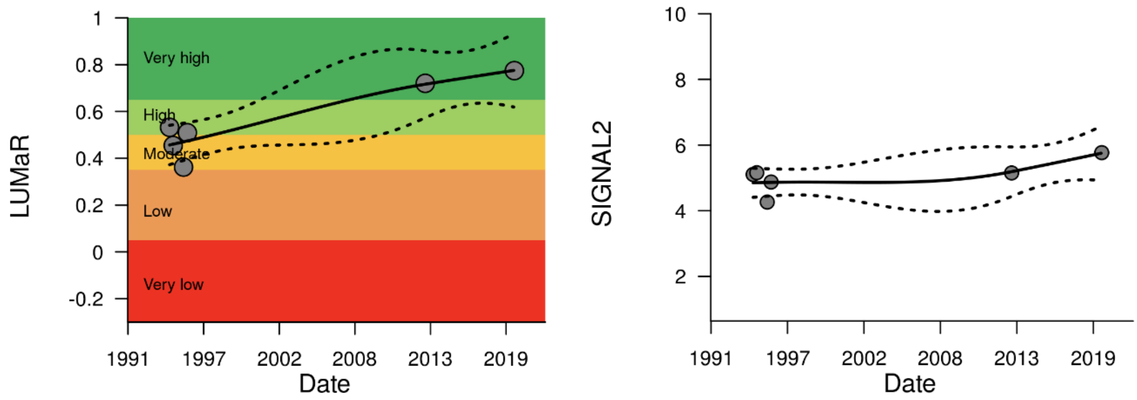

Figure 23. The (left) LUMaR index values (grey dots) and (right) SIGNAL2 scores (grey dots) for Cockatoo Creek (CCK). The trend line (solid line) and 95 % confidence intervals of the trend line (dashed line) are also displayed.

Overall catchment changes

Directly Connected Imperviousness (DCI) was very low (0.04%) at the beginning of the HWS and is predicted to increase to 0.62% (unless adequately managed) with future development around Gembrook. There is evidence of a shift in the type of agriculture in the catchment away from potato farming and market gardening towards greater large-block residential life-style development.

Macroinvertebrate community

The increase in LUMaR index over time can be explained by an increase in the number of macroinvertebrate taxa collected at Cockatoo Creek. Samples collected in 2013 and 2019 have a greater number of Diptera, Odonata, and Trichoptera families than were recorded prior to 1997. Ecologically, this points to an increase in overall stream condition over time, including the presence of predator taxa. The increase in shredders and scrapers potentially indicates greater coarse particulate organic matter (CPOM; leaves, twigs, etc) in the stream.

Water regime

The Woori Yallock sub-catchment is a productive rural area that has a large number of diversion licenses that service the needs of stock, horticulture and grazing industries. The Cockatoo Creek catchment area upstream of our macroinvertebrate site is particularly dense with irrigation licenses (Figure 24, Woori Yallock SFMP, 2012).

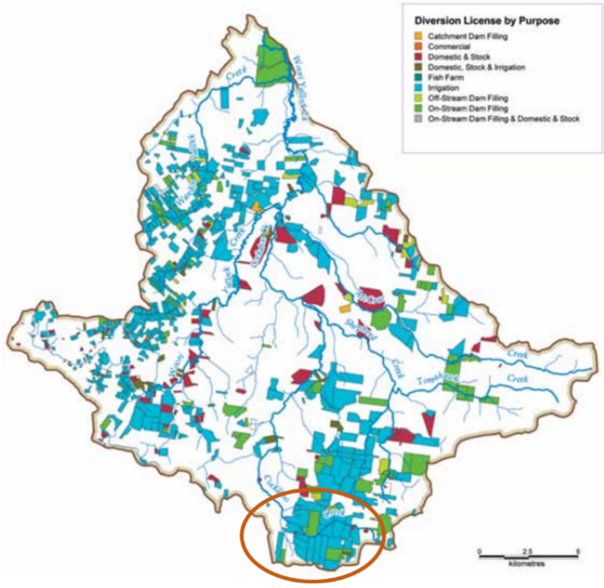

Figure 24. Map of the Woori Yallock sub-catchment showing the density of irrigation licenses in the catchment area upstream of CCK-1538-8 (orange line).

Examination of the license data collated between 2005 and 2020 (data source MW, data not shown) indicates there are 31 licenses in this area for a total allocation of 620ML/year. Of this total allocation, over 60% have not been used recently (sleeper licenses) or have temporarily been traded downstream. This is an increase from the 2005-2009 period when only 28% of licenses were inactive. The number of large licenses in the catchment used to irrigate either market gardens or potatoes has also declined over time. Today there are only 3 active large licenses (25ML/yr or greater) whereas in the 2004-2009 period there were 12. Overall, this could indicate a reduction in pressure on the stream that may have contributed to the improvement in macroinvertebrate scores. It also highlights the potential threat from sleeper licenses in the catchment should drought conditions return.

Water for stock and domestic use is an area that is unregulated currently and could become more concerning in a drying climate. An assessment of the pressure estimated to relate to stock and domestic use, which is unregulated and unmeasured under current policy, undertaken by Larsen *et al* in 2014, suggests the average S&D use in the Cockatoo Creek catchment is 11% of the overall license allocation.

An examination of streamflow taken from Cockatoo Creek at Nangana generally demonstrates that there may be some small difference between summer flows during the Millennium drought years and more recent non-drought years but that winter flows can be quite different with drought years remaining low throughout autumn (Figure 25).

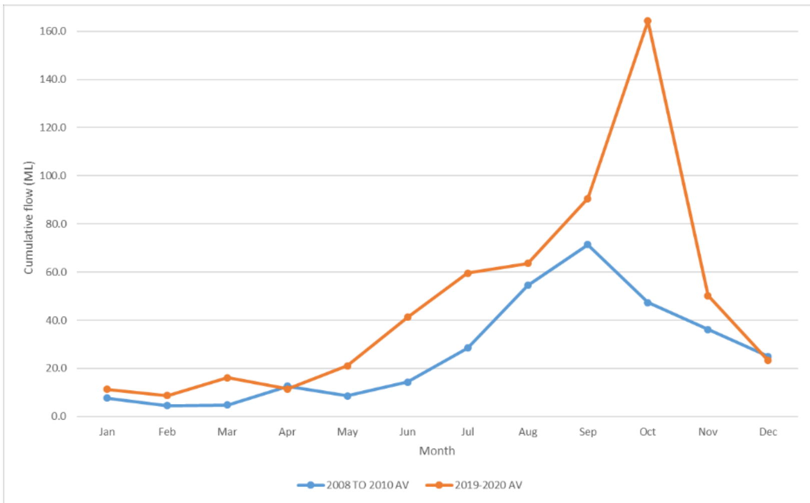

Figure 25. Graph of average streamflow in Cockatoo Creek comparing drought years 2008-2010 (blue) with non –drought period 2019-2021 (orange).

The Woori Yallock Creek Water Supply Catchment Stream Flow Management Plan (2012) has bans and restriction in place to protect low flows in the creek and reports each year on compliance across the catchment.

The HWS (2018) has performance objectives that target the protection of environmental values from low flow conditions in the Woori Yallock sub-catchment:

- *Identify and implement opportunities to maintain or improve the flow regime in refuge reaches to support platypus populations.*
- *Identify and implement opportunities to reduce the key threat of summer low flow stress by addressing causal factors such as water for domestic and stock uses, climate change, diversions or urbanisation.*

In summary, there appears to be reasonable evidence to suggest there has been an easing of irrigation demand in recent years that has contributed to the improvement of macroinvertebrate scores.

Vegetation

Vegetation quality is rated at low (vegetation visions score of 2) along Cockatoo Creek and medium along Gembrook Creek (level 3). Time-lapse imagery over the period 1984-2020 (data not shown) does not show a detectable change in either land clearing or revegetation of the riparian zone over this time period. Attenuated forest cover was 46% in 2006 and 46.5% in 2016.

Figure 26. Macroinvertebrate monitoring site location and upstream reach (aerial image is from OpenStreetMap 2021).

Water Quality

No water or sediment quality data is available for this immediate location from the Melbourne Water monitoring programs. However, water quality sites further downstream on the Woori Yallock Creek have been generally improving over the time period 2000-2020 (data in Site 2, Site 2: YAWOO0098 Woori Yallock Creek at Macclesfield-Woori Yallock Rd, YellingboAppendix 6). Turbidity, dissolved oxygen and nutrients all appear to generally improve over time. This may indicate changes in land management practises over time but may also be related to better flow conditions in the stream.

The Rural Land Incentives Program are grants available to landholders that target the improvement of water quality by fencing headwater streams and gullies, reducing erosion, implementing improved pesticide management and other such activities. The Woori Yallock catchment has been a priority area for this program for at least 10 years. This and other grants programs that support riparian restoration, as well as increased awareness of farmers regarding the value of regenerative agricultural practises may have also contributed to improvements over time, but there is little direct evidence available to draw these conclusions.

Data collated for the HWS 2018 development process indicates that pesticides associated with market gardens and potato farming, including some that are persistent in the environment, are at moderate levels in stream sediments in Cockatoo Creek (Figure 27) downstream of the macroinvertebrate site. This suggests that pesticides are likely to be impacting macroinvertebrates, but that the decline of farming activity over time in this catchment is likely to reduce this threat over time.

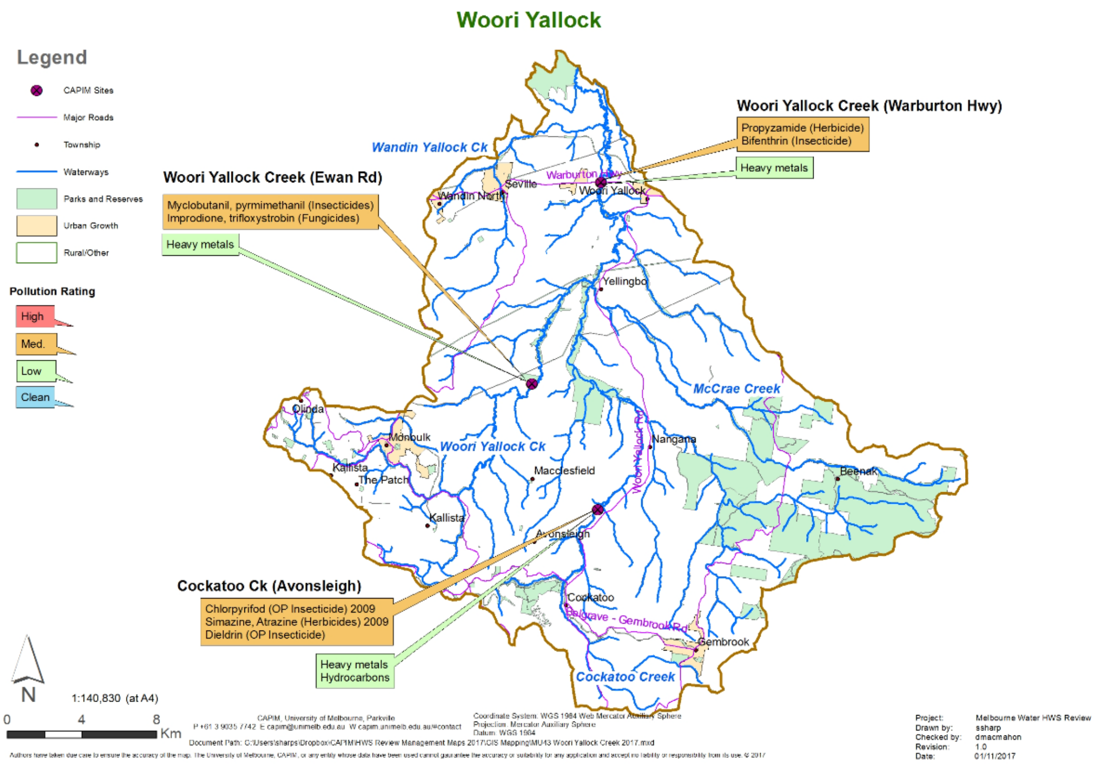

Figure 27. Map of the Woori Yallock sub-catchment showing moderate levels of pesticides and insecticides associated with market gardening and potatoes in sediment collected in Cockatoo Creek. Pollution rating is based on sediment quality guidelines (ANZECC 2000, ANZG 2018) to assess the ecological threat (for invertebrates) against a concentration threshold (known as mean probable concentration quotients). Rating is based on data from 2010 – 2016.

In summary it is possible that water quality has improved in Cockatoo Creek as the overall number of potato and market gardens have reduced. This could have contributed to the improvement in macroinvertebrate communities in the creek, though pesticide contamination is still present and likely to be having some effect.

Physical form

Not available.

Conclusions and Recommendations

In summary, the improvements in macroinvertebrates at this site seems to correlate with a reduction in water abstraction associated with a reduction in market gardens and potato growing in the area. The shift in agricultural practises has likely improved the flow regime and may possibly contribute to some water quality improvements over time, though evidence of persistent pesticides still present in the catchment are likely to be continuing to impact.

YAR-275352-4 (Yarra River Lower sub-catchment)

Site description

The Yarra River at Fitzsimons Lane, Templestowe (Figure 28Figure 18), is within the Yarra River Lower sub-catchment and was first sampled for macroinvertebrates in June 1994. The site is upstream of the Plenty River confluence and downstream of Diamond Creek. The upper reaches of the Yarra contain forested headwaters, the remaining catchment is a mix of agricultural and small townships (eg Healesville and Yarra Glen) transitioning to predominately urban areas draining off the southern tributaries of Mullum Mullum and Olinda Creek, through the suburbs of Croydon and Mt Evelyn.

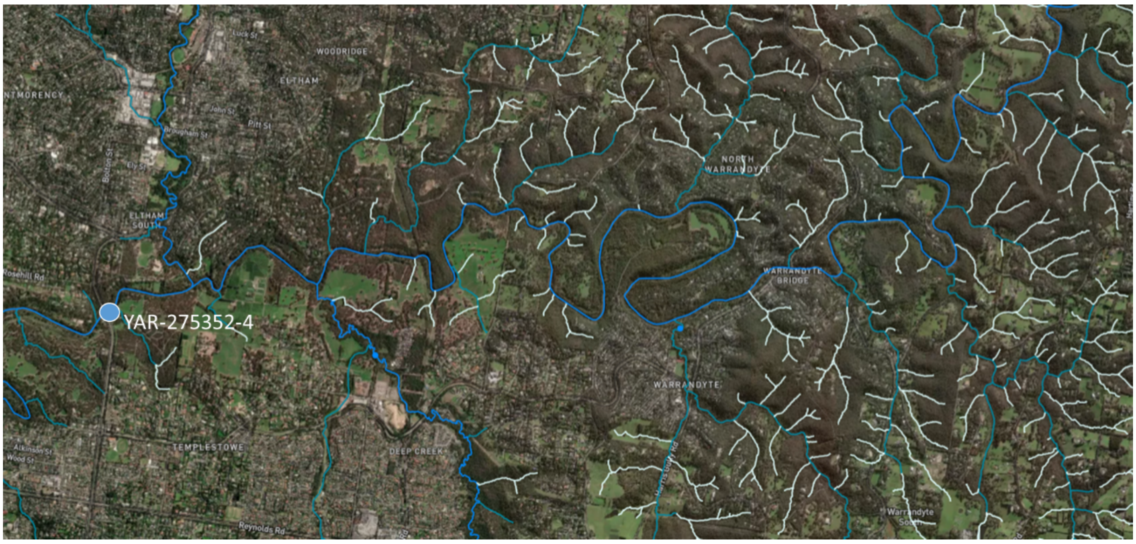

Figure 28. Aerial image of location of YAR-275352-4 Yarra River at Fitzsimons Lane macroinvertebrate sampling location and its upstream catchment area. Headwaters are shown in white, tributaries in teal and main stem in blue.

Photo 4. YAR-275352-4 Yarra River at Fitzsimons Lane(Yarra River Lower sub-catchment).

Site trend and indicators of change

The LUMaR index and SIGNAL2 score show a consistent and gradual decline over time. There is a moderate level of uncertainty associated with the LUMaR index trend line, likely due to the relative temporal clustering of samples and the low number of recent samples (only two since 2013).

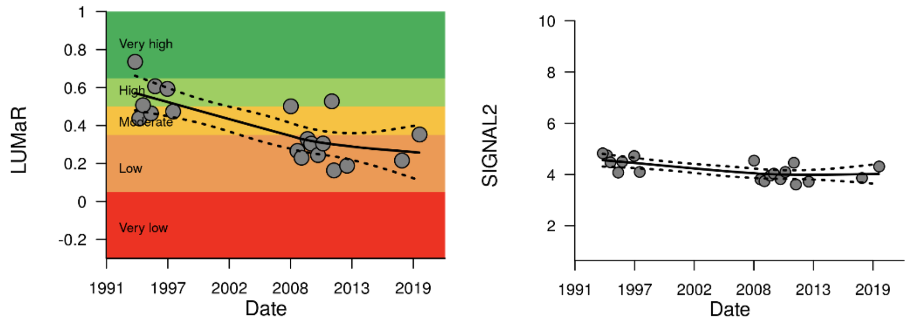

Figure 29. The (left) LUMaR index values (grey dots) and (right) SIGNAL2 scores (grey dots) for Yarra River (YAR-275352-4). The trend line (solid line) and 95 % confidence intervals of the trend line (dashed line) are also displayed.

Overall catchment changes

In 2018 DCI along this reach was 0.18% and is predicted to increase to 2.3% in the long term unless adequately managed. This is largely due to developments around Croydon North and Lilydale and the expansion of small townships further upstream. Data from the HWS annual report shows recent development is largely in-fill as opposed to greenfield, which has not been mitigated. Agricultural landuses in the catchment are a mix of vineyards, grazing and horticulture.

Macroinvertebrate community

The declining trend line is likely due to a gradual loss of a range of macroinvertebrate families over time. In particular, there has been a decline in the abundance and occurrence of Coleopteran and Odonatan predators. There have also been a decline in the abundance and occurrence of taxa within Hemiptera, Plecoptera and Trichoptera orders. Changes in such a large and diverse number of groups is difficult to link to changes in any particular issue.

Water regime

The area immediately upstream of Fitzsimons Lane has undergone significant urbanisation since the late 80's, which has likely contributed to macroinvertebrate decline. The impact of urbanisation on macroinvertebrate communities is well documented (Walsh, et al. 2001). The images in Figure 30 Figure 30. Catchment area upstream of YAR-275352-4 Yarra River at Fitzsimons Lane depicting change in urbanisation n in Templestowe, North Ringwood and Lilydale between 1984 and 2020.show a time series of aerial images that depict the changes in urbanisation over time.

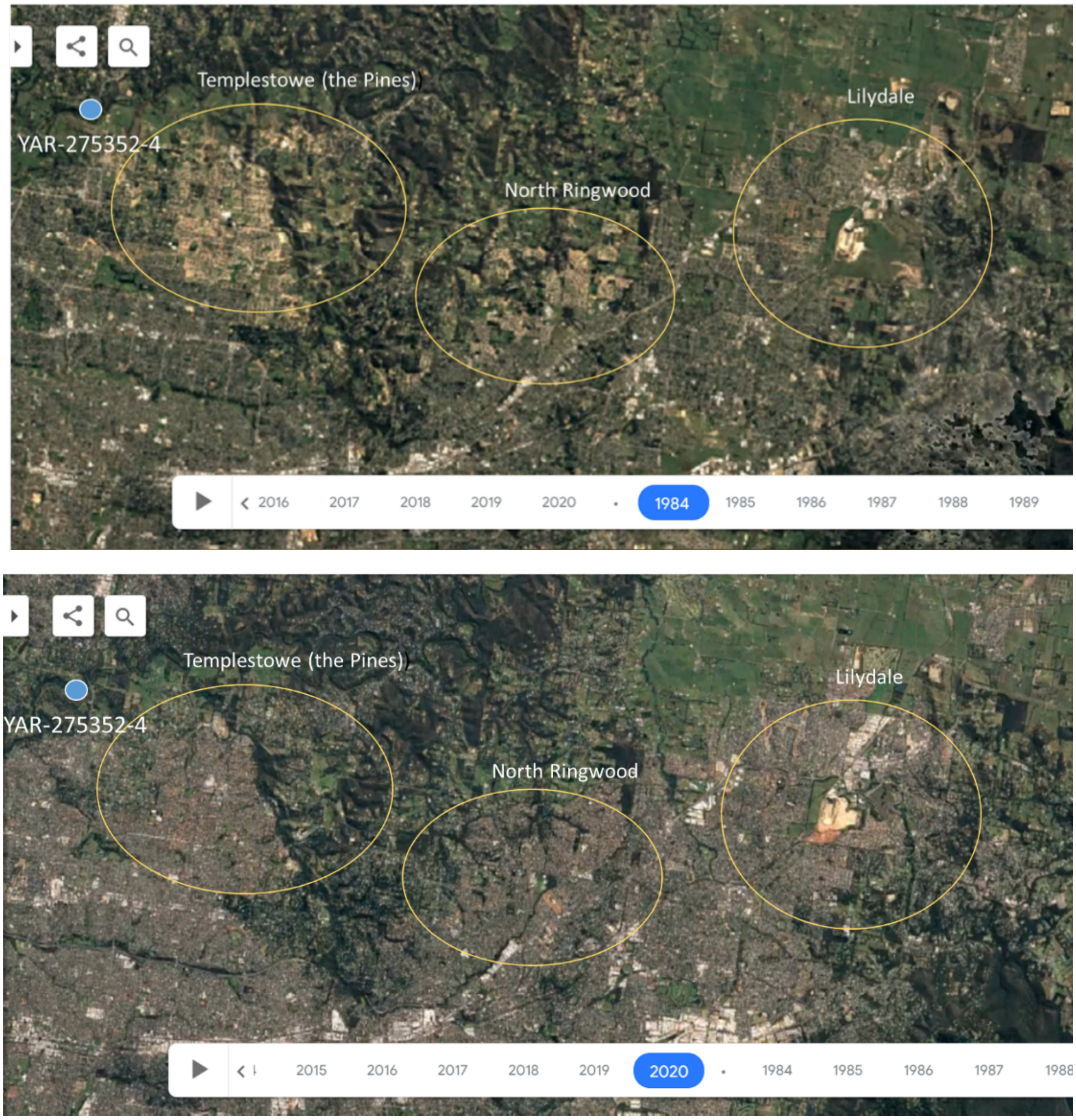

Figure 30. Catchment area upstream of YAR-275352-4 Yarra River at Fitzsimons Lane depicting change in urbanisation n in Templestowe, North Ringwood and Lilydale between 1984 and 2020.

In addition to changes in urbanisation and stormwater inputs, flows in the Yarra have declined over time due to a warming climate. The long-term water resource assessment (Government of Victoria, 2020) has determined that flows in the Yarra have declined significantly, even since 1997 (Figure 31).

Urbanisation and the increase in impervious surfaces and stormwater impact the immediate upstream catchment. This, in combination with a long-term decline in the natural water regime, would result in increased flashy stormwater flows when it rains and lower base flows due to climate change and impervious cover.

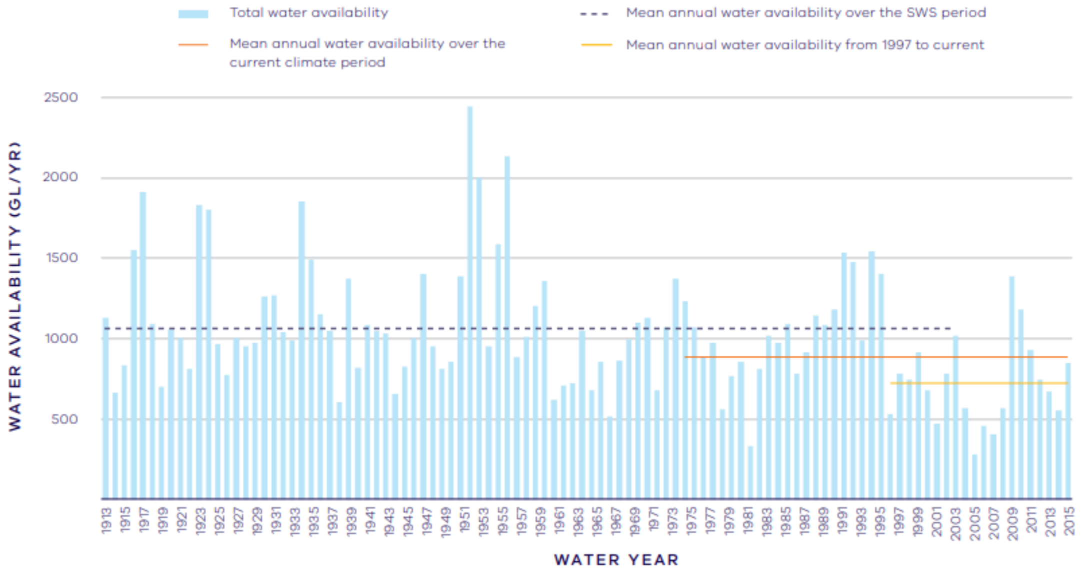

Figure 31. Surface water available in the Yarra catchment showing decline in mean annual water availiabity (taken from LTWRA, 2020).

Vegetation

Vegetation is rated as medium (vegetation vision level 3) along this reach (Figure 32). There has been no change in vegetation extent between 2006 and 2016, with attenuated forest cover at 52% along this reach.

Figure 32. Macroinvertebrate monitoring site location (in blue) and upstream reach (aerial image is from OpenStreetMap 2021).

Water Quality

There are no long-term water quality monitoring locations close enough to the macroinvertebrate site to be useful for interpreting the trend data. The closest upstream site is in Warrandyte, and the closest downstream site is at Rudder Grange/Chandler Hwy. No sediment quality data has been collected in the nearby catchment to assist with our analysis.

Physical form
Not available.

Conclusions and Recommendations
In summary, the decline at this site is likely due to increased urbanisation in the immediate upstream vicinity. However, the role of declines in flow resulting from climate change is worthy of further investigation. Also worthy of consideration in this assessment is the role of environmental flow delivery.

Dandenong

DBS-363-4 (Dandenong Creek Upper sub-catchment)

Site description
Dobsons Creek is located upstream of Basin-Olinda Road in the Dandenong Creek Upper sub-catchment and has been the focal area for some significant stormwater intervention works. The sub-catchment is considered to be urban with forested headwaters. The location of the site is shown in Figure 33.

Figure 33. Aerial image of location of DBS-363-4 Dobsons Creek macroinvertebrate sampling location and its upstream catchment area. Headwaters are shown in white, tributaries in teal.

Photo 5. DBD-363-4 (Dandenong Creek Upper sub-catchment).

Site trend and indicators of change

The LUMaR index and SIGNAL2 score both show a positive trend over time, and the site has been within the 'Very high' LUMaR index category for the past decade (Figure 34). There is a moderate level of uncertainty associated with the LUMaR index trend line. This uncertainty is likely due to variable sample scores, particularly prior to ~2010, when scores were highly variable between sampling occasions.

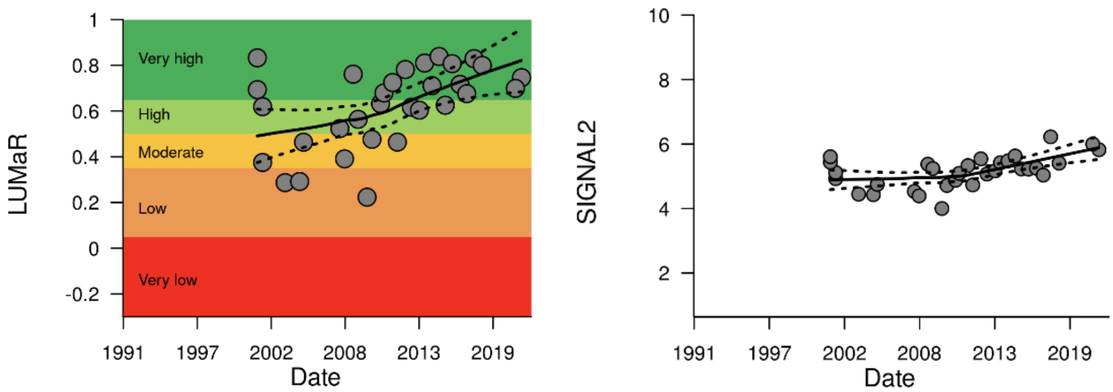

Figure 34. The (left) LUMaR index values (grey dots) and (right) SIGNAL2 scores (grey dots) for Dobsons Creek (DBS-363-4). The trend line (solid line) and 95 % confidence intervals of the trend line (dashed line) are also displayed.

Overall catchment changes

The Directly Connected Imperviousness (DCI) in this reach was 2.01% resulting from development in The Basin. There is a very small predicted increase in DCI 2.04% in the long term if not adequately treated. This catchment, however, has been the focus of a large catchment-wide stormwater disconnection project since the late 2000s with noticeable improvements, with DCI now less than 1%.

Macroinvertebrate community

There are no clear patterns in the macroinvertebrate community that explain the increase in LUMaR index over time.

Water regime

In 2010, Melbourne Water and Knox City Council initiated a pilot program to retrofit the 1300 hectare Dobsons Creek catchment with stormwater disconnection measures on public and private land. The pilot program involved the retrofitting of a large-scale parkland bioretention system, installation of 'leaky' rainwater tank on over 180 properties in the catchment, and streetscape water sensitive urban design (WSUD) retrofit projects.

Retrofit projects across the catchment reduced directly connected imperviousness from around 2% to <1% in the full catchment, and to 1.4% in the smaller main monitoring catchment. These reductions in DCI may have led in part to the improved trend in macroinvertebrates over time and, in particular, to the reduction in variability between samples.

Vegetation

Vegetation quality is rated as medium (vegetation vision score of 3 out of 5) along this reach (Figure 35). There has been no change in vegetation extent between 2006 and 2016, with attenuated forest cover at 87.4% along this reach.

Figure 35. Macroinvertebrate monitoring site location and upstream reach (aerial image is from OpenStreetMap 2021).

Water Quality

There are no long-term water quality monitoring locations close enough to the macroinvertebrate site as to be useful for interpreting the trend data. Sediment quality data collated in 2017 indicates no contamination at this location.

Physical form

Not available.

Conclusions and Recommendations

In summary, improved trends in macroinvertebrates at this location are possibly related to stormwater interventions that have been undertaken in the catchment.

Previously, stormwater discharge during rainfall events may have led to temporally variable disturbance to the site, which may explain the highly variable LUMaR index values early in the time period.

Recommendation: That lessons from the stormwater interventions project be shared as part of the Implementation Inquiry. That improved monitoring across a range of environmental conditions (WQ, vegetation, geomorphology etc.) as well as flow and macroinvertebrates should be considered during major stormwater intervention projects.

DNG-23690-8 Dandenong Creek at Brady's Rd (Dandenong Creek Middle sub-catchment) and DNG-31881-3 Dandenong Creek at Pillars Crossing (Dandenong Creek Lower sub-catchment)

Site description

Dandenong Creek at Brady Road (Endeavour Hills) (Photo 6) is situated in the Dandenong Creek Middle sub-catchment and was first sampled for macroinvertebrates in December 1993. Dandenong Creek at Pillars Crossing (Dandenong South) (Photo 7) is situated in the Dandenong Creek Lower sub-catchment and was first sampled for macroinvertebrates in June 1994. Both sub-catchments are highly urbanised and are located downstream of large artificial stormwater wetlands.

Photo 6. DNG-23690-8 (Dandenong Creek Middle sub-catchment).

Photo 7. DNG-31881-3 (Dandenong Creek Lower sub-catchment).

Site trend and indicators of change

The LUMaR index trend line for both these Dandenong Creek sites shows an improvement over time, particularly in the past 10 years (Figure 36). While the highest SIGNAL2 scores were recorded prior to 1997, there has been a slight, positive trend post 2005, mirroring the recent LUMaR index trend (Figure 37). It is worth noting that this change has only been from very low to low, with some data points reaching moderate, and that overall, the Dandenong Creek macroinvertebrate populations are not in good condition. Also, there is a moderate level of uncertainty associated with the trend line at both sites, and this is likely due to the large variation in LUMaR scores over short time scales.

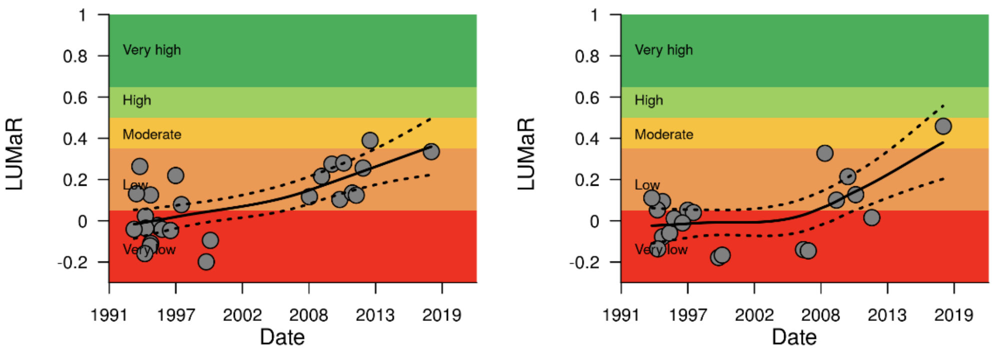

Figure 36. The LUMaR index values (grey dots), trend line (solid line), and 95 % confidence intervals of the trend line (dashed line) for Dandenong Creek DNG-23690-8 (left) and DNG-31881-3 (right).

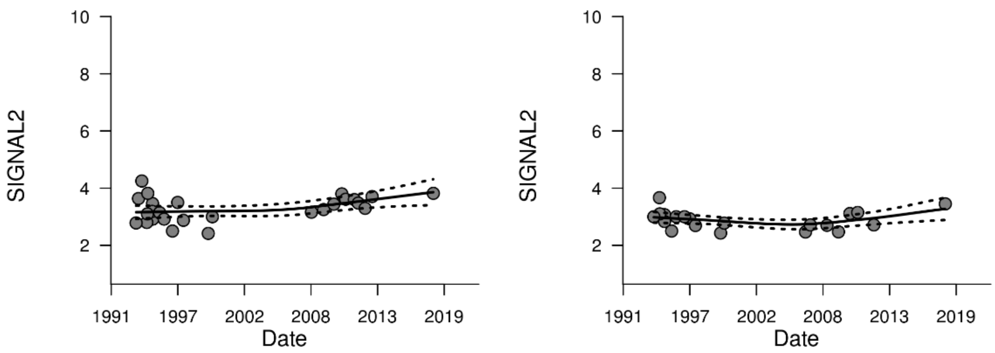

Figure 37. The SIGNAL2 index values (grey dots), trend line (solid line), and 95 % confidence intervals of the trend line (dashed line) for Dandenong Creek DNG-23690-8 (left) and DNG-31881-3 (right).

Overall catchment changes

The majority of the Dandenong Creek was significantly modified during the 60's, primarily for flood management. The creek meanders were straightened and the riparian area cleared. Artificial riffles were constructed to assist with aeration during low flow conditions. A lot of what was the original floodplain has been retained as public land. Under the Dandenong Valley Authority, several sewage treatment plants discharged to the Dandenong Creek have since been decommissioned.
The Dandenong catchment is highly urbanised but has headwaters in the forested Dandenong Ranges. DCI along this reach in 2018 was 21% and is expected to increase to 28% unless adequately managed. Long-term targets are aiming to reduce DCI to 16%, which is still very high.

A major road infrastructure project that linked the South Eastern freeway through to Carrum, Eastlink, was constructed during the Millennium drought between 2006 and 2008.
As part of Melbourne Water's commitment to the Port Phillip Environmental Management Plan and the Better Bays and Waterways joint government strategy, Melbourne Water committed to programs of work that would reduce the load of total nitrogen discharging into Port Phillip Bay by 100 tonnes. This led to the construction of many stormwater treatment wetlands across the region. The Dandenong catchment was a focal area for these stormwater wetlands because of the availability of public land in the floodplain.

Macroinvertebrate community

There are two main changes in the macroinvertebrate community that have led to recent increases in the LUMaR index along Dandenong Creek. First, there has been an increase in the presence and abundance of families that contain taxa classified as filter feeders (Simuliidae, Hydropsychidae, and some Chironominae) or filtering collectors (Atyidae). Second, there has been an increase in the presence and abundance of taxa from the sensitive Trichoptera order (Ecnomidae, Helicopsychidae, Hydroptilidae, Leptoceridae).

Water regime

Significant urbanisation occurred across the catchment from the late 80's when many industrial and residential areas expanded and impervious areas increased dramatically. Time-lapse photography of the region of the Dandenong Creek catchment upstream of DNG-23690-8 (an area corresponding to Figure 40) shows the scale of change both in urbanisation and revegetation along the main stem of the Dandenong Creek over the time period 1984 to 2020 (Figure 38).

Figure 38. Photo extract from time lapse movie of a portion of the Dandenong catchment upstream on DNG-23690-8 which shows urbanisation between 1984 and 2020 and riparian restoration and stormwater wetland construction along the main stem of the Dandenong Creek.

Vegetation

Significant revegetation along the main stem of the creek has been undertaken since the 80's, indicating a change from the 60's when this urban waterway was primarily managed for flood protection and vegetation along the banks was considered a hindrance to floodwater discharge. Timelapse photography (Figure 38) depicts the scale of revegetation along the main stem of the Dandenong creek over the time period 1984 to 2020.

Vegetation quality is rated as low along both reaches (ie vegetation vision score of 2 out of 5). Attenuated forest cover is 48.4% along the middle Dandenong Creek reach and 11% along the lower Dandenong Creek reach. Neither sites have changed between 2006 and 2016.

Figure 39. Macroinvertebrate monitoring sites location and upstream reach - DNG-23690-8 (left) and DNG-31881-3 (right). (aerial image is from OpenStreetMap 2021).

Water Quality

There are many large urban industrial areas in the Dandenong catchment. Stormwater surface run-off from these industrial areas and illegal connections and discharges to stormwater drains make the Dandenong Creek and its tributaries some of the most polluted in the region. Pollution incidents are relatively frequent and result in significant fish-kill events plus longer-term accumulation of a range of pollutants in sediments. The improvement of macroinvertebrate scores in this catchment is somewhat surprising based on the known catchment threats and historical frequency of water quality pollution incidents.

Significant stormwater treatment wetlands have been constructed since the early 2000's in the Dandenong Creek catchment upstream of the two macroinvertebrate sites of interest (Figure 40). The Police Road Retarding Basin wetlands was constructed in 2003/04. The Dandenong Valley wetlands were constructed in 2010 to treat 28 tonnes of nitrogen, almost one-third of the overall 100 tonne target committed to by Melbourne Water under the Better Bays and Waterways plan (EPA & Melbourne Water, 2009). The Tirhatuan wetlands are a remnant meander that was modified into a stormwater wetland in the early 2000's. Wetlands were also built on the Corhanwarrabul Creek – Kellet's Road wetland and the Knoxfield outfall wetlands. The locations of these wetlands relative to monitoring sites are depicted in Figure 40.

DNG-23690-8

A long-term water quality monitoring site (DADAN0235 – Dandenong Creek at Brady's Road, Dandenong) is located directly upstream of a macro monitoring site, so is well situated to inform how water quality has tracked over the same time period as the observed macro trend.

The Water Quality Index (WQI) trend for DADAN0235 shows no improvement between 2000 and 2020 (Figure 41).

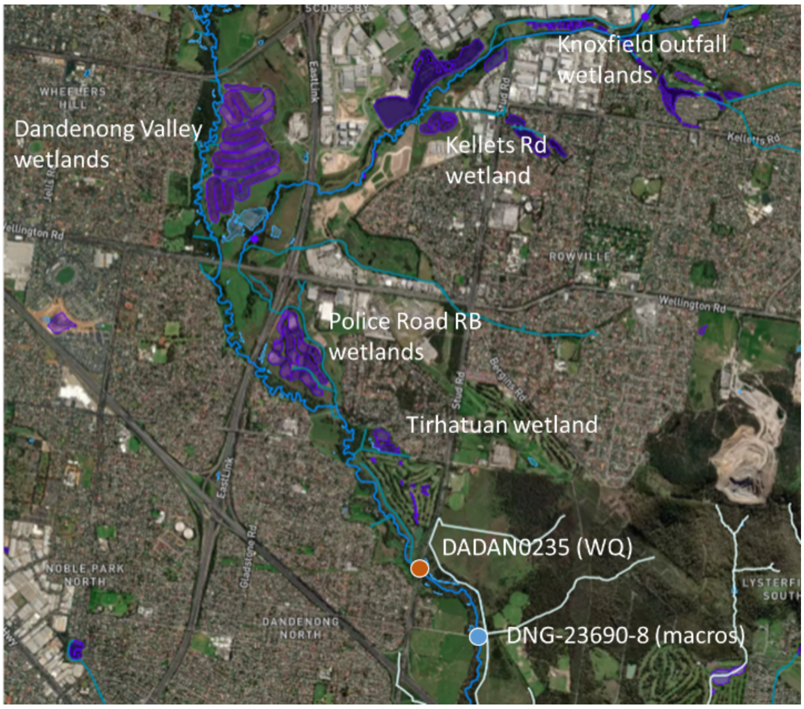

Figure 40. Map of Dandenong creek catchment area depicting the location of macroinvertebrate and water quality monitoring locations downstream of constructed wetlands.

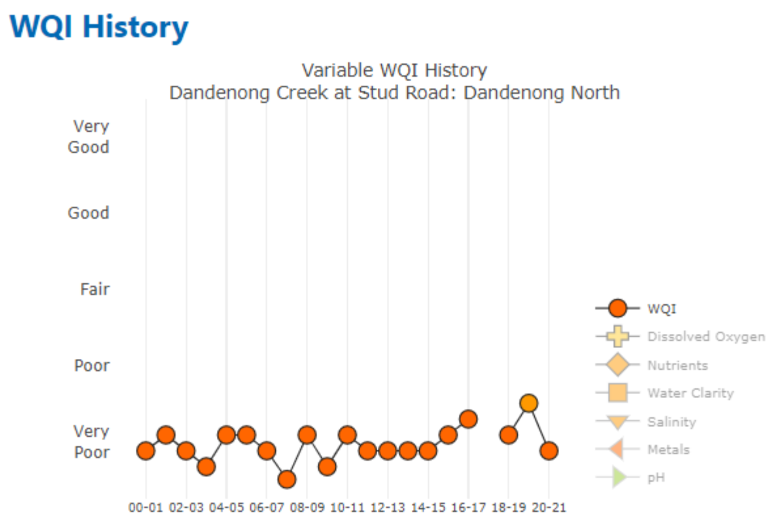

Figure 41. Graph of Water Quality Index (WQI) for DADAN0235 Dandenong Creek at Brady's Road between 2000 and 2021 shows overall compliance is very poor. No real improvement over time is detected.

Examination of the individual water quality parameters indicates that there has been little change over time for most measured parameters; turbidity, total nitrogen, total phosphorus, electrical conductivity, pH, dissolved oxygen and temperature (Figure 42 - full data shown in Site 4. DADAN0235 Dandenong Creek at Stud Road, Appendix 6). However, several metals appear to be declining in concentration over time.

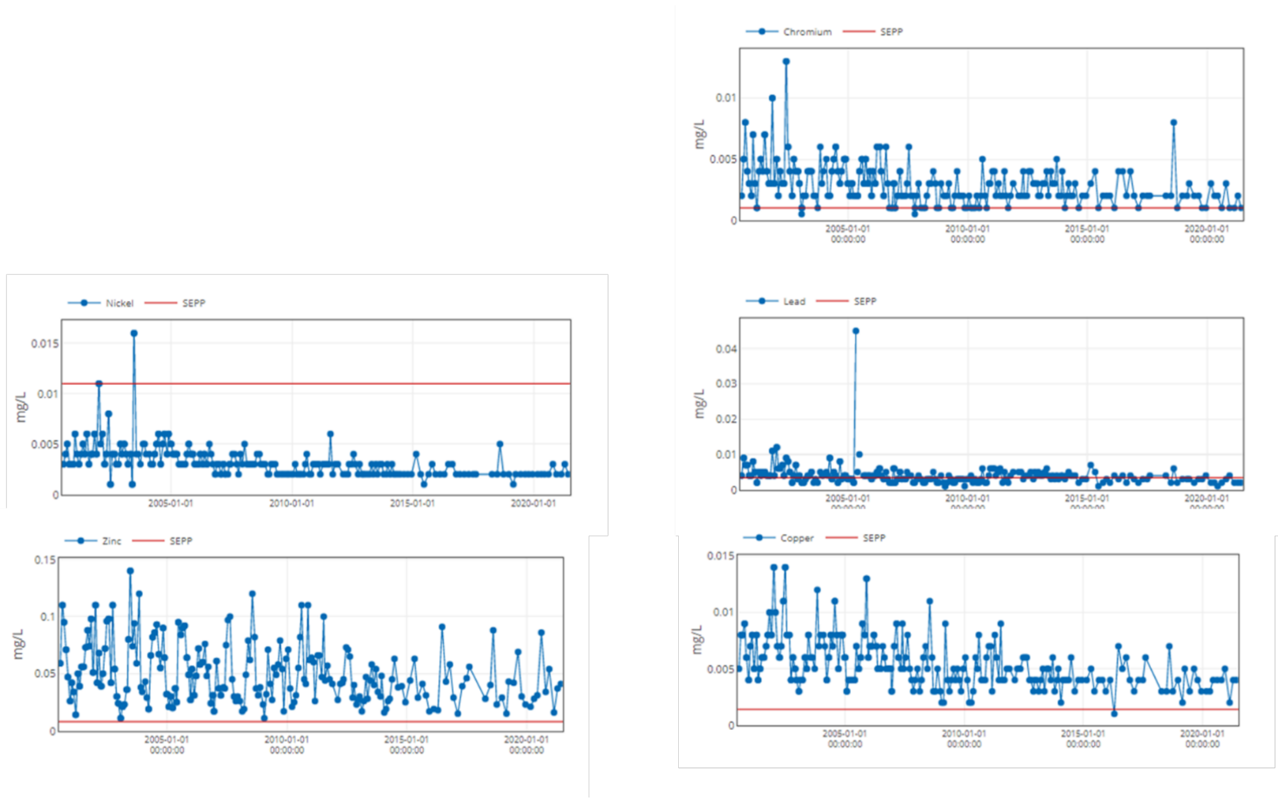

Figure 42. Total metals data showing a slow declining trend for water samples taken at DADAN0235 Dandenong Creek at Stud Rd. between 2000 and 2021. Red line indicate the Environmental Reference Standard for this area of the catchment.

The decline in metals is observed based on the data presented above and has not been statistically validated as part of this analysis.

Both nickel and lead levels are well below the Environmental Reference Standard guideline levels throughout the period so are unlikely to be impacting the majority of species present and are showing a general decline alongside other metals such as chromium, copper and zinc. Despite the apparent declining trend over the last 20 years in chromium, zinc and copper, these metals are still substantially above guideline levels so are likely to be limiting the species diversity at these locations. Further analysis is required to understand the causes of these trends in metals.

DNG-31881-3

Another long-term water quality monitoring site (DADAN0322 – Dandenong Creek at Pillar's Crossing (Greens Rd)) is co-located with the downstream macro monitoring site DNG-31881-3 (Figure 43).

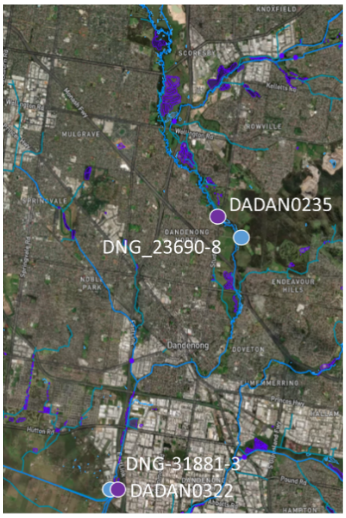

Figure 43. Map of Dandenong Creek catchment area depicting the location of macroinvertebrate and water quality monitoring locations relative to stormwater treatment wetlands.

Water quality data at this site shows a similar overall trend to the upstream site in that there has been no overall improvement in the WQI or many of the water quality parameters however, concentrations of several metals appear to be declining over time (Figure 44, Figure 45, full data shown in Site 5. DADAN0322 Dandenong Creek at Pillars Crossing, Keysborough, Appendix 6).

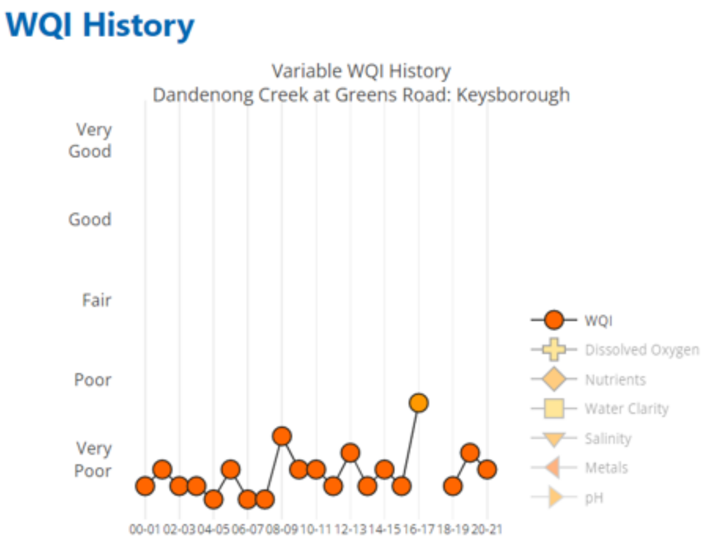

Figure 44. Graph of Water Quality Index (WQI) for DADAN0322 Dandenong Creek at Pillars Crossing between 2000 and 2021 showing overall compliance is very poor. No real improvement over time is detected.

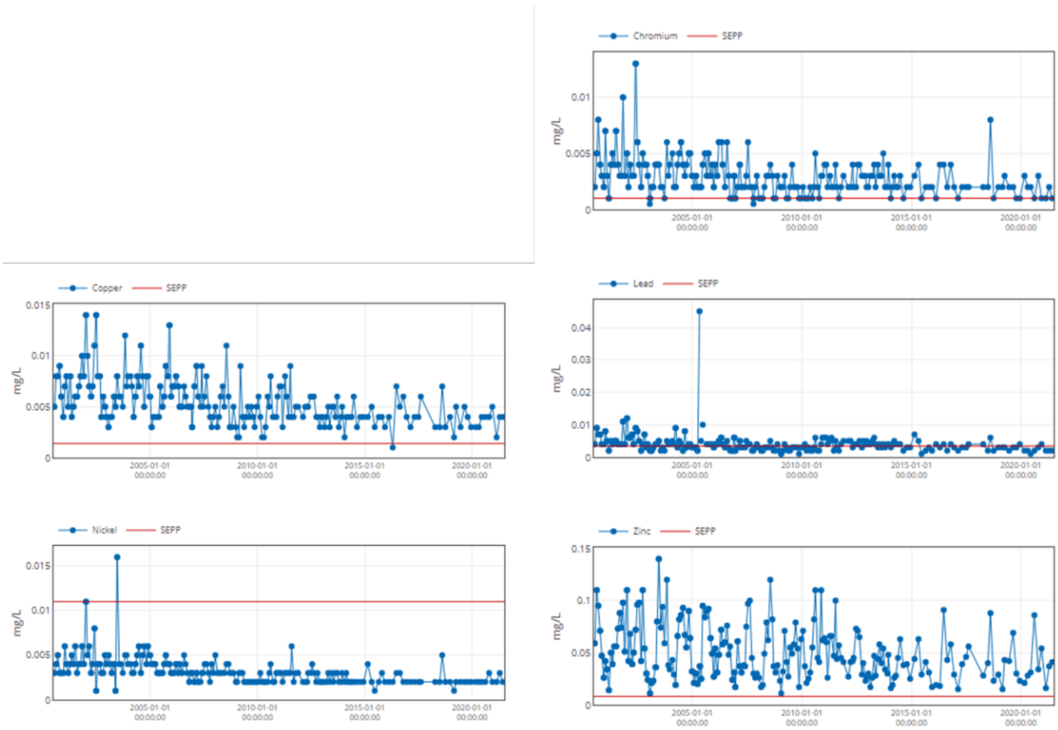

Figure 45. Total metals data showing a slow declining trend for water samples taken at DADAN0322 Dandenong Creek at Pillars Crossing. between 2000 and 2021. Red line indicate the Environmental Reference Standard for this area of the catchment.

Sediment quality data, collated for the HWS development process in 2017, indicates that low levels of both Zinc and bifenthrin have been detected in the Dandenong Valley wetlands.

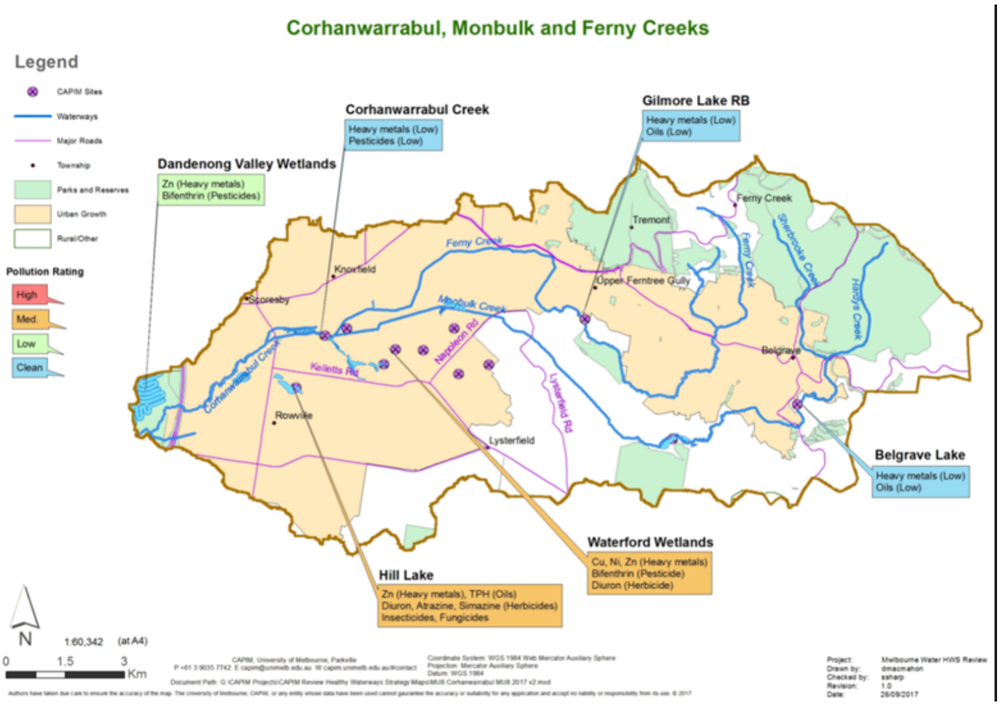

Figure 46. Map of sub-catchment in the Dandenong catchment that indicates low level Zinc and bifenthrin have been detected in the Dandenong Valley wetlands prior to 2017. Pollution rating is based on sediment quality guidelines (ANZECC 2000, ANZG 2018) to assess the ecological threat (for invertebrates) against a concentration threshold (known as mean probable concentration quotients). Rating is based on data from 2010 – 2016.

Physical form

The Dandenong Creek catchment historically terminated in the Carrum Carrum Swamp, and there are multiple channels draining the swamp into Port Phillip Bay. In the late 1880s the swamp was 'cut' to drain the land to make it more accessible to agriculture and the Patterson River and large parts of the Mordialloc Creek were formed (Photo 8).

Photo 8. Map of the former Carrum Carrum Swamp from 1968 with an overlay of later works showing the Patterson River 'cut' and drain that forms most of Mordialloc Creek.

The Dandenong Creek, similar to the Carrum Swamp, has historically been primarily managed for drainage and flood protection purposes, so many reaches were straightened and channelised during the 1960's. Many rock structures were installed along the creek to create artificial riffles to help oxygenate the water during the warmer summer period. Rock-lining has also been used in many places to stabilise embankments.

Conclusions and Recommendations

While it is promising to see a positive trend in LUMaR within the lower reaches of Dandenong Creek, the condition is still relatively poor and reflective of a highly urbanised catchment and physically modified waterway. Further investigations are required to better understand if the changes in the macroinvertebrate community are related to the water quality changes from the large floodplain wetlands or from practise change in the catchment.

Recommendation: Further characterise reasons for improving macroinvertebrate trend in the lower Dandenong Creek including relationship to water quality changes arising from the large floodplain wetlands and observed declines in metal concentrations over time.

Westernport

LNG-16294-3 (Lang Lang River sub-catchment)

Site description

This site along the Lang Lang River is located off Drouin-Korumburra Road in Athlone (Figure 47) and was first sampled for macroinvertebrates in June 1994. It is situated within the Lang Lang River sub-catchment and is characterised as having a predominately rural land cover.

Figure 47. Aerial image of location of LNG-16294-3 Lang Lang River macroinvertebrate sampling location and its upstream catchment area. Headwaters are shown in white, tributaries in teal.

Photo 9. LNG-16294-3 Lang Lang River, Athlone (Lang Lang River sub-catchment).

Site trend and indicators of change

The LUMaR index and SIGNAL2 trend lines both show a declining trend over time (Figure 48). The decline in LUMaR has corresponded with a change in rating categories from 'very high' to 'low' in less than three decades. The declining trends are associated with low to moderate levels of uncertainty owing to the tight 95 % confidence intervals around each trend line.

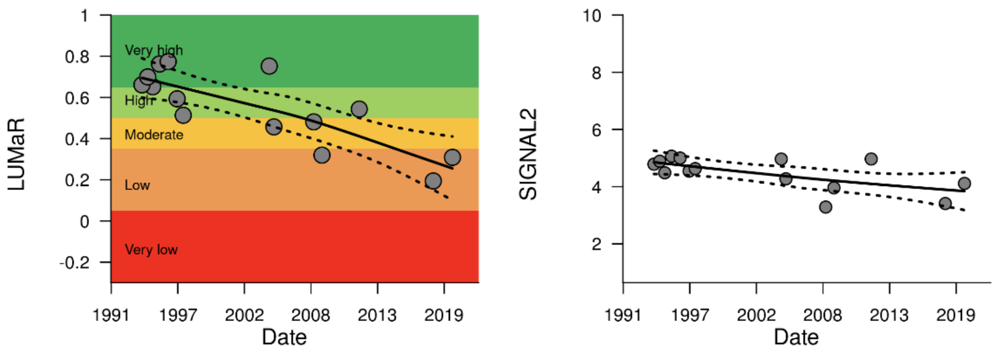

Figure 48. The (left) LUMaR index values (grey dots) and (right) SIGNAL2 scores (grey dots) for Lang Lang River (LNG-16294-3). The trend line (solid line) and 95 % confidence intervals of the trend line (dashed line) are also displayed.

Overall catchment changes

Despite many erosion control structures in the catchment, concerns remain that incision along the Lang Lang River may lead to a rejuvenated phase of gullying of tributaries such as Little Lang Lang River. The stream power analysis undertaken by GHD and CEAH (1998) clearly shows that a large proportion of flood flows are capable of causing further erosion and adjustments to the channel configuration of the lower reaches of the Lang Lang River. The middle reach, where the macroinvertebrate site is located, is more stable than the lower reaches. Further details are provided below in the physical form section.

There is minimal urban development in the catchment and the DCI rating along this reach is 0% with no increases expected in the future.

Macroinvertebrate community

There is a general reduction in the occurrence of a range of macroinvertebrate families. Of particular concern is the reduction in the occurrence of families from some sensitive orders (Plecoptera and Odonata). We have also recorded absences of taxa from Megaloptera (dobsonflies, alderflies), Hemiptera (true bugs), Diptera (flies), Coleopotera (beetles), and Amphipoda (side-swimmers, crustaceans) over time.

Water regime

An investigation of the detailed flow data for this location was not undertaken as part of this assessment, but other verified forms of information on flow regime have been used.

The Lang Lang River has no major water storages that supply water for consumptive uses. However, changes in climate led to a decline in the amount of water in the system (Figure 49). The long-term water resource assessment has determined that there has been a small decrease in the water share available for the environment in this system.

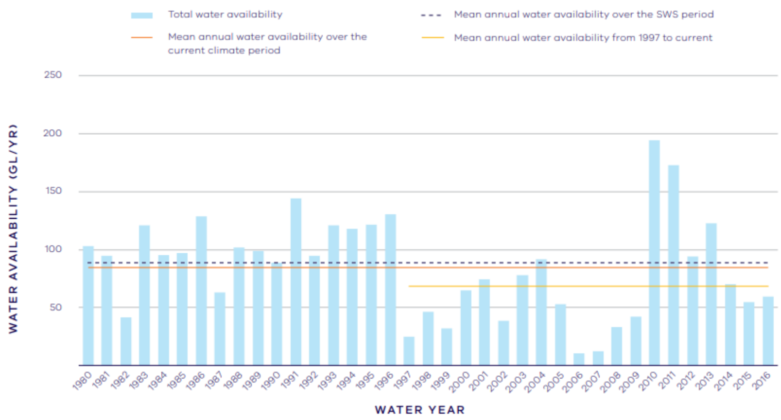

Figure 49. Annual water availability for the Lang Lang River. (Source from Government of Victoria, 2020)

Other local factors that may be influencing stream flow include;

- interception by domestic and stock dams which is significant due to large numbers of these dams spread throughout the catchment.
- groundwater pumping in the Koo Wee Rup WSPA has reduced waterway flow in the Lang Lang River by approximately 0.7 GL/ year, which has contributed to the decline in surface water availability.

Overall, though there is evidence for declining flow in the Lang Lang River, which may have contributed to declining macroinvertebrate trends, this does not appear to have been significant enough to account for the significant declining trend.

Vegetation

Riparian vegetation quality rating along this reach is moderate (level 3 vegetation visions)(Figure 50). Attenuated forest cover along this reach is 38.9% and has not changed between 2006 and 2016.

Figure 50. Macroinvertebrate monitoring sites location and upstream reach (aerial image is from OpenStreetMap 2021).

Vegetation time series (2010-present) along the main stem (6km upstream) and along Minnieburn Creek seems to show an increase in riparian vegetation cover over time. Minnieburn Creek tributary shows no observable change.

Water Quality

There is a long-term water quality monitoring location at exactly the same site as the macroinvertebrate monitoring site WPLAN0164, providing a good opportunity to relate this condition to the observed macroinvertebrate trend (Figure 51).

Figure 51. Map of Lang Lang catchment area depicting the location of macroinvertebrate and water quality monitoring locations.

There appears to be no decline in the WQI over the time frame and if anything, there has likely been a slight improvement since the drought years(Figure 52) . Examination of the detailed water quality parameters (see Site 6: WPLAN0164 Lang Lang River at Drouin-Poowong Rd, Athlone, Appendix 6) shows an improvement over time for both DO and copper. Nutrients are high at this location. No complementary sediment or pollutant data has been collected for this area to help explain trends.

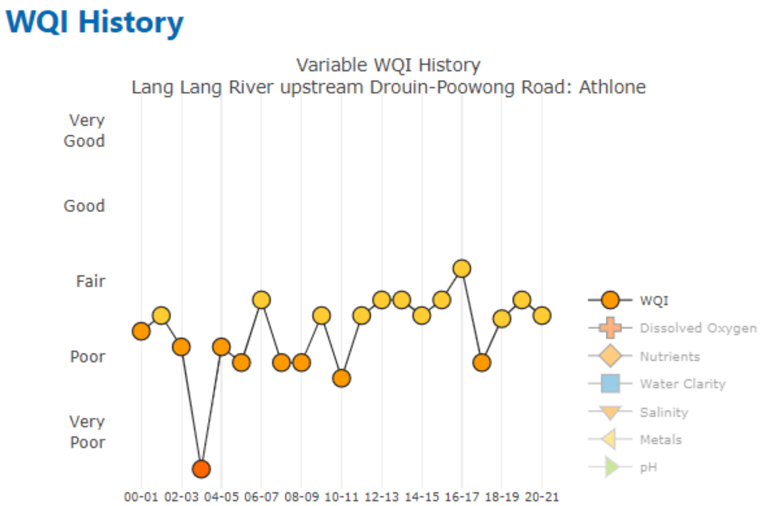

Figure 52. Graph of Water Quality Index (WQI) for WPLAN0164 Lang Lang River Creek at Athlone between 2000 and 2021 showing overall compliance is fair. Some improvement may have been detected since the end of the drought in 2010.

In summary, there appears to be little evidence in the available water quality data to explain the decline. It should be recognised that we have no data here on sediment pollutants and pesticides and that on the basis of this trend, we should prioritise the collection of this data.

Physical form

A geomorphological study of the upper Lang Lang River was carried out in 2004 by Sinclair Knight Mertz). The key findings of this study are:

- Tunnelling and gully erosion are active in the upper Lang Lang, Mountain View Creek and Pheasant Creek sub-catchments.
- Sediments eroded in the past have been transported downstream and stored on the floodplain of major tributaries;
- No erosional problems were noted in the O'Mahony/Minnieburn catchment.
- Gullying in the Little Lang Lang catchment has largely been stabilised.
- A low degree of sediment connectivity presently exists between the processes eroding the steeper slopes of the Strzelecki Ranges and the transfer of these sediments to the Lang Lang River. Eroded sediments are deposited in alluvial fans at the base of the steep hillslopes.
- Instream willows pose a significant problem throughout the catchment. Clearing of vegetation from the floodplain has decreased the resistance of the floodplain to erosion and increased the potential for channel migration and meander cutoffs.
- The channel has eroded its bed down to the underlying bedrock preventing further incision.
- Active bank erosion and channel widening was noted at a number of locations, however the major phase of erosion is believed to have passed.
- There is strong field evidence to indicate that sediments input into the Western Port Bay are now largely sourced from bed and bank erosion in the lower reaches of the Lang Lang River and not from the erosion in the Strzelecki Ranges.
- This does not take away from the fact that the erosional problems in the upper parts of the catchment are significant land management issues, but it does indicate that the offsite impacts of sediments eroded from these areas are low.

Conclusions and Recommendations

Despite observable increase in riparian cover upstream of the site and some water quality improvement, the macroinvertebrate trend is declining. Reduced flow due to climate change may be contributing to the decline but is probably not substantial enough over the measured time frame to fully account for it.

Recommendation: We recommend this area is prioritised for a full pollutant investigation to help in our understanding of this trend.

TOO-4334-2 (Cardinia, Toomuc, Deep and Ararat Creeks sub-catchment)

Site description

This site on Toomuc Creek is located upstream of Henry Road, off Hull Crescent in Pakenham, and was first sampled in February 1999. The site is in a highly urbanised area within Pakenham (Figure 53).

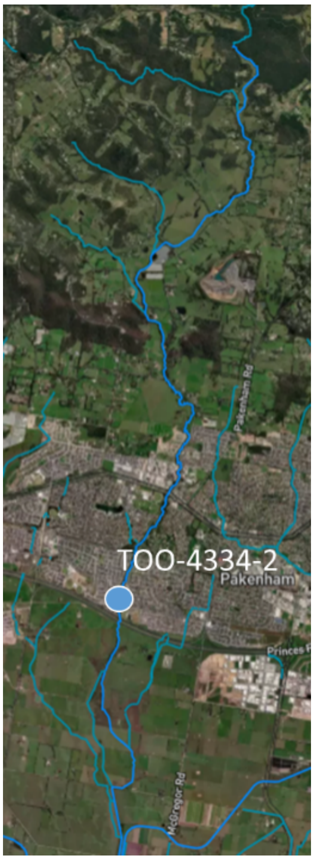

Figure 53. Aerial image of location of TOO-4334-2 Toomuc Creek macroinvertebrate sampling location and its upstream catchment area. Tributaries in teal, main creek in blue.

Photo 10. TOO-4334-2 Toomuc Creek, Packenham (Cardinia, Toomuc, Deep and Ararat Creeks sub-catchment).

Site trend and indicators of change

The site has seen a sharp decline in the LUMaR index trend line from the first sample in 1999, corresponding with population growth in Pakenham (Figure 54).

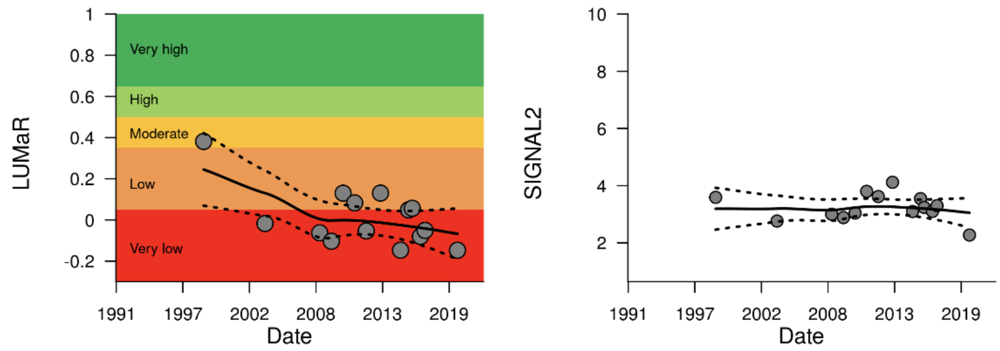

Figure 54. The (left) LUMaR index values (grey dots) and (right) SIGNAL2 scores (grey dots) for Toomuc Creek (TOO-4334-2). The trend line (solid line) and 95 % confidence intervals of the trend line (dashed line) are also displayed.

Overall catchment changes

There has been large population growth in Pakenham, increasing from 9,512 in 1996 to 33,999 in 2011 (Census data). This greater population has been associated with increased urban land cover. DCI along this reach was 2.6 % in 2018 and is expected to increase to 4.2 % unless adequately managed. The long-term target is to reduce DCI to 2.5 %.

Macroinvertebrate community

There has been a clear and sustained decline in the presence of sensitive taxa from the orders Ephemeroptera (Baetidae, Leptophlebiidae, Caenidae), Trichoptera (Hydrobiosidae, Hydropsychidae, Leptoceridae), and Odonata. However, there were few data point samples in the early 90's prior to urbanisation to confidently predict significantly higher LUMaR scores.

Water regime

An assessment of aerial time-lapse imagery confirms that substantial urban growth has taken place in the catchment since the 1990's. Whilst flow is yet to be scrutinised, it is expected that this would have significantly impacted the flow regime in Toomuc Creek and contributed to the decline in macroinvertebrate populations.

Vegetation

There does not appear to be significant changes in riparian vegetation over time. A comparison of aerial images taken in 2006 and 2021 does not show substantial areas of revegetation change (Figure 55).

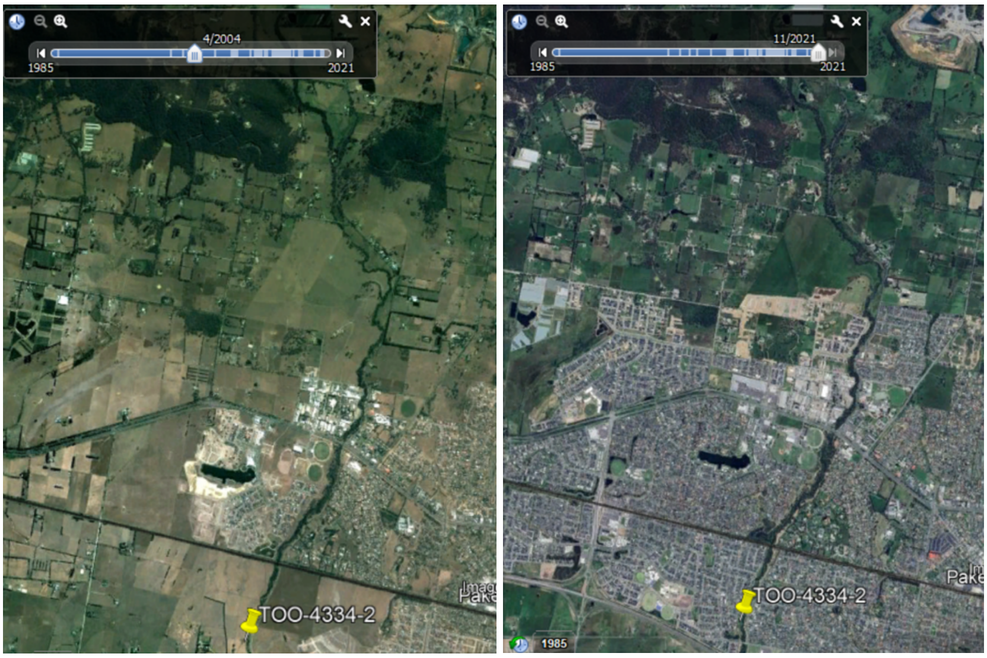

Figure 55. Aerial images of Toomuc Creek taken in 2004 and 2021 showing significant urbanisation but no substantial change in riparian vegetation along the creek over time.

Vegetation quality is rated as low (vegetation vision 2). Attenuated forest cover was 30.2% in 2006 and there was insignificant change in 2016.

Water Quality

Water Quality monitoring locations are present upstream and downstream of the macroinvertebrate location that has declined over time (Figure 56).

Figure 56. Map showing relative location of Macroinvertebrate site TOO-4334-2 (in blue) and upstream and downstream water quality monitoring site WPTOO0041 and WPTOO0062 (in purple).

Water quality is poor overall at both sites but more consistently so at the site downstream of the urban area of Packenham (Figure 57). Both sites also include significant catchment area of agricultural land.

WPTOO0062 **WPTOO0041**

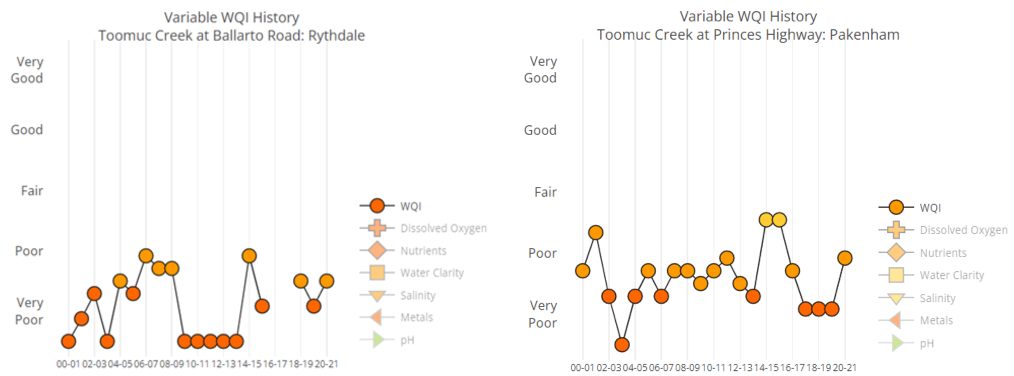

Figure 57. WQI for two sites on Toomuc Creek in Westernport, upstream and downstream of macroinvertebrate monitoring site. WPTOO0041 is upstream at Princess Hwy, Packenham and WPTOO0062 is downstream at Ballarto Rd Rythdale.

Further examination of the data (Figure 58) indicates that downstream of Packenham, there has been a significant increase in turbidity since 2010/11 that may have been a response to the drought-breaking and rain carrying sediment-laden run-off from the development in Packenham into the waterway, potentially impacting macroinvertebrates and Westernport.

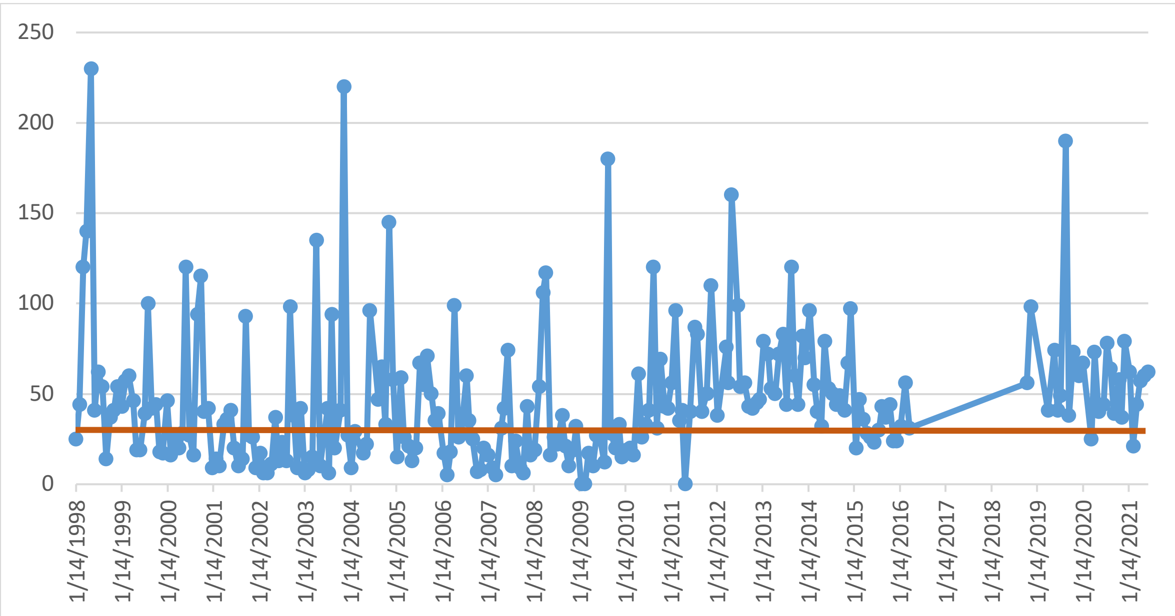

Figure 58. Graph depicting turbidity from the late 1980's to 2021 at WPTOO0062. Red line indicates the ERS for this area of the catchment (25NTU).

The same substantial increase in turbidity from 2010 is not observed in the upstream site WPTOO0041 (Figure 59).

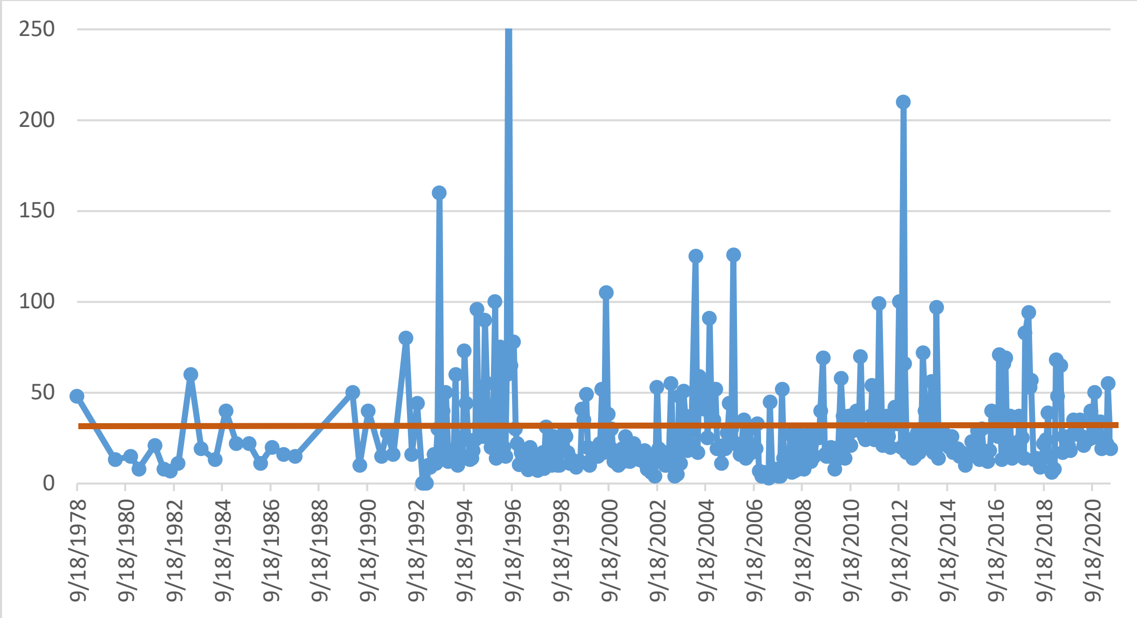

Figure 59. Graph depicting turbidity from the late 1970's to 2021 at WPTOO0041. Red line indicates the ERS for this area of the catchment (25NTU).

Other water quality parameter changes can be found in Site 7: WPTOO0041 Toomuc Creek at Princess Hwy, Pakenham and Site 8: WPTOO0062 Toomuc Creek at Ballarto Rd, Rythdale, (Appendix 6) but no other trends of significance were detected.

No sediment quality data or pollutant investigations have been undertaken in the Toomuc Creek catchment to help further inform the macroinvertebrate decline. However, data collated during the strategy development period documents the synthetic pyrethroid insecticides bifenthrin and permethrin and cyhalomethrin in Deep Creek, waterways draining the same urban growth corridor (Figure 60). Bifenthrin is a termite control product that is frequently sprayed on soils during construction. It adheres tightly to the soil but can contaminate waterways when bare soil from construction sites is carried into the waterway when it rains. Bifenthrin and the other insecticides detected can also come from agricultural land use but given the significant period of urbanisation with no identified change in agricultural intensification, it may be that insecticides are contributing to the decline seen in Toomuc Creek.

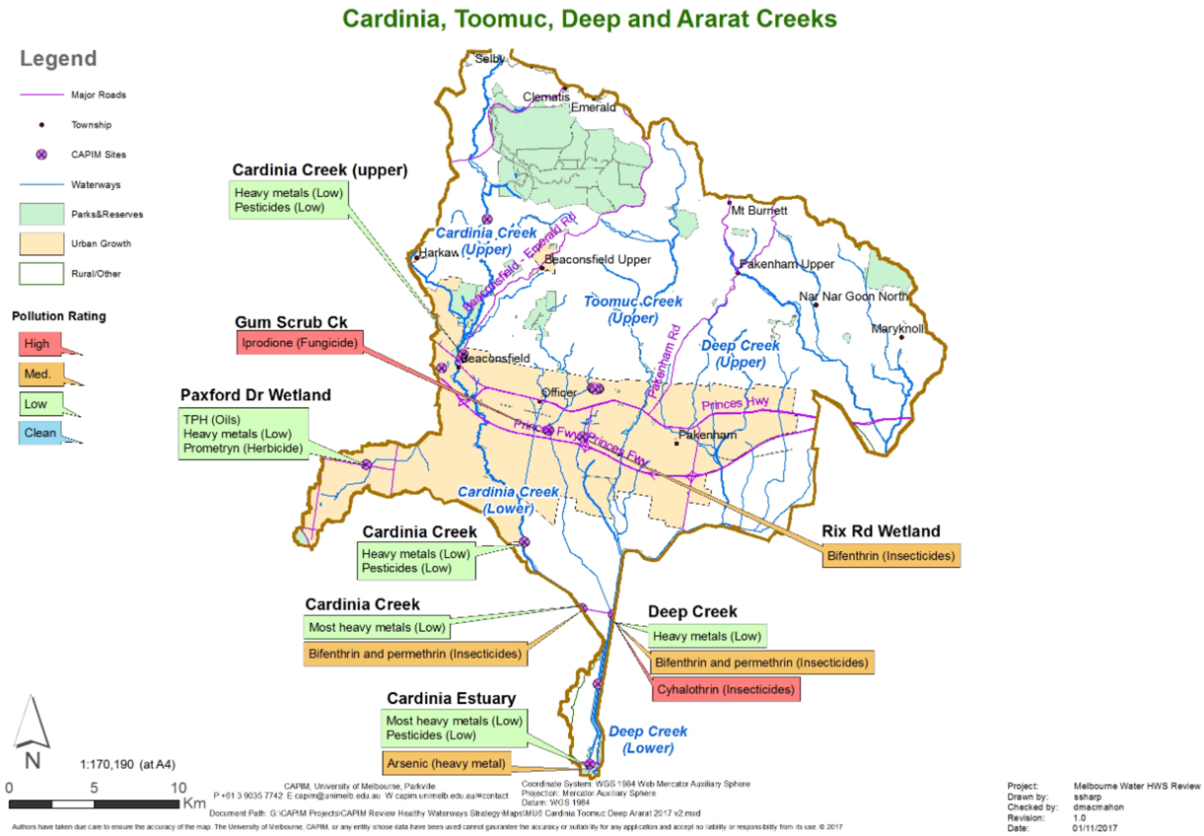

Figure 60. The presence of contaminants in Cardinia, Toomuc, Deep and Ararat Creeks. Pollution rating is based on sediment quality guidelines (ANZECC 2000, ANZG 2018) to assess the ecological threat (for invertebrates) against a concentration threshold (known as mean probable concentration quotients). Rating is based on data from 2010 – 2016.

Physical form

The channel along this reach is constrained by the proximity of urban development (Figure 61).

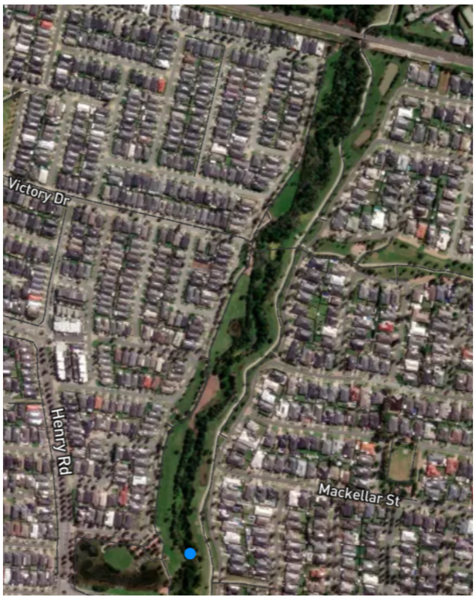

Figure 61. Macroinvertebrate monitoring site location and upstream reach (aerial image is from OpenStreetMap 2021).

Conclusions and Recommendations

The decline in sensitive taxa highlights the impact of urbanization on stream health. Increases in turbidity since 2010 are likely a contributing factor and will be impacting Westernport as well as stream health.

Werribee

WER-35204-8 (Werribee River Middle sub-catchment)

Site description

This site along the Werribee River is located at the Bacchus Marsh Gauge in Bacchus Marsh and was first sampled for macroinvertebrates in March 1995. The site has a predominately rural catchment but is located adjacent to land that is rapidly urbanizing (Figure 62).

Figure 62. Aerial image of the location of WER-35204-8 Werribee River macroinvertebrate sampling location and its upstream catchment area. Headwaters are in white, tributaries in teal, main creek in blue.

Photo 11. WER-35204-8 Werribee River at Bacchus Marsh (Werribee River Middle sub-catchment).

Site trend and indicators of change

The declining trend for LUMaR at Werribee River, Bacchus Marsh Gauge, is largely driven by the two recent samples in 2018 and 2019 (Figure 63). There is a moderate level of uncertainty associated with this negative trend. There is also a decline in SIGNAL2 scores over time.

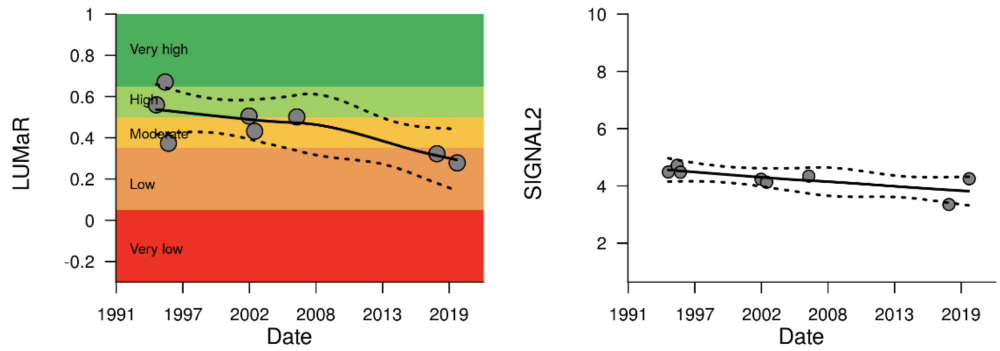

Figure 63. The (left) LUMaR index values (grey dots) and (right) SIGNAL2 scores (grey dots) for Werribee River (WER-35204-8). The trend line (solid line) and 95 % confidence intervals of the trend line (dashed line) are also displayed.

Overall catchment changes

DCI along this reach was low in 2018 at 0.26%, but with development around Bacchus Marsh, it is expected to increase to 1.25% unless adequately managed. The long-term DCI target for this reach is to maintain baseline levels.

Macroinvertebrate community

The most recent samples (2018 and 2019) lack a number of sensitive families from the orders Odonata, Ephemeroptera, Plecoptera, and Trichoptera.

Water regime

An investigation of the detailed flow data for this location was not undertaken as part of this assessment but other verified forms of information on flow regime have been used.

The Werribee River has major water storages that supply water for consumptive uses and changes in climate has meant that there is a declining amount of water in the system (Figure 64 taken from, Government of Victoria, 2020). The long-term water resource assessment has determined that there has been a 28% decrease in the water share available for the environment in this system. Competition between demand for consumptive use and the water available for the environment is high, with the share of decline hitting the environment in order to maintain as much security as possible for consumptive use.

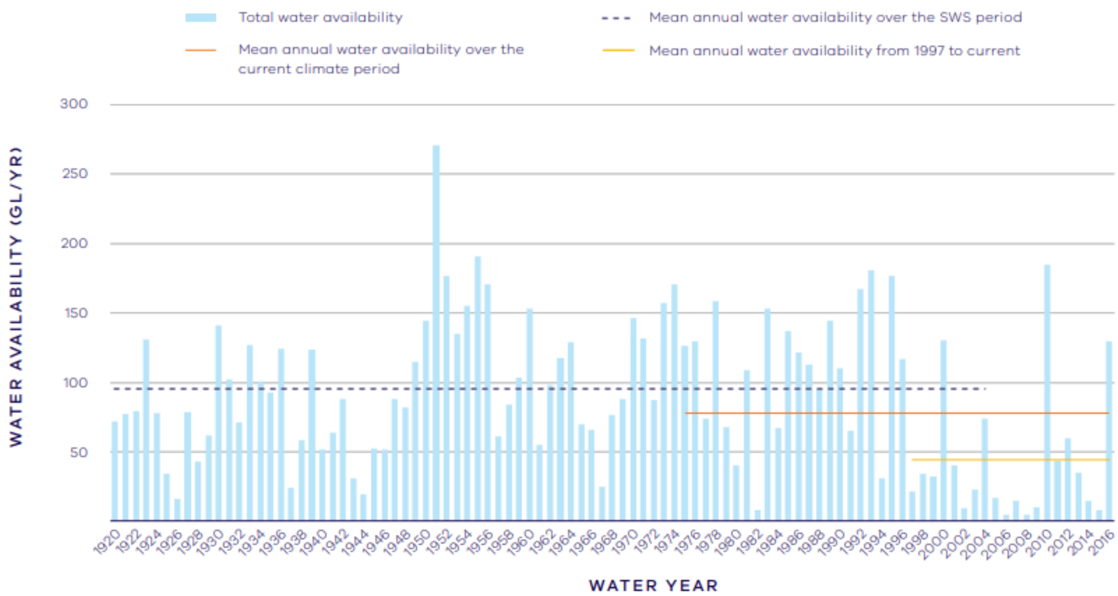

Figure 64. Annual water availability in the Werribee River (including tributaries) (graph taken from the LTWRA, 2020).

Additionally, there this area has undergone urban growth in recent years which has likely had an impact on the waterway here (Figure 65).

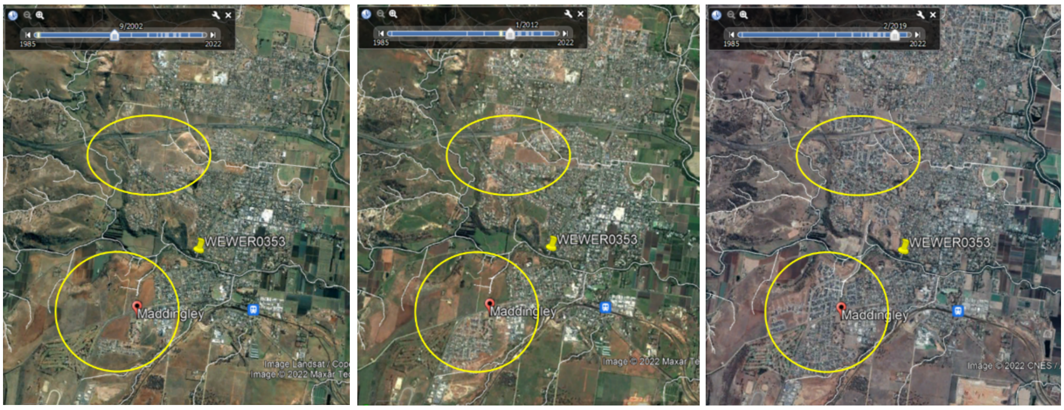

Figure 65. Catchment area upstream of WEWER0353 Werribee River Maddingley depicting change in urbanisation in between 2002 and 2019.

In light of changes in flow in this system and pressures from urban growth it seems likely that changes to the flow regime are a contributing factor in the observed macroinvertebrate decline.

Vegetation

Vegetation quality is rated as low along this reach (i.e. level 2 out of 5 vegetation visions score)(Figure 66). Attenuated forest cover was 22% in 2006 with no change detected in 2016.

Figure 66. Macroinvertebrate monitoring site location and upstream reach (aerial image is from OpenStreetMap 2021 scale 1:8,000).

Water Quality

There is an overlap between the long-term water quality monitoring and the macroinvertebrate monitoring site in this location (Figure 67).

Figure 67. Map of Werribee River catchment area depicting the location of macroinvertebrate and water quality monitoring locations.

There appears to be an improvement in the WQI at this site since monitoring began in 2007. Examination of the detailed water quality parameters (Figure 68 and see Site 9, Appendix 6) shows multiple parameters are rated as good. Nutrients are low at this location. However, little data has been collected at this site since 2015-16, so the impacts of recent urbanisation may not have been detected.

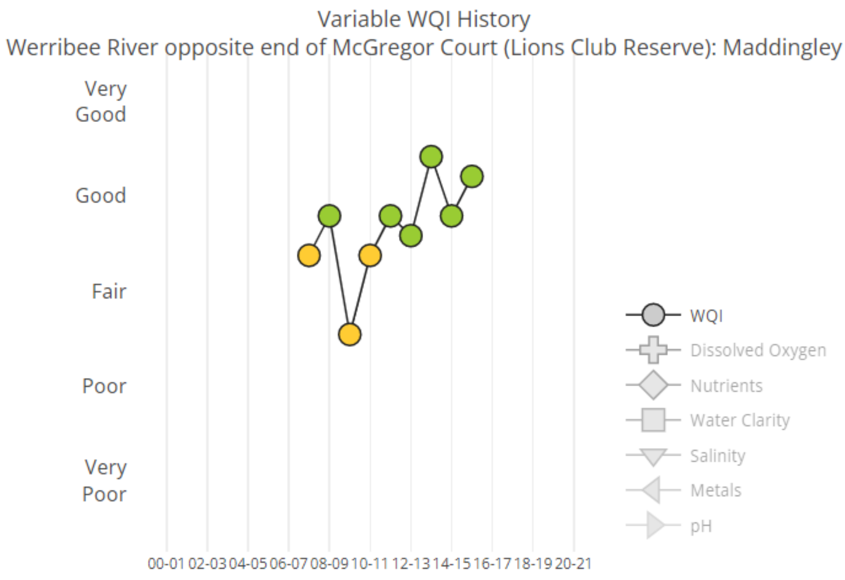

Figure 68. Graph of Water Quality Index (WQI) for WEWER0353 Werribee River at McGregor Ct. Maddingley between 2007 and 2021 showing overall compliance is fair to good.

No complimentary sediment or pollutant data has been collected for this area to help explain trends. Given the recent urbanisation at this site, this investigation would be helpful here as there are often pollutants such as the pesticide bifenthrin associated with new housing development, and this could be contributing to the recent decline in the macroinvertebrate community.

In summary, the water quality data may not be adequate because of insufficient data being available to capture the impacts of recent construction activities. It should also be recognised that we have no data on sediment pollutants and pesticides and that on the basis of this trend, the collection of this data should be prioritised.

Physical form

A geomorphological study of the Werribee was conducted by Earth Tech for Melbourne Water in 2006. The following is an excerpt of a general overview of the middle section of the Werribee River. '*The Werribee flows from the incised valley on the basalt plateau and falls into the Werribee Gorge. This is a region of considerable geologic complexity, containing sediments from the Permian, Ordovician and Silurian periods and the granitic intrusions of the Devonian. After continuing through the incised valley of Werribee Gorge the river enters the alluvial fan downstream of the Rowsley Fault, located in the vicinity of Bacchus Marsh. Below the fault the river gradually reverts to an alluvial continuous form. This form is retained until the Werribee enters the backwaters of the Melton Reservoir, slightly downstream of the confluence with Parwan Creek' (p75).*

Urbanisation and agricultural development along this reach have significantly altered stream form.

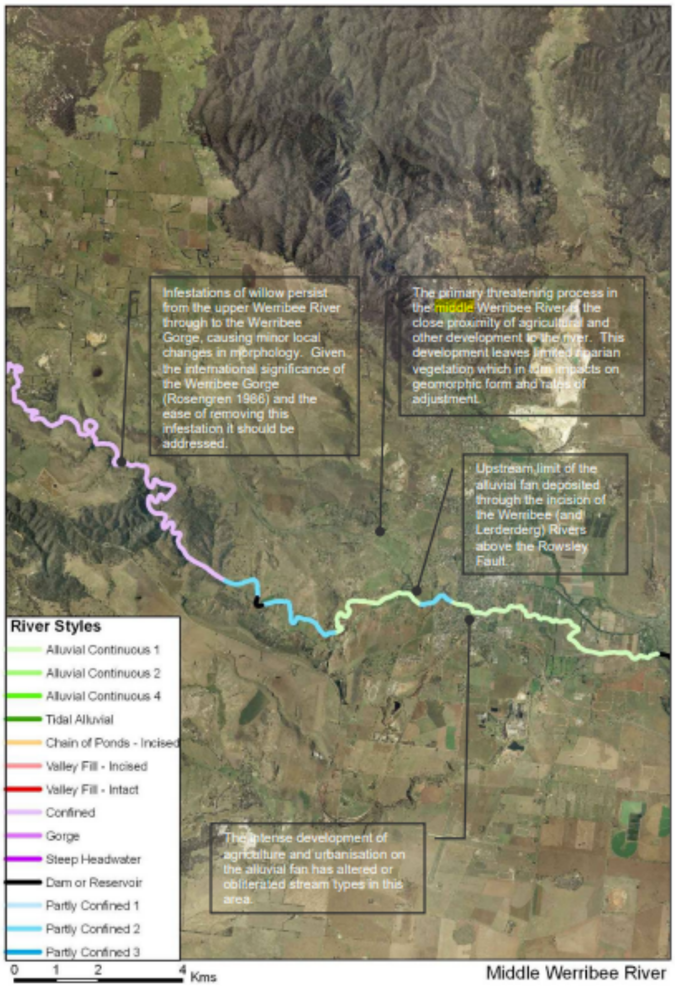

Figure 69. Threatening processes and condition trajectory of middle Werribee River (from Earth Tech, Figure 4-30).

Conclusions and Recommendations

The evidence suggests that macroinvertebrate decline at this location is likely to be associated with a combination of recent urbanisation and reduced flows in the river.

Recommendation: We recommend this location be prioritised for improving the regular collection of macroinvertebrate and water quality data and that a full pollutant investigation is conducted to help in our understanding of this decline in macroinvertebrate trend. Regular collection of impervious changes over time is also recommended. At present, this data is only collected in a semi-quantitative way for the Stormwater Priority areas, which does include this reach.

KRT-26894-4 (Kororoit Creek Lower sub-catchment)

Site description

Kororoit Creek, off Buckingham Crescent by Buckingham Reserve in Sunshine, is situated in the Kororoit Creek Lower sub-catchment and was first sampled in June 1994. The stream drains a predominately urban catchment (Figure 70).

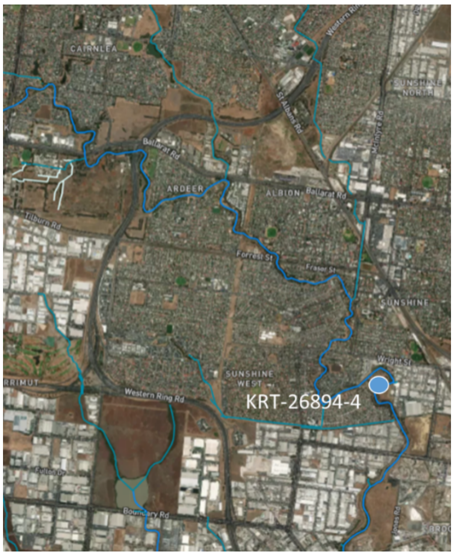

Figure 70. Aerial image of location of KRT-26894-4 Kororoit Creek macroinvertebrate sampling location and its upstream catchment area. Tributaries in teal, main creek in blue.

Photo 12. KRT-26894-4 Kororoit Creek, Sunshine (Kororoit Creek Lower sub-catchment).

Site trend and indicators of change

The increasing LUMaR index trend line at this site is influenced by two recent samples (2018 and 2019) (Figure 71). Excluding the two most recent samples, the site would be categorised as having a 'very low' macroinvertebrate condition. There is a moderate level of uncertainty associated with this trend line. There is a stable SIGNAL2 score trend line over time.

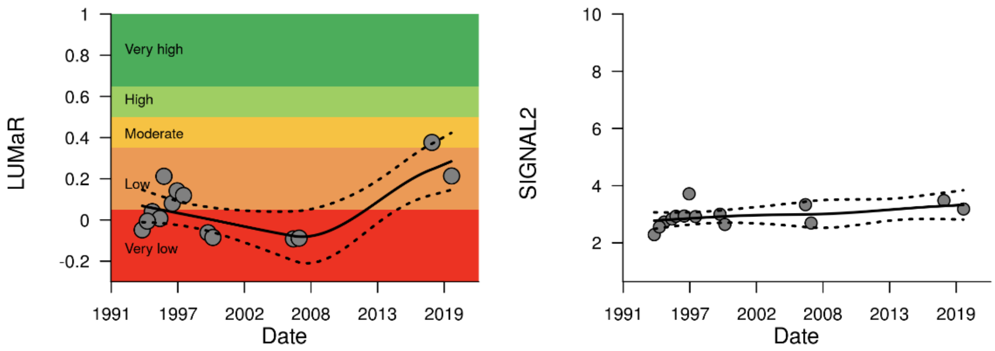

Figure 71. The (left) LUMaR index values (grey dots) and (right) SIGNAL2 scores (grey dots) for Kororoit Creek (KRT-26894-4). The trend line (solid line) and 95 % confidence intervals of the trend line (dashed line) are also displayed.

Overall catchment changes

Historical development in this catchment has resulted in a DCI score of 9.5% along this reach (Figure 72). This is predicted to increase to 23% due to significant greenfield development proposed in the catchment. The long-term target is to reduce DCI to 7%. This reach is within a HWS stormwater priority area.

There has been significant urban growth in the catchment since 2018. This data is captured as part of the HWS annual reporting process for stormwater priority areas.

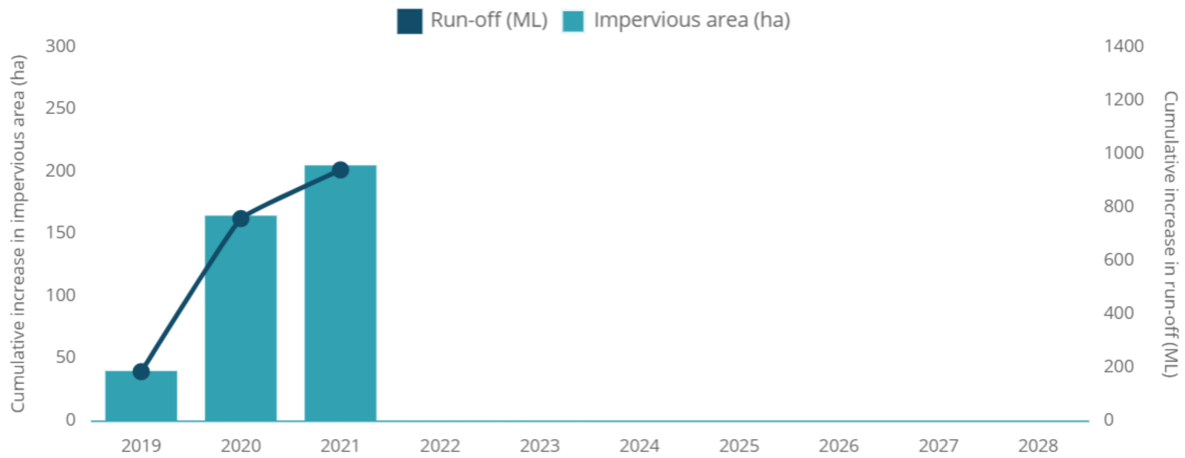

Figure 72. Cumulative increase in impervious surfaces and associated stormwater runoff from new development in the Lower Kororoit Creek sub-catchment (HWS annual report [Report card | Healthy Waterways Strategy for Port Phillip and Westernport, Victoria](#)).

Macroinvertebrate community

Samples in 2018 and 2019 recorded taxa from a number of sensitive families not previously recorded at the site, including: Tanypodinae (order Diptera), and three families in the order Trichoptera (Hydroptilidae, Ecnomidae, Leptoceridae). The positive trend should be confirmed with further sampling.

Water regime

The flow regime along this reach is likely to be significantly impacted by urbanisation given the high levels of DCI. It is likely that flows are more flashy than normal, which can lead to higher erosive flows and, as such, disturbance to physical habitat. Analysis of flow data would be useful to verify this impact.

Vegetation

Vegetation quality is rated as low (level 2 vegetation visions score) (Figure 73). This is the only site where trends have been assessed where attenuated forest cover has increased between 2006 and 2016 from 10% to 14%.

Figure 73. Macroinvertebrate monitoring site location and upstream reach (aerial image is from OpenStreetMap 2021).

Water Quality

No water quality monitoring site is close enough to the macroinvertebrate site to assist with interpretation of the trend. Water quality monitoring sites are located well upstream in Deer Park and downstream at the top of the estuary.

Sediment quality data collated in 2017 did not have any specific data collected close to the macroinvertebrate site. However, wetlands upstream of the monitoring location detected pollutants such as metals, petroleum hydrocarbons and pesticides at low and moderate levels. This may be reflective of what is found in creek sediments higher in the catchment.

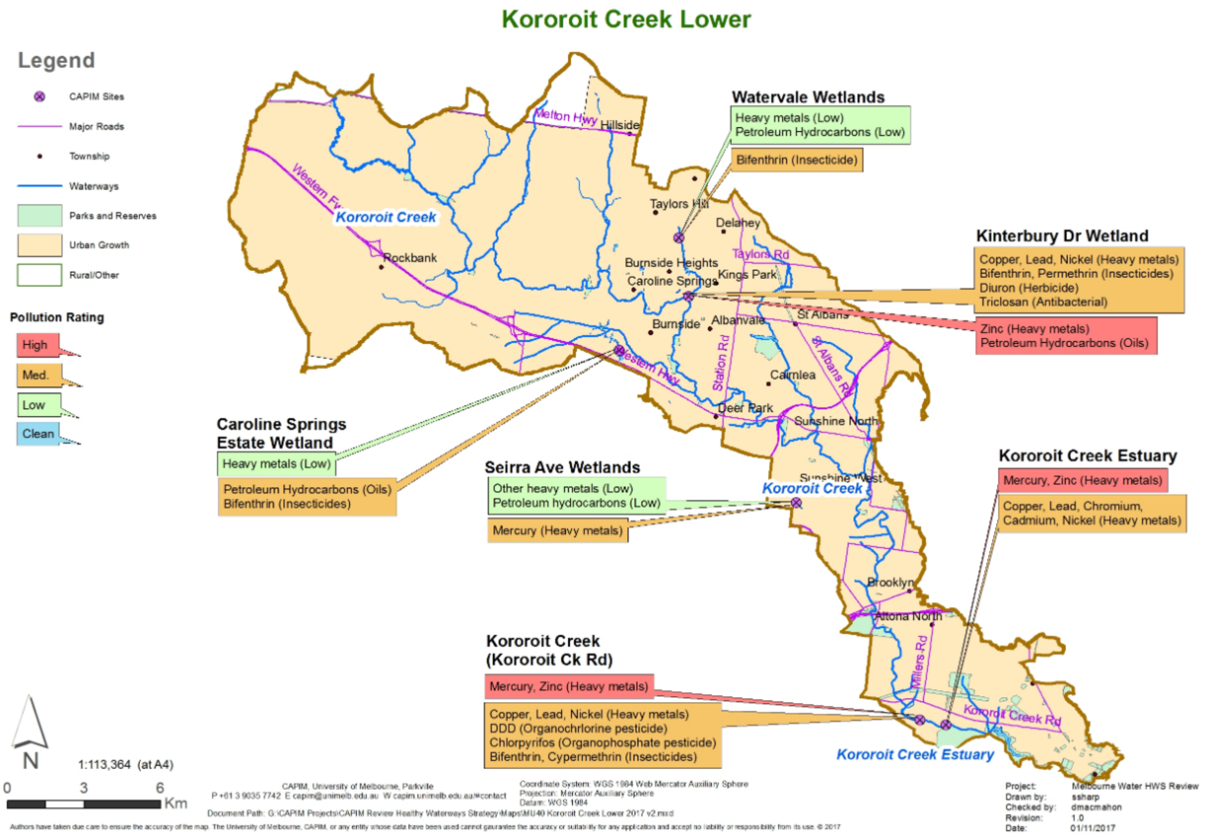

Figure 74. Map of Kororoit Creek sub-catchment that indicates pollutants detected in the catchment prior to 2017. Pollution rating is based on sediment quality guidelines (ANZECC 2000, ANZG 2018) to assess the ecological threat (for invertebrates) against a concentration threshold (known as mean probable concentration quotients). Rating is based on data from 2010 – 2016.

Physical form

The geology of the catchment is dominated by the basalt flows of the newer volcanics. As discussed above, the high DCI levels along this reach are likely to have led to an increased frequency of erosive events, which in turn may have degraded the physical form.

Conclusions and Recommendations

The increasing macroinvertebrate trend is uncertain and needs to be verified with future monitoring data. A possible improvement from revegetation efforts should also be followed up with future monitoring and analysis.

Maribyrnong

BAR-1063-1 (Jacksons Creek sub-catchment)

Site description

Barringo Creek is situated upstream of the influence of the weir, off Barringo Road, but downstream of Shannons Road. It is within the Jacksons Creek sub-catchment and was first sampled for macroinvertebrates in December 1994. The stream drains a predominately dry-forest catchment with some rural land cover (Figure 75).

Figure 75. Aerial image of location of BAR-1063-1 Barringo Creek macroinvertebrate sampling location and its upstream catchment area. Headwaters in white, tributaries in teal.

Photo 13. Photo of BAR-1063-1 (Jacksons Creek sub-catchment).

Site trend and indicators of change

There is potentially a decline in the LUMaR index over time at Barringo Creek, and this trend is also evident in the SIGNAL2 scores (Figure 76). However, there is a large uncertainty in this decline due to the small number of samples and the large gap (~ two decades) in monitoring.

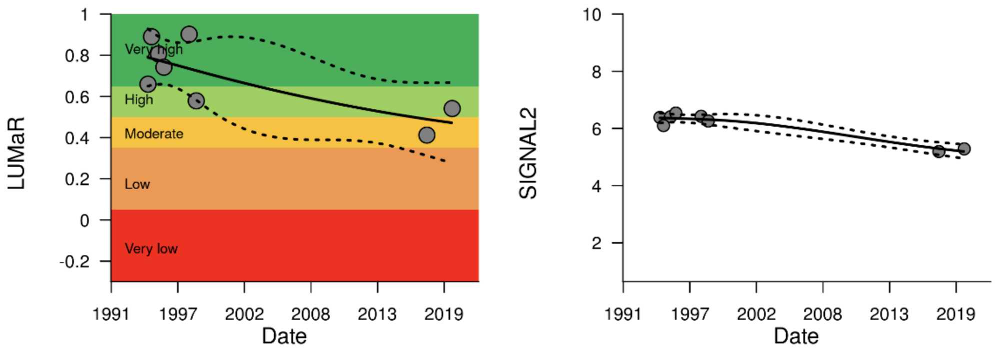

Figure 76. The (left) LUMaR index values (grey dots) and (right) SIGNAL2 scores (grey dots) for Baringo Creek (BAR-1063-1). The trend line (solid line) and 95 % confidence intervals of the trend line (dashed line) are also displayed.

Overall catchment changes

DCI in this catchment is 0% and not expected to increase in the future.

Macroinvertebrate community

Sensitive macroinvertebrate families from several orders (Amphipoda, Coleoptera, Odonata, Plecoptera, Trichoptera) were not recorded in the two most recent samples. While this is concerning, additional samples are required to confirm this trend.

Water regime

Flow gauge data is yet to be sourced and analysed for this site.

Vegetation

Vegetation quality is rated as very high (vegetation visions score of 5)(Figure 77)along this reach, although the confidence in this rating is low. In 2016, attenuated forest cover along this reach was 87.2% with no change detected from the earlier data in 2006.

Figure 77. Macroinvertebrate monitoring site location and upstream reach (aerial image is from OpenStreetMap 2021).

Water Quality

There is a long-term water quality monitoring location nearby (Figure 78 but it has a forested upstream catchment area, so is not considered useful to help determine the causes of decline at the macroinvertebrate site.)

No sediment quality data has been collected in the nearby catchment to assist with the analysis.

Figure 78. Map of Barringo creek catchment area depicting the location of macroinvertebrate and water quality monitoring locations.

Physical form

A geomorphological study of the Maribyrnong River catchment (GHD, 2008) has stated that Baringo Creek has low fragility. The River Style of this reach is "C1-Steep Headwater i.e. steep gradient channels that are gravel, boulder or bedrock dominated - the channel may erode slowly". It can be assumed that the instream physical habitat would be in good condition due to very limited disturbances in the catchment.

Conclusions and Recommendations

Given the long period between data points, it is recommended that this site be re-evaluated in the future to ascertain whether the declining trend is persistent. Consolidation of existing environmental condition data, such as flow conditions, is required to better understand the site conditions and to determine critical data gaps.

DPW-28678-1 (Deep Creek Upper sub-catchment)

Site description

Deep Creek (Trib of Maribyrnong) is located ~80m downstream of Joyces Road and is within the Deep Creek Upper sub-catchment (Figure 79). The site was first sampled for macroinvertebrates in November 1994 and has a rural land cover.

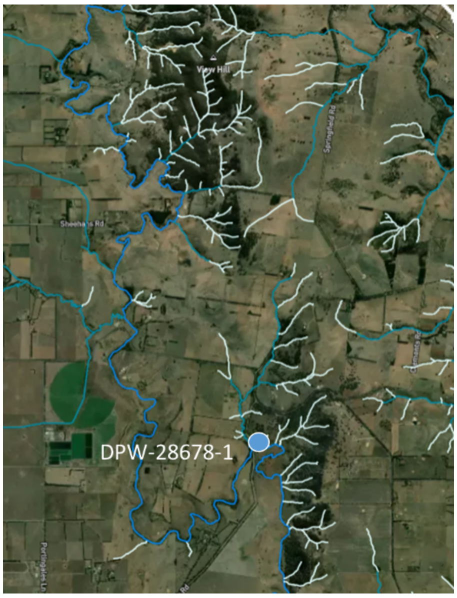

Figure 79. Aerial image of location of DPW-2868-1 Deep Creek macroinvertebrate sampling location and its upstream catchment area. Headwaters in white, tributaries in teal, main creek in blue.

Photo 14. Photo of DPW-28678-1 (Deep Creek Upper sub-catchment).

Site trend and indicators of change

The LUMaR index trend line at Deep Creek (Trib of Maribyrnong) has shown a small but clear decline, particularly in recent samples (Figure 80). This decline is also evident in the SIGNAL2 score trend line.

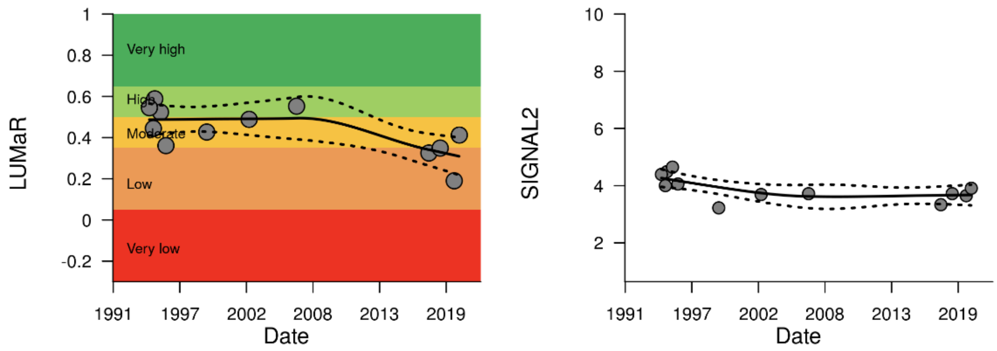

Figure 80. The (left) LUMaR index values (grey dots) and (right) SIGNAL2 scores (grey dots) for Deep Creek (DPW-28678-1). The trend line (solid line) and 95 % confidence intervals of the trend line (dashed line) are also displayed.

Overall catchment changes

The vast majority of the Deep Creek catchment has been cleared for agriculture. The bed of the channel is mostly stable as it is controlled by natural rock bars throughout the majority of the catchment.

Macroinvertebrate community

The recent decline in LUMaR and SIGNAL2 is associated with the absence of a number of Trichopteran and Odonata families from a variety of functional feeding groups (shredders, scrapers, filtering collectors, gathering collectors, predators).

Water regime

Deep Creek is in the Maribyrnong catchment, and a discussion of the change in overall flow and water availability across the catchment is presented in the water regime section as part of the discussion of similarly declining Maribyrnong sites (see Water regime).

In summary, there appears to be evidence to suggest that declining flows in the system are contributing to the declining macroinvertebrate trends in Deep Creek.

Vegetation

Vegetation quality is rated as medium along this reach (vegetation vision score of 3 out of 5) (Figure 81). Attenuated forest cover along this reach was 21.4% in 2006 and 2016.

Figure 81. Macroinvertebrate monitoring site location and upstream reach (aerial image is from OpenStreetMap 2021).

Water Quality

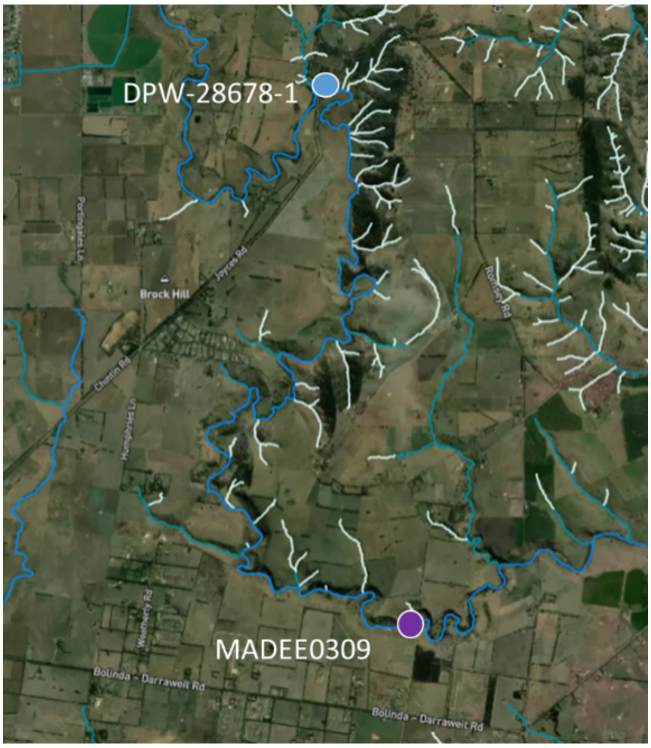

Figure 82. Map of Deep Creek catchment area depicting the location of macroinvertebrate and water quality monitoring locations.

There appears to be an improvement in the WQI at this site since monitoring began in 2007 that is linked to the end of the drought (Figure 83). Examination of the detailed water quality parameters (see Site 10. MADEE0309 Deep Creek at Kennedy's Lane, Romsey, Appendix 6) shows multiple parameters are rated as good. Nutrients are low at this location. Salinity is good and DO has improved since the drought years. Some evidence of high Copper and Chromium was evident in the years around 2010. No complimentary sediment or pollutant data has been collected for this area to help explain trends.

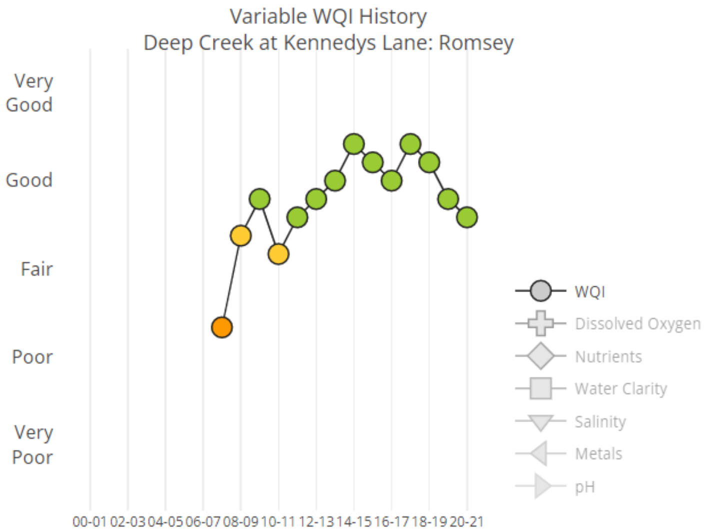

Figure 83. Graph of Water Quality Index (WQI) for MADEE0309 Deep Creek at Kennedys Lane, Romsey between 2007 and 2021 showing overall compliance is good.

Overall, water quality at this location is better than the majority of rural streams in the region.

There is little evidence in the data to explain the macroinvertebrate decline. It should be recognised that the locations are some distance away from each other and we have no data on sediment pollutants and pesticides. On the basis of this unexplained trend, the collection of this data should be prioritised.

Physical form

A Geomorphological Study of Maribyrnong Catchment by GHD in 2008 has categorised the River Styles of this reach as CP3 – floodplain pockets with a low geomorphic fragility. The bed of the channel is mostly stable as it is controlled by natural rock bars throughout the majority of the catchment.

Conclusions and Recommendations

There is some evidence to suggest that declining flows in the system are contributing to the declining macroinvertebrate trends. Despite declining macroinvertebrate trends, water quality is improving and is thought to be a recovery response from the millennium drought.

Recommendation: We recommend a full pollutant investigation to help in our understanding of this trend plus an investigation as to the contribution that declining flows may have on the declining trend in macroinvertebrates.

MRB-130320-1 and MRB-134012-8 (Maribyrnong River sub-catchment)

Site description

These two sites are located on the main stem of the Maribyrnong River. MRB-130320-1 is located at Flora Street, Keilor, downstream of the Calder Freeway bridge. MRB-134012-8 is located at Solomon's Ford, Canning Street, Avondale Heights, and is the last riffle on the Maribyrnong before the river becomes estuarine-influenced (Figure 84). Both sites were first sampled for macroinvertebrates in June 1994.

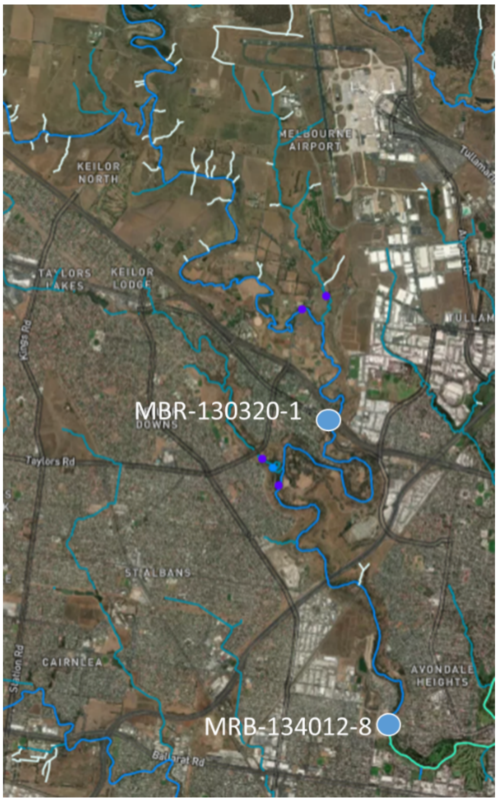

Figure 84. Aerial image of location of MBR-130320-1 and MBR-134012-8 Maribyrnong River macroinvertebrate sampling location and its upstream catchment area. Headwaters in white, tributaries in teal, main creek in blue.

Photo 15 MRB-130320-1 Maribyrnong River at Keilor (Maribyrnong River sub-catchment).

Photo 16. MRB-134012-8 Maribyrnong River at Canning St Ford (Maribyrnong River sub-catchment).

Site trend and indicators of change

The LUMaR index trend line at both Maribyrnong River sites display a consistent yet subtle decline over time (Figure 85). While there is some variation in LUMaR index values over short time periods, the high sampling frequency has led to only a moderate level of uncertainty associated with the trend lines. The SIGNAL2 score trend line is relatively stable for both sites over time.

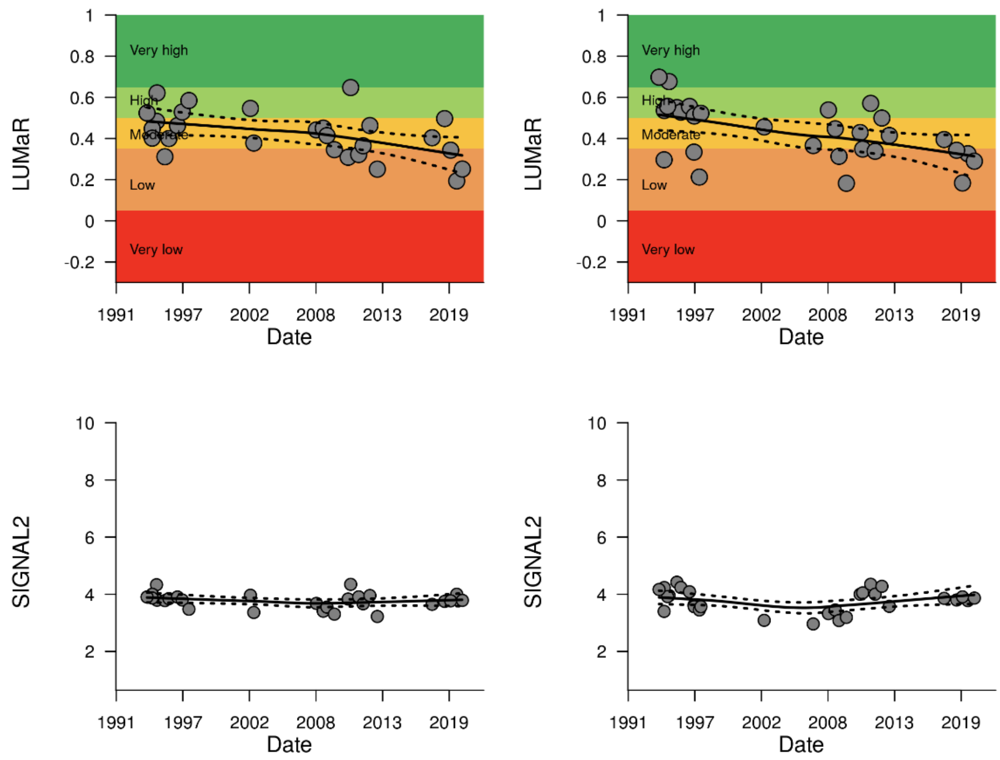

Figure 85. The (left) LUMaR index values (grey dots) and (right) SIGNAL2 scores (grey dots) for Maribyrnong River (MRB-130320-1) and Maribyrnong River (MBR-134012-8). The trend line (solid line) and 95 % confidence intervals of the trend line (dashed line) are also displayed.

Overall catchment changes

The DCI at MRB-130320-1 at Keilor was fairly low i.e. 0.75%, in 2018 but is predicted to increase to 3% from development around Sunbury unless adequately managed. The long-term target for this reach is to reduce DCI to 0.5%. The second site at Avondale Heights MRB-134012-8 has a baseline DCI of 1.5% and is expected to increase to 3.9% unless adequately managed. The long-term target is to reduce DCI to 1.1%.

The HWS Annual report tracks increases in impervious surfaces annually within Stormwater Priority areas – which includes all areas upstream of the Jacksons Creek and Deep Creek confluence before it becomes the Maribyrnong River. The expansion of Sunbury is largely responsible for observable increases in imperviousness (Figure 86).

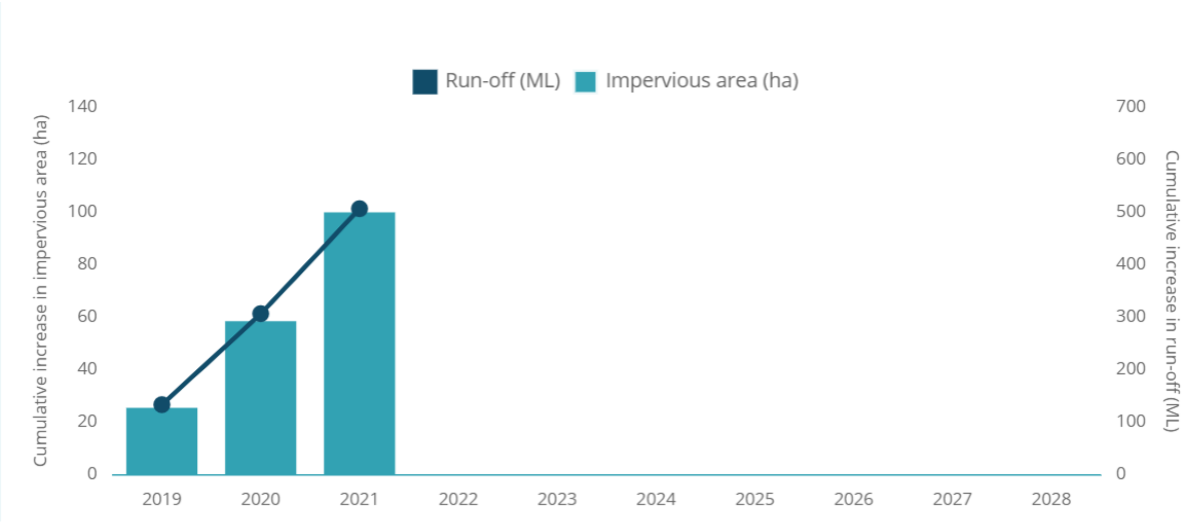

Figure 86. Cumulative increases in impervious surface and runoff from the HWS stormwater priority areas of the Maribyrnong catchment.

Macroinvertebrate community

There are some macroinvertebrate community changes common to both sites that are likely responsible for the declining LUMaR index trend lines. The abundance and occurrence of Atyidae shrimps have declined in recent samples, particularly post-2013. Further, there has been a reduction in the abundance and occurrence of many Ephemeroptera (Baetidae, Leptophlebiidae, Caenidae) and Odonata families.

Water regime

An investigation of the detailed flow data for this location was not undertaken as part of this assessment, but other verified forms of information on flow regime have been used.

There is no dedicated environmental allocation for the Maribyrnong River and the changes in climate has meant that there is a declining amount of water in the system (Figure 87, taken from, Government of Victoria, 2020).

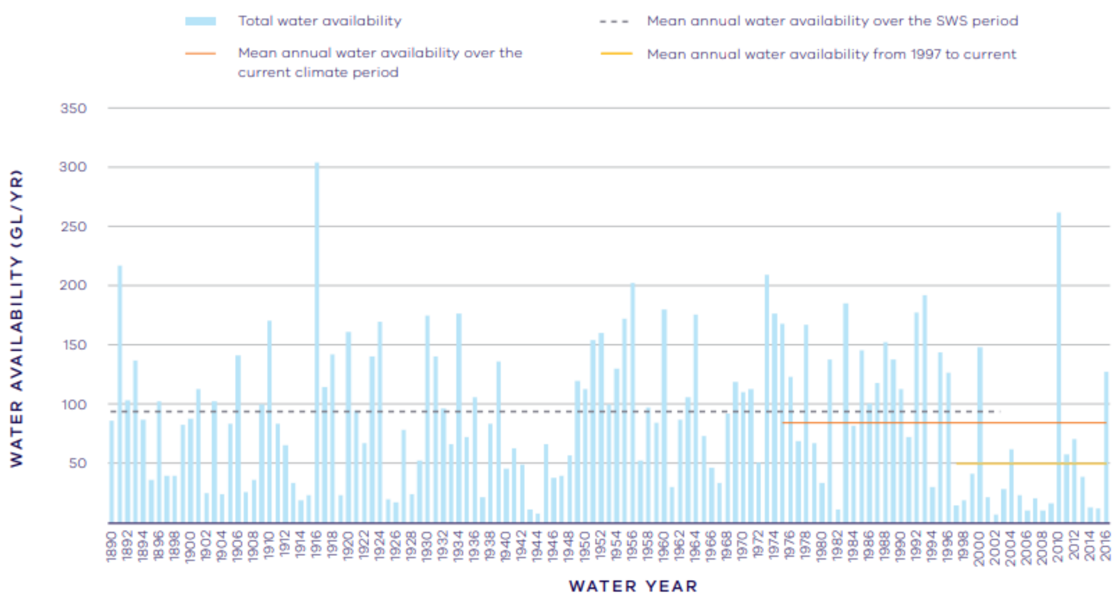

Figure 87. Annual water availability in the Maribyrnong River (including tributaries) (graph taken from the LTWRA, 2020).

The Long-term Water Resource Assessment (Government of Victoria, 2020) has determined that there has been a 17GL decrease in the water share available for the environment in the Maribyrnong system.

Related to this, there has been a decline in the provision of all recommended environmental flow components in the Maribyrnong basin (Figure 88) with dramatic declines in these flow components in Deep, Emu, Riddells and Jacksons creeks and in the Maribyrnong River. It's noteworthy that, on average, based on the current period, only about 20% of all flow components are adequately provided in this system.

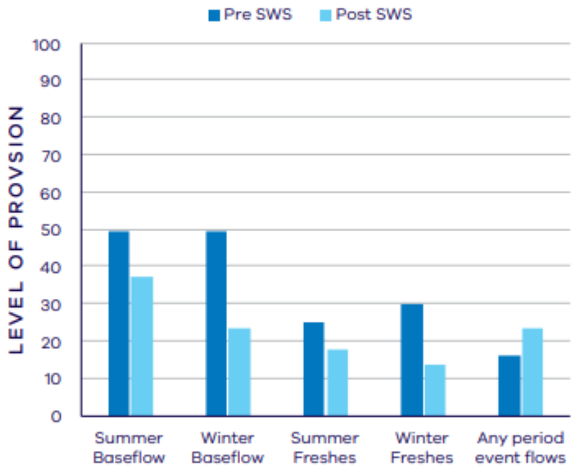

Figure 88. Average change in ecologically important flow components pre SWS (1908 – 2006) and post SWS (2007 – 2018) (graph taken from LTWRA,2020).

In summary it appears clear that flows are reducing as a result of climate change across the Maribyrnong catchment and this is likely to be a contributing factor to the declining macroinvertebrate trend.

Vegetation

Vegetation quality at MRB-134012-8 (left) is medium (ie vegetation vision 3 out of 5) while the rating at MRB-130320-1 (right) is low (2 out of 5) (Figure 89). Attenuated forest cover was 30% in 2006 and 2016 at MRB-130320-1 and 34.6% in 2006 and 2016 at MRB-134012-8.

Figure 89. Macroinvertebrate monitoring sites location and upstream reach MRB-134012-8 (left) MRB-130320-1 (right) *(aerial image is from OpenStreetMap 2021 – scale 1:8,000).*

Water Quality

Water quality monitoring locations overlap and are upstream and downstream of the macroinvertebrate monitoring site (Figure 90).

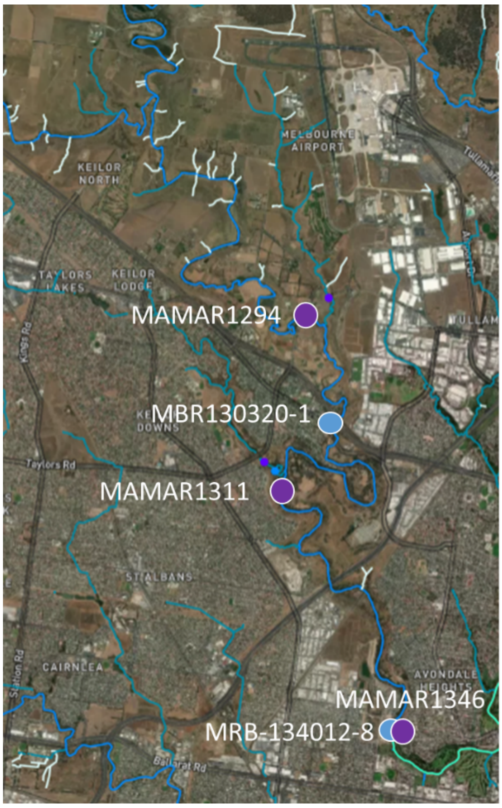

Figure 90. Map of Maribyrnong River catchment area depicting the location of macroinvertebrate and water quality monitoring locations.

There has been no observable decline in water quality (as determined by the WQI) across the three sites that helps to explain the macroinvertebrate trend (Figures 91 – 93). The most downstream site at Canning St. Ford is typically poorer than the upstream, less urbanized sites and rates overall as poor.

Further investigation of the more detailed data shows that DO becomes more variable and chromium and copper increase as the catchment becomes more urbanized (Data available in Site 11. MAMAR1294 Maribyrnong River at Arundel Rd, Keilor, Site 12. MAMAR1311 Maribyrnong River at Brimbank Park, Site 13. MAMAR1346 Maribyrnong River at Canning St Ford, Appendix 6).

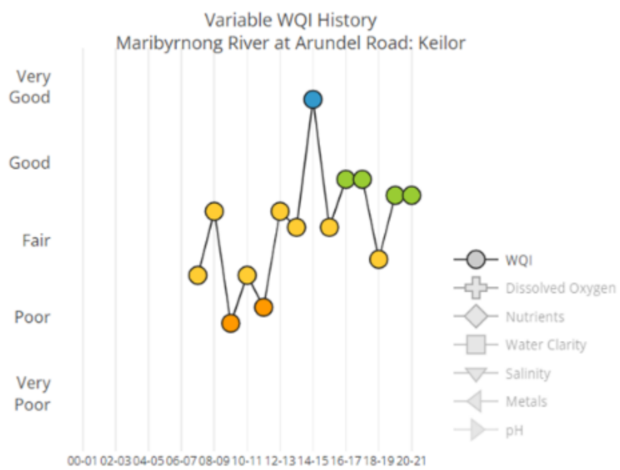

Figure 91. Graph of Water Quality Index (WQI) for MAMAR1294 Maribyrnong River at Keilor between 2007 and 2021 showing overall compliance after the drought fair to good. This site is upstream of the upstream macroinvertebrate monitoring site.

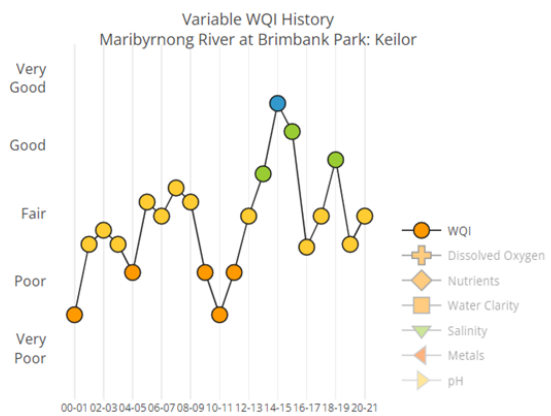

Figure 92. Graph of Water Quality Index (WQI) for MAMAR1311 Maribyrnong River Brimbank Park between 2000 and 2021 showing improvement after the drought. This site is downstream of the upstream macroinvertebrate monitoring site.

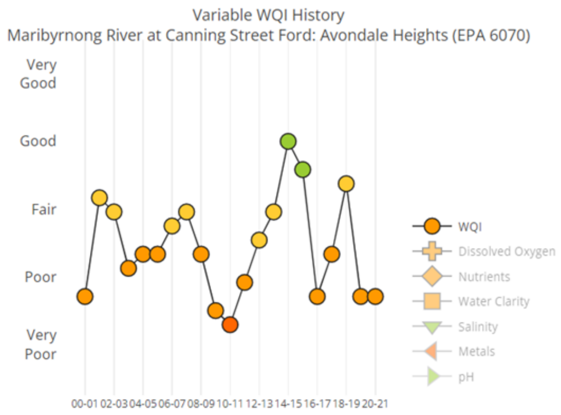

Figure 93. Graph of Water Quality Index (WQI) for MAMAR1461 Maribyrnong River Canning St Ford between 2000 and 2021 showing overall compliance is poor. This site is a direct overlap with the downstream macroinvertebrate site.

Sediment and pollutant data collated for the HWS development period indicates that sediments at Canning St Ford have been recorded as being polluted with nickel petroleum hydrocarbons (Figure 94). Also noteworthy is the high pollutant levels, including insecticides, detected in Arundel Creek which enters the Maribyrnong River just downstream of MAMAR1294 and is likely be impacting water quality at the upstream macroinvertebrate site.

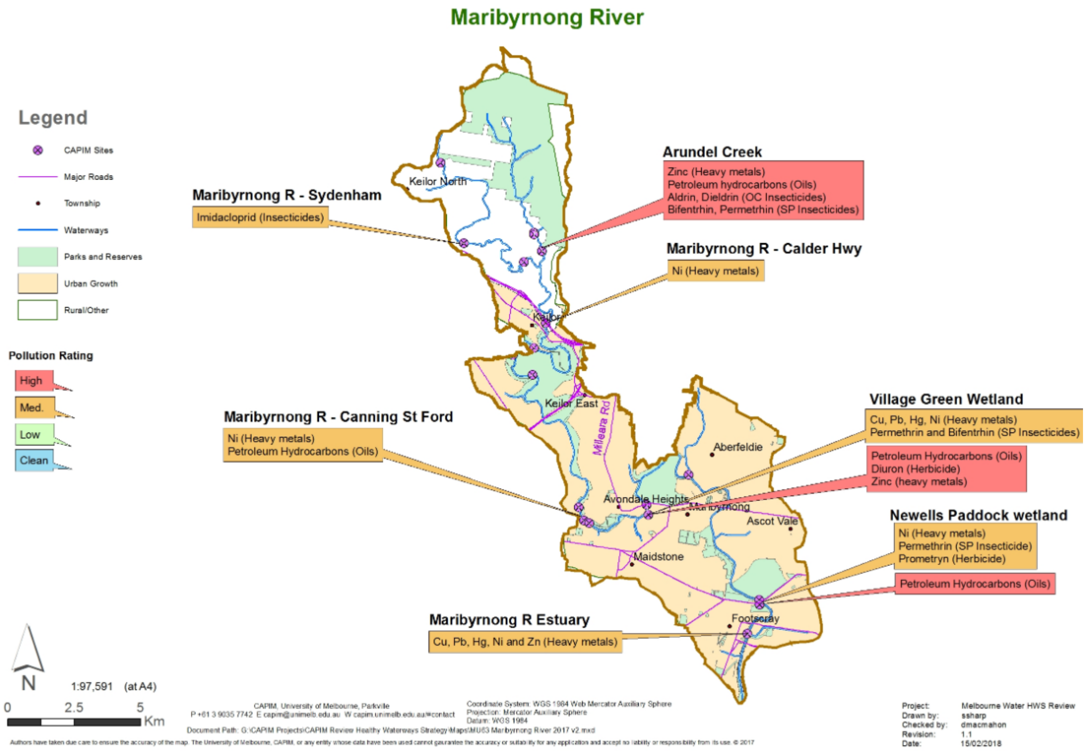

Figure 94. Map of Maribyrnong River sub-catchment that indicates pollutant levels detected prior to 2017. Pollution rating is based on sediment quality guidelines (ANZECC 2000, ANZG 2018) to assess the ecological threat (for invertebrates) against a concentration threshold (known as mean probable concentration quotients). Rating is based on data from 2010 – 2016.

Updated data for MAMAR1461 Canning St Ford collected since 2017 (data not shown, Keller and Pettigrove, *pers comm*) indicate a possible increase in copper and zinc levels in water and sediment samples.

Additionally, several pesticides were detected in water samples. In 2009 atrazine and simazine were detected. In 2012/2103 8 herbicides were detected (atrazine, simazine, diuron, terybutrin, prometryn, metolachlor, 2-4-D, MCPA, Triclopyr) 4 insecticides (dieldrin, chloroyrifos, bifenthrin, primicarb) and 1 Funcigicide (metalaxyl) was detected. This may be an indication of increased pesticide contamination in this catchment that may be impacting macroinvertebrates.

Recent toxicity testing of sediments collected at Canning St Ford suggests no toxicity to macroinverbrates but some inhibition in growth and photosynthetic activity in algae.

In summary although the usual suite of physico chemical parameters collected does not show much evidence of a decline in water quality corresponding to the decline in macroinvertebrates, other pollutants such as insecticides from Arundel Creek and local impacts from urbanised areas upstream of Canning St Ford could be contributing to the declining trend.

Physical form

Not available.

Conclusions and Recommendations

In summary the LUMaR index trend line at both Maribyrnong River sites display a consistent yet subtle decline over time.

There is good evidence that flows are reducing and this is likely to be a contributing factor to the declining macroinvertebrate trend. This is worthy of further investigation.

Evidence of a water quality contributing to the decline in macroinvertebrates is not clear, however insecticides from Arundel Creek and local impacts from urbanised areas upstream of Canning St Ford could be contributing to the trend.

In summary it is likely to be multiple, interactive stressors relating to urbanization and climate change which is driving a downward trajectory of macroinvertebrates.

4. Threatened macroinvertebrate species

Recent investigations (Tsyrlin et al 2022; Tsyrlin and Carew 2022) have been undertaken to determine the current distribution of five aquatic macroinvertebrates, all of which are listed as threatened or potentially threatened within the region (Government of Victoria, 1988).

The target species are known to occur either predominantly (but in some cases not exclusively) in the Dandenong Ranges or at Mount Donna Buang. They include two amphipods: Dandenong amphipod, *Austrogammarus australis* and Sherbrook amphipod, *Austrogammarus haasei* and three stoneflies: Kallista Flightless stonefly *Leptoperla kallistae* Hynes 1974 (Hynes, 1974), Warburton predatory stonefly, *Thaumatoperla robusta* Tyllyard 1921 (Tillyard, 1921) and Mt Donna Buang stonefly, *Riekoperla darlingtoni* (Illies, 1968). They all have restricted distribution, some greater than others, and all are vulnerable to the impacts of climate change, habitat modification, changes in hydrology and/or water quality. Traditional methods of sampling and identification were undertaken, as well as the use of new eDNA techniques.

In summary, the results show a significant increase in the extent of occurrence (EOO) and area of occupancy (AOO) in the known distribution range compared to historical records for the Kallista flightless stonefly, the Warburton predatory stonefly, the Sherbrook amphipod and the Mt Donna Buang Stonefly. The distribution of the Dandenong amphipod did not substantially change. The detected increase in distribution of these species is likely a reflection of the effectiveness of the use of new eDNA methods to detect target species and the value of conducting targeted fauna surveys rather than relying solely on habitat assessments and traditional sampling methods.

Even though the Kallista flightless stonefly was detected at three new sites on Rundells Creek and Casells Creek, there was a partial reduction in the distribution range observed. The species is no longer found in Sassafras Creek at Beagley's picnic ground where it was collected a few years ago. This coincides with the increase of silt and algae on top of rocks observed in recent years at this site.

Detection of Warburton predatory stonefly at Mt Donna Buang is an important finding as the species has not been reliably observed for more than 50 years. Potentially positive samples collected at Mt Baw Baw require genetic confirmation, and the lack of detection in Britannia Creek could be related to a lack of good previous records of the exact location rather than reflect a change in distribution.

Despite the distribution of Mount Donna Buang stonefly being detected across a wider range of sites, population abundance of both nymphs and adults was observed to decrease significantly overall as a result of drying climatic conditions between 2005 and 2019, especially after the particularly dry winter of 2006. The use of eDNA was a very effective and accurate way to monitor this cryptic species. The current study area was confined to the western side of the mountain. Further investigation of the habitats in the 4km area north and south-east of Mt Donna Buang is required to further define the species range. This flightless stonefly inhabits very small headwater streams that are particularly susceptible to climate change and habitat impacts from visitors. Management actions that involve the improved stockpiling of snow cleared from the car park during winter months, as well as the potential installation of tanks linked to smart technology to provide some water security during dry months, are suggested. The species would benefit from being considered for conservation assessment under national environmental conservation legislation in Australia.

The distribution of *Austrogammarus sp.* across the region using eDNA sampling improved our knowledge of the distribution of this genus and indicated the presence of potentially new species.

Five DNA species groups (which included the Dandenong and Sherbrook amphipod) were found in the Dandenong Ranges (Figure 95). While the distribution range of the Dandenong amphipod (*A. austalis*) has not substantially changed, the Sherbrook amphipod (*A. haasei*) was found to have a broader distribution than previously known. This suggests that there may be a more suitable habitat for this species available outside of its previous distribution.

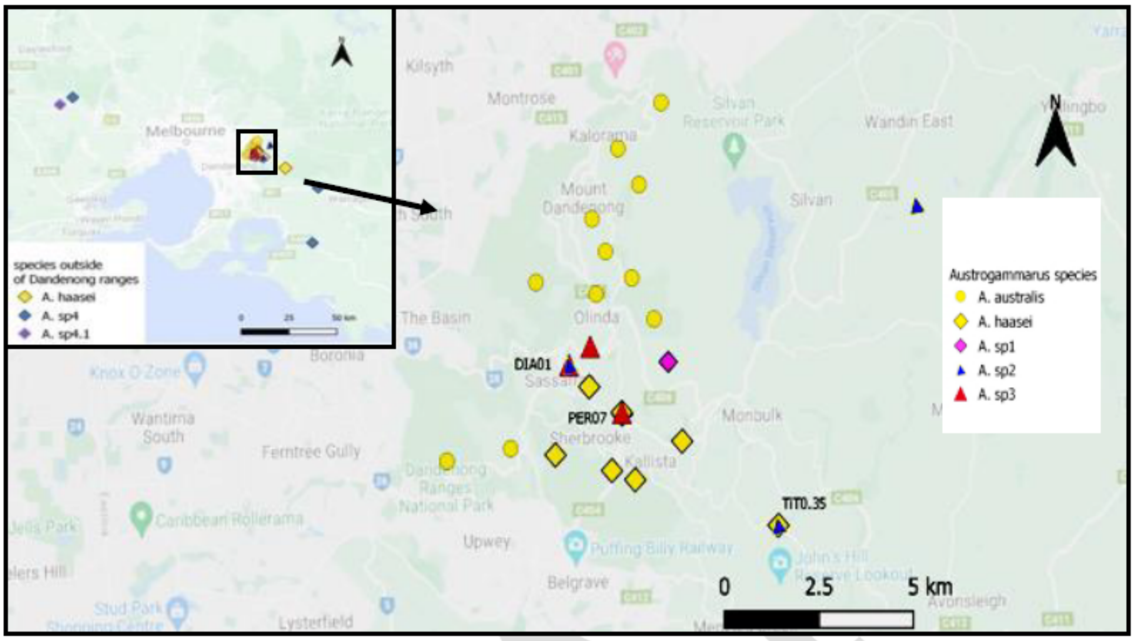

Figure 95. Collection Sites for the Austrogammarus spp. The insert shows wider geographic area outside of the Dandenong Ranges. The sites where two species co-occured are Diane trickle (Dia01), Perrins Creek upstream of Sassafras Creek (Per 7) and Ti-tree Creek (TiT0.35).

Austrogammarus'sp.4' is unusual in having four disjoint populations, separated as far as 150 km from each other while genetically distinct populations and species of this genus have been found within close geographic proximity. This is interesting from the evolutionary point of view and also highlights the importance of the Dandenong ranges as a freshwater biodiversity hot spot.

These studies provide the first steps towards baseline data for assessing temporal changes in the distribution of these species rather than a reliable comparison with the historical distribution using contrasting methods.

Knowledge and data gaps in relation to the species that were studied are listed below:

- Based on findings, the current distribution of many of the study species is wider than previously thought. This allows a baseline for monitoring species distribution in future studies. Recurrent sampling every three to five years could be used to monitor reductions or expansions in species distributions.
- The distribution range of *Austrogammarus* species is wider than the Melbourne Water management area, and it would be beneficial to clarify these areas and who manages them in cooperation with other agencies like DEECA and Parks Victoria.
- Genetic analysis of *Thaumatoperla* from Mt Baw Baw is required to determine if this species is the Warburton predatory stonefly.
- Further morphological analysis of DNA based groups of *Austrogammarus* species, to determine if the unidentified groups represent described or new species.

- Once the taxonomy of the genus is clarified, identifying species-specific, eDNA probes for *Austrogammarus* species to simplify the species surveys and enable citizen scientists to detect these species.
- While the ecology of *A. australis* has been studied, the ecology and natural history of all other threatened invertebrate species is poorly understood. This fundamental knowledge is required to set meaningful management targets for the protection of these species.
- Further investigation of the habitats in the 4km area north and south-east of Mt Donna Buang is required to further define the species range of the Mt. Donna Buang stonefly, *R. darlingtoni*.
- A formal assessment of the effective population size of the Mt. Donna Buang stonefly and the genetic relatedness of the known populations is required to fully understand the vulnerability of the species

We identified the following recommendations for management priorities:

- Addressing the data gaps described above to effectively manage the 5 threatened species investigated.
- Repeated sampling of Kallista flightless stonefly at Beagley's Picnic Ground is required. If the species is not detected, this should be followed by a targeted investigation of the upper Sassafras Creek for stormwater and sewage impacts.
- Efficient and standardised collection of eDNA by creating a "DNA sample bank"; a centralised and independent repository and a database for all future eDNA samples made available online. This will help to promote biodiversity research, monitoring and comparison for all aquatic organisms.
- Investigate a range of short-term management interventions on Mt. Donna Buang to support populations of both Mt Donna Buang and Warburton predatory stonefly populations such as improved snow clearing management, stormwater harvesting from the adjacent carpark and roads, along with a slow release of harvested water to the spring to offset potential reductions in rainfall associated with climate change.
- Advocate for the conservation assessment of Mt Donna Buang stonefly under the federal Environment Protection and Biodiversity Conservation Act (EPBC) 1999, and investigate and shortlist alpine springs that may be suitable for translocations under a climate change future.

5. Synthesis and key findings

Inferential strength, transfer and scaling

This section concerns the inferential strength and potential broader application of the findings in this investigation. Ultimately, this relates to how true the relationships (i.e. is there demonstrated cause and effect) of interest are and where else and when could the relationship be validly applied (how general is the relationship)?

Our investigation draws on a blend of inductive and deductive reasoning and includes correlative / observational data, manipulative experimental data (laboratory, field), expert opinion derived through elicitation and multiple lines and levels of evidence, combining some or all of the above. Where we are not confident in the relationship, we have stated so.

f. In summary, a method was developed to assess trend in LUMaR at site scale based on historical trend. The rubric used for this to answer KEQ3b is presented in

Table 6. The site scale assessment conducted in this analysis was brought together with updated HSM outputs and is presented in the HWS Science Inquiry Report (Melbourne Water, 2023a). An overview of the results for this used to answer KEQ3a is presented in : HWS macroinvertebrate Mid-Term Evaluation rubric

Table 9 and visualised in Figure 96.

Our investigation for this report was site based, meaning the findings can primarily be transferred to other sites with similar characteristics. However, many of the relationship between macroinvertebrate community changes and environmental conditions that we uncovered as part of this investigation are general patterns documented elsewhere at a variety of spatial and temporal scales. We can therefore, under certain circumstances and with caution, make inferences at larger spatial and temporal scales assessed in this investigation. So our assessment against KEQ2a is not based on strict evaluative criteria.

Conclusions

Of the 77 sites with trends, we focused our attention on 15 These sites had either increasing or declining trends where confidence in the trend was moderate to good. The key findings from this analysis include:

- LUMaR identified key trends in the macroinvertebrate communities, but more detailed information on specific taxa and functional feeding groups helped uncover potential mechanisms underlying the changes observed. SIGNAL2 and EPT families were also useful and enabled a more holistic picture of site trends compared with using only LUMaR or any single indicator on its own.
- While it was challenging to confidently explain casual factors for observed trends in many cases using empirical data, there was sufficient evidence using multiple environmental conditions data sets, in combination with knowledge of mechanisms from published literature, to draw inferences regarding the likely major drivers of trends.
- The impacts of the millennium drought were not necessarily very clear or dominant in the LUMaR or SIGNAL2 trend data, and the recovery that we expected to see was not detected. This may be due to continued flow stress in many areas of the catchment, or it may be that the indices are not designed for this purpose.

- Sites with predominately urban catchments were in moderate to poor LUMaR and SIGNAL2 ranges, while sites in forested catchments were high
- The range of SIGNAL2 scores across the region are smaller than LUMaR, which can better differentiate across the region. However, neither index works well for ephemeral streams
- There were limited flow gauges in the upper parts of the catchment
- There was a general pattern of sites declining from high LUMaR scores as opposed to improving sites which generally started from a much lower base.

A summary of the sites which were declining includes:

- The unexpected declining trend observed in a forested catchment can be explained by the black Saturday bushfires, which led to an initial increase in LUMaR followed by a decline. It is expected that this decline is due to the system re-stabilising.
- There is a concerning trend of a number of sites that are declining from a high or very high LUMaR score to more moderate levels. These tend to be sites along main stems with mostly rural catchments and, in some cases, increasing levels of urbanisation. It has been difficult to attribute casual factors to these trends.

A summary of the sites which were improving includes:

- Increasing LUMaR scores in the middle and lower Dandenong Creek sites were unexpected due to the extent of historical and on-going urbanisation in the catchment. While promising, further investigation is required to better understand the drivers of this trend. And it is considered unlikely that health will improve beyond moderate condition.

While further analysis is required, there was only one site that showed a response relatable to the millennium drought and improved flow management.

Recommendations for consideration in the Science Inquiry

While there are site scale recommendations within relevant sections, the following recommendations more broadly include:

- Investigate nominated sites in order to better understand causal factors, prioritising declining sites;
- Ensure annual data collection for uncertain sites and review trends by 2025 and if confidence in the trends increases, add to the list of sites to investigate causal factors;
- To protect priority reaches and threatened species from flow stress during dry periods, improve monitoring and available management options (e.g. more regular and targeted species and condition monitoring, location of flow gauges, implementation of bans and restrictions and explore options for the proactive management of sleeper licences, explore site scale management options to improve habitat requirements);
- Consider management options for threatened species recovery following disturbance events (e.g. stormwater harvesting, treatment and slow release, translocation of species into recovered habitats);
- Install long-term flow gauges in upper catchment reaches (perennial and non-perennial) to better understand impacts of climate change; and,
- Prioritise acquisition of impervious surface mapping across the region including historical data in order to track urban development, ensuring infill development is captured.

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7. Appendices

Appendix 1: Macroinvertebrate monitoring program design

The objectives for broad-scale monitoring of macroinvertebrates include:

- Provide an ability to report status of instream values in all 69 HWS sub-catchments of the region – including rare and threatened species.
- Track trajectories of change in stream ecosystem health (current using macroinvertebrates) over time.
- Track trajectories of change in critical background conditions (i.e. temperature, discharge depth, antecedent runoff, stormwater, vegetation and instream barriers) that influence instream values (and are included in the habitat suitability models).
- Assess macroinvertebrate responses to climate change, and if those responses differ for reference streams, streams subject to agricultural impacts, streams subject to urban impacts, streams subject to flow regime modification.
- Assess macroinvertebrate responses to management interventions in the strategy specifically the stormwater and vegetation performance objectives.
- Reporting attainment of SEPP macroinvertebrates objectives.

In addition to these objectives, there is a need for continual testing and refinement of the Habitat Suitability Models for macroinvertebrates that are used to predict the current status across all stream reaches, as well as the likely long-term benefits of implemented works that may take several years for benefits to be realised.

Appendix 2: Habitat Suitability Models

Model Development

Habitat Suitability Models (HSMs) predict where habitat is suitable across the region for macroinvertebrates. They are an important tool to investigate the impact on habitat suitability due to different management interventions and future environmental conditions like changes to climate. A detailed explanation of model development and use can be found in Chee et al. (2020).

In summary, the HSMs used a waterway network dataset which contains ~8,400 kms of streams (currently excludes headwater streams) throughout the Melbourne Water region and were developed to describe habitat suitability for 52 macroinvertebrate families. HSMs were also developed for a macroinvertebrate index, LUMaR, which is based on the presence-absence of these 52 macroinvertebrate families.

For each taxon of interest, 10-12 environmental characteristics were carefully selected to describe instream habitat suitability. The rationale for predictor selection was to develop models that would provide direct predictions of the biotic response to climatic changes, land use changes, mitigating management actions, and their interactions. Predictors of natural environmental variability was informed by ecological information reported in the published literature and included catchment area, mean annual air temperature and mean annual runoff depth.

The models were constructed using data for values and predictor variables collected from 1995 to 2009. "Current state" of the values was modelled using 2016 predictor variable datasets (CURR).

For the purposes of long-term strategic planning over a 50-year horizon, a scenario called the business-as-usual future (BAUF) was devised. This scenario focused on important widespread threats in the form of climate change (warming and drying) and increased impervious cover (due to urbanisation) and was expressed relatively simply. Warming was represented by a 1.5^{0}C increase in mean annual temperature and drying was represented by a reduction in mean annual runoff depth (equivalent to a 25% reduction in long-term mean annual discharge at the mouth of the Yarra River). These options were chosen to be broadly consistent with DELWP (2016), and still largely within the 'experience' of the training data used to develop our HSMs. The extent of future impervious land cover was estimated using Victoria's VicMap Planning dataset's planning scheme zone data (downloaded 21 Sept 2017 from https://www.data.vic.gov.au/data/dataset/vicmap-planning).

HSM scenarios run with the above conditions but no additional intervention were called Business-as-Usual Future (BAUF).

For the purpose of setting long-term targets at the sub-catchment scale HSMs were used to determine a length-weighted average LUMaR score from model predictions. The 2068 targets are long-term i.e. 50 years and are based on a number of assumptions. These assumptions are outlined in the HWS Resource Document – but the key ones are:

- Higher standards of stormwater harvesting and infiltration can be achieved in new urban areas with the outcome that pre-development flow conditions could be conserved
- Urban impacts will be reduced progressively in already urbanised areas by incorporating interventions as infill development and/or redevelopment/asset renewal progresses and creates opportunities for redesign. It was assumed that a 25% reduction in attenuated imperviousness would be achievable over 50 years under 2018 policy settings. Since the strategy targets were set in 2018, Urban Stormwater Guidance has been updated that supports this assumption.

- Climate change projection assumptions of 1.5°C increase in mean annual temperature applies as it does under the BAUF scenario but it was assumed that flows could be maintained. Since 2018, new climate change assumptions have been developed. This work is detailed in HSM mid-term climate change report.
- The HWS aims to prevent decline due to climate change and urbanisation for an overall outcome of no net decline across the region with improvement in trajectory in some sub-catchments.
- Revegetation will achieve a moderate vegetation quality (level 3 vegetation visions) which supports indigenous trees and shrubs but not an intact ground cover layer.

A summary of the CURR, BAUF and target scenarios is presented in Table 7.

A more comprehensive overview of model development and use can be found in Chee et al (2022).

Table 7. Details of the current (CURR) scenario, the business-as-usual-future (BAUF) scenario and the long-term HWS targets.

Scenario Code	Mean annual air temperature (°C)	Mean annual runoff depth (mm)	Attenuated Forest	Attenuated Imperviousness
CURR	2016 values	2016 values	2016 values	2016 values
BAUF	2016 values + 1.5 °C	Equivalent to a 25% reduction in the long-term mean value at the mouth of the Yarra River*	2016 values	Values reflecting attenuated imperviousness when all parcels within the MW region with 'urban' planning scheme zone codes have been developed to their full capacity.
Long-term HWS target	2016 values + 1.5°C	2016 values	Values reflecting revegetation 20m either side of all stream length in rural areas and 10m either side in urban areas	Attenuated imperviousness in existing urban areas is reduced to 75% of 2016 levels All urbanisation after 2016 is fully treated so that these areas remain at 2016 values

*To represent drier conditions reflecting a 25% reduction in the long-term mean annual flows at the mouth of the Yarra River, Walsh & Webb (2013) identified a 4-year period (that happened to be the 48 months prior to December 2000) where mean annual discharge was 75% of the long-term average. The monthly discharge estimates for this particular 4-year period was used as an analogue for drier conditions. (In practice, dryMeanQ for each reach was set to mean annual discharge calculated from monthly discharge estimates in Geofabric (Bureau of Meteorology 2011) over that particular 4-year period.)

Table 8 summarises the HWS 2018 long-term targets across the region for macroinvertebrates. Almost half the sub-catchments are aiming to improve condition from the 2018 baseline (defined as "current" in the HWS), which for some sub-catchments (11) requires a significant amount of effort to overcome a declining business as usual trajectory (BAU in the HWS) predicted to result from urbanisation and climate change. The target for a small number (7) sub-catchments is to simply prevent the sub-catchment from declining which still requires significant effort. The remaining sub-catchments (28) are not predicted to decline (i.e. urbanisation is not a threat and climate change impacts were small) and the target is to maintain the status quo (i.e. to maintain the baseline of 2018 current). It is also worth noting that these are length weighed average scores for each sub-catchment and reach scale predictions are likely to be more variable e.g. smoothing of results can occur as a consequence of some reaches improving and some declining.

Table 8. Number of sub-catchment where targets that are set to improve, maintain or decline in LUMaR scores over 50 years.

Target type	Number of sub-catchments	explanation
Improve from current	34	11 sub-catchments are predicted to decline under business as usual trajectory 23 sub-catchments are not predicted to decline under business as usual trajectory.
Maintain current	28	Sub-catchments are not predicted to decline under the business as usual trajectory. Target is to maintain current levels.

Using models in the Mid-Term Review

Information on how HSMs were used to inform the Mid-Term Review can be found in the Science Inquiry Report (Melbourne Water, 2023a).

Appendix 3: HWS macroinvertebrate Mid-Term Evaluation rubric

Table 9. Rubric for macroinvertebrates that was used during the mid-term evaluation combined site scale trends and updated HSM outputs. The rubric was used to categorise sub-catchments as on-track or significantly off-track.

Performance rating	Performance criteria / evidence
On-track to achieving long-term target	Updated HSMs in 2022 (based on revegetation and stormwater works to 2022 and un-mitigated urban development in priority areas since 2018) do not have declining reaches from the 2018 baseline by more than 0.15 LUMaR AND/OR one or more macroinvertebrate monitoring sites are stable or improving.
Slightly off-track to achieving long-term target	Not assessed at mid-term
High chance that long-term targets will not be met	Updated HSMs in 2022 (based on revegetation and stormwater works to 2022 and un-mitigated urban development in priority areas since 2018) have declining reaches from the 2018 baseline by 0.15 LUMaR or more AND/OR one or more macroinvertebrate monitoring sites are showing long-term declines.

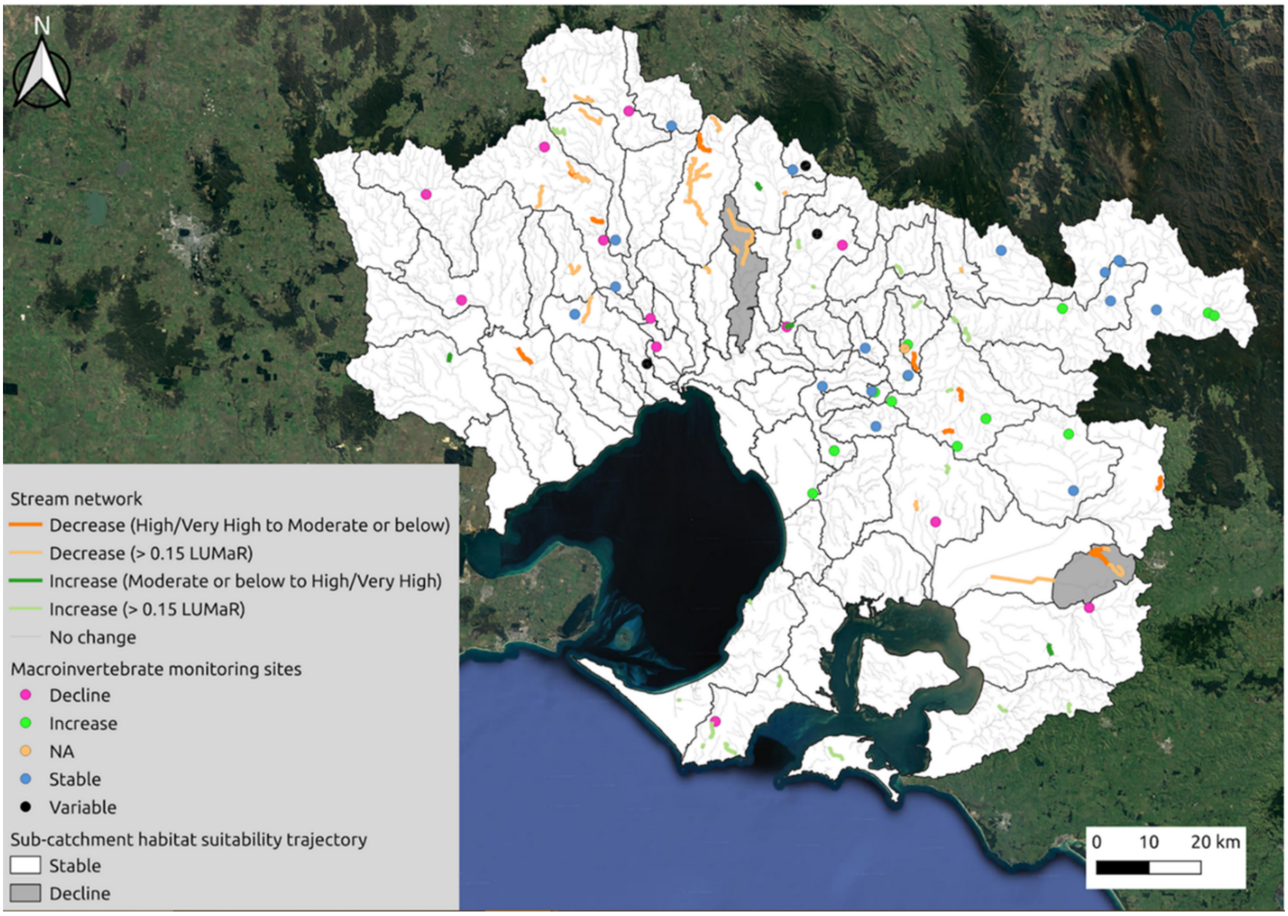
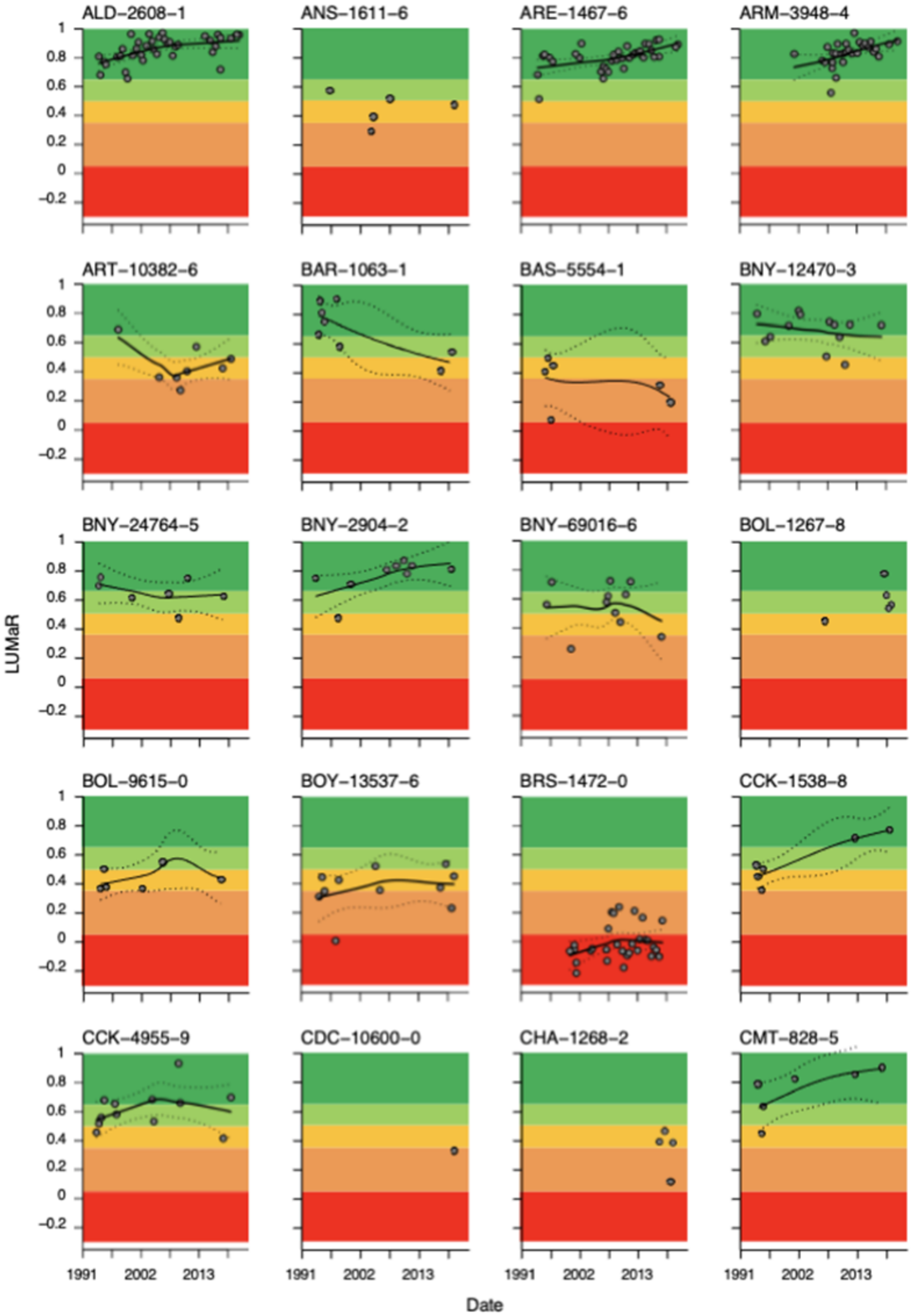
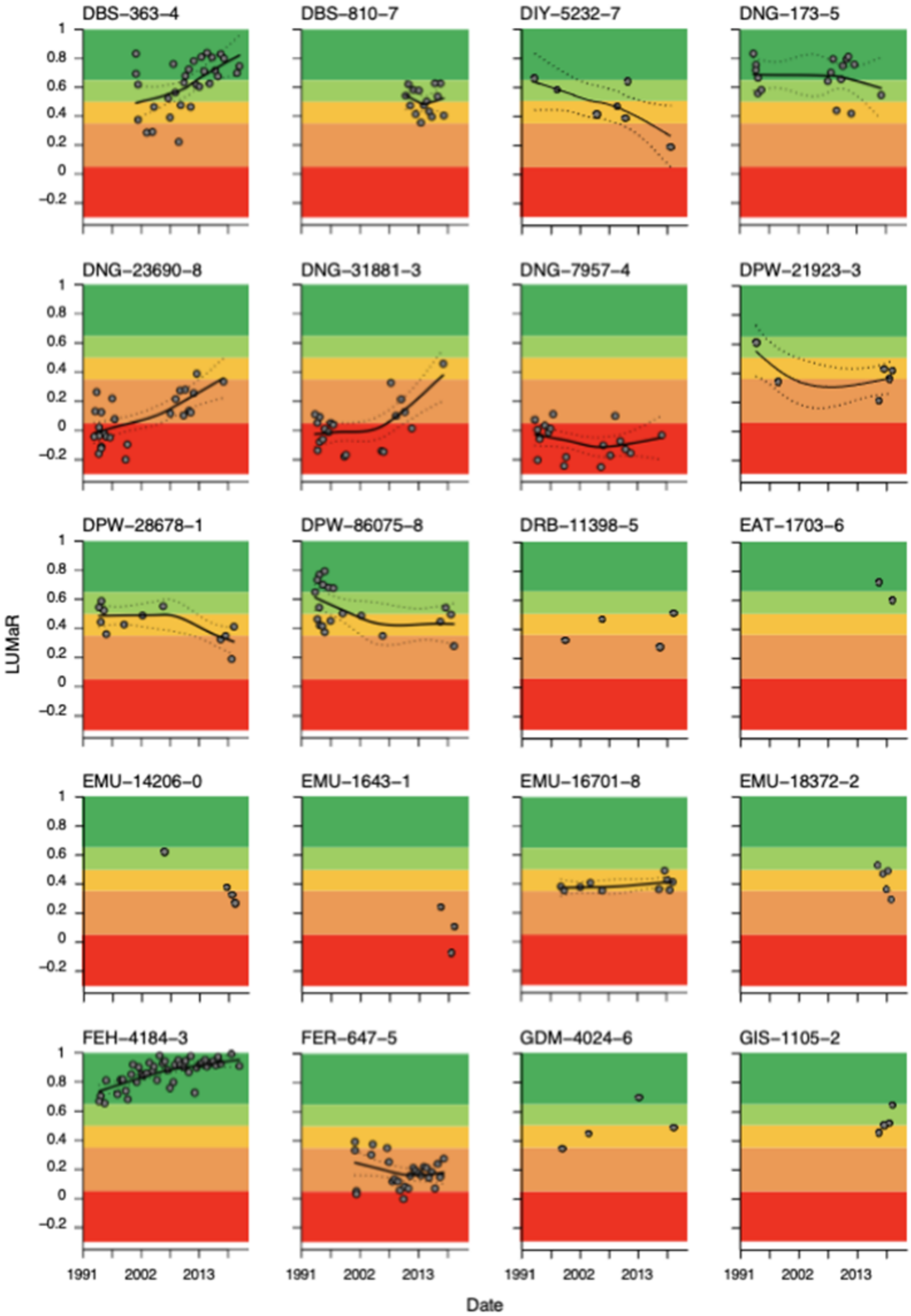


Figure 96. Synthesis of HSM macroinvertebrates model Works-To-Date outputs with site scale assessments. Sub-catchments were categorised according to rubric in Table 9.

Appendix 4: LUMaR trends for macroinvertebrates

For sites sampled as part of the HWS Macroinvertebrate monitoring program

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DBS−810−7
DIY−5232−7
DNG−173−5
DNG−23690−8
DNG−31881−3
DNG−7957−4
DPW−21923−3
DPW−28678−1
DPW−86075−8
DRB−11398−5
EAT−1703−6
EMU−14206−0
EMU−1643−1
EMU−16701−8
EMU−18372−2
FEH−4184−3
FER−647−5
GDM−4024−6
GIS−1105−2
LUMaR
1
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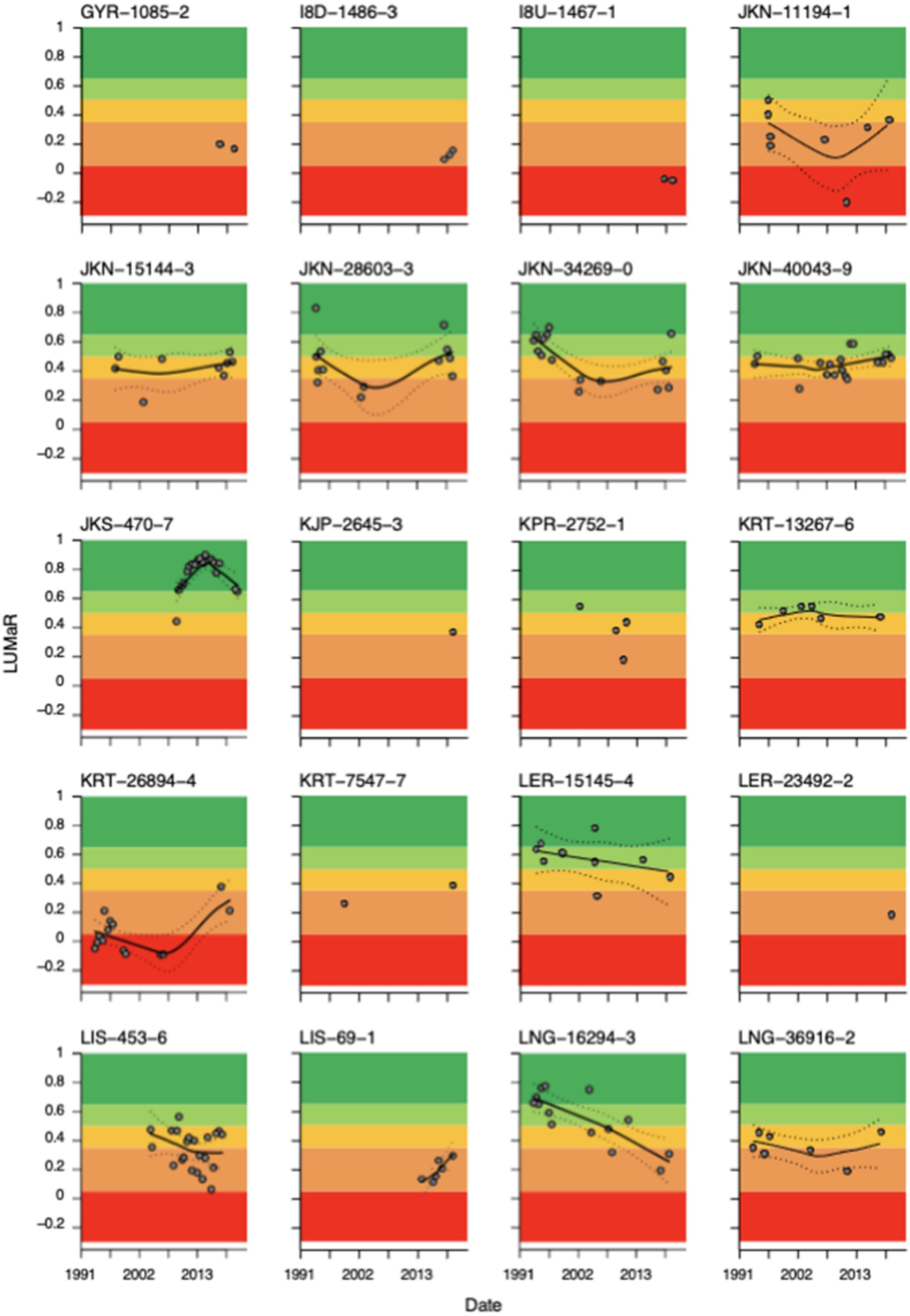
0.6
0.4
0.2
0
−0.2
1991
2002
2013
Date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I8D−1486−3
I8U−1467−1
JKN−11194−1
JKN−15144−3
JKN−28603−3
JKN−34269−0
JKN−40043−9
JKS−470−7
KJP−2645−3
KPR−2752−1
KRT−13267−6
KRT−26894−4
KRT−7547−7
LER−15145−4
LER−23492−2
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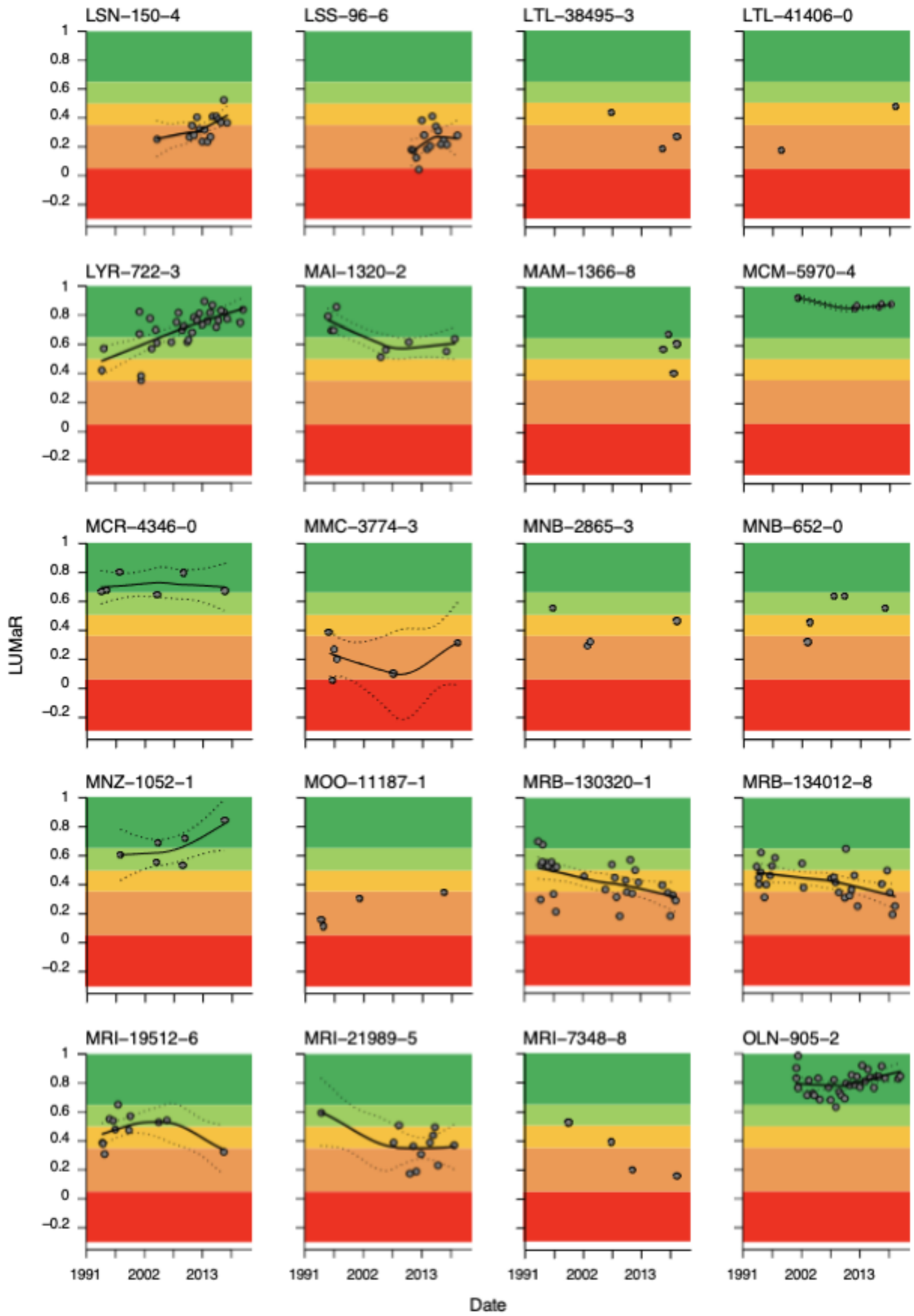
LIS−69−1
LNG−16294−3
LNG−36916−2
LUMaR
Date
1991
2002
2013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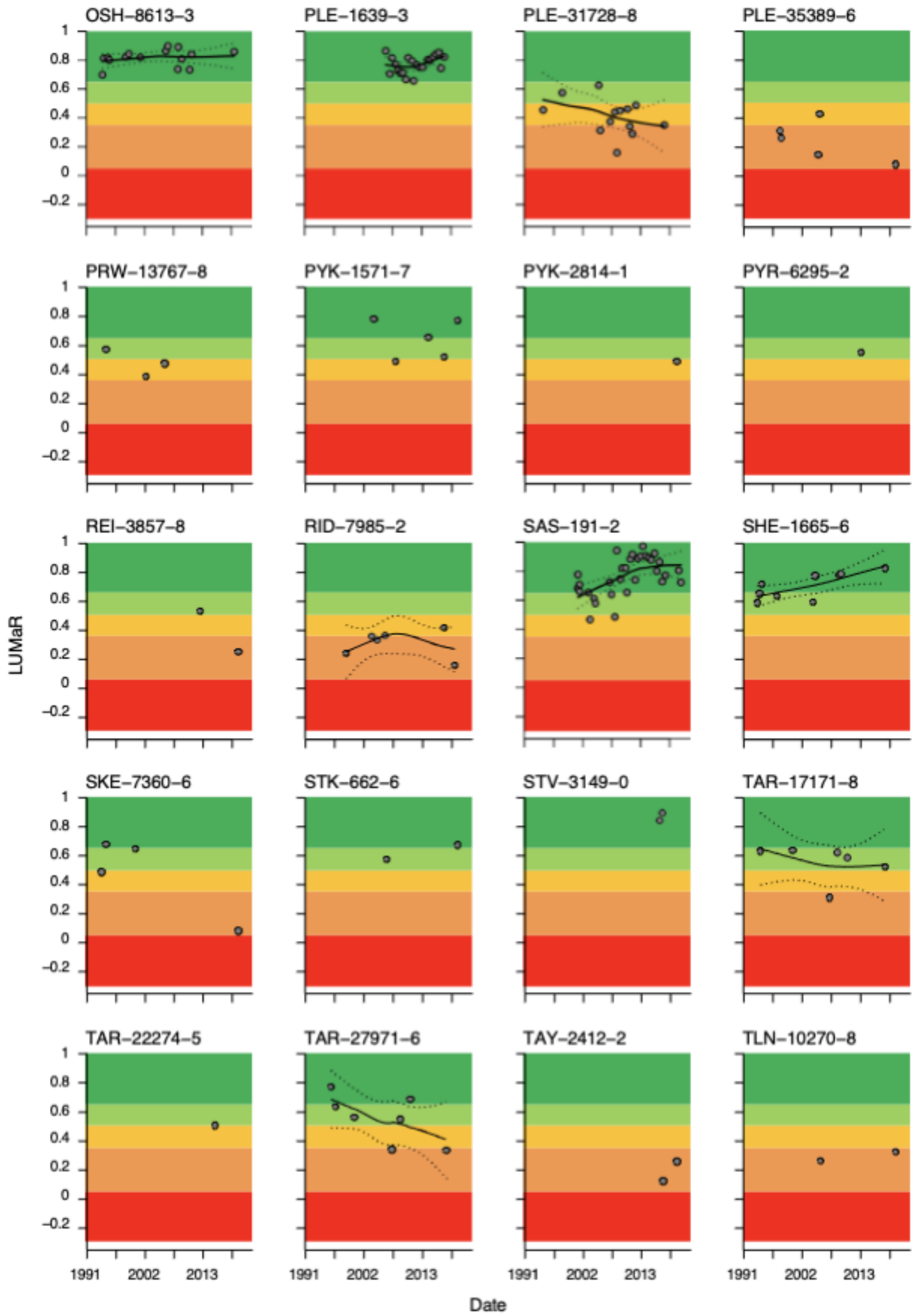
LSS−96−6
LTL−38495−3
LTL−41406−0
LYR−722−3
MAI−1320−2
MAM−1366−8
MCM−5970−4
MCR−4346−0
MMC−3774−3
MNB−2865−3
MNB−652−0
MNZ−1052−1
MOO−11187−1
MRB−130320−1
MRB−134012−8
MRI−19512−6
MRI−21989−5
MRI−7348−8
OLN−905−2
LUMaR
1
0.8
0.6
0.4
0.2
0
−0.2
1991
2002
2013
Date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PLE–1639–3
PLE–31728–8
PLE–35389–6
PRW–13767–8
PYK–1571–7
PYK–2814–1
PYR–6295–2
REI–3857–8
RID–7985–2
SAS–191–2
SHE–1665–6
SKE–7360–6
STK–662–6
STV–3149–0
TAR–17171–8
TAR–22274–5
TAR–27971–6
TAY–2412–2
TLN–10270–8
LUMaR
Date
1991
2002
2013

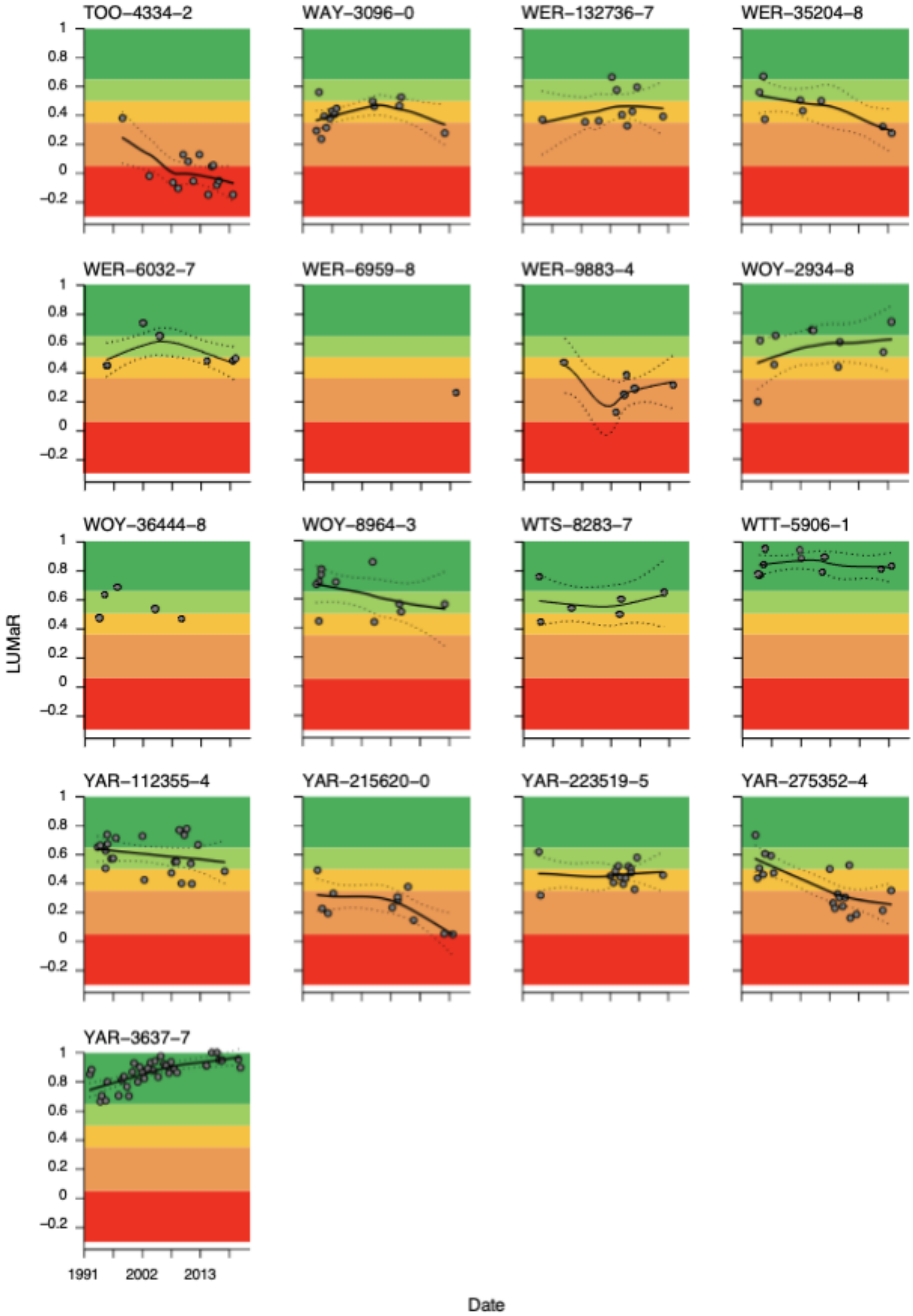

TOO-4334-2
WAY-3096-0
WER-132736-7
WER-35204-8
WER-6032-7
WER-6959-8
WER-9883-4
WOY-2934-8
WOY-36444-8
WOY-8964-3
WTS-8283-7
WTT-5906-1
YAR-112355-4
YAR-215620-0
YAR-223519-5
YAR-275352-4
YAR-3637-7
LUMaR
1
0.8
0.6
0.4
0.2
0
-0.2
1991
2002
2013
Date

Table 10. Werribee macro sites, showing which sub-catchment the site is located in, the sub-catchment HWS long-term trajectory and the mid-term site-based trajectory assessment.

sitecode	Location	MW subcatchment name	Land use	2018 baseline	2068 target	2022 value (site based)	Difference 2018 (sub-catchment) to site	Trajectory (historic)	Trajectory (recent)	Confidence
KRT-13267-6	Beatties Rd-Rockbank	Kororoit Creek Lower	urbanising	Low	Low	Moderate	Higher rating	Stable	Stable	Moderate
KRT-26894-4	Off Buckingham Cres by Buckingham Reserve	Kororoit Creek Lower	urban	Low	Low	Low	Same rating	Variable	Variable	Moderate
LER-15145-4	80 m d/s of weir at O'Briens Crossing	Lerderderg River	forested	Very high	Very high	Moderate	Lower rating	Decline	Stable	Moderate
WER-132736-7	Werribee river at Cobbledick's Ford road	Werribee River Lower	rural	Low	Moderate	Moderate	Higher rating	Stable		Low
WER-35204-8	Bacchus Marsh Gauge	Werribee River Middle	rural	High	Very high	Low	Lower rating	Decline	Decline	Low
WER-6032-7	Bunding Blakeville Road	Werribee River Upper	forested	Very high	Very high	Moderate	Lower rating	Stable	Stable	Low
WER-9883-4	Upper Werribee River @ Spencer Rd Bridge	Werribee River Upper	rural	Very high	Very high	Low	Lower rating	Variable		Low

Table 11. Maribyrnong macro sites, showing which sub-catchment the site is located in, the sub-catchment HWS long-term trajectory and the mid-term site-based trajectory assessment.

sitecode	Location	MW subcatchment name	Land use	2018 baseline	2068 target	2022 value (site based)	Difference 2018 (sub-catchment) to site	Trajectory (historic)	Trajectory (recent)	Confidence
BAR-1063-1	Upstream of the influence of the weir, off Barringo Road, downstream of Shannons Road	Jacksons Creek	forested	Moderate	High	High	Higher rating	Decline	Uncertain	Low
BOL-9615-0	Melbourne Lancefield Road, Bolinda Bridge, Clarkefield	Emu Creek	rural	Moderate	High	Moderate	Same rating	Stable	Uncertain	Low
BOY-13537-6	110m u/s Romsey Road	Boyd Creek	rural	Moderate	Very high	Moderate	Same rating	Stable		Moderate
DPW-21923-3	80m d/s Kilmore-Lancefield Road	Deep Creek Upper	rural	Moderate	Very high	Moderate	Same rating	Decline		Low
DPW-28678-1	80m d/s Joyces Road	Deep Creek Upper	rural	Moderate	Very high	Low	Lower rating	Decline	Variable	Moderate
DPW-86075-8	at Trap Street Reserve, 50m d/s of weir	Deep Creek Lower	urbanising	Moderate	High	Moderate	Same rating	Decline		Low
EMU-16701-8	at Gellies Rd, 20m d/s of bridge. u/s of 50 Gellies Rd property boundary.	Emu Creek	rural	Moderate	High	Moderate	Same rating	Stable		High
JKN-11194-1	d/s of works Kilmore Road at bowling club	Jacksons Creek	urban	Moderate	High	Moderate	Same rating	Variable	Uncertain	Low
JKN-15144-3	d/s Riddell Road, 165m d/s of old bridge	Jacksons Creek	rural	Moderate	High	Moderate	Same rating	Stable		Low

sitecode	Location	MW subcatchment name	Land use	2018 baseline	2068 target	2022 value (site based)	Difference 2018 (sub-catchment) to site	Trajectory (historic)	Trajectory (recent)	Confidence
JKN-28603-3	immediately u/s Settlement Road	Jacksons Creek	rural	Moderate	High	Moderate	Same rating	Variable	Stable	Low
JKN-34269-0	immediately u/s Macedon St/Sunbury Road	Jacksons Creek	urbanising	Moderate	High	Moderate	Same rating	Decline		Moderate
JKN-40043-9	at Tessellated Pavement, Organ Pipes National Park	Jacksons Creek	urbanising	Moderate	High	Moderate	Same rating	Stable		Moderate
MRB-130320-1	at Flora Street, Keilor, 55m d/s of Calder Fwy bridge	Maribyrnong River	urbanising	Low	Low	Low	Same rating	Decline	Variable	Moderate
MRB-134012-8	at d/s end of riffle, Solomon's Ford, Canning Street, Avondale Heights.	Maribyrnong River	urbanising	Low	Low	Low	Same rating	Decline	Variable	Moderate
RID-7985-2	Riddells Creek at Riddells Creek	Jacksons Creek	rural	Moderate	High	Low	Lower rating	Stable		Low

Table 12. Yarra macro sites, showing which sub-catchment the site is located in, the sub-catchment HWS long-term trajectory and the mid-term site-based trajectory assessment.

sitecode	Location	MW subcatchment name	Land use	2018 baseline	2068 target	2022 value (site based)	Difference 2018 (sub-catchment) to site	Trajectory (historic)	Trajectory (recent)	Confidence
ALD-2608-1	Alderman Ck at Track 32, Upper Yarra Reservoir catchment	Yarra River Upper (Source)	forested	Very high	Very high	Very high	Same rating	Stable		High
ARE-1467-6	u/s diversion weir, off East Armstrong Rd	Yarra River Upper (Source)	forested	Very high	Very high	Very high	Same rating	Stable		High
ARM-3948-4	u/s diversion weir, by flow gauge off Armstrong Rd	Yarra River Upper (Source)	forested	Very high	Very high	Very high	Same rating	Stable		High
ART-10382-6	Arthurs Creek Road- Arthurs Creek	Diamond Creek (Rural)	rural	Moderate	High	Moderate	Same rating	Variable		Moderate
BRS-1472-0	u/s Diane Cr- Mooroolbark	Brushy Creek	urban	Very low	Low	Very low	Same rating	Stable		Moderate
CCK-1538-8	d/s Brisbane Rd bridge Cockatoo	Woori Yallock Creek	rural	Very high	Very high	Very high	Same rating	Increase		Low
CCK-4955-9	Tschampions Rd	Woori Yallock Creek	rural	Very high	Very high	High	Lower rating	Stable		Low
CMT-828-5	Eighteen Rd	Yarra River Upper (Rural)	forested	Very high	Very high	Very high	Same rating	Increase		Moderate
DIY-5232-7	Marriot Lane- St. Andrews	Diamond Creek (Rural)	rural	Moderate	High	Low	Lower rating	Decline		Low
FEH-4184-3	at Road 9, Upper Yarra Reservoir catchment	Yarra River Upper (Source)	forested	Very high	Very high	Very high	Same rating	Increase		High
JKS-470-7	Jacks Creek @ Road 10	Plenty River (Source)	forested	Very high	Very high	Very high	Same rating	Variable		Moderate
LIS-453-6	Between Evans Grove and Victoria St- 2 properties u/s of	Stringybark Creek	urban	Low	High	Moderate	Higher rating	Decline		Low

sitecode	Location	MW subcatchment name	Land use	2018 baseline	2068 target	2022 value (site based)	Difference 2018 (sub-catchment) to site	Trajectory (historic)	Trajectory (recent)	Confidence
	Meyland Construction									
LSN-150-4	upstream of private bridge across the stream in No. 5 Birch Drive, Mt Evelyn (private road)	Stringybark Creek	urban	Low	High	Moderate	Higher rating	Increase		Moderate
LSS-96-6	u/s of The Entrance-Mount Evelyn	Stringybark Creek	urban	Low	High	Low	Same rating	Stable		Low
LYR-722-3	d/s Olinda Ck Rd	Olinda Creek	forested	Moderate	High	Very high	Higher rating	Increase		High
MCM-5970-4	Mc Mahons Creek Road Picnic Area	Yarra River Upper (Rural)	forested	Very high	Very high	Very high	Same rating	Stable		Moderate
MCR-4346-0	Healesville-Koo Wee Rup Rd-Yellingbo	Woori Yallock Creek	rural	Very high	Very high	Very high	Same rating	Stable		Low
MMC-3774-3	Blackburn Rd	Mullum Mullum Creek	urban	Very low	Very low	Low	Higher rating	Stable	Uncertain	Low
MNZ-1052-1	Emerald-Monbulk Rd-Monbulk	Woori Yallock Creek	rural	Very high	Very high	Very high	Same rating	Increase		Low
MRI-19512-6	Summerhill Rd-Craigieburn	Merri Creek Upper	urbanising	Low	Moderate	Low	Same rating	Stable		Low
MRI-21989-5	~150 m u/s Craigieburn Rd East Rd (d/s Malcolm Creek)	Merri Creek Upper	urbanising	Low	Moderate	Moderate	Higher rating	Decline		Low
OLN-905-2	nr Olinda Ck Track- ~50m u/s Lyrebird	Olinda Creek	forested	Moderate	High	Very high	Higher rating	Stable		High
OSH-8613-3	Road 10 u/s reservoir	Yarra River Upper (Source)	forested	Very high	Very high	Very high	Same rating	Stable		High

sitecode	Location	MW subcatchment name	Land use	2018 baseline	2068 target	2022 value (site based)	Difference 2018 (sub-catchment) to site	Trajectory (historic)	Trajectory (recent)	Confidence
PLE-2190-0	Access Track 200m north Toorourong Res- Whittlesea	Plenty River (Source)	forested	Very high	Very high	Very high	Same rating	Stable		High
PLE-31728-8	Plenty River upstream of Kurrack Rd Bridge	Plenty River Lower	forested	Low	Low	Moderate	Higher rating	Decline		Low
SAS-191-2	The Crescent u/s Nobles Lane (and u/s small trib)- Sassafras	Woori Yallock Creek	forested	Very high	Very high	Very high	Same rating	Increase		Moderate
SHE-1665-6	Beenak Rd	Woori Yallock Creek	forested	Very high	Very high	Very high	Same rating	Increase		Moderate
WAY-3096-0	Sunnyside Rd	Woori Yallock Creek	rural	Very high	Very high	Low	Lower rating	Stable		Low
WOY-2934-8	Old Emerald Rd u/s Junction with Menzies Creek- Monbulk	Woori Yallock Creek	rural	Very high	Very high	High	Lower rating	Increase		Low
WOY-8964-3	Macclesfield-Woori Yallock Rd- Yellingbo (u/s Cockatoo confluence)	Woori Yallock Creek	rural	Very high	Very high	High	Lower rating	Decline		Low
WTS-8283-7	Henley Rd-Kangaroo Rd	Watsons Creek	rural	Very high	Very high	High	Lower rating	Stable		Low
WTT-5906-1	Fernshaw jump fence u/s ford	Watts River (Source)	forested	Very high	Very high	Very high	Same rating	Stable		Moderate
YAR-112355-4	Healesville-Koo Wee Rup (Dalry) Rd	Yarra River Upper (Rural)	rural	Very high	Very high	High	Lower rating	Stable		Low
YAR-215620-0	Spadonis Reserve d/s Olinda Ck- Coldstream	Yarra River Middle	rural	Moderate	Very high	Low	Lower rating	Decline		Low

sitecode	Location	MW subcatchment name	Land use	2018 baseline	2068 target	2022 value (site based)	Difference 2018 (sub-catchment) to site	Trajectory (historic)	Trajectory (recent)	Confidence
YAR-223519-5	Wittons Reserve- Wonga Park	Yarra River Middle	rural	Moderate	Very high	Moderate	Same rating	Stable		Low
YAR-275352-4	Fitzsimons Lane-Templestowe	Yarra River Lower	urban	Low	Moderate	Low	Same rating	Decline		Low
YAR-3637-7	at Road 12, Upper Yarra Reservoir catchment	Yarra River Upper (Source)	forested	Very high	Very high	Very high	Same rating	Increase		High

Table 13. Dandenong macro sites, showing which sub-catchment the site is located in, the sub-catchment HWS long-term trajectory and the mid-term site-based trajectory assessment.

sitecode	Location	MW sub-catch name	Land use	2018 baseline	2068 target	2022 value (site based)	Difference 2018 (sub-catchment) to site	Trajectory (historic)	Trajectory (recent)	Confidence
DBS-363-4	u/s Basin Olinda Rd	Dandenong Creek Upper	urban	Very high	Very high	Very high	Same rating	Increase		Moderate
DBS-810-7	Salvo's property, ~400 m d/s of driveway, d/s of wicks reserve stormwater drain.	Dandenong Creek Upper	urban	Very high	Very high	High	Lower rating	Stable		Moderate
DNG-173-5	Doongala Forest Access Rd- Dandenong Ranges National park	Dandenong Creek Upper	forested	Very high	Very high	High	Lower rating	Stable		Low
DNG-23690-8	Brady Rd- Endeavour Hills	Dandenong Creek Middle	urban	Very low	Very low	Low	Higher rating	Increase		Moderate
DNG-31881-3	Pillars Crossing- Dandenong South	Dandenong Creek Lower	urban	Very low	Very low	Moderate	Higher rating	Increase		Moderate
DNG-7957-4	u/s Boronia Rd- Wantirna	Dandenong Creek Middle	urban	Very low	Very low	Very low	Same rating	Stable		Moderate
FER-647-5	u/s Morris Rd- Upwey	Corhanwarrabul, Monbulk and Ferny Creeks	urban	Low	Moderate	Low	Same rating	Stable		Moderate

Table 14. Westernport macro sites, showing which sub-catchment the site is located in, the sub-catchment HWS long-term trajectory and the mid-term site-based trajectory assessment.

sitecode	Location	MW subcatchment name	Land use	2018 baseline	2068 target	2022 value (site based)	Difference 2018 (sub-catchment) to site	Trajectory (historic)	Trajectory (recent)	Confidence
BAS-5554-1	Ferriers Rd- Loch (u/s Sth Gippsland Hwy)	Bass River	rural	Moderate	High	Low	Lower rating	Stable		Low
BNY-12470-3	North Labertouche Rd	Bunyip River Middle and Upper	rural	Very high	Very high	Very high	Same rating	Stable		Low
BNY-24764-5	Syphon via Ellis Rd	Bunyip River Middle and Upper	rural	Very high	Very high	High	Lower rating	Stable		Moderate
BNY-2904-2	u/s Bunyip Weir	Bunyip River Middle and Upper	forested	Very high	Very high	Very high	Same rating	Increase		Moderate
BNY-69016-6	Little Rd- Iona	Bunyip Lower	rural	Moderate	Very high	Moderate	Same rating	Stable		Low
LNG-16294-3	Off Drouin-Korumburra Rd-Athlone	Lang Lang River	rural	Moderate	Very high	Low	Lower rating	Decline		Moderate
LNG-36916-2	South Gippsland Highway	Lang Lang River	rural	Moderate	Very high	Moderate	Same rating	Stable		Low
MAI-1320-2	u/s of Baldry Crossing and of Splitters Creek	Mornington Peninsula South-Eastern Creeks	rural	Moderate	High	High	Higher rating	Decline		Moderate
TAR-17171-8	Main Neerim Rd- Drouin West	Tarago River	rural	Very high	Very high	High	Lower rating	Stable		Low
TAR-27971-6	Morrisons Rd-Labertouche	Tarago River	rural	Very high	Very high	Moderate	Lower rating	Decline		Low
TOO-4334-2	us Henry Rd, off Hull Cres	Cardinia, Toomuc, Deep and Ararat Creeks	urban	Moderate	High	Very low	Lower rating	Decline		Low

Appendix 5: Summary of LUMaR index trends by river catchment

Table 15. The number of sites in each MW river catchment classified as having 'stable', 'increasing', 'declining', 'variable', or 'not yet assessable' LUMaR index trends over the entire data time span (historical).

	Stable	Increasing	Declining	Variable	Not yet assessable	Catchment total
Dandenong	4	3	0	0	3	10
Maribyrnong	6	0	7	2	12	27
Werribee	3	0	2	2	16	23
Westernport	6	1	4	0	8	19
Yarra	18	10	7	2	16	53
Trend total	37	14	20	6	55	132

Table 16. The number of sites in each MW river catchment classified as having 'stable', 'increasing', 'declining', 'variable', or 'not yet assessable' LUMaR index trends over the last decade (recent).

	Stable	Increasing	Declining	Not yet assessable	Catchment total
Dandenong	4	3	0	3	10
Maribyrnong	8	2	5	12	27
Werribee	5	1	1	16	23
Westernport	7	0	4	8	19
Yarra	27	6	5	15	53
Trend total	51	12	15	54	132

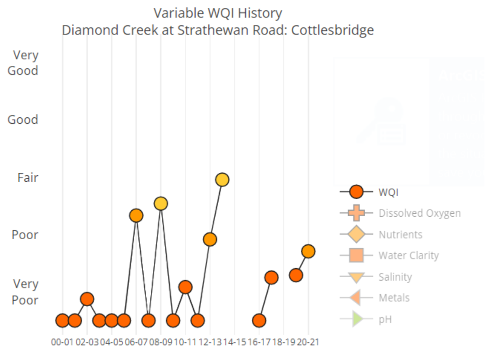
Appendix 6: Water Quality data

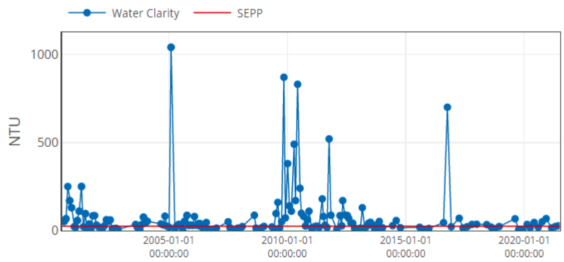
All data below is taken from the interagency water quality dashboard at [Front Page - MW WQI Portal (hydronumerics.com.au)]() and depicts the date range 2000-2021.

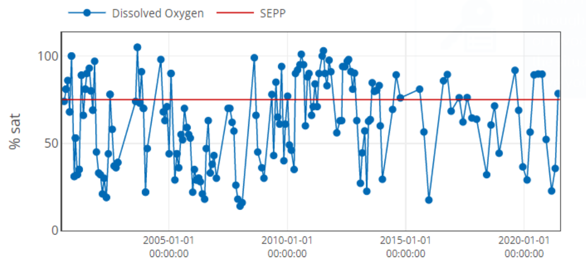
Yarra catchment

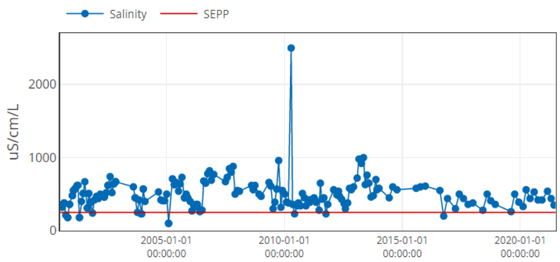
Site 1. YADAI0068 Diamond Creek at Strathewan Road: Cottlesbridge

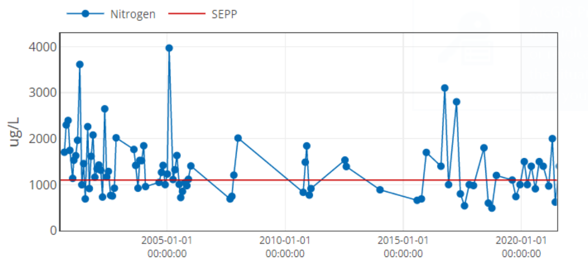
WQI History

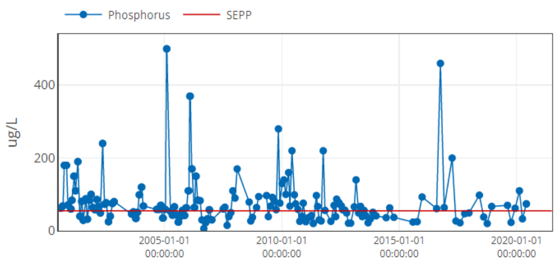


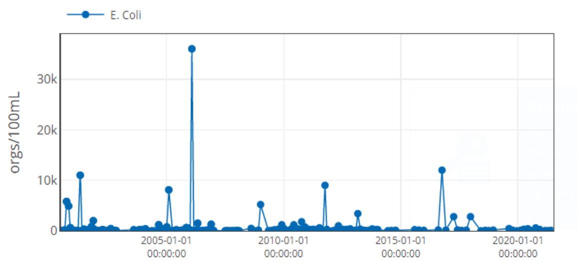


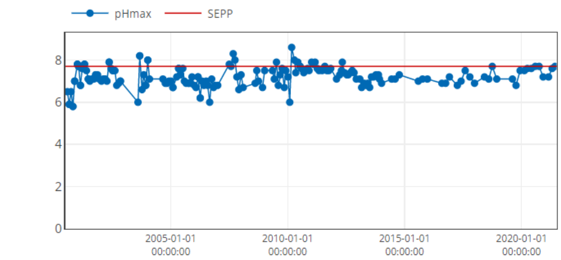








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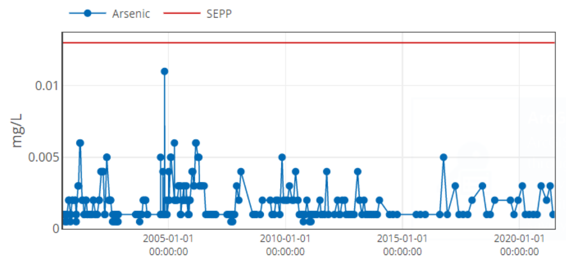
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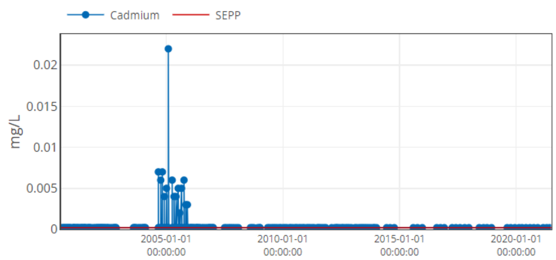
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mg/L
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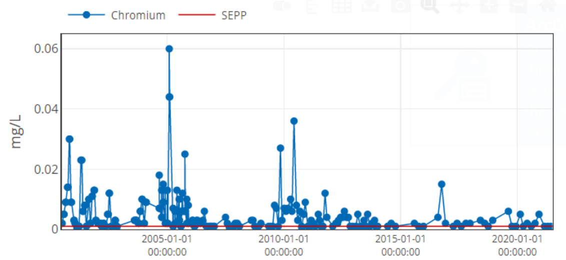
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SEPP
mg/L
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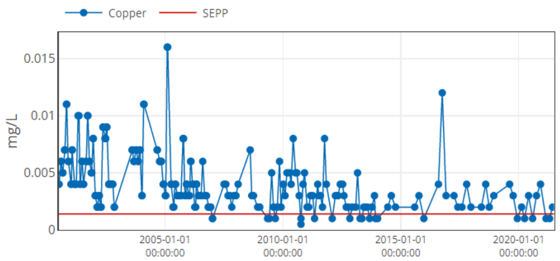
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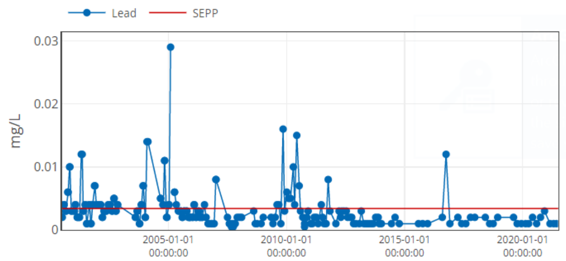
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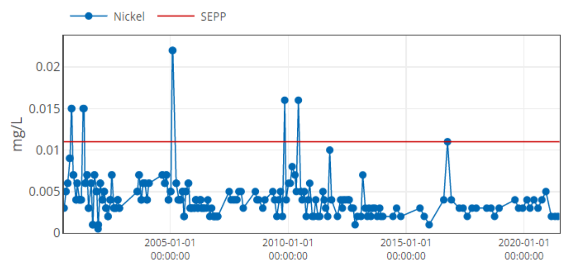
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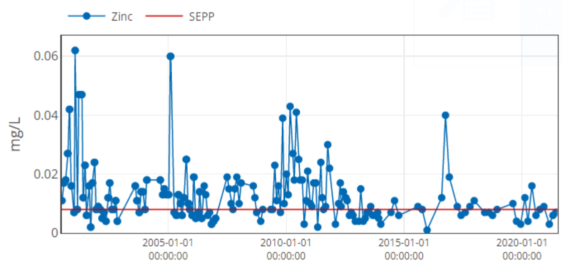
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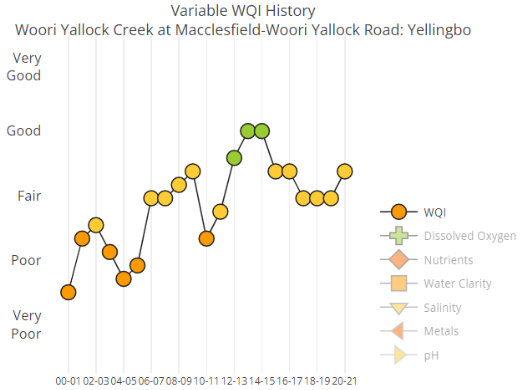
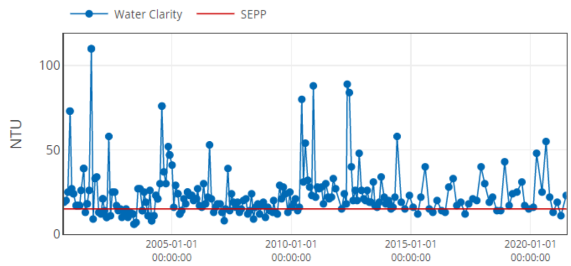
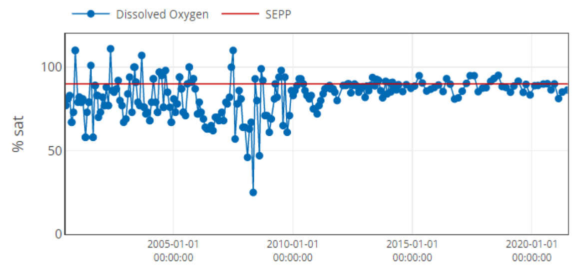
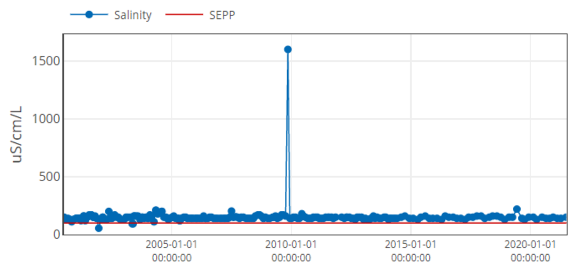
Site 2: YAWOO0098 Woori Yallock Creek at Macclesfield-Woori Yallock Rd, Yellingbo

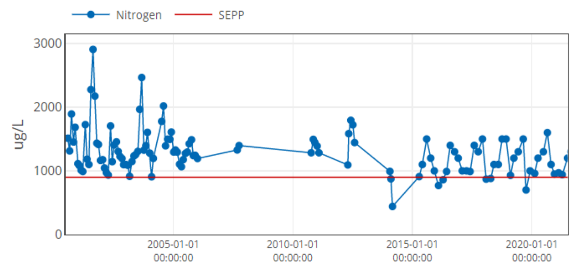
WQI History

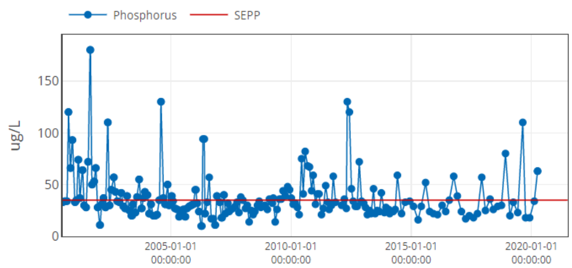


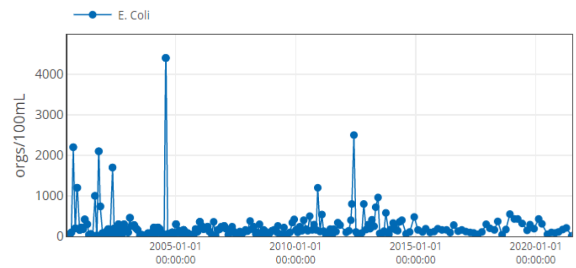


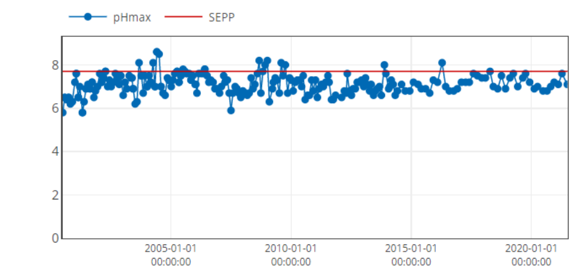


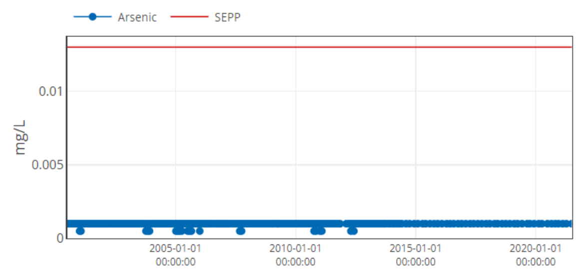


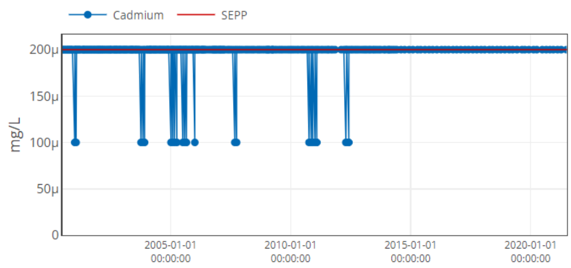








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SEPP
mg/L
200μ
150μ
100μ
50μ
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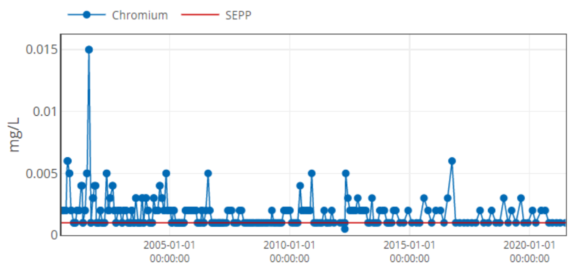
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SEPP
mg/L
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0.01
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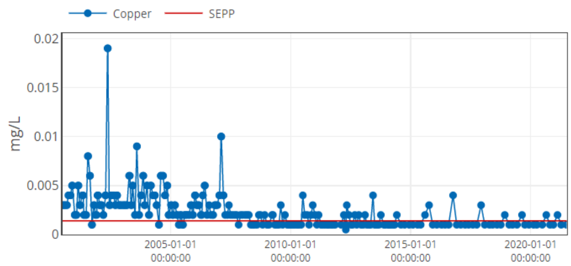
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SEPP
mg/L
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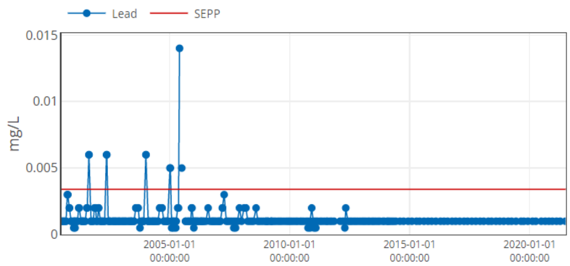
Lead
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mg/L
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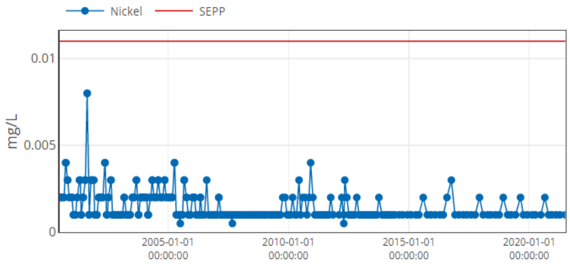
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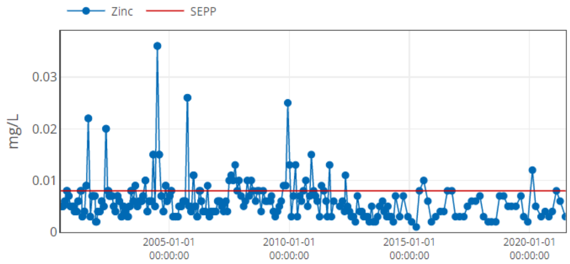
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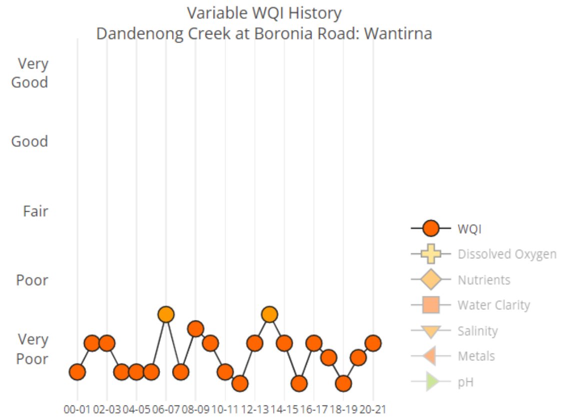
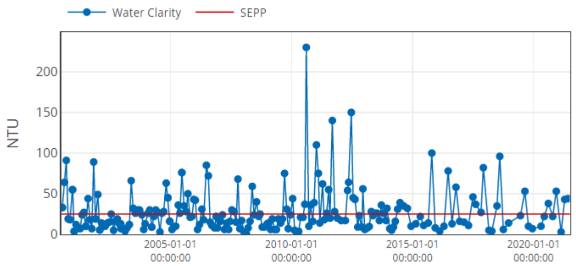
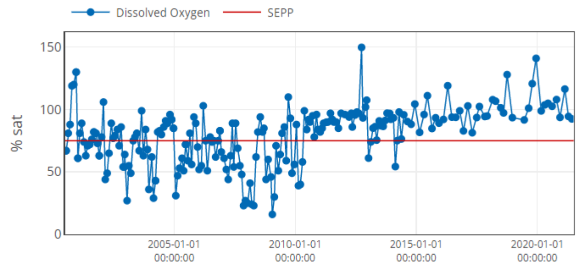
Dandenong catchment

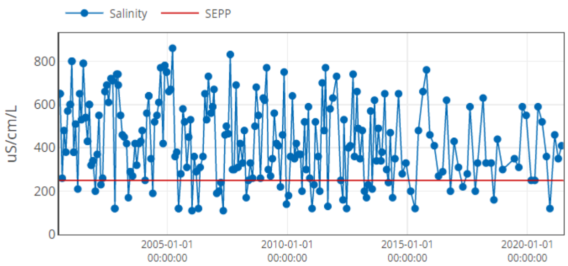
Site 3. DADAN0077 Dandenong Creek at Boronia Rd, Wantirna

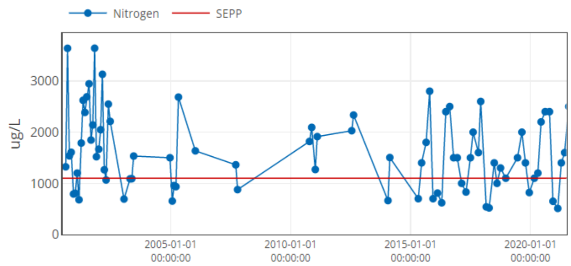
WQI History

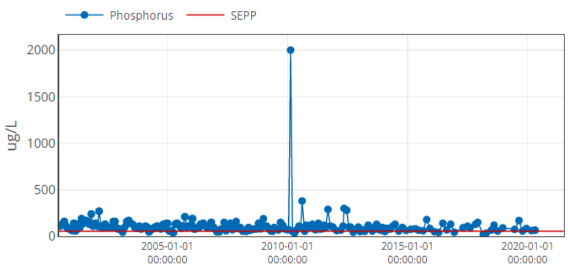


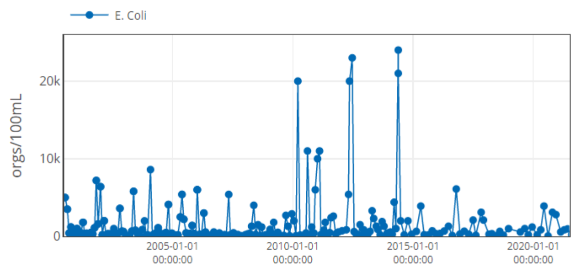


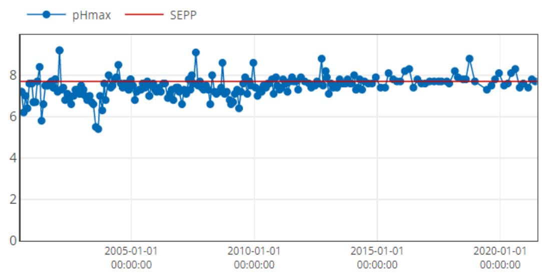


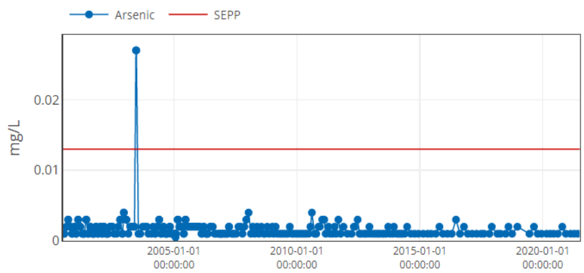


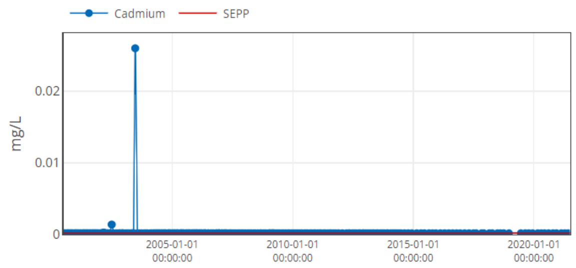


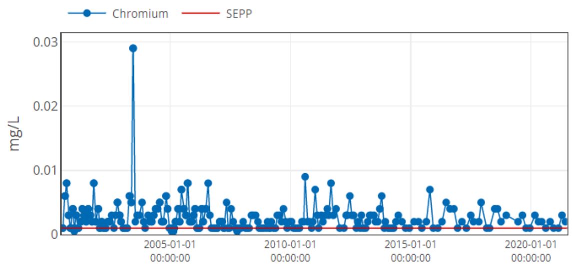


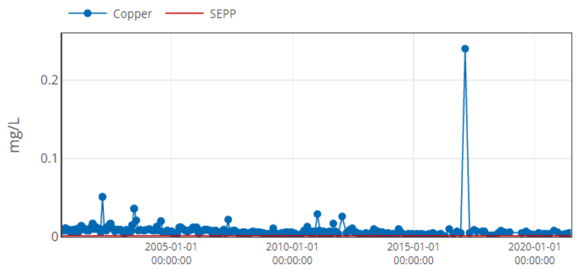


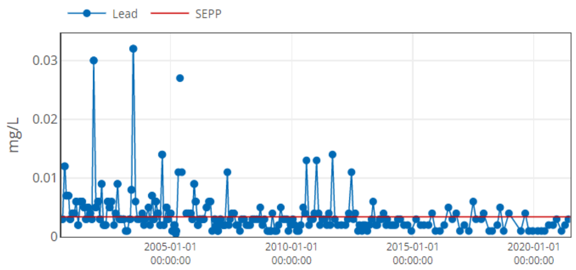


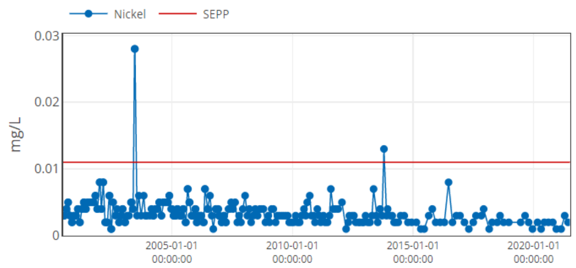


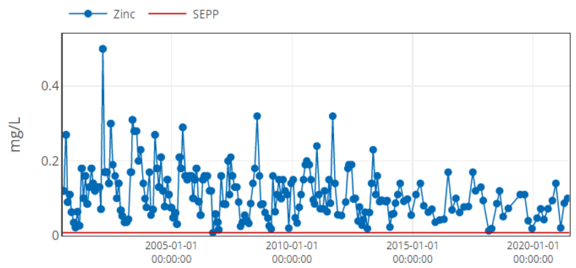






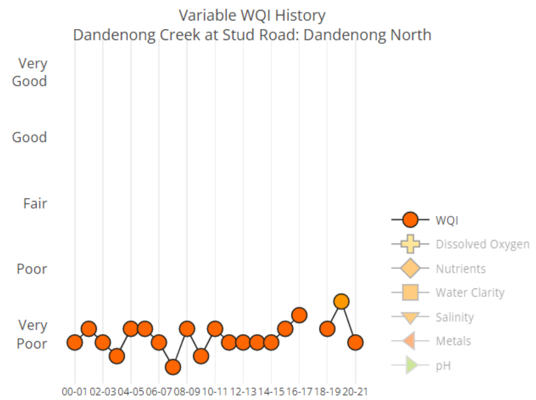


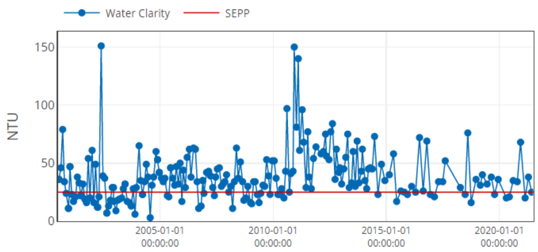




Site 4. DADAN0235 Dandenong Creek at Stud Road

WQI History




Water Clarity
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NTU
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100
50
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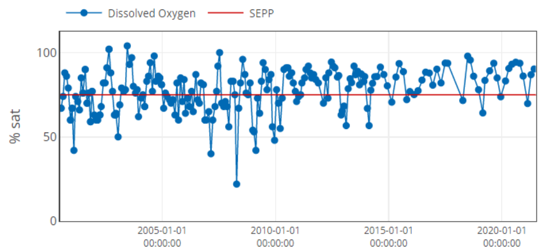
2010-01-01 00:00:00
2015-01-01 00:00:00
2020-01-01 00:00:00


Dissolved Oxygen
SEPP
% sat
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50
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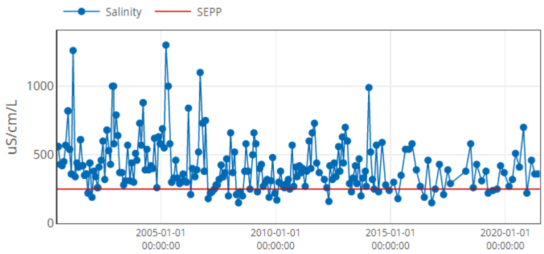
2015-01-01 00:00:00
2020-01-01 00:00:00


Salinity
SEPP
uS/cm/L
1000
500
0
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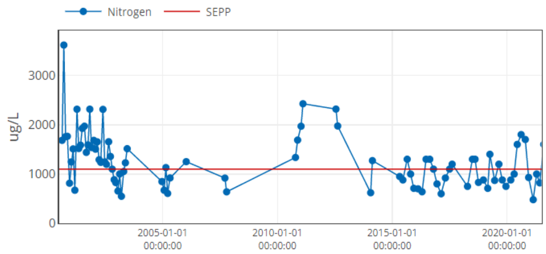
2010-01-01 00:00:00
2015-01-01 00:00:00
2020-01-01 00:00:00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ug/L
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1000
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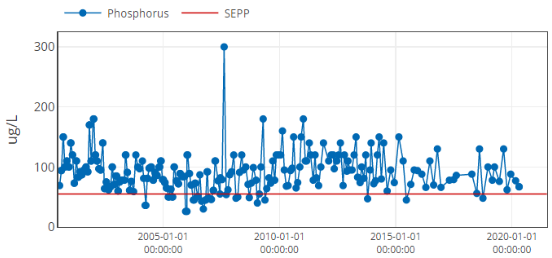
2020-01-01 00:00:00


Phosphorus
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ug/L
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200
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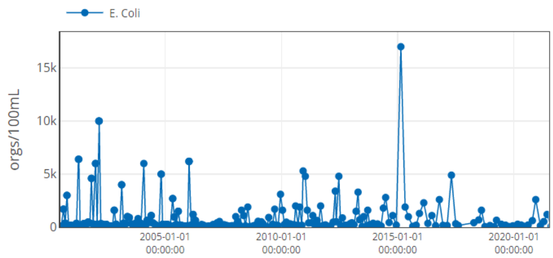
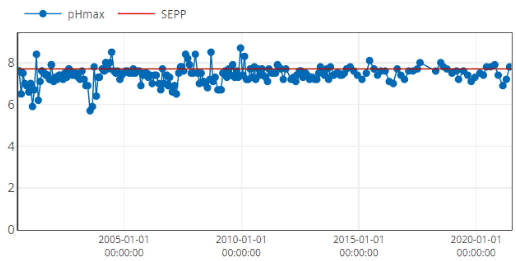
2020-01-01 00:00:00


E. Coli
orgs/100mL
15k
10k
5k
0
2005-01-01 00:00:00
2010-01-01 00:00:00
2015-01-01 00:00:00
2020-01-01 00:00:00


pHmax
SEPP
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6
4
2
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2010-01-01 00:00:00
2015-01-01 00:00:00
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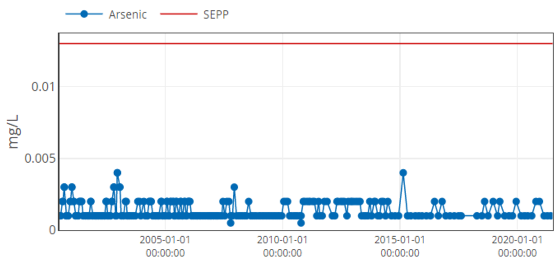
Arsenic
SEPP
mg/L
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0.005
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2010-01-01 00:00:00
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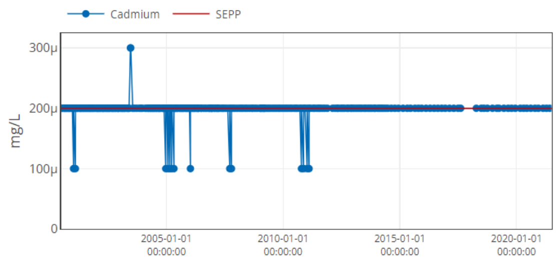
Cadmium
SEPP
mg/L
300µ
200µ
100µ
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2005-01-01 00:00:00
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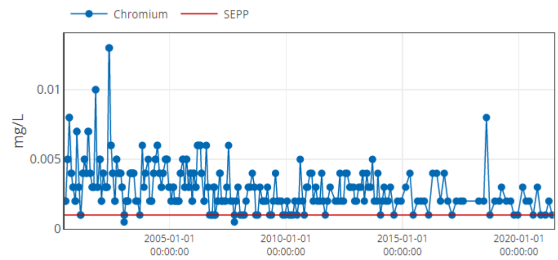
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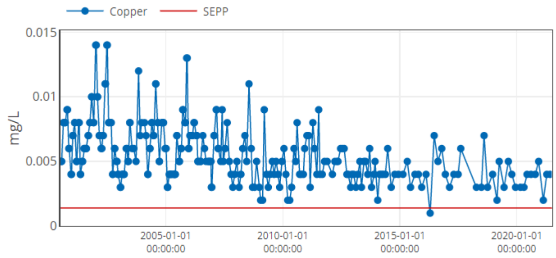
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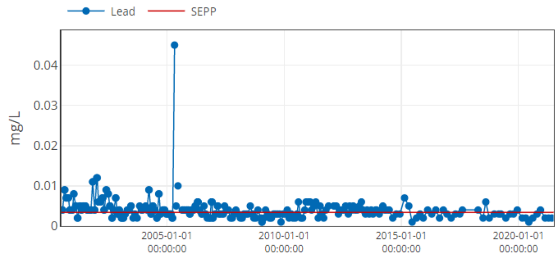
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0.02
0.01
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2005-01-01 00:00:00
2010-01-01 00:00:00
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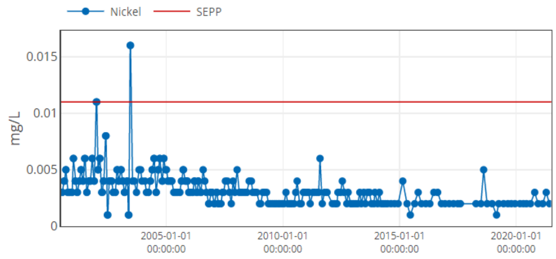
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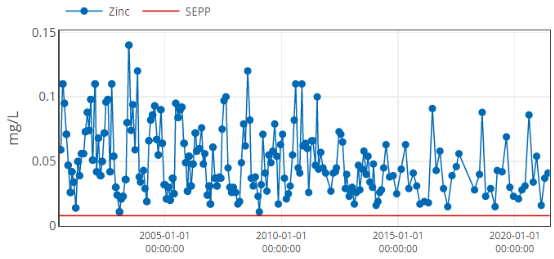
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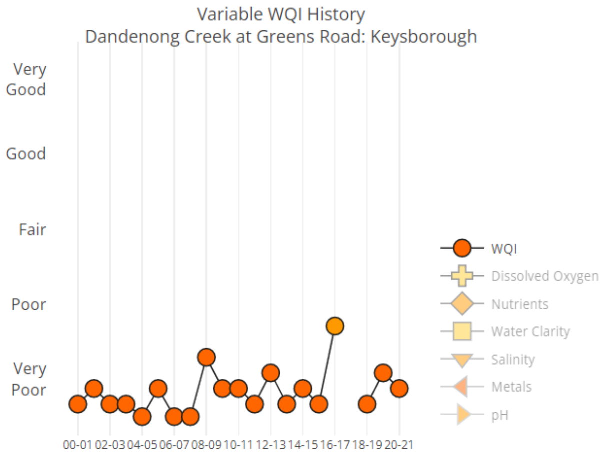
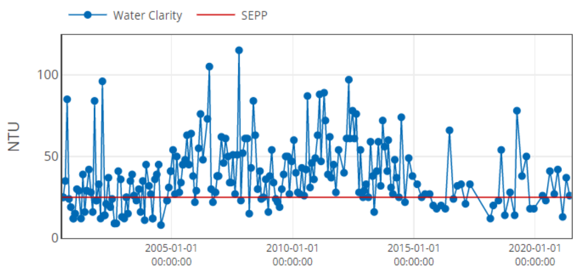
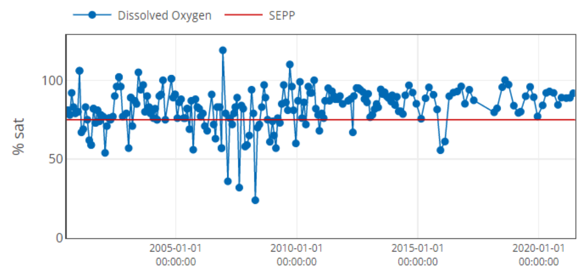
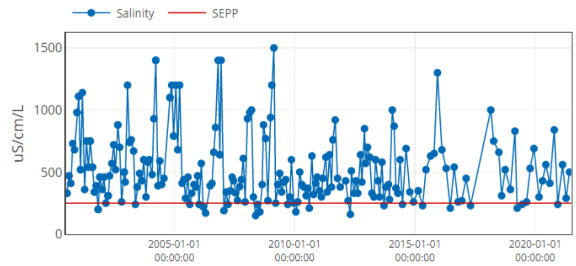
Site 5. DADAN0322 Dandenong Creek at Pillars Crossing, Keysborough

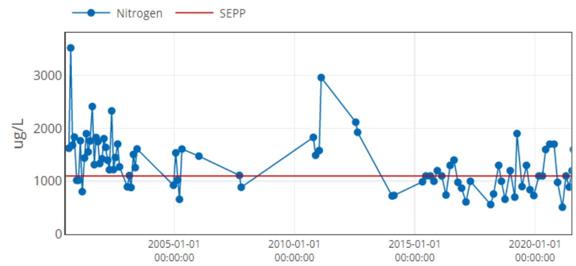
WQI History

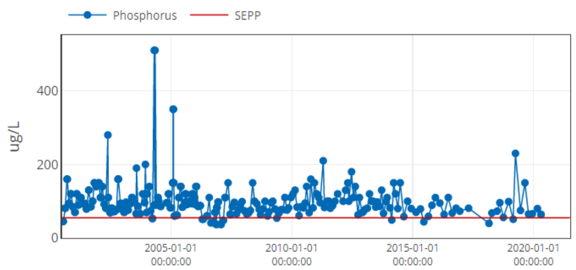


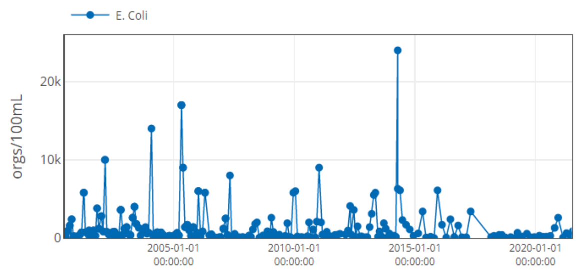


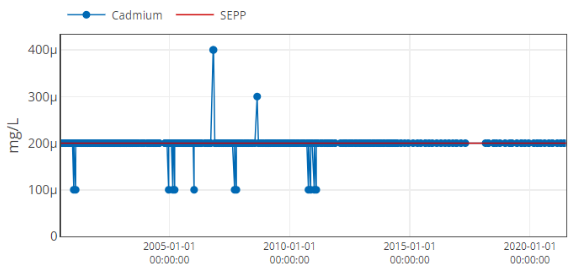


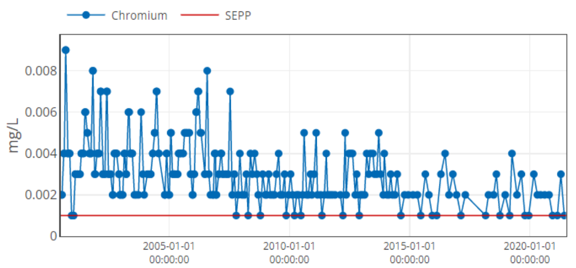


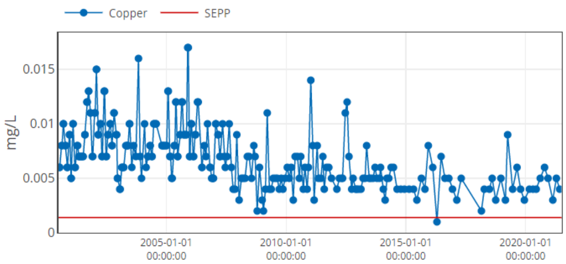








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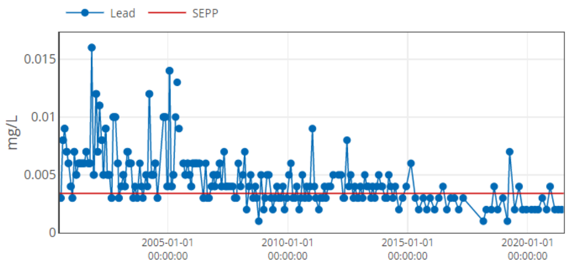
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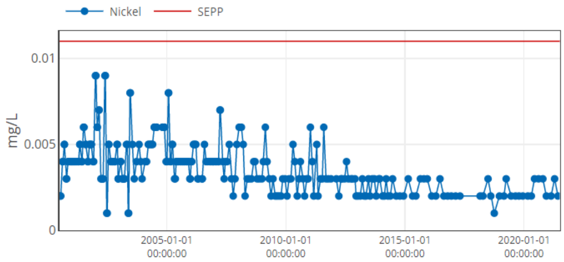
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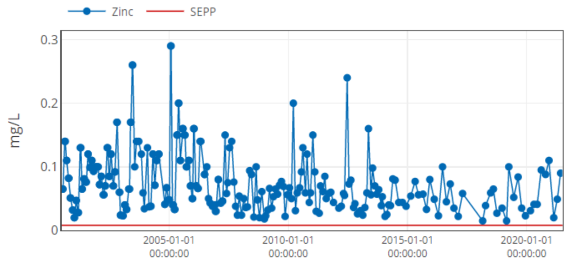
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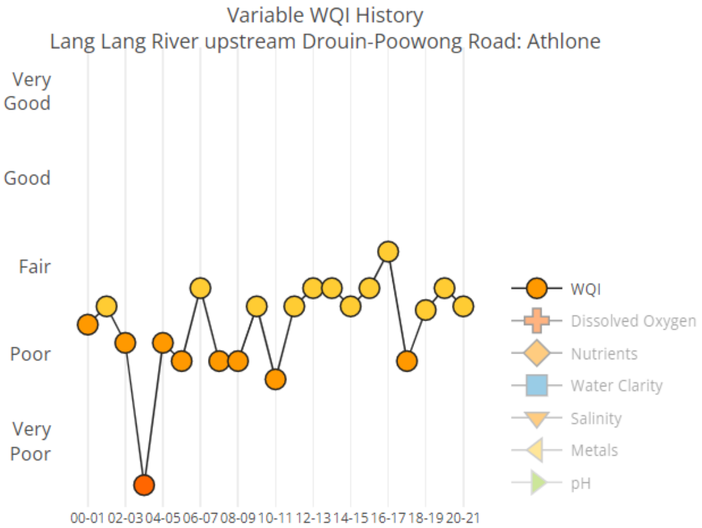
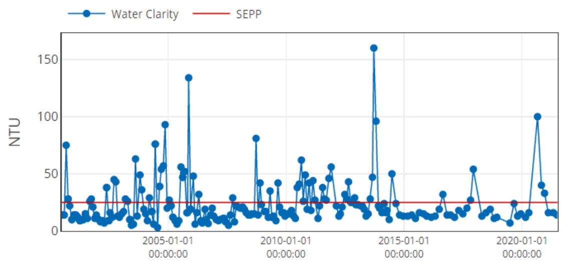
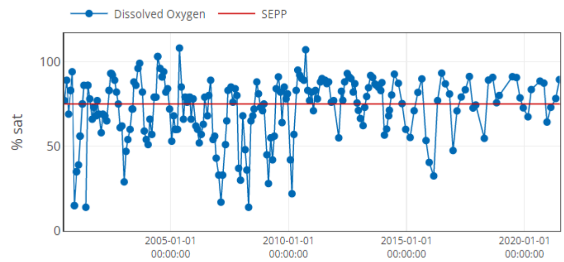
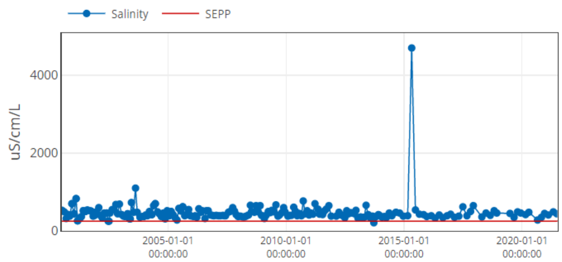
Westernport catchment

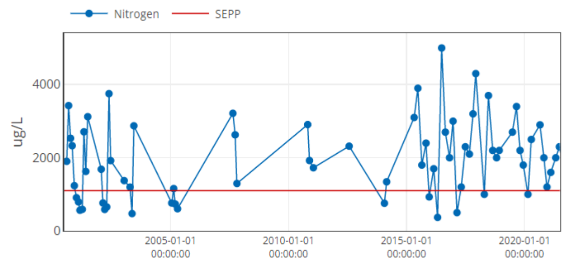
Site 6: WPLAN0164 Lang Lang River at Drouin-Poowong Rd, Athlone

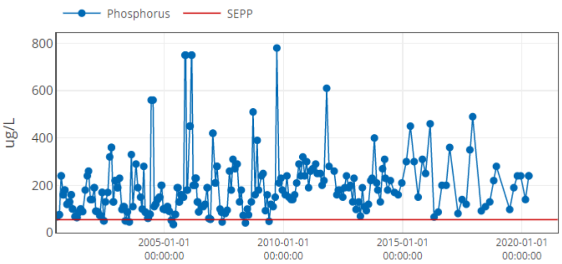


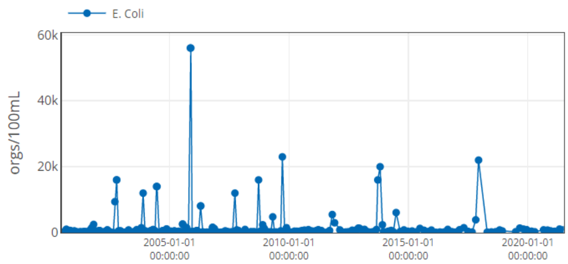


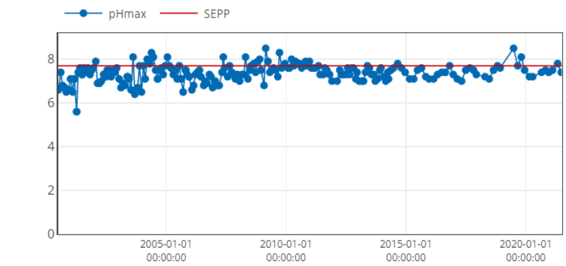








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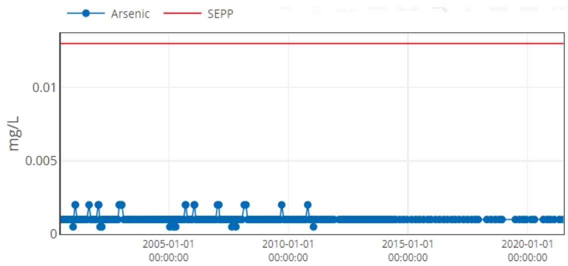
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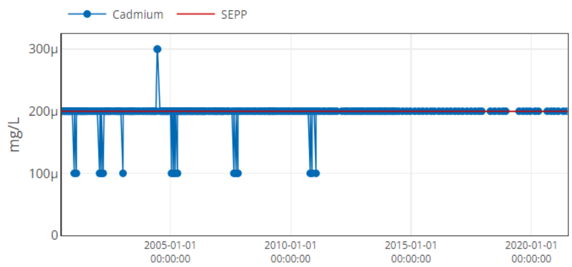
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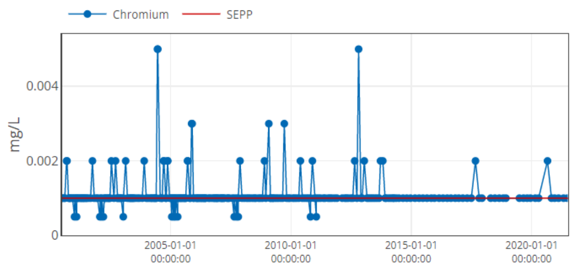
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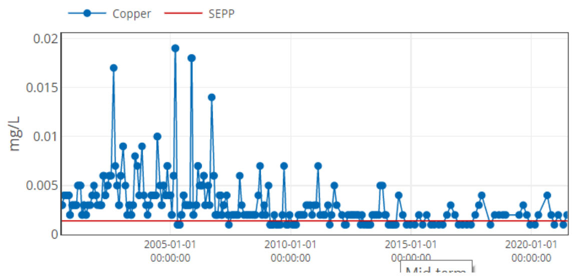
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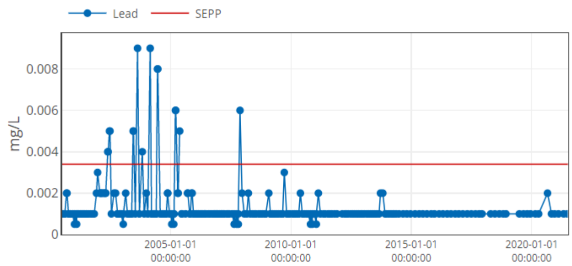
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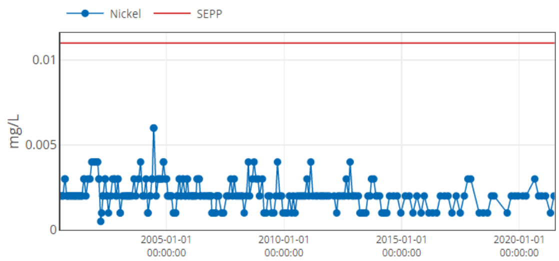
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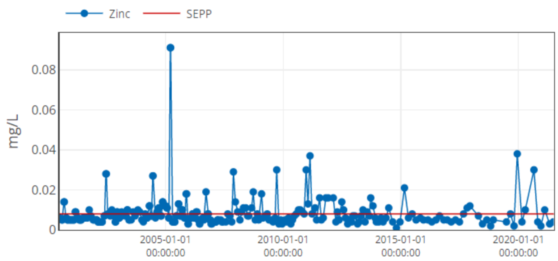
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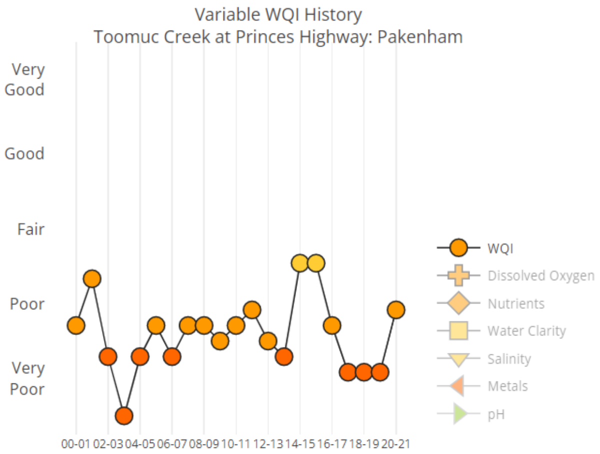
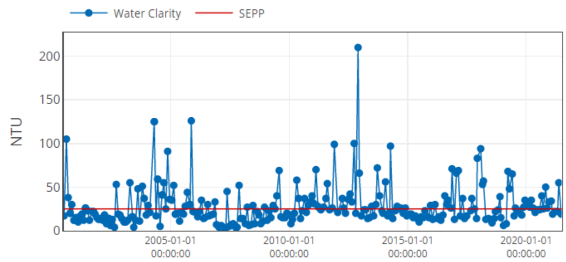
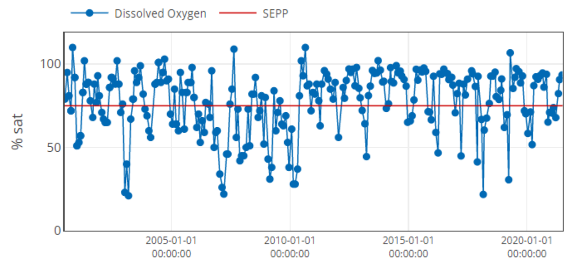
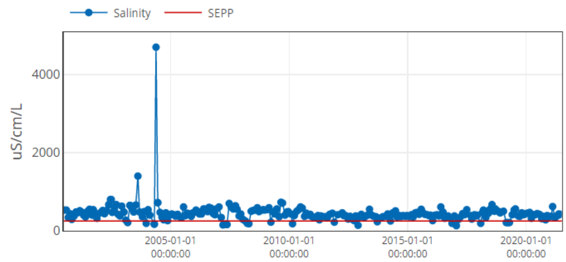
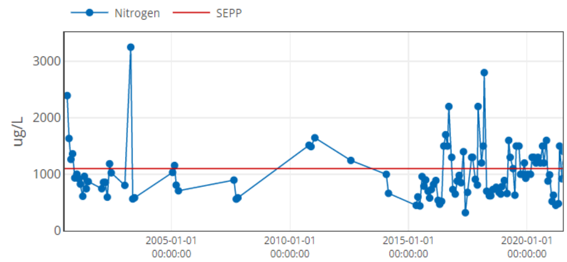
Site 7: WPTOO0041 Toomuc Creek at Princess Hwy, Pakenham

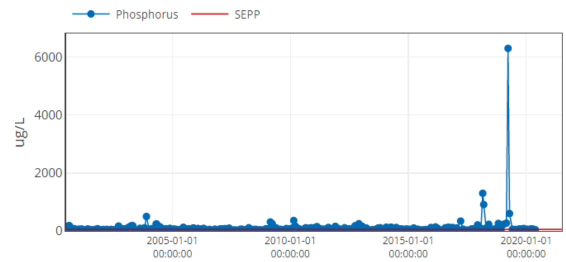


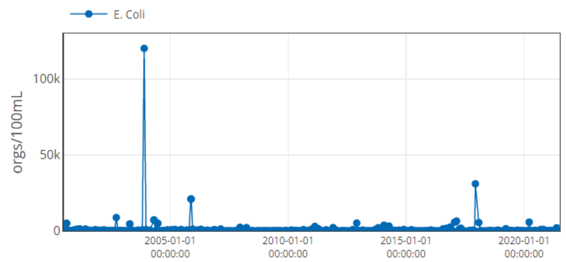


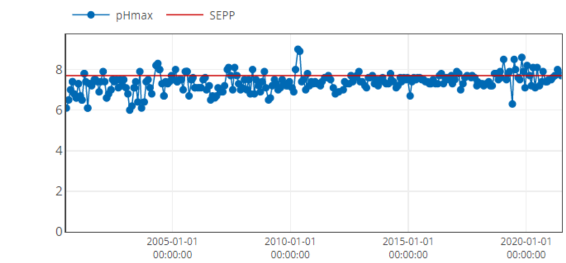


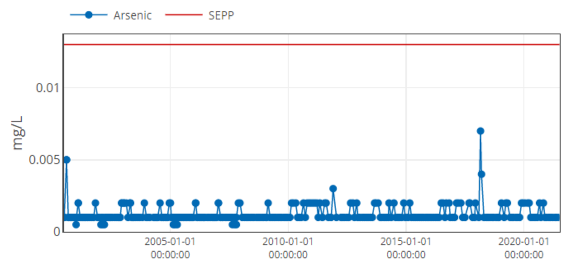


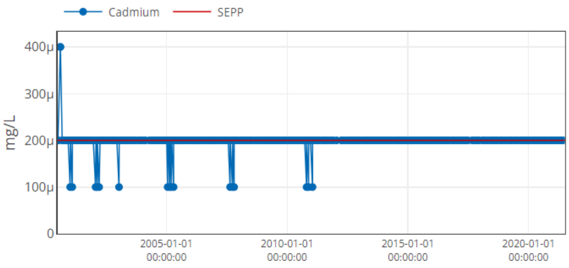








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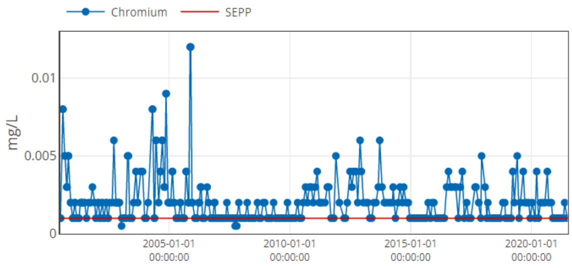
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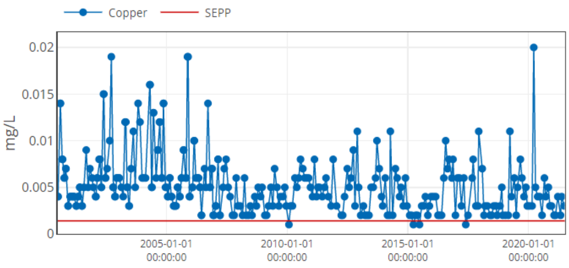
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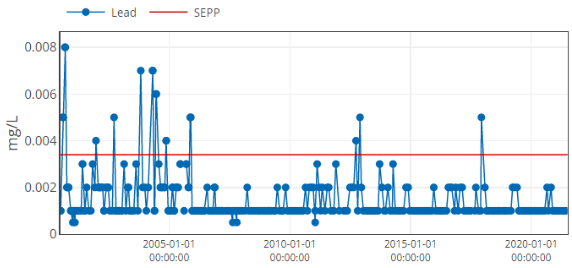
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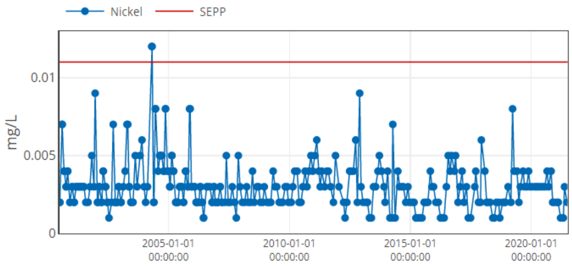
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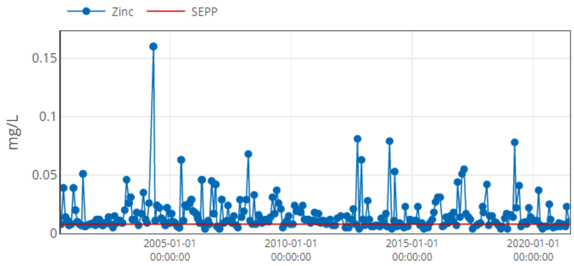
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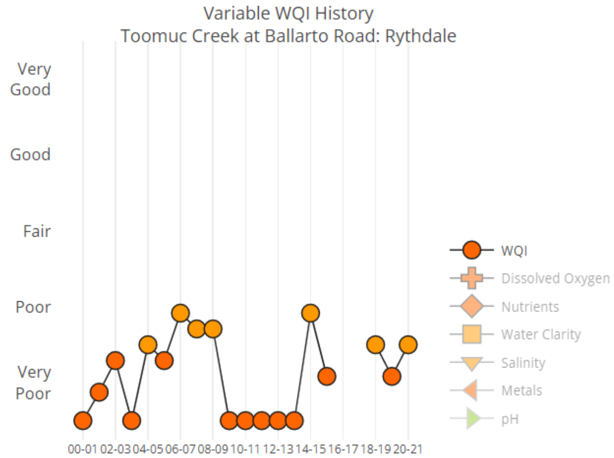
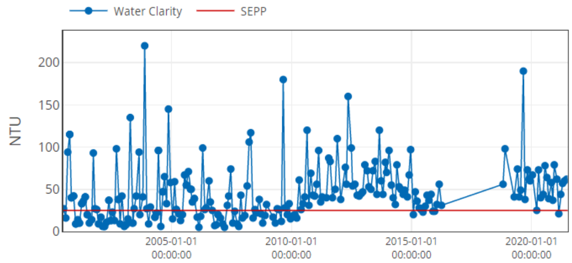
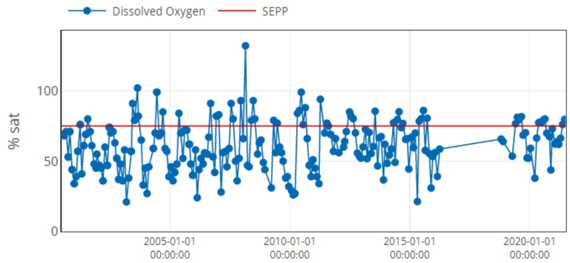
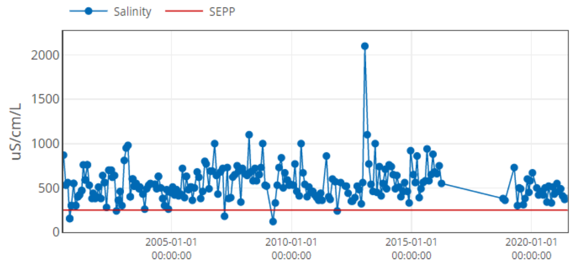
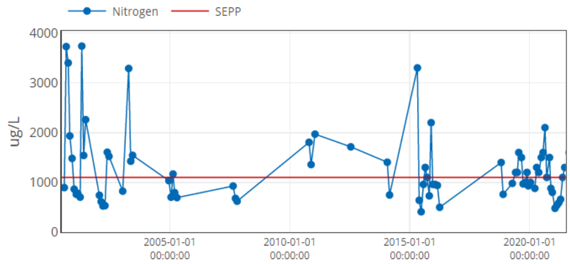
Site 8: WPTOO0062 Toomuc Creek at Ballarto Rd, Rythdale

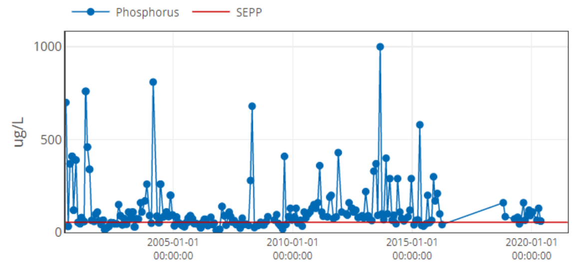


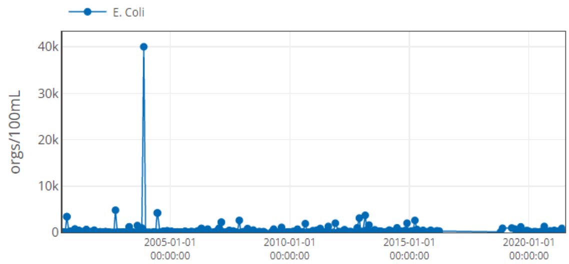


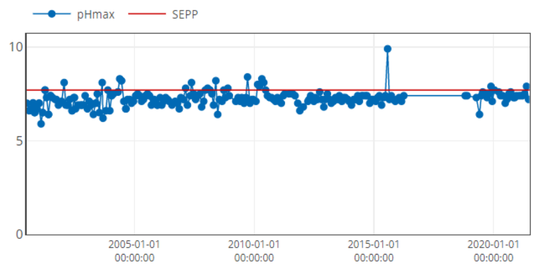


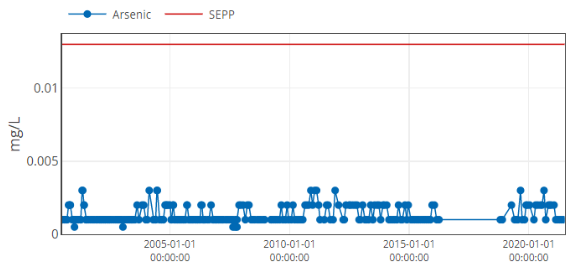


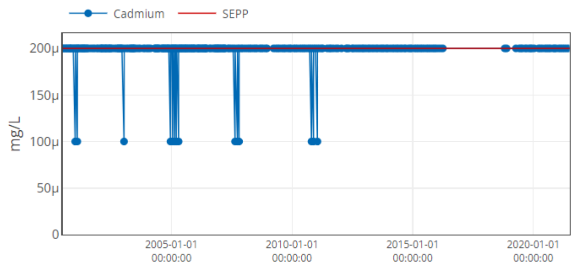








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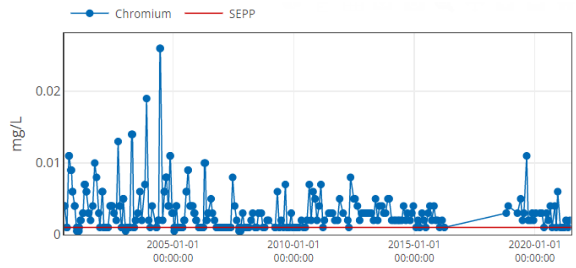
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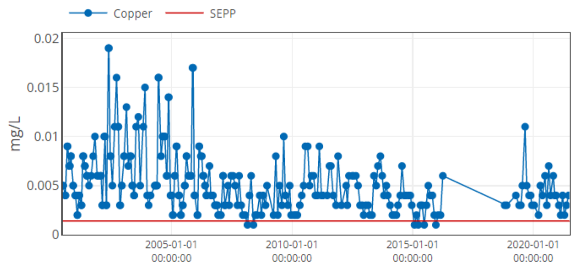
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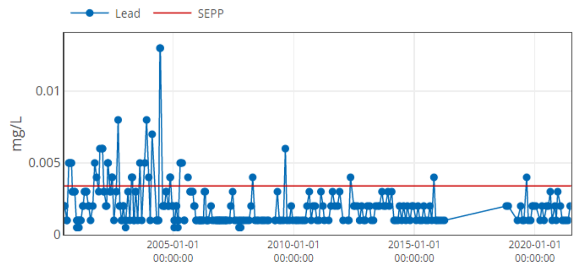
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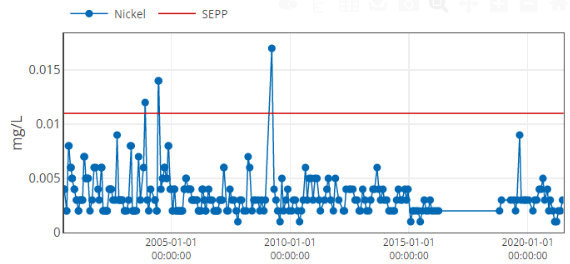
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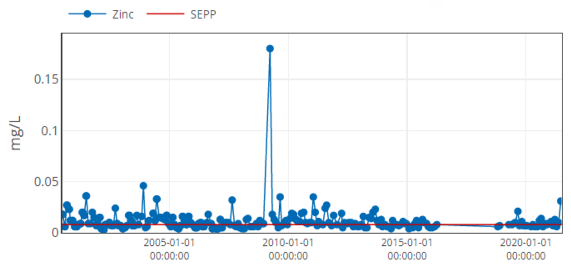
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0.05
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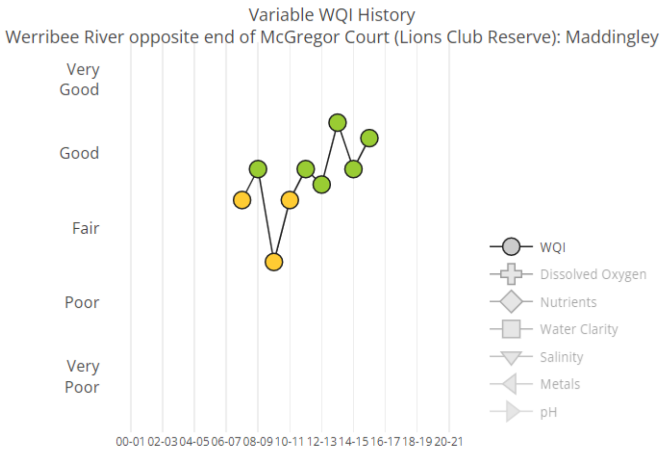
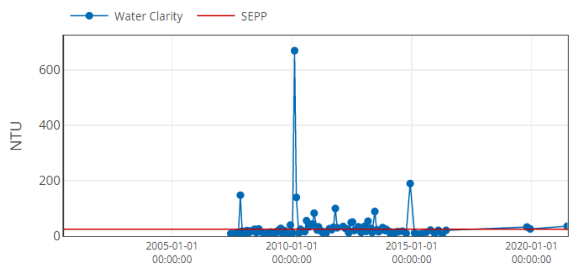
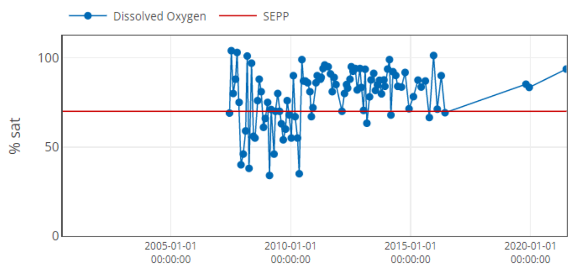
2020-01-01 00:00:00

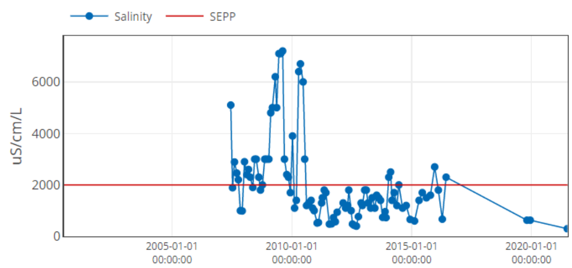
Werribee catchment

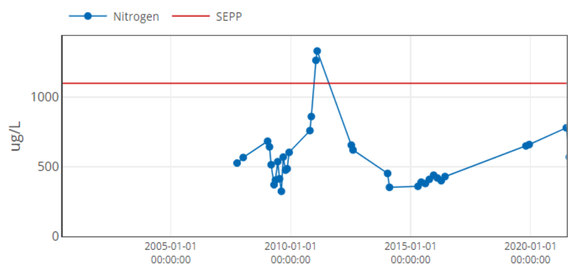
Site 9. WEWER0353 Maribyrnong River at Brimbank Park

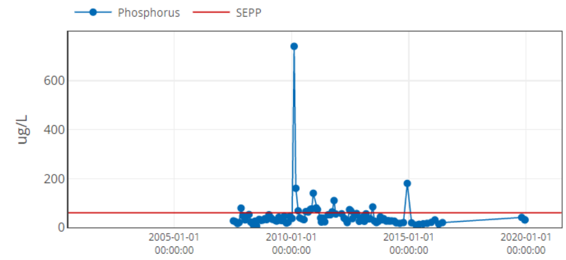








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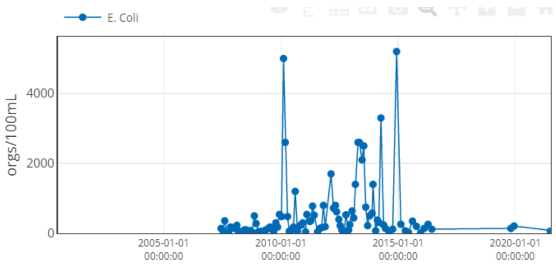
E. Coli
orgs/100mL
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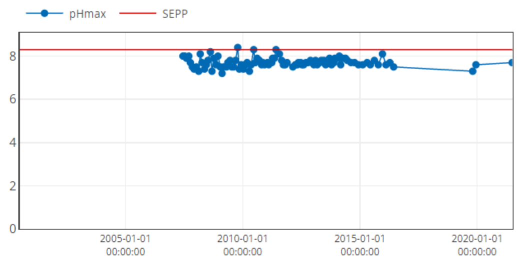
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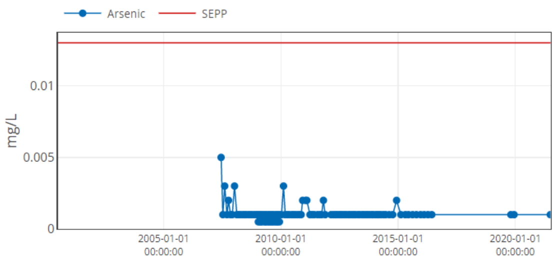
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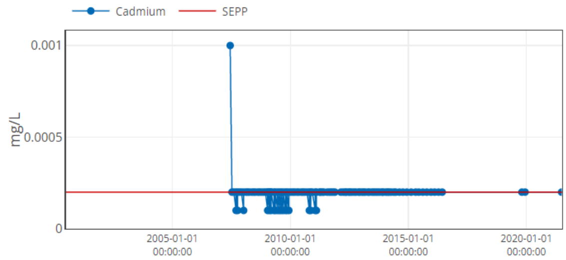
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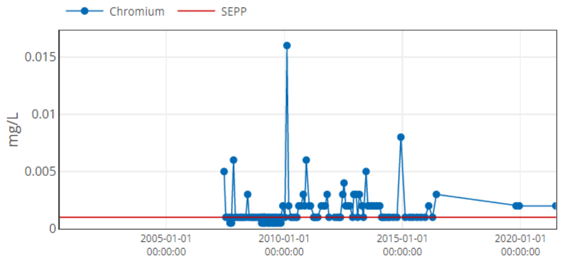
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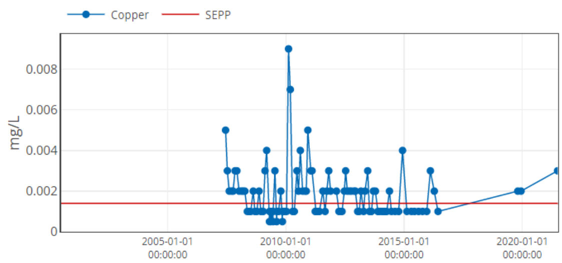
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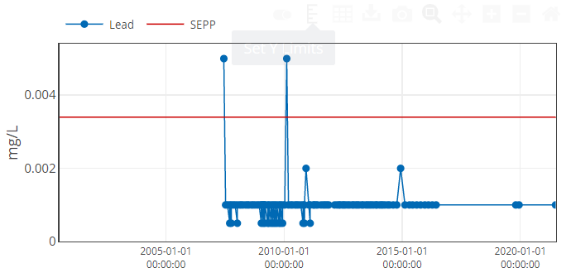
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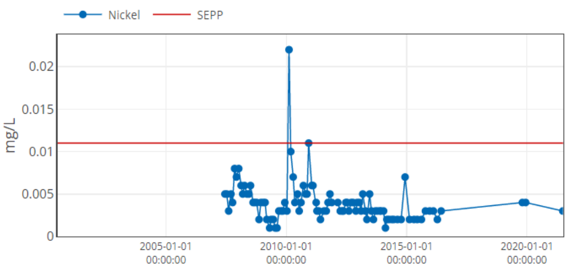
2020-01-01 00:00:00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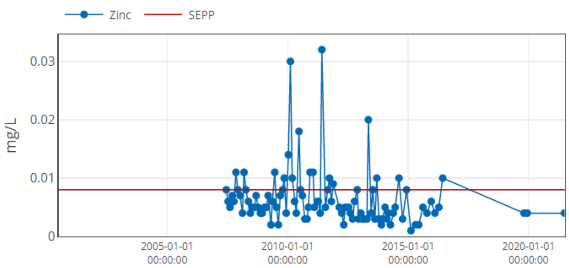
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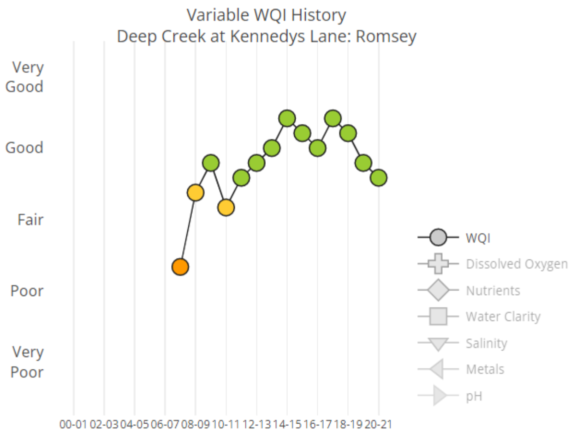
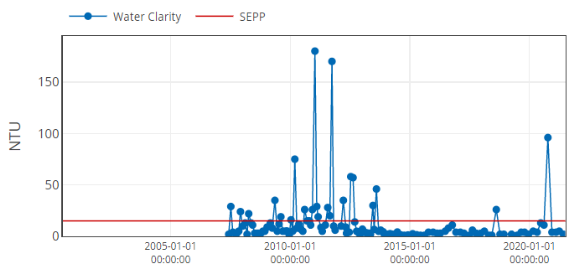
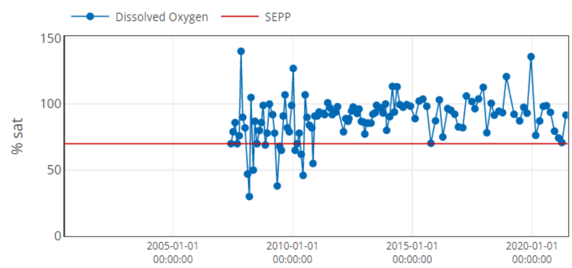
2020-01-01 00:00:00

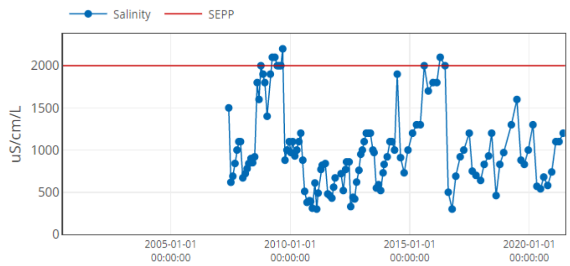
Maribyrnong catchment

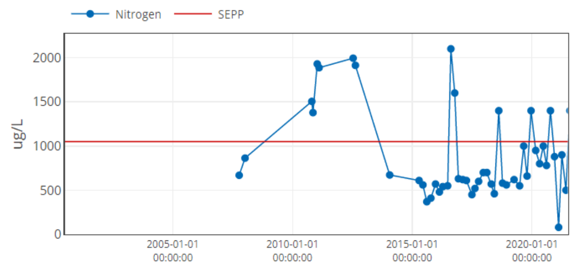
Site 10. MADEE0309 Deep Creek at Kennedy's Lane, Romsey

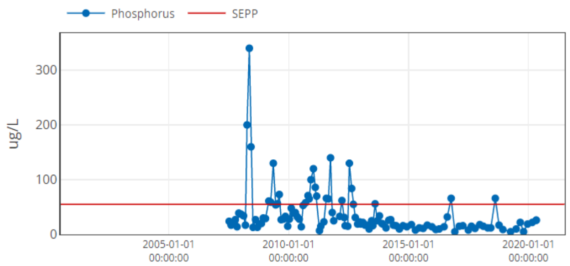


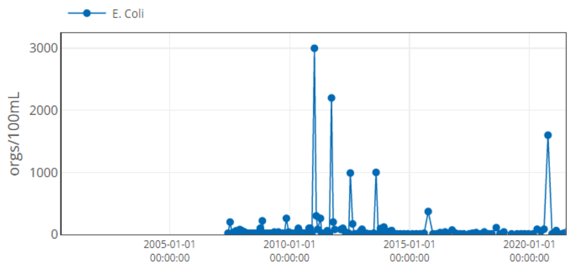


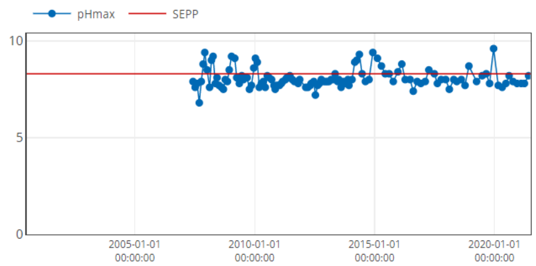


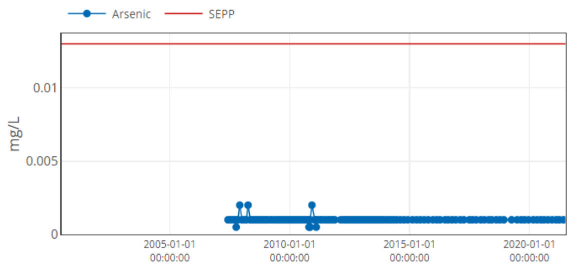


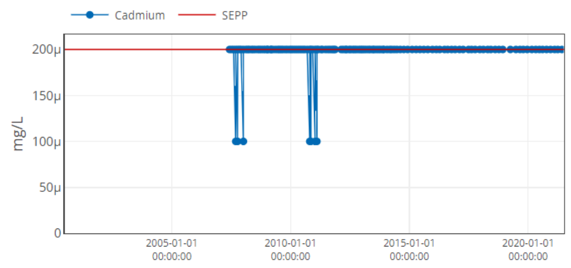








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mg/L
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150µ
100µ
50µ
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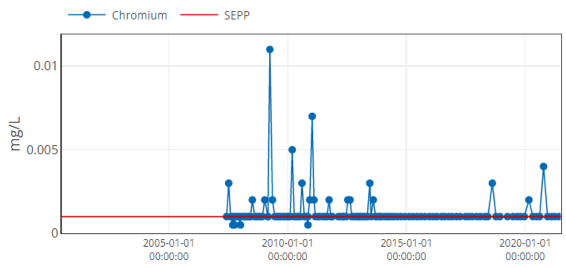
2010-01-01 00:00:00
2015-01-01 00:00:00
2020-01-01 00:00:00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mg/L
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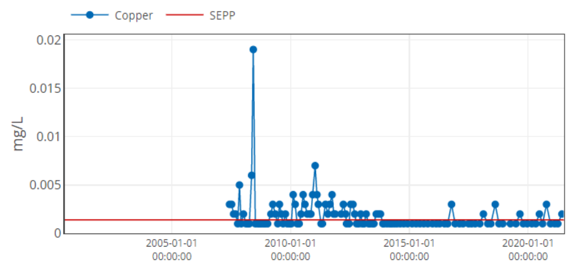
Copper
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mg/L
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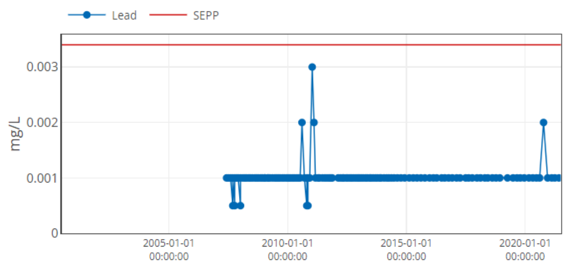
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SEPP
mg/L
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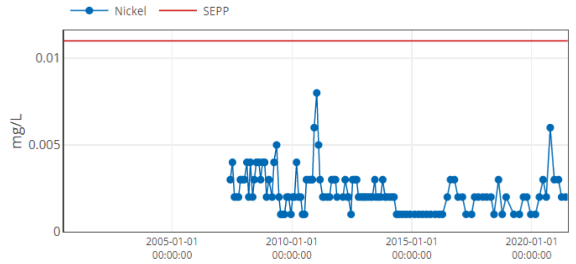
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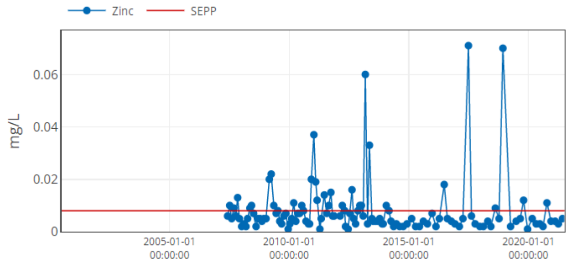
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0.04
0.02
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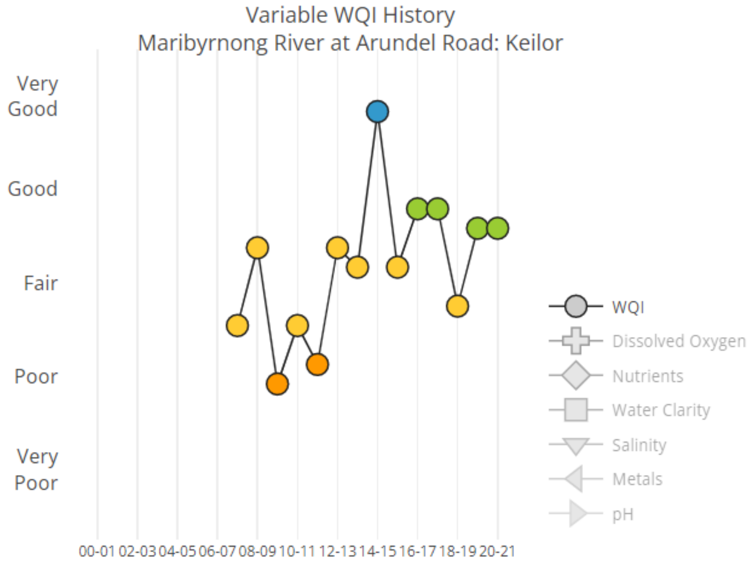
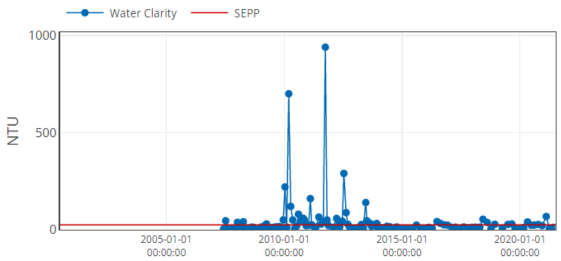
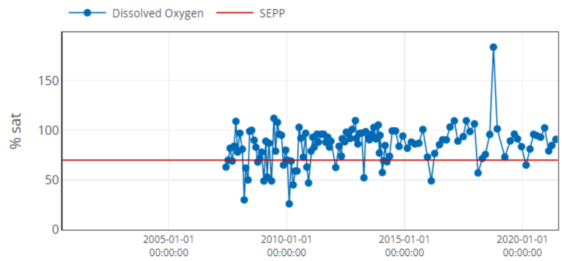
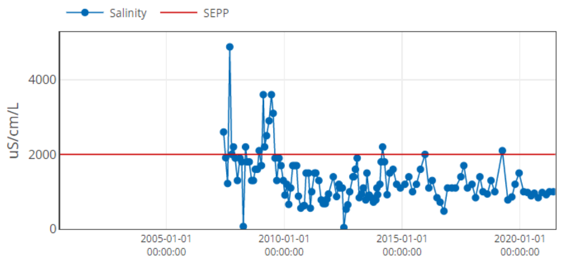
2020-01-01 00:00:00

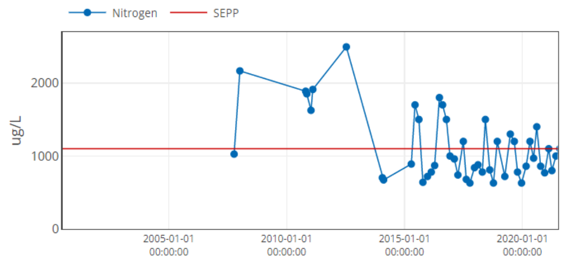
Site 11. MAMAR1294 Maribyrnong River at Arundel Rd, Keilor

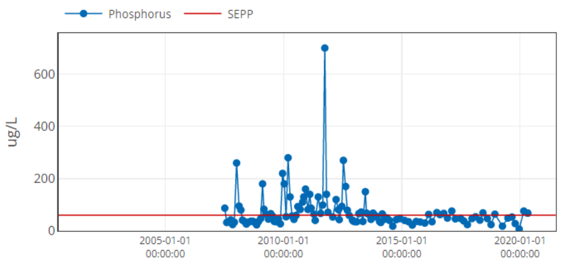


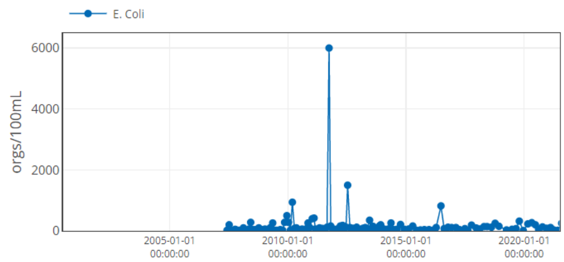


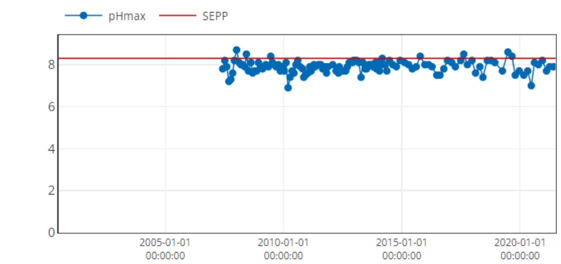


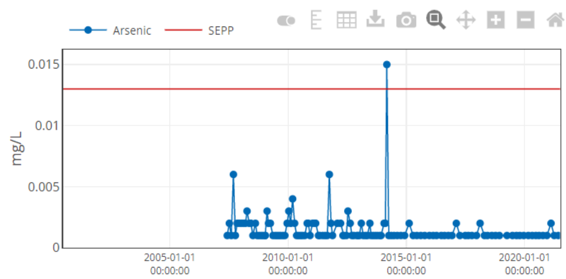


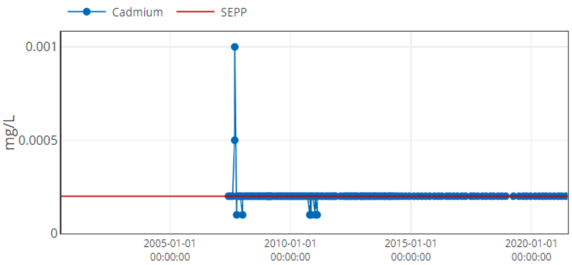








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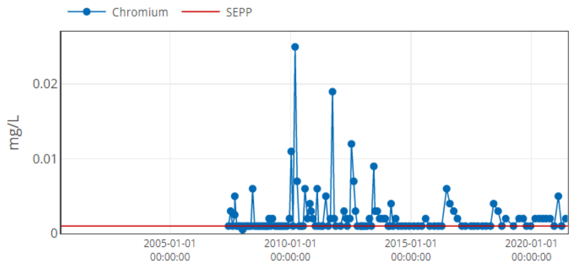
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mg/L
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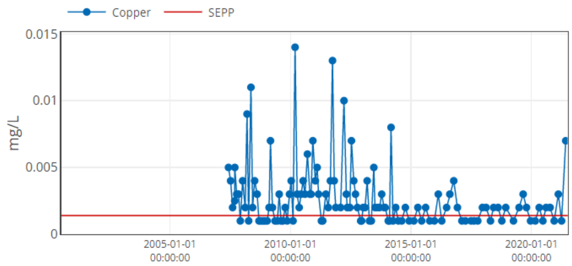
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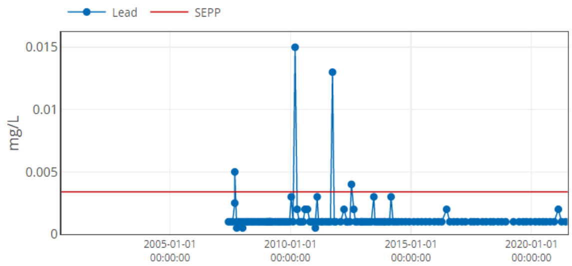
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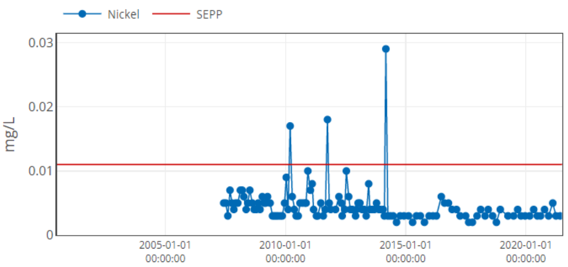
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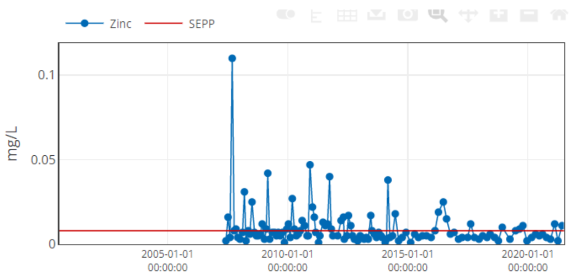
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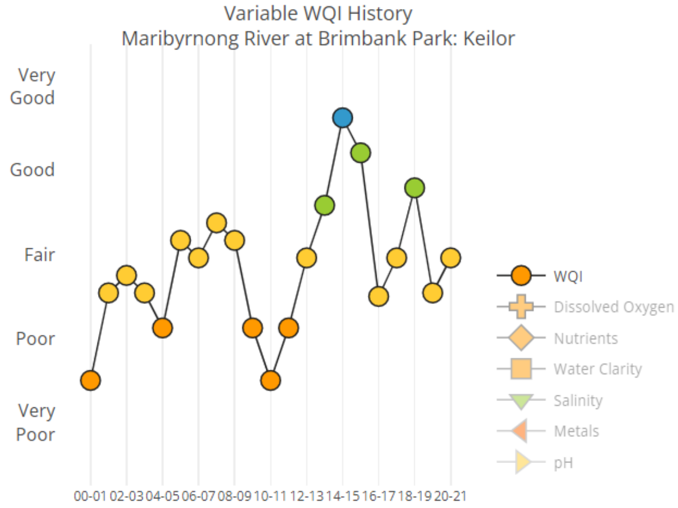
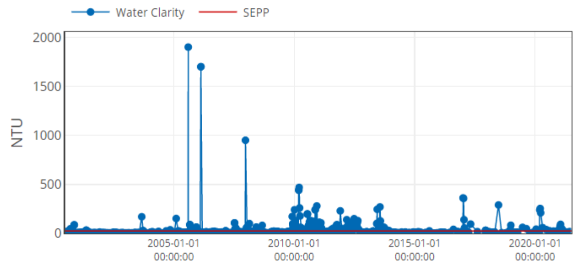
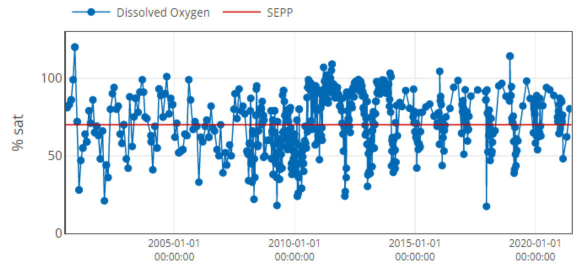
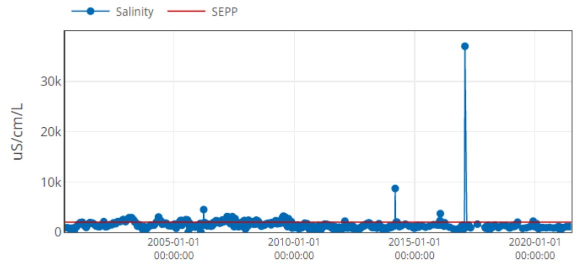
2020-01-01 00:00:00

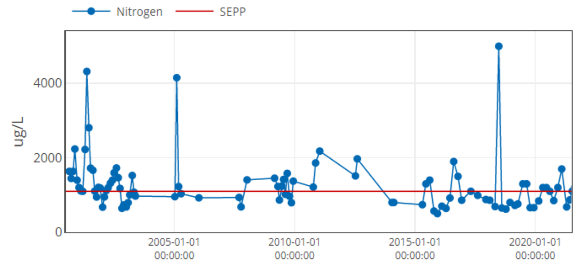
Site 12. MAMAR1311 Maribyrnong River at Brimbank Park

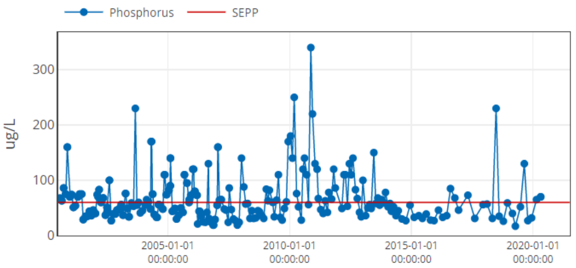


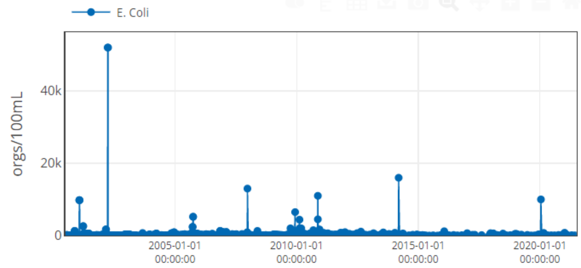


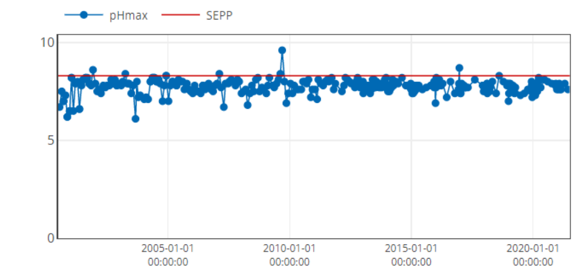


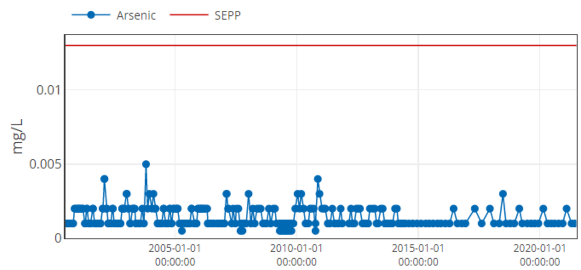


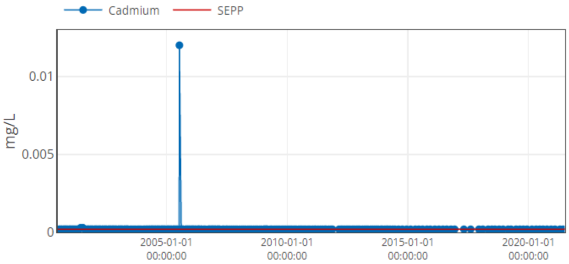








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mg/L
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2010-01-01 00:00:00
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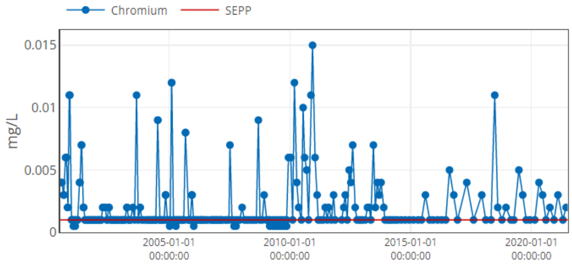
2020-01-01 00:00:00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2010-01-01 00:00:00
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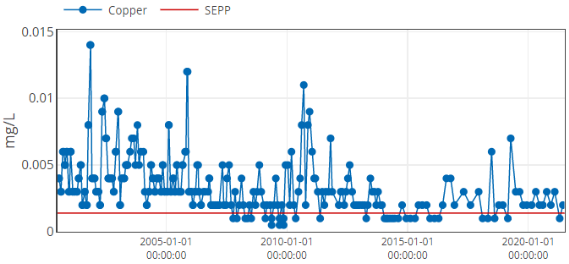
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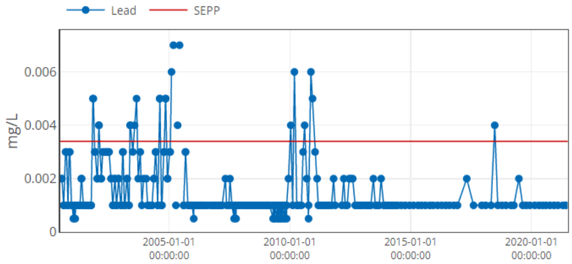
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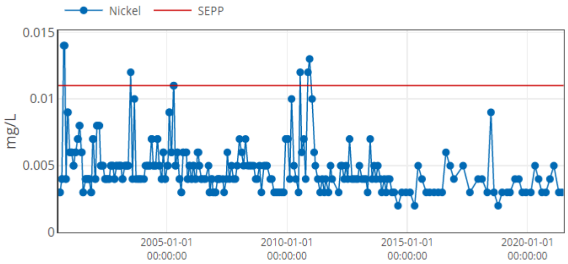
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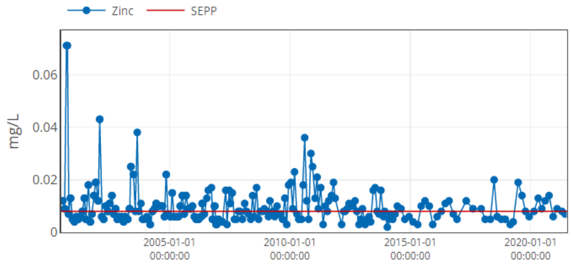
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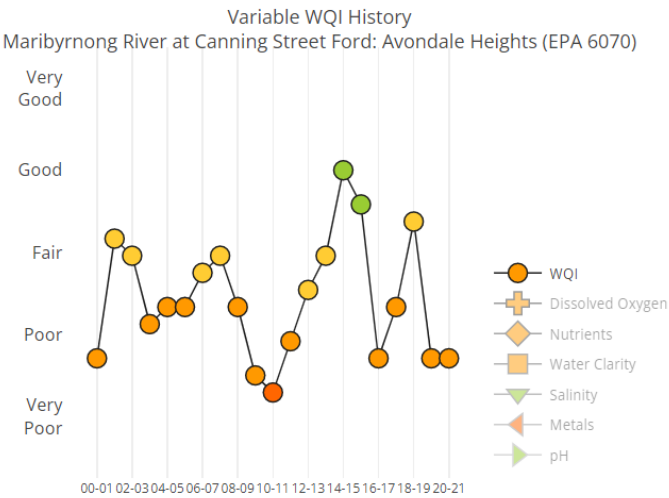
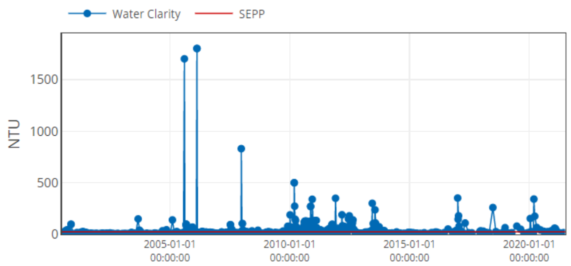
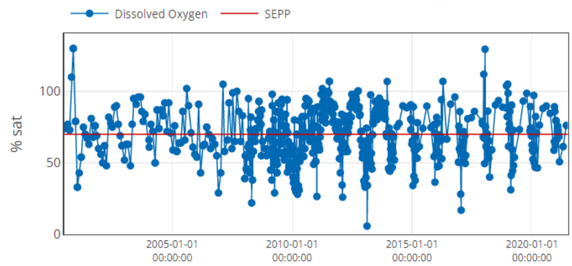
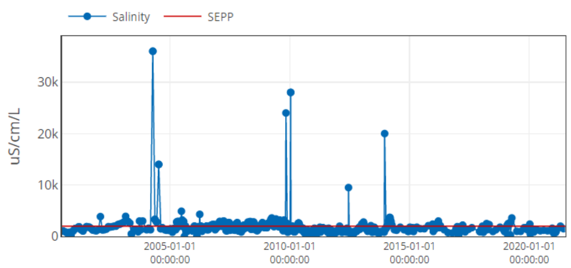
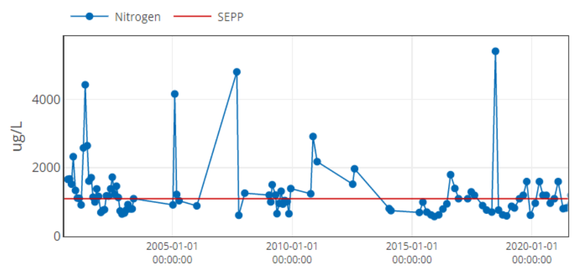
Site 13. MAMAR1346 Maribyrnong River at Canning St Ford

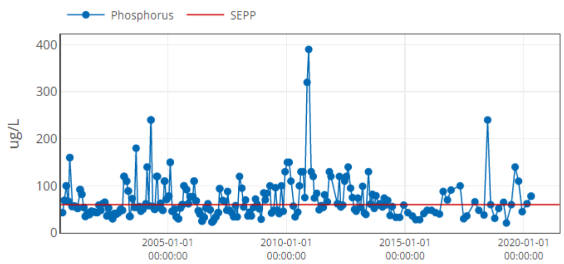


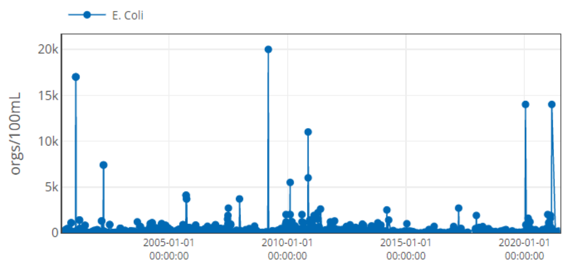


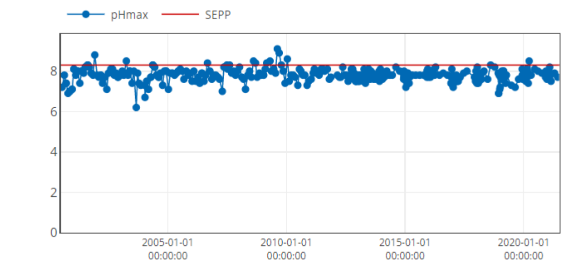


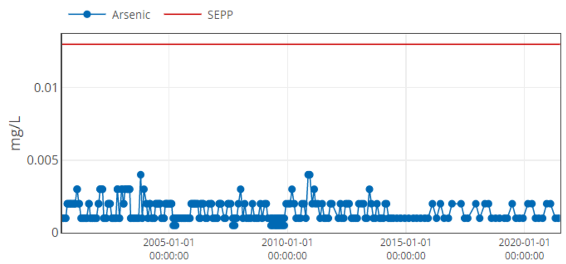


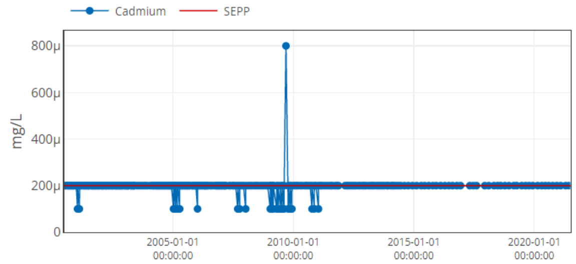








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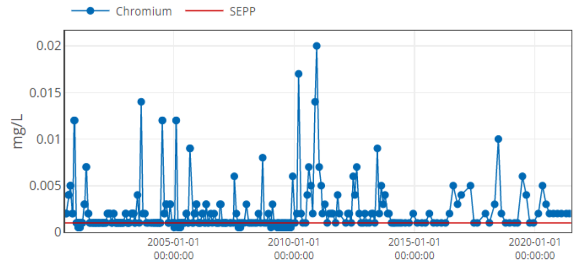
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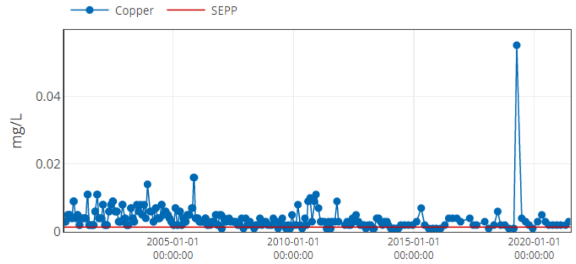
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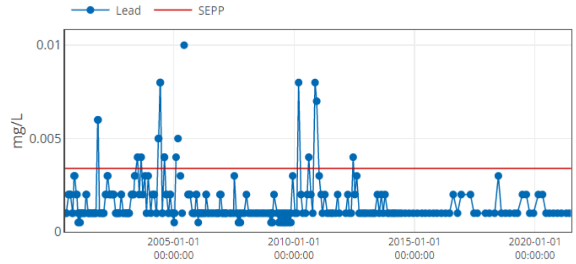
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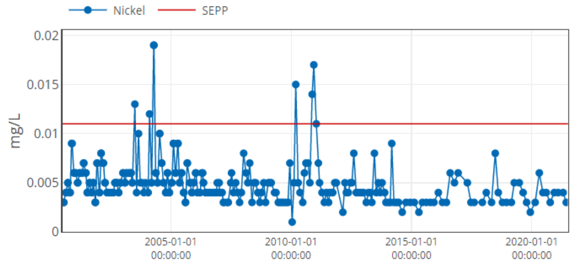
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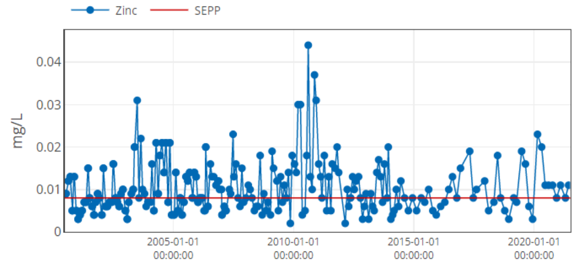
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Appendix 7: Summary of key literature cited

Summary of scientific evidence describing relationships between variation in environmental conditions and changes in macroinvertebrate community condition in streams.

Table 17. Summary of scientific evidence describing relationships between variation in environmental conditions and changes in macroinvertebrate community condition in streams.

Environmental conditions	Scientific publication	Location	Key aspect/s
Water quality	Imberger et al (2013)	Melbourne	Protection or restoration of riparian vegetation, in the absence of stormwater control measures and treatment, is insufficient to mitigate the effects of urbanisation on water quality (dissolved and particulate organic matter)
Water regime	Webb and Walsh (2006)	Melbourne	Variable response to antecedent discharge, with some families negatively impacted (mostly rheophilic) and some families positively impacted by drier conditions
Water regime	Webb and Walsh (2006)	Melbourne	Flow augmentation, via leaky pipes and irrigation, may act to sustains physical environments during drought, enabling some families to persist that would otherwise perish. NOTE: stormwater and drought have a much larger negative impact
Water regime	Imberger et al (2016)	Melbourne	Species resistance and resilience responses to drought is variable e.g. Dandenong Ranges amphipod. Some species may not poses resistance and resilience traits to recover and/or recolonise after prolonged drought
Vegetation	Imberger et al (2013)	Melbourne	Protection or restoration of riparian vegetation, in the absence of stormwater control measures and treatment, is insufficient to mitigate the effects of urbanisation on water quality (dissolved and particulate organic matter)
Vegetation	Webb and Walsh (2006)	Melbourne	Afforestation likely to have a minimal effect on family occurrence than adequately addressing urban-stormwater-derived stress in stream catchments with higher imperviousness cover
Physical form	White and Walsh (2020)	Melbourne	Restoring habitat complexity will not likely be effective unless negative impacts of stormwater runoff are first addressed.
	Walsh and Breen (2001)	Melbourne	
Threateded species	Tsyrlin and Carew (2022) and Tsyrlin et al (2022)	Melbourne	Climate change is significant threat to threatened species habitat loss.

978-1-921603-67-9 (PDF)

More Information

Healthy Waterways Strategy

Access the Mid-term Review Summary Report >>
Access the Mid-term Review Science Inquiry Report >>
Access the Implementation Inquiry Report >>

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