Victorian Water Quality Trends 1991-2016

June 2018

Final

ventia

Issue/ Rev	Date	Revision Description	By	Checked	Approved
Draft	21/1/18	Draft Report	JL	MP	MP
Draft v2	23/4/18	Draft Report v2	JL	MP	MP
Final	22/6/18	Final Report	JL	MP	MP

1. Executive Summary

Water quality is an important indicator of water resource management and managers have a keen interest in understanding the state of water quality in our river and streams, and in understanding the patterns of change across time. Such information informs the management of waterways and provides broad feedback as to the need for, and success in management actions to maintain or improve water quality.

This study uses a range of data analysis tools, to present information on status and change of water quality over time.

This report presents the results from a two-staged approach to identifying water quality trends across the State, using time series plots, statistics, control charts and run charts to assess trends in water quality from 2011 to 2016 compared to the historical record (1991 to 2010).

Stage 1 consisted of assessing water quality data at 79 monitoring sites across the State to identify large scale trends.

Stage 2 consisted of a more in-depth investigation of six candidate sites, chosen to represent a range of waterways and water quality management issues within Victoria:

- Wimmera River at Eversley (415207)
- Broken River at Goorambat (404216)
- Barwon River at Pollocksford (233200)
- Oven River at Peechelba (403241A)
- La Trobe River at Rosedale (226228)
- Yarra River @ Chandler Highway Kew (229143).

Key tools use in the assessment included:

- Data graphs
- Control charts
- Run charts
- Summary statistics
- Relative change graphs
- Regression techniques and
- Modelling

Data graphs, Control charts and run charts are used throughout this investigation to assist with visualizing what patterns in water quality are present and whether water quality measurements taken at a particular site of interest are within or outside an expected range, given other prevailing conditions, such as flow or weather conditions.

The tools and resulting assessments can assist catchment managers because they facilitate understanding of whether any observed change in a new water quality measurement is within expectations, given both the inherent variability and dynamic nature of the site, hence allowing problems that are outside of expectations to be identified as they arise. These tools were used in both Stage 1 and Stage 2.

Historical quality trends were informed by the complete period (1991 to 2010) analysed under the 2013 water quality trend analysis assessment and the current trends were informed by data obtained from 2011 to 2016. This method of comparing historical to current data is common amongst trend reporting (Department of Environment and Primary Industries 2013, EPA 2011), and such approaches work well when background conditions during the historical period are similar to those in the current period.

As part of Stage 1, data graphs were produced and graphs visually interrogated to identify significant increase or decrease in the water quality parameter. Furthermore, summary statistics and relative change graphs were developed for each water quality parameters to identify where the historical data differed from the current data to assess broad scale statewide changes.

Under Stage 2, multiple regression techniques were applied to identify a combination of predictor variables that best described variation in the water quality parameter of interest between January 1991 and December 2010 at each site. Separate models were developed for each water quality variable at each site. The regression model that best described historical variation in each dataset was then used to predict the value for that water quality variable on each sampling occasion between January 2011 and December 2016. Water quality data collected between 2011 and 2016 were compared against the predicted values to determine whether the trends were as expected. Individual observations that differed from predicted values by more than a designated threshold (equal to 1.5 times the inter-quartile range recorded during the historical data period) were considered to be 'out of control' and warranted closer inspection. Data were also compared against SEPP trigger levels to determine whether particular water quality variables were likely to pose a risk to aquatic biota or beneficial uses at each site.

Run charts were used to show the number of consecutive observations that were either above or below the predicted value at each site. Long runs of consecutive observations that were either all above or all below the predicted value were considered to potentially indicate a deviation from historical patterns (where models were a good fit).

The objective of the study was to assess whether water quality was as expected at these sites, or whether water quality changed relative to the expected historical trajectories.

1.1 General observations in water quality

A number of the predictor variables determined for each water quality metric were common across of the six candidate sites, including:

- Dissolved Oxygen –water temperature, flow and date
- Turbidity – flow, rain and date
- Electrical Conductivity – flow and season
- Total Nitrogen – flow and water temperature
- Total Phosphorus – flow and rain

As such, it is evident that the effect of reduced rainfall and river flows during the Millennium drought (1996 to mid-2010) dominated the water quality trends over the historical record (1991 to 2010) and were frequent predictor variables across each of the sites (refer to Figure 1).

During the historical period, most sites, when site-specific factors were taken into account, showed trends of **declining** turbidity and nutrients, **declining** dissolved oxygen levels and **increasing** electrical conductivity from prolonged periods of low flow conditions

Record rainfall and flooding in late 2010 to 2012 from a La Niña weather pattern broke the Millennium Drought, signaling the return to average conditions post 2012 (refer to Figure 2 and Figure 3). These climatic drivers caused a shift in water quality conditions in the current data (2011 to 2016) at most sites.

During the current period, dissolved oxygen levels **improved** at most sites from increased flow in the rivers. Turbidity and nutrient levels **increased** with higher catchment runoff, although site-specific factors were at play

Rainfall and the resulting catchment runoff has a large impact on what materials are washed into a stream for example leaf litter, soil particles and other particulates. If there is less rainfall, these particulates tend to remain in the catchment and are not transported by runoff into rivers. Similarly having less flow in rivers as a result of reduced runoff increases the electrical conductivity of a watercourse as there is not as much volume of water to dilute the salts.

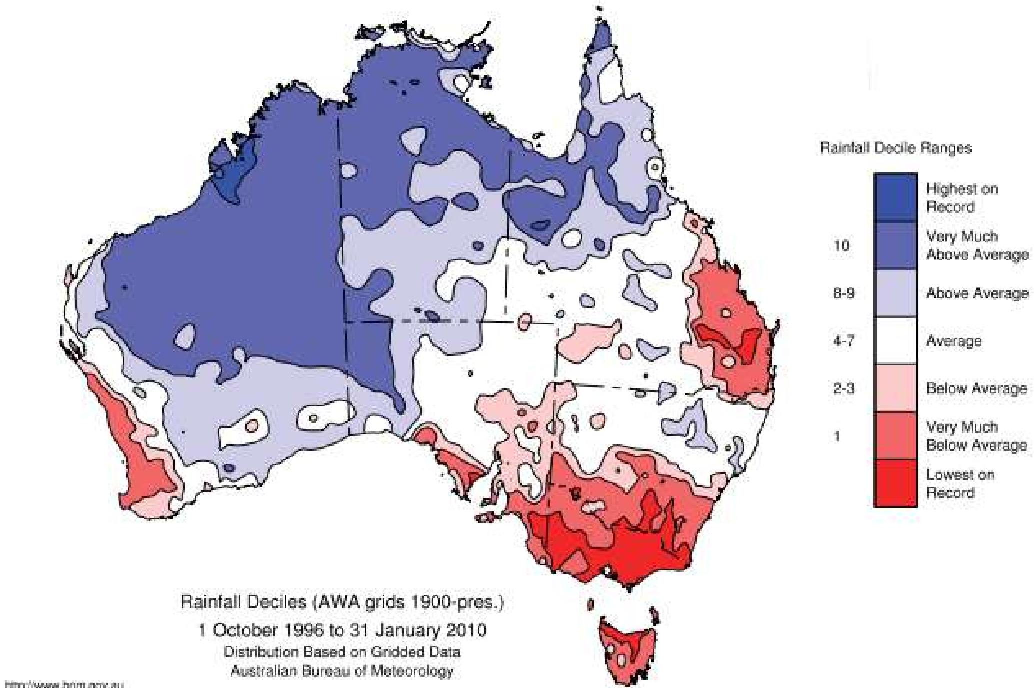


Figure 1: Rainfall Deciles across Australia, 1 October 1996 to 31 January 2010, the “Millennium Drought”.

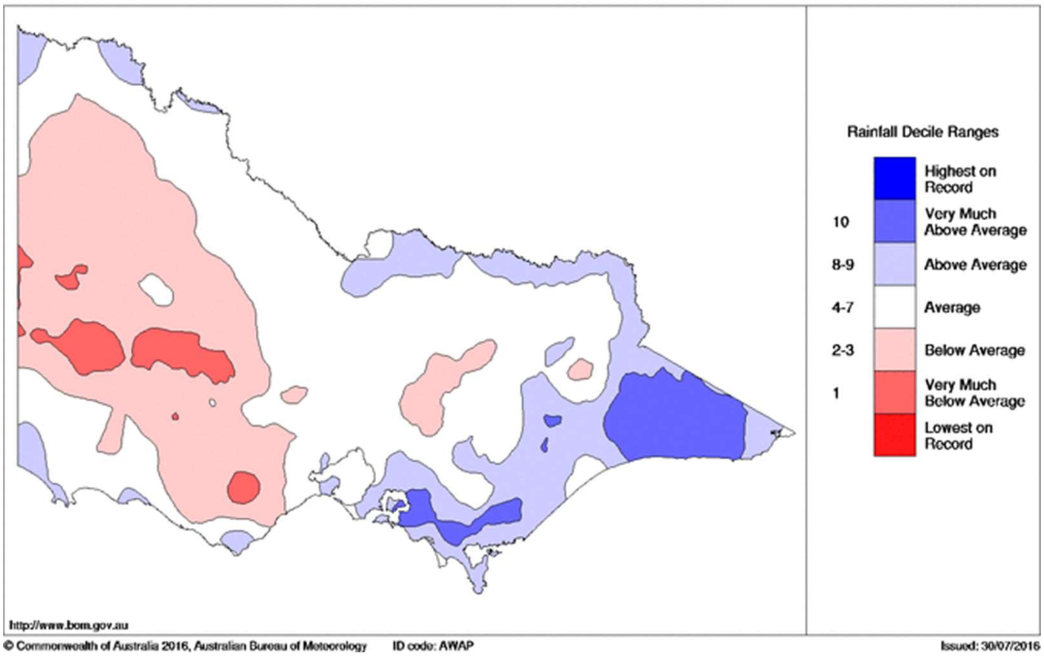


Figure 2: Rainfall Deciles across Victoria, 1 January 2011 to 31 December 2014.

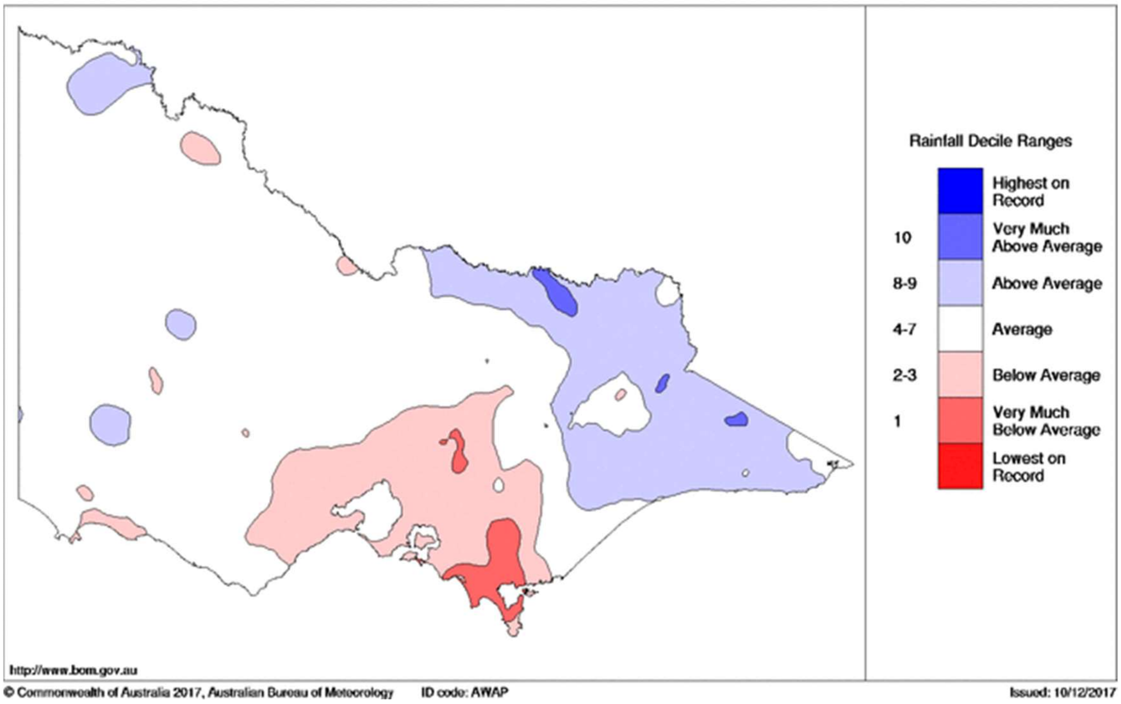


Figure 3: Rainfall Deciles across Victoria, 1 January 2015 to 31 December 2016.

Given the large change in climate between the historical and current period, the historical models developed based on drought years were not good predictors of the current wet/average conditions. This was especially the case in the Wimmera River that was highly flow stressed during the drought. Despite flow and rainfall being included as predictor variables, this work shows that the scale of changes in these water quality drivers were not able to be effectively captured in the model and therefore the models were mostly non-transferable between wet and dry years. However, the outcome of this modelling has shown the rapid changes (mostly improvements) in water quality post-drought and the reversal in historical trajectories, which may not have been as obvious with basic water quality analysis.

1.2 Detailed observations at six selected sites

Summary comments on the analysis at each site are provided below. Table 1 contains a summary of observed changes in the water quality parameters in the current period compared to the historic period.

Table 1: Summary of water quality parameters per site, arrow direction indicates a change in water quality parameter from historic levels (dry conditions) to current levels. Colors reflect if the change is advantageous from a water quality point of view (green), if there is no change (blue arrows) or if the change is detrimental from a water quality point of view (red arrows).

Site	Site number	DO	Turbidity	EC	TN	TP
Wimmera River @ Eversley	415207	↑ (green)	↑ (red)	↑ (red)	↑ (red)	↑ (red)
Broken River @ Goorambat	404216	↑ (green)	↑ (red)	↓ (green)	→ (blue)	↓ (green)
Barwon River @ Pollocksford	233200	↓ (red)	↑ (red)	↓ (green)	→ (blue)	↓ (green)
Oven River @ Peechelba	403241	→ (blue)	↑ (red)	↓ (green)	→ (blue)	↑ (red)
La Trobe River @ Rosedale	226228	↑ (green)	↑ (red)	↓ (green)	↑ (red)	↑ (red)
Yarra River @ Chandler Highway, Kew	229143	↑ (green)	↑ (red)	↓ (green)	↓ (green)	↓ (green)

1.2.1 Wimmera River at Eversley

The Wimmera River at Eversley is located in the upper reaches of the Wimmera River, upstream of the junctions with Mount Cole and Spring Creeks. This site was selected to assess impacts of severe drought on water quality. The Wimmera River is in moderate condition according to the Third Index of Stream Condition in 2010. While the river reach scored well for physical form (7) and hydrology (7), the reach scored lower for streamside zone (5), aquatic life (5) and water quality (3). Nutrients and EC were the main water quality issues.

The following trends in water quality were observed from 2011 to 2016 compared to the historical record:

- DO levels have generally increased significantly compared to the historical trajectory from higher flows in the catchment. However, the model did not predict low DO events that were likely to have been caused by the breakdown of large amounts of accumulated organic matter entrained in the river channel during heavy rainfall events post-drought. Model predictor variables for DO were season, date, water temperature and rainfall, with R^2 values of 0.42 and 0.35 for DO (mg/L) and DO (percentage saturation), respectively.
- Turbidity levels have increased significantly from the historical trends as a result of increased flow and runoff from the catchment following the end of the Millennium Drought. Model predictor variables for turbidity were season, date, flow, water temperature and rainfall. An R^2 value of 0.15 was achieved.
- EC levels have increased slightly compared to the historical trends. The model accurately predicted EC levels in winter but not in summer. The Wimmera River has very low flow during summer (and drought conditions) and the pool where water quality samples are taken for this site becomes very shallow. Processes such as evapo-concentration and/or increased groundwater intrusion from rising water tables post-drought may be important

drivers of EC levels at this site that were not captured by the model. Predictor variables for EC were season and flow. An R^2 value of 0.66 was achieved.

- Total nitrogen and total phosphorus levels increased in the Wimmera River in response to higher rainfall and flow. Generally, the model over-predicted TN and TP nutrient levels when compared with observations from 2011 to 2016. A number of high observations late in this period were also not predicted well by the model, both exceeding model controls and SEPP levels. Predictor variables were turbidity, rainfall, season, date and flow. R^2 values of 0.56 and 0.55 were achieved for TN and TP, respectively.

1.2.2 Broken River at Goorambat

The Goorambat water quality monitoring site is located midway along the Broken River, immediately downstream of Casey's Weir. This site was selected to evaluate changes following decommissioning of Lake Mokoan in 2009, which returned outflows to the Broken River at Casey's Weir. Overflow from Lake Mokoan, which is currently undergoing rehabilitation, still enters the Broken River at Casey's Weir. Many of the historical water quality issues such as turbidity and algal blooms associated with outflow water from Lake Mokoan are likely to still be relevant. Broken River at Goorambat is in moderate condition according to the Third Index of Stream Condition in 2010. While the river reach scored well for physical form (7), streamside zone (7) and aquatic life (7), the reach scored lower for hydrology (4) and water quality (5). Total phosphorus and turbidity were the main water quality issues.

The following trends in water quality were observed from 2011 to 2016 compared to the historical record:

- DO levels have increased significantly compared to the historical trends. Model predictor variables for DO were water temperature, flow and date, with R^2 values of 0.61 and 0.55 for DO (mg/L) and DO (percentage saturation), respectively.
- The decommissioning of Lake Mokoan in 2009 significantly reduced turbidity levels in the Broken River compared to the historical trends. The historical model was a poor predictor of the current turbidity levels. Variation in turbidity levels were very poorly explained (R^2=0.18) initially by water temperature, date, flow and rainfall predictor variables. A secondary regression model was fitted using a combination of season, date, rainfall, conductivity and flow data from Lake Mokoan pre-2009 (R^2=0.54). The improvement in regression attributes the historical turbidity trends in Broken River to inflows from Lake Mokoan.
- EC levels have declined significantly compared to the historical trends most likely due to increased river flows. Predictor variables for EC were date, water temperature, flow and rainfall with an R^2 value of 0.11.
- Total nitrogen levels have reduced from the decommissioning of Lake Mokoan in 2009 and are slightly lower than predicted. Predictor variables for were season, date, turbidity and rainfall with an R^2 value of 0.32.
- Total phosphorus levels have reduced in Broken Creek most likely due to the decommissioning of Lake Mokoan in 2009, compared to the historical trajectory. Predictor variables for turbidity were season, flow and turbidity with an R^2 value of 0.32.

1.2.3 Barwon River at Pollocksford

The Barwon River at Pollocksford is located in the lower reaches of the Barwon River, downstream of the junction with the Leigh River. This site was selected to continue to assess water quality responses to land management improvements in catchment. Barwon River at Pollocksford was in poor condition according to the Third Index of Stream Condition in 2010. While the river reach scored well for aquatic life (8) and physical form (6), the reach scored lower for hydrology (1), water quality (5) and streamside zone (5). Elevated nutrients were the main water quality issue.

The following trends in water quality were observed from 2011 to 2016 compared to the historical record:

- The model was not a strong predictor of DO data. Observed data were lower than predicted in summer and higher in winter. Predictor variables for DO were season, water temperature, date, flow and rainfall, with R^2 values of 0.22 and 0.06 for DO (mg/L) and DO (percentage saturation), respectively.
- Turbidity levels have increased slightly from historical levels most likely due to heavy rainfall and increased catchment runoff. The predictor variable for turbidity was flow with an R^2 value of 0.71.
- EC levels have declined compared to the historical trends, most likely due to increased river flows. Predictor variables for EC were season, water temperature and flow with an R^2 value of 0.50.
- Total nitrogen levels in the current period did not deviate from the predicted trajectory from the historical period given the identified drivers (water temperature, flow, rainfall and date) of total nitrogen levels in the Barwon River. The model had an R^2 value of 0.36.
- A decline in total phosphorus levels in the Barwon River over the historical period continued into the current period as predicted. Predictor variables were season, date, flow and cumulative rainfall over 72 hours with an R^2 value of 0.26.

1.2.4 Ovens River at Peechelba

Peechelba is located on the Ovens River on the Murray lowland plains, north-east Victoria, between Wangaratta and Yarrawonga. This site was selected to increase the geographic spread of sites and to represent a relatively un-impacted stream (no dams, only minor weirs and offtakes). Ovens River at Peechelba was in moderate condition according to the Third Index of Stream Condition in 2010. The river reach scored well for water quality (9), streamside zone (8), physical form (7), aquatic life (7) and only slightly lower for hydrology (5). Water quality was in good condition.

The following trends in water quality were observed from 2011 to 2016 compared to the historical record:

- DO levels were generally well predicted using historical trends. Model predictor variables that were established from the historical period and applied to predict DO levels in the current period were season, water temperature, flow and rainfall, with R^2 values of 0.74 and 0.31 for DO (mg/L) and DO (percentage saturation), respectively.
- Turbidity levels were generally as predicted from historical levels. Predictor variables for turbidity were season, date, flow and cumulative rainfall over 72 hours with an R^2 value of 0.32.
- EC levels declined compared to the historical period, but levels were slightly higher than predicted by the model. Predictor variables for EC were season, date, flow and days since a 20mm rainfall event with an R^2 value of 0.57.
- Total nitrogen levels were generally as predicted by the historical trends. Total phosphorus levels were slightly higher than predicted. Predictor variables were water temperature, rainfall, turbidity and flow for nutrients. R^2 values of 0.38 and 0.15 were achieved by the model for TN and TP, respectively.

1.2.5 La Trobe River at Rosedale

La Trobe River at Rosedale monitoring site (226228) is located on the Gippsland Plain in the lower reach of the Latrobe River, downstream of all the major tributaries and industrial discharges, except the Thomson River. Analyses at this site provided geographic spread and establishes baseline for assessing changes associated with coal mine rehabilitation. La Trobe River at Rosedale was in poor condition according to the Third Index of Stream Condition in 2010. While the river reach scored well for physical form (9) and streamside zone (6), the reach scored lower for hydrology (2), aquatic life (4) and water quality (4). Nutrients and turbidity were identified as the main water quality issues.

The following trends in water quality were observed from 2011 to 2016 compared to the historical record:

- DO levels increased compared to the historical trends. Model predictor variables were water temperature, date and flow, with R^2 values of 0.70 and 0.22 for DO (mg/L) and DO (percentage saturation), respectively.
- Turbidity levels were higher than historical trends from 2010 and 2014 owing to the heavy rainfall and major flooding (including the Morwell Diversion Collapse). Turbidity was slightly lower than predicted from 2014 to 2016. Predictor variables were temperature, date, flow and 72 hour cumulative rainfall with an R^2 value of 0.58.
- EC levels were slightly lower than expected compared to the historical trends. Predictor variables for EC were water temperature and flow with an R^2 value of 0.36.
- Total nitrogen and total phosphorus levels were slightly higher compared to the historical levels most likely due to catchment runoff associated with high rainfall in the current period. Predictor variables were season, water temperature, flow and 72-hour cumulative rainfall. R^2 values of 0.58 and 0.44 were achieved for TN and TP, respectively.

1.2.6 Yarra River at Chandler Highway

Yarra River at Chandler Highway monitoring site is located in an urban area of inner Melbourne, a short distance upstream of Dights Falls. This Melbourne Water site was selected because it is located in the Melbourne region and was suitable for assessing impacts of a range of catchment management decisions relating to water supply and urbanisation. Yarra River at Kew was in very poor condition according to the Third Index of Stream Condition in 2010. While the river reach scored well for physical form (8) and streamside zone (7), the reach scored lower for hydrology (1) and water quality (4). Turbidity, dissolved oxygen and nutrients are the main water quality issues.

The following trends in water quality were observed from 2011 to 2016 compared to the historical record:

- DO levels have increased significantly compared to the historical trends. Predictor variables for DO were season, water temperature, flow and rainfall, with R^2 values of 0.69 and 0.56 for DO (mg/L) and DO (percentage saturation), respectively.
- Turbidity levels have increased slightly from historical levels. Predictor variables for turbidity were flow and rainfall with an R^2 value of 0.45.
- EC levels have declined significantly compared to the historical trends. Predictor variables for EC were season, date, flow and cumulative rainfall in the preceding 72 hours with an R^2 value of 0.28.
- Total nitrogen and total phosphorus levels have decreased compared to the historical levels. Predictor variables were water temperature, rainfall and flow. R^2 values of 0.47 and 0.46 were achieved for TN and TP, respectively.

1.3 Are control charts an effective tool for analysing water quality trends?

Control charts are potentially an effective tool for assessing water quality trends over time and for assessing new data as they are collected. However, their effectiveness is closely linked to the fit of the predictive model that they are based on. Models that explain a large proportion of the historical variation will more accurately predict future observations and will therefore provide a more sensitive test of unexpected changes to water quality. However, climatic shifts can cause rapid changes to water quality trends compared to the historical trajectories. The models created for this assessment only explained a small to moderate percentage of the variation in water quality parameters as the R^2 values ranged from 0.064 (extremely poor fit) to 0.74 (moderately good fit).

Further work is needed to understand the important role of climatic conditions including the impacts of drought and floods, first-flush rainfall and time since rainfall, on water quality trends. A solution may be to develop separate control and run charts for wet, dry and average years.

1.4 Conclusions and recommendations

Overall, the effect of reduced rainfall and river flows during the Millenium Drought (1996 to mid-2010) dominated the water quality trends over the historical record (1991 to 2010). Most sites, when site-specific factors were taken into account, showed trends of declining turbidity and nutrients from reduced runoff, and declining dissolved oxygen levels and increasing electrical conductivity from prolonged periods of low flow conditions.

Record rainfall and flooding in late 2010 to 2012 from a La Niña weather pattern broke the Millenium Drought, signaling the return to average conditions post 2012. These climatic drivers caused a shift in water quality conditions in the current data (2011 to 2016) at most sites. Dissolved oxygen levels improved at most sites during the current period from increased flow in the rivers. Turbidity and nutrient levels increased with higher catchment runoff, although site-specific factors were at play.

2. Introduction

2.1 Background

Water quality is an important indicator of river health and suitability of water for different beneficial uses. River managers have a keen interest in monitoring changes in water quality and in implementing management actions to maintain or improve water quality. In 2013, the third Statewide assessment of trends in water quality was conducted, which compared trends for six water quality parameters at 75 Regional Water Monitoring Partnership (RWMP) sites over the period 2005 to 2010 against trends prior to 2005.

The 2013 study evaluated the use of control charts and run charts to assess trends in water quality and concluded that this approach has the potential to significantly increase the use of water quality data throughout Victoria. Control charts and run charts assess whether water quality measurements taken at a particular site of interest are within or outside an expected range, given other prevailing conditions, such as flow or weather. These assessments can assist catchment managers because they facilitate understanding of whether any observed change in a new water quality measurement is within expectations, given both the inherent variability and dynamic nature of the site, hence allowing problems that are outside of expectations to be identified as they arise.

Ventia Pty Ltd (Ventia) were engaged by the Victorian Government Department of Environment, Land, Water and Planning (DELWP) to conduct the 2017 statewide assessment of trends in water quality to include data collected up until the end of 2016. Water quality monitoring sites were assessed over the period 2011 to 2016 ("current" period) against trends from 1991 to 2011 ("historic" period).

Under the RWMPs, water quality and quantity data is collected at over 800 sites across Victoria, mostly on a monthly basis. A subset of these sites, where sufficient data was available, was chosen for analysis as well as water monitoring sites falling within the Melbourne Water management boundary that are not part of the RWMP. This is the first time that Melbourne Water managed sites have been included in the analysis.

2.2 Objective of report

The objective of this report is to identify long term trends to support policy makers and resource managers make informed decisions about existing management regimes and programs to drive change in the value and quality of Victoria's water resources. Furthermore, the study also assessed whether water quality was as expected at the sites investigated, or whether water quality changed relative to the expected historical trajectories.

Two stages of data analysis and assessment were undertaken to meet the objective, the first, a Statewide assessment of water quality data collected at a 79 monitoring sites, and the second stage, a more focused investigation on six sites of interest. Six sites were chosen for the analyses to represent a range of waterways and water quality management issues across Victoria. In both cases the data from the historical period (January 1991 – December 2010) was compared with the most recent data collected (January 2011 – December 2016).

The standard water quality parameters collected as part of the long-term water quality monitoring program were investigated in this study and included:

- Dissolved Oxygen (DO): Spot parameter measured by water quality meter on site
- Electrical conductivity (EC): Spot parameter measured by water quality meter on site
- pH: Spot parameter measured by water quality meter on site
- Turbidity: Spot parameter measured by water quality meter on site
- Total phosphorus (TP): Parameter analysed in the laboratory from a water sample collected on site

- Total Nitrogen (TN): Parameter analysed in the laboratory from a water sample collected on site. TN is a combination of Total Kjedhal Nitrogen (TKN) and NOx parameters.

2.3 Control charts

Control charts are a useful tool for identifying if a recorded value is within expected limits given an understanding of factors that are naturally variable at the site and historical patterns. Natural variation is quantified by using historical data such as rainfall. These relationships are then used to develop a model, which can be used to forward predict values expected given the natural variability of the site or to assess whether recent values are within the predicted levels. Confidence limits in the form of boxplots can be assigned to the data to assist with determining which readings may be considered out of control due to environmental or anthropogenic factors.

In this report, control charts were created for the six sites investigated in depth. In each case a model was firstly determined based on natural variability in historical data. One or more parameters were then identified as being the best explanation of variation at the site. This same relationship was then used to "predict" the data expected in subsequent years (Jan 2010 – Dec 2016). Each data point can then be compared with the predicted value to determine if they are consistent with what would be expected. If the observed values are within the expected values, data is considered within expected limits. If data is outside of confidence levels, we can assume that something in the catchment has affected the parameter of concern in an unexpected way. This would then lead to further investigations to determine the cause of this anomalous data.

The 2013 study concluded that Control Charts are potentially an effective tool for assessing water quality trends over time and for assessing new data as they are collected. Their effectiveness, however, is closely linked to the ability of the predictive model to adequately represent the inherit variability at the site, which is not always the case. Nevertheless, control charts have been created for the six in-depth water monitoring sites for Stage 2 of this assessment.

2.4 Run charts

Two different types of run charts were used for this assessment. During Stage 1, run charts were developed to show the number of consecutive observations above and below the median value for that parameter recorded during the historic period (1991 – 2010) and the current period (2011 – 2016). Runs were reset to 0 when a data point was missing as it was unknown what occurred during this time.

During Stage 2, the predictive models were used to determine how many consecutive observations were above and below the predicted value for the parameter in question. These consecutive runs were then plotted to create the run charts. When a parameter is following a predictable pattern, defined by the model, the run chart should appear like the skeleton of a fish, with relatively short runs both above and below the line. The strength of the run charts lie in their ability to identify significant runs of values that are either below or above the predicted value and may represent the start of a departure from previous patterns.

2.5 State Environment Protection Policy (SEPP)

The 2013 report concluded that control charts have the potential to improve the application of State Environment Protection Policy (Waters of Victoria) (SEPP WoV) trigger values and in particular make the values more sensitive to individual circumstances at a particular site. In this way, control charts and SEPP WoV trigger values can be used to determine whether water quality observations at a site are within expected boundaries and whether those differences are likely to represent a risk to beneficial uses. For this reason, the data analysis in this report has used SEPP WoV trigger values for assessment. Please note that a new SEPP is currently being reviewed by DELWP, however the existing SEPP values have been used throughout this assessment.

3. Project stages

The Project was divided into two stages; an assessment of Statewide trends using data collected at geographically spread water monitoring sites, and the second stage, a more in depth assessment of water quality at six candidate sites.

3.1 Stage one: Statewide assessment of trends

3.1.1 Assessment and quality of data

The list of sites investigated in the 2013 report (75 sites) was the starting point for this assessment. These 75 sites were a subset of the over 800 monitoring sites managed under the Regional Water Monitoring Partnership (RWMP). Refer to Figure 4 for location of all current RWMP sites. Those initial 75 sites were chosen from the 800 monitoring sites, as they had relatively complete records for all six water quality parameters dating back to January 1991. To be able to extend the assessment of these sites, the data set from January 1991 – December 2016 needed to contain at least 75% of all possible monthly measurements and have no more than 24 months of missing data. The water quality data was visually inspected to determine whether sites satisfied these prerequisites which left a total of 70 sites from the 2013 study to be used in the analysis. In addition, Melbourne Water managed sites located in the Bunyip, Yarra and Maribyrnong basins were included to expand the geographic spread of the analysis. For Melbourne Water sites to be included in the analysis, the above prerequisites also had to apply, which was the case for nine sites. Therefore, a total of 79 sites across the State were analyzed as part of Stage one (refer to Appendix A for a complete site list).

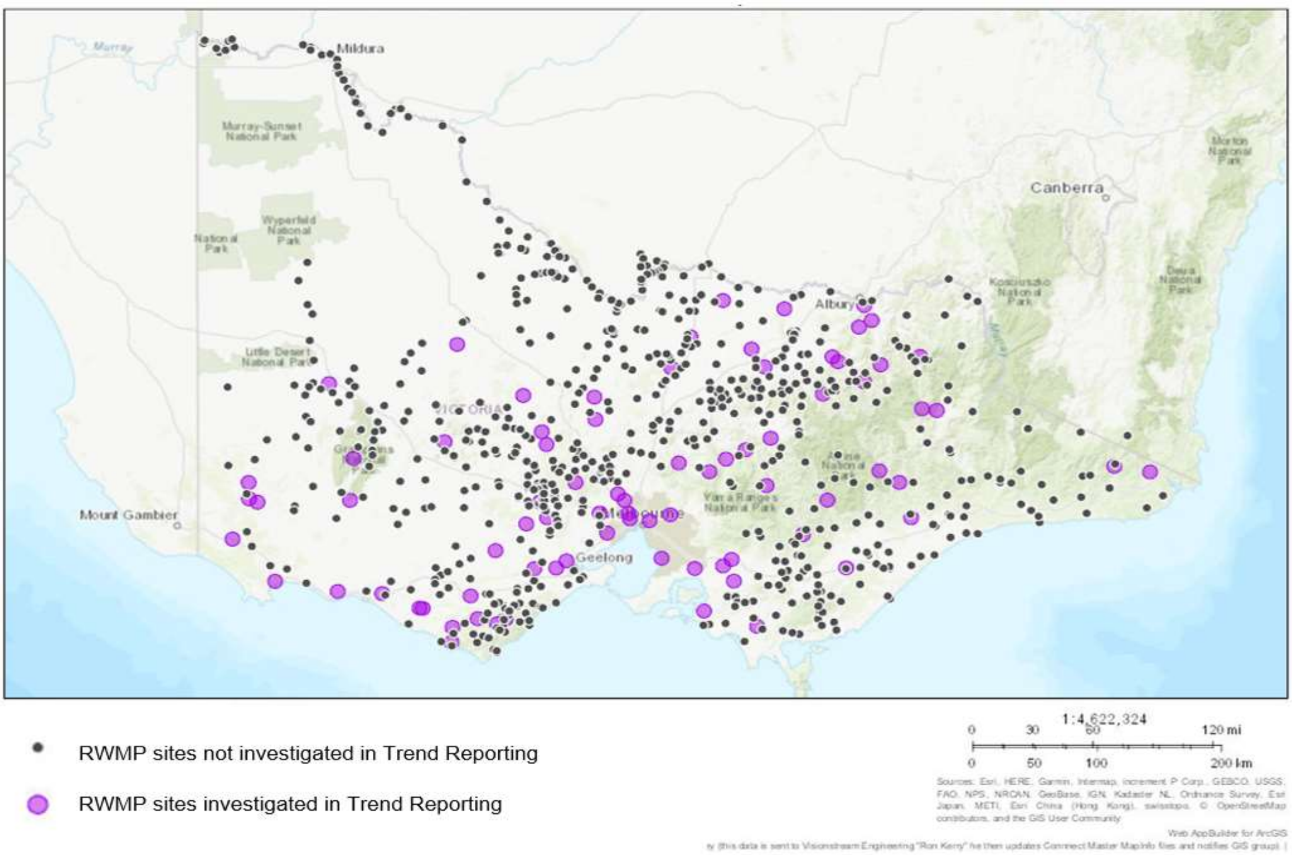


Figure 4: Map showing all Regional Water Monitoring sites active in 2018

3.1.2 Method for preparing time series plots

Detailed models were not developed for each of the 79 sites analysed, which meant that predictive control charts and run charts could not be developed. Instead, time series plots were derived for each of the water quality parameters investigated at each site for the period January 1991 – December 2016. The historical data (January 1991 – December 2010) were plotted in a different colour to the current data (January 2011 – December 2016) to highlight differences since the last investigation. State Environment Protection Policy (Waters of Victoria) (SEPP WoV) trigger values for all parameters were obtained from the State Environment Protection Policy guidelines (SEPP 2003) were plotted on the time series plots. The SEPP WoV guidelines only specify a trigger value for the percent saturation of dissolved oxygen and so the control charts for dissolved oxygen don't have an upper trigger value, only a lower trigger value.

SEPP WoV guidelines and trigger values varied dependent on the site location and type. To identify the appropriate trigger values for each parameter at each site, the EPA's Ecosystem Protection Water Quality and Nutrient Objectives for Rivers and Streams (EPA, 2003) information bulletin was used.

3.1.3 Method for preparing run charts

Run charts were prepared to display the number of consecutive data points in the current period (January 2011 – December 2016) above or below the median value for the historical period (January 1991 – December 2010). Whilst these charts are in no way predictive, the historical median provides a useful reference against which trends and consistent changes can be identified since January 2011.

At a "normal" site, the number of consecutive data points above or below the modelled estimates would be relatively short, and would produce a run chart that mimics the bones of a fish (refer to Figure 5).

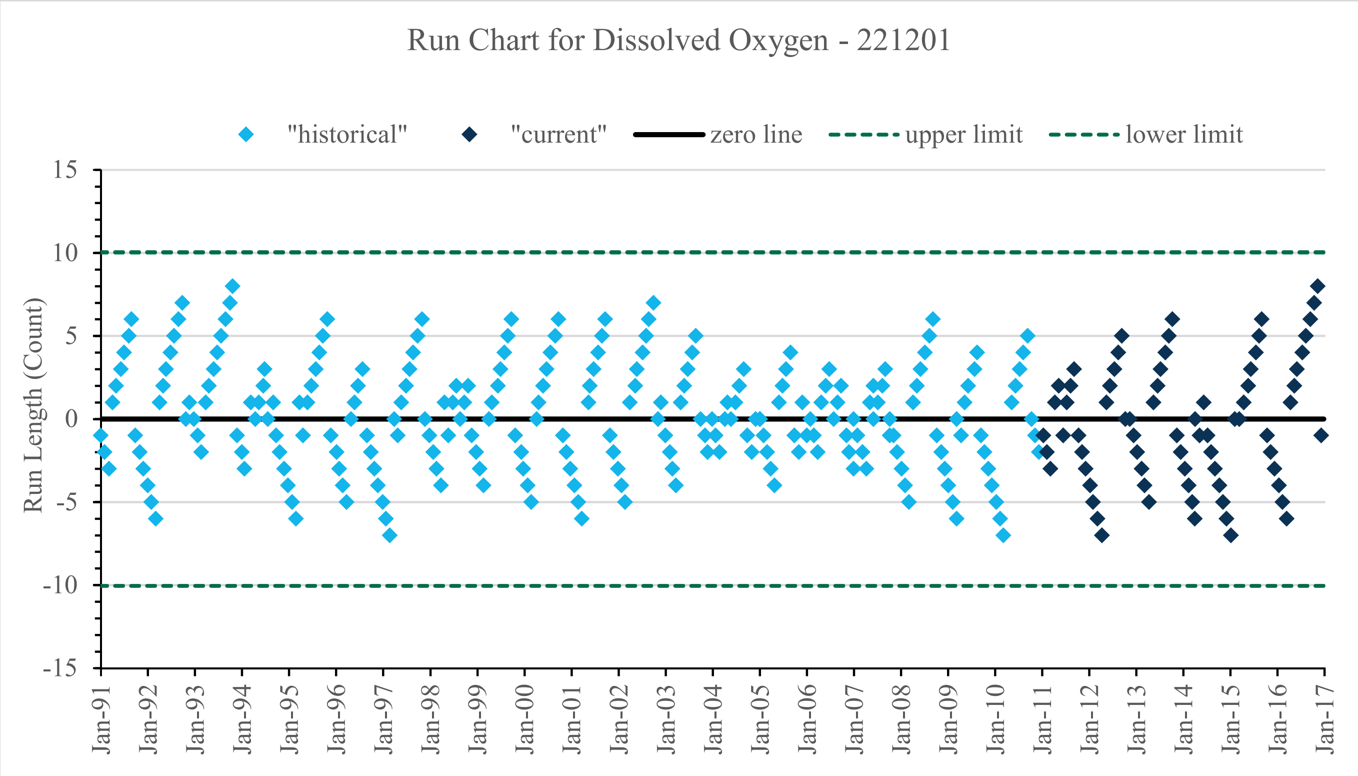


Figure 5: Example run chart of Dissolved Oxygen (DO) values at site 221201, Cann River (West Branch) @ Weeragua

Long runs above or below the historic median indicate consistent deviation from the anticipated conditions. This deviation can be interpreted as a trend for improving or worsening conditions (refer to Figure 6). Run chart limits were set at three standard deviations from the mean run length recorded during the historical data period between 1991 and 2010. Runs after 2010 that exceeded chart limits were considered irregular and potentially indicate a more sustained variation in the data, as can be seen in Figure 6.

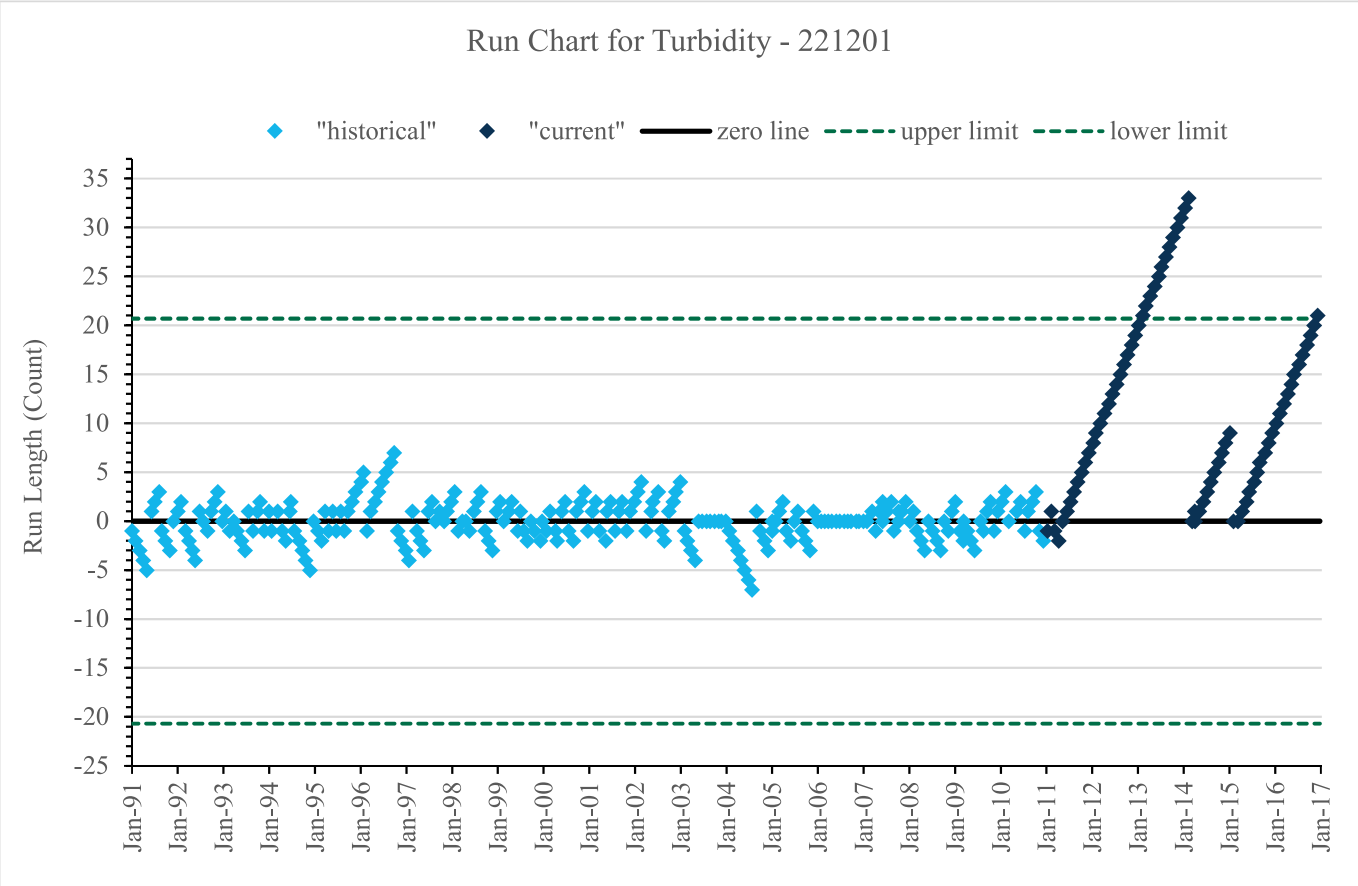


Figure 6: Example run chart of turbidity values at site 221201, Cann River (West Branch) @ Weeragua

3.1.4 Regional Assessment of water quality trends

Formal statistical trend tests were not undertaken at all 79 sites, however simple statistics and visual observations were used to identify trends. The following method was undertaken:

- Each time series plot was examined, visually comparing the historical data to current data and looking for obvious changes in patterns.
- Summary statistics were calculated for each parameter at each site including standard deviation, mean and median. Additional statistics calculated included:
    - Number of standard deviations between the mean and Upper / Lower SEPP
    - Number of occasions per year SEPP trigger levels were exceeded

- Average interval between events outside SEPP trigger levels before 2011 and after 2011 and for all data
- Maximum run of consecutive observations above and below the median

Relative change plots were created for each water quality parameter of interest. The change in mean value for each parameter between the current and historical periods was calculated (mean for current period – historical mean = change in mean). The change in mean was then divided by the historical mean to make sure that sites with very high or very low levels for a specific water quality parameter did not biased the results. This was also calculated based on the median. These results were graphed with results grouped into ranges to visually assist with interpretation. Each of the Victorian River Basins were labelled to assist with interpreting any basin patterns (refer to Appendix B for full list of basins). Each site's results were also plotted on a bar graph in site number order to visually determine the sites with the biggest difference between basins. The top four sites with the biggest increase or decrease as per the relative change plot for each water quality parameter across the State were investigated further. A description of the strength of trend (relative change) was provided based on the bounds outlined below:

3.1.5 Results for 79 selected sites

Individual results for each parameter and summary statistics at each of the 79 sites can be found in the accompanying report, *Victorian Water Quality Trends: 1991- 2016 Summary Tables and Plots*. The preceding section outlines the results of the assessment and overall trends observed for each of the water quality parameters across all 79 sites.

3.1.5.1 Dissolved Oxygen

There was no significant consistent trend in Dissolved Oxygen (DO) levels at the 79 sites assessed in the current analysis period of 1 January 2011 – 31 December 2016 when compared to the historic data, January 1991 to December 2010. In general, sites either showed a minor increase or decrease in DO values. Those sites in the south west generally decreased and those in the north east increased (refer to Figure 7).

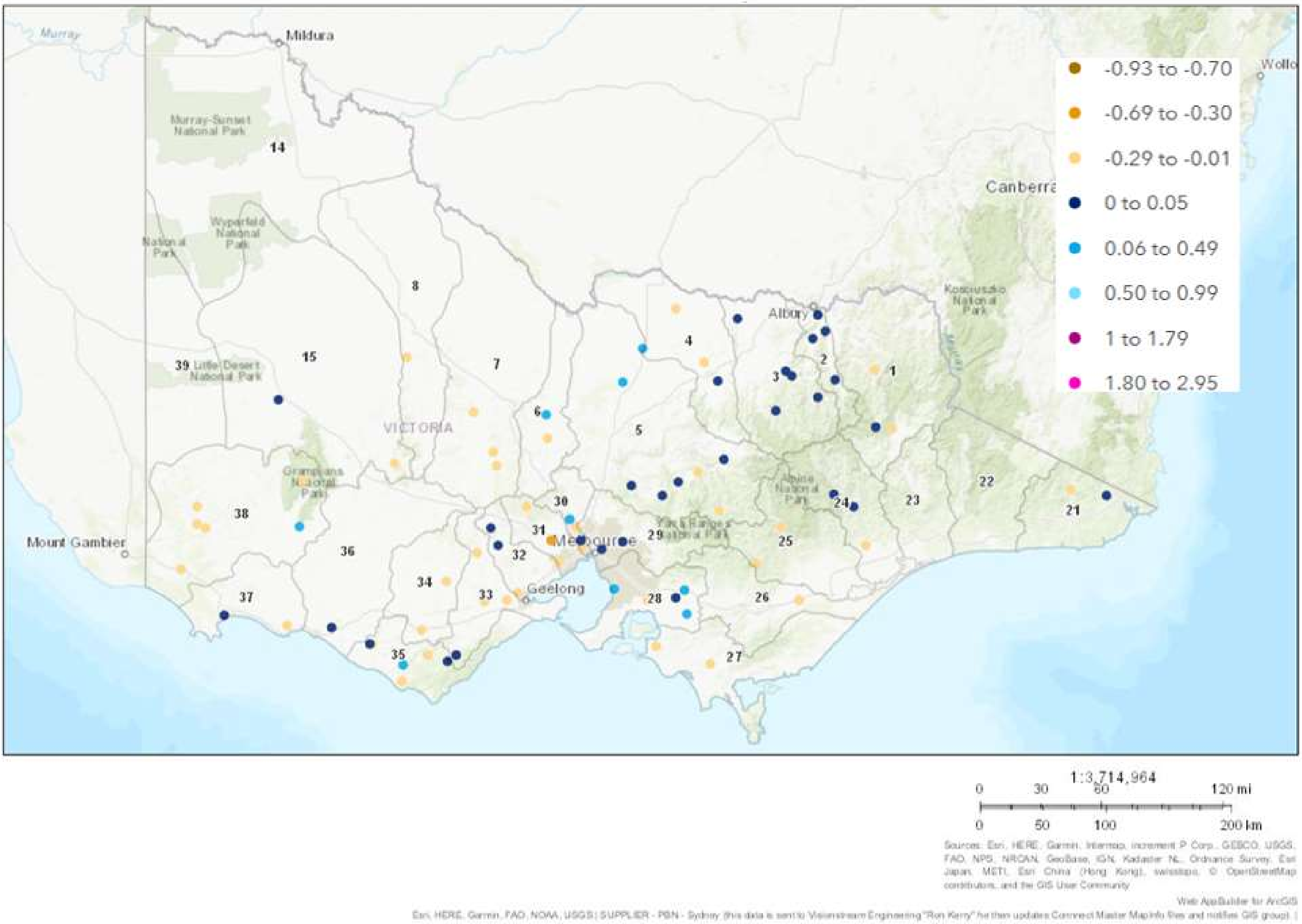


Figure 7: Change in DO (mg/L) data. The ranges represent the "current" period DO data median – "historical" period DO data median

Table 2 shows the top four sites with the biggest increase or decrease in DO across the State, however the magnitude of difference values are relatively small and unlikely to be significant. All sites display seasonal fluctuations in DO, representing temperature's effect on DO.

It is expected that DO levels would generally increase compared to the historical trajectory from higher flows in the catchment after the Millennium Drought, however, the overall data shows that other site-specific factors are influencing DO levels.

Table 2: Top four sites showing largest increase or decrease in median and mean DO across the State

Site number	Site name	Magnitude of difference	Median Historical	Median current	Long term median	Standard deviation Historical	Standard deviation Current	Strength of trend in timeseries plot
231231	Toolern Creek @ Melton South	-0.34	7.90	5.20	7.30	2.21	2.45	Minimal decline when compared to long term median
406207	Campaspe River @ Eppaloch	0.20	8.30	9.95	8.65	1.98	1.21	Very minimal increase when compared to long term median
235237	Scott's Creek @ Curdie	-0.16	6.60	5.55	6.20	2.47	2.28	Very minimal decline when compared to long term median
404214	Broken Creek @ Katamatite	-0.13	6.90	6.00	6.60	2.22	2.22	Very minimal decline when compared to long term median
Site number	**Site name**	**Magnitude of difference**	**Mean Historical**	**Mean current**	**Long term mean**	**Standard deviation Historical**	**Standard deviation Current**	**Strength of trend in timeseries plot**
231231	Toolern Creek @ Melton South	-0.31	7.57	5.23	7.03	2.21	2.45	Very minimal decline when compared to long term mean
406207	Campaspe River @ Eppaloch	0.19	8.16	9.74	8.53	1.98	1.21	Minimal increase when compared to long term mean
234203	Pirron Yallock Creek @ Pirron Yallock	-0.17	7.70	6.36	7.44	1.95	2.24	Minimal decline when compared to long term mean
415207	Wimmera River @ Eversley	-0.131	8.33	7.25	8.09	2.33	2.04	Very minimal decline when compared to long term mean

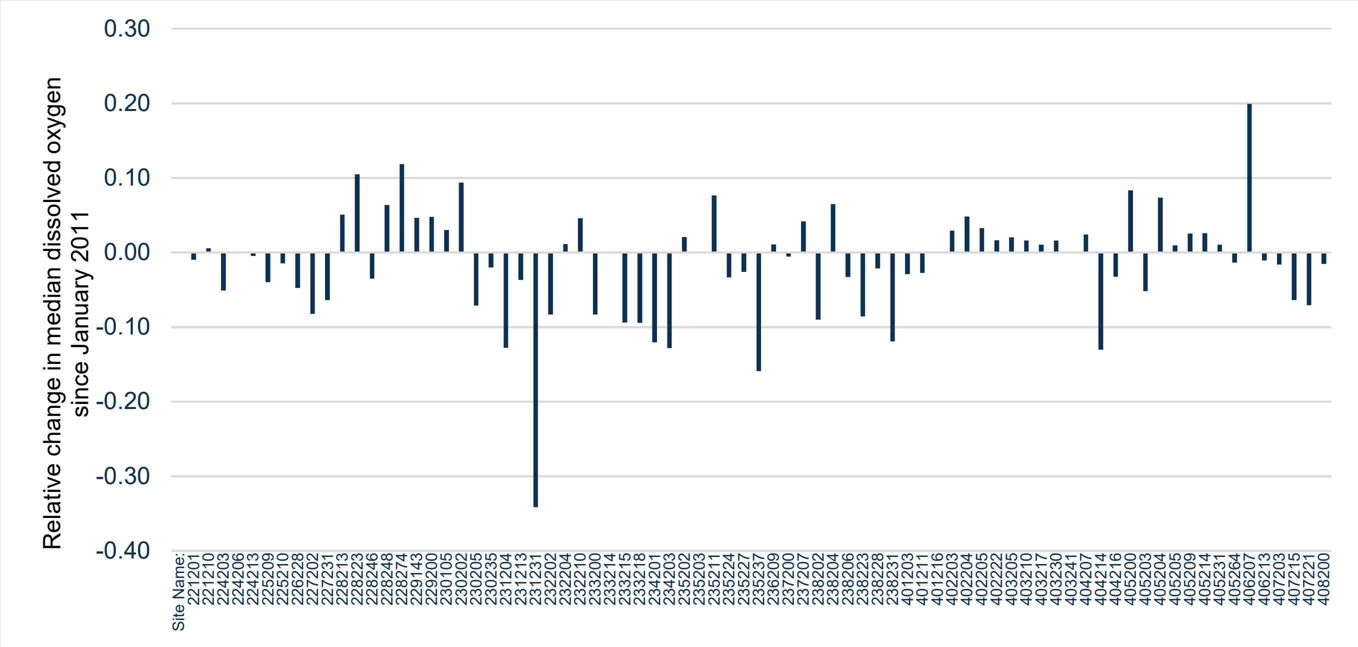


Figure 8: Relative change in median DO levels at 79 water monitoring sites since January 2011. Bars show difference in median DO between the period January 2011 – December 2016 and the period January 1991 – December 2010 at each site divided by the historical median for that site.

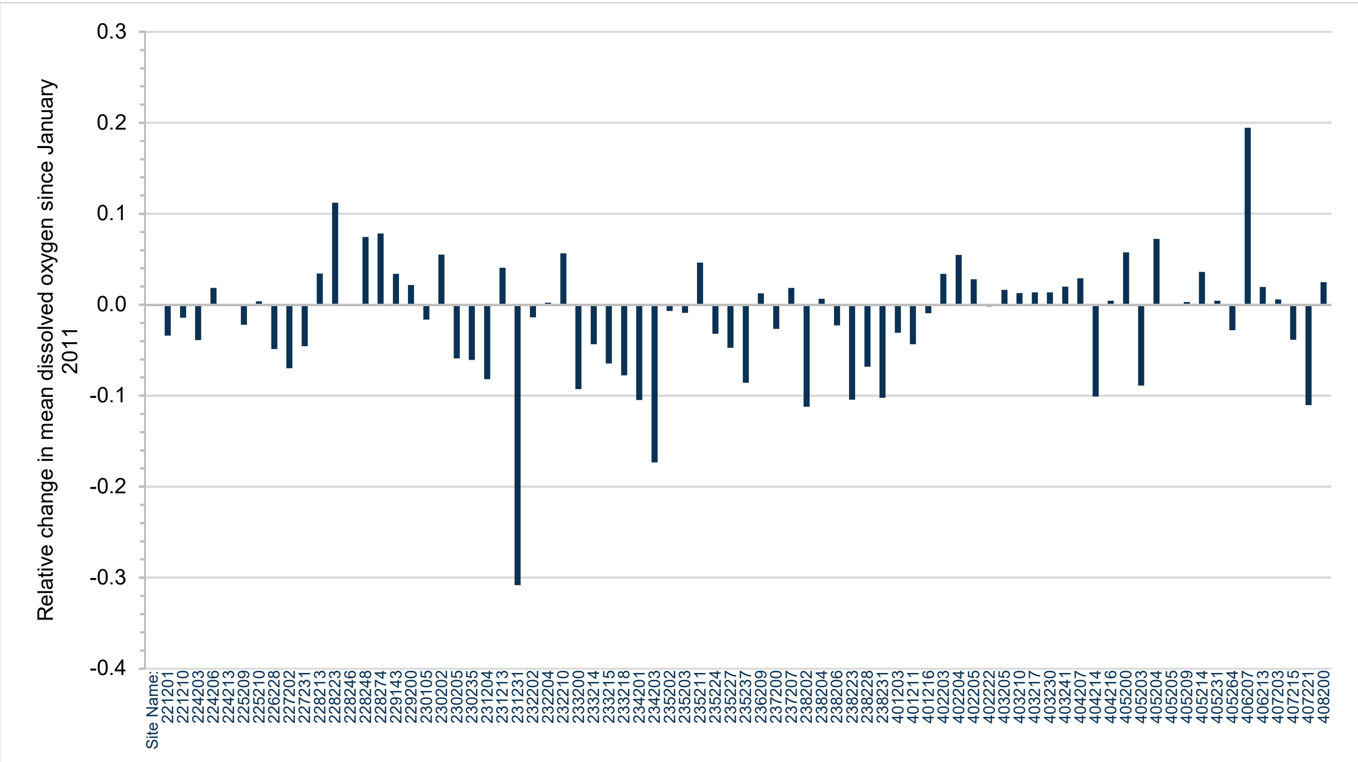


Figure 9: Relative change in mean DO levels at 79 water monitoring sites since January 2011. Bars show difference in mean DO between the period January 2011 – December 2016 and the period January 1991 – December 2010 at each site divided by the historical mean for that site.

3.1.5.2 Electrical Conductivity

There was no consistent trend in Electrical Conductivity (EC) concentrations across the 79 sites investigated in the period January 2011 – December 2016 when compared with the historical data (January 1991 – December 2010), although there were some minor patterns observed within basins (refer to Figure 10).

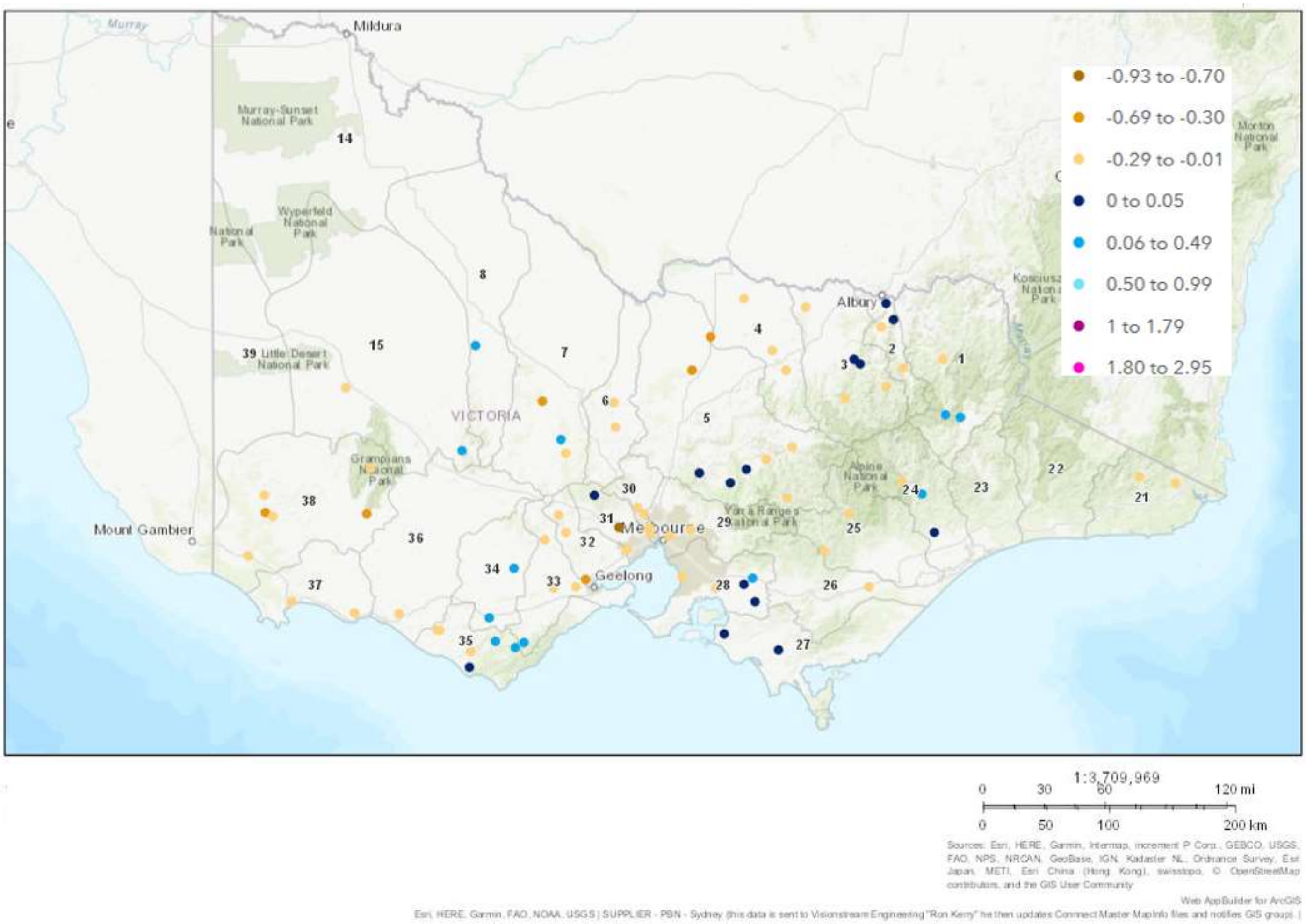


Figure 10: Change in EC data. The ranges represent the "current" period EC data median – "historical" period EC data median

Since 2011, EC mostly decreased in the basins in the far south west of the State (Otway Coast (35), Hopkins River (36), Portland Coast (37) and Glenelg River (38)), and also mostly decreased in the following basins north of the divide, Kiewa (2), Ovens (3), Broken (4), Goulburn (5) and Campaspe (6).

This is most likely reflective of the change in rainfall conditions after the Millennium drought broke in 2010, as during the historic period, electrical conductivity increased from prolonged periods of low flow conditions and potential saline groundwater intrusion.

Table 3 shows the top four sites with the largest increase or decrease in median and mean EC across the State. The lack of a strong magnitude of difference across the sites indicates that there are other site-specific factors that influence EC trends.

Table 3: Top four sites showing largest increase or decrease in median and mean EC across the State

Site number	Site name	Magnitude of difference	Median Historical	Median current	Long term median	Standard deviation Historical	Standard deviation Current	Strength of trend in timeseries plot
231231	Toolern Creek @ Melton South	-0.93	2,750.00	194.50	1,915.00	2,224.75	527.96	Very large decline when compared to long term median
405204	Goulburn River @ Shepparton	-0.45	160.00	88.00	140.00	48.60	28.35	Moderate decline when compared to long term median
405200	Goulburn River @ Murchison	-0.4	120.00	71.50	110.00	50.13	31.52	Moderate decline when compared to long term median
407203	Loddon River @ Laanecoorie	-0.37	1,200.00	751.00	980.00	561.11	215.15	Large decline when compared to long term median
Site number	**Site name**	**Magnitude of difference**	**Mean Historical**	**Mean current**	**Long term mean**	**Standard deviation Historical**	**Standard deviation Current**	**Strength of trend in timeseries plot**
408200	Avoca River @ Coonooer	0.97	6,778.62	13,326.51	8,153.68	5,214.12	13,840.79	Very large increase when compared to the long term mean
231231	Toolern Creek @ Melton South	-0.88	3,348.27	406.41	2,679.67	2,224.75	527.96	Very large decrease when compared to the long term mean
228274	Paterson River @ National Water Sports Centre	-0.67	1,354.11	444.44	1,219.82	3,876.67	123.06	Very large decrease when compared to the long term mean
405204	Goulburn River @ Shepparton	-0.44	165.64	93.29	148.89	48.60	28.35	Moderate decrease when compared to the long term mean

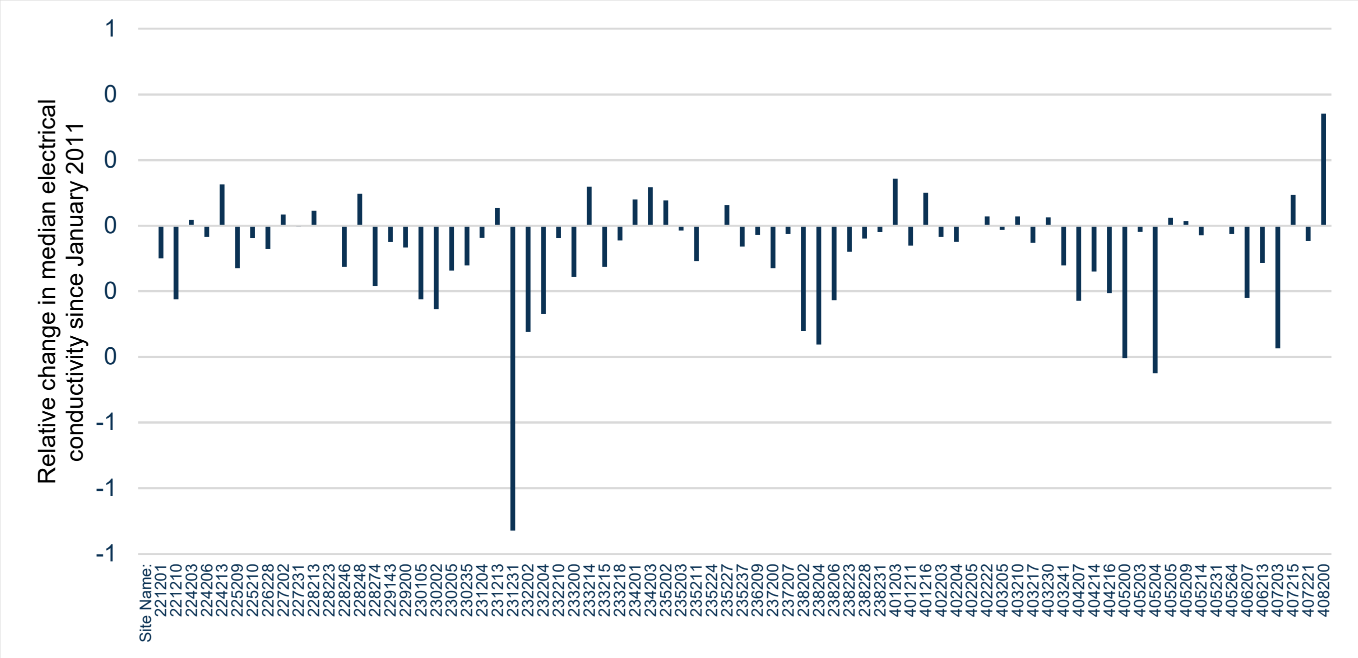


Figure 11: Relative change in median electrical conductivity levels at 79 water monitoring sites since January 2011. Bars show difference in median EC between the period January 2011 – December 2016 and the period January 1991 – December 2010 at each site divided by the historical median for that site.

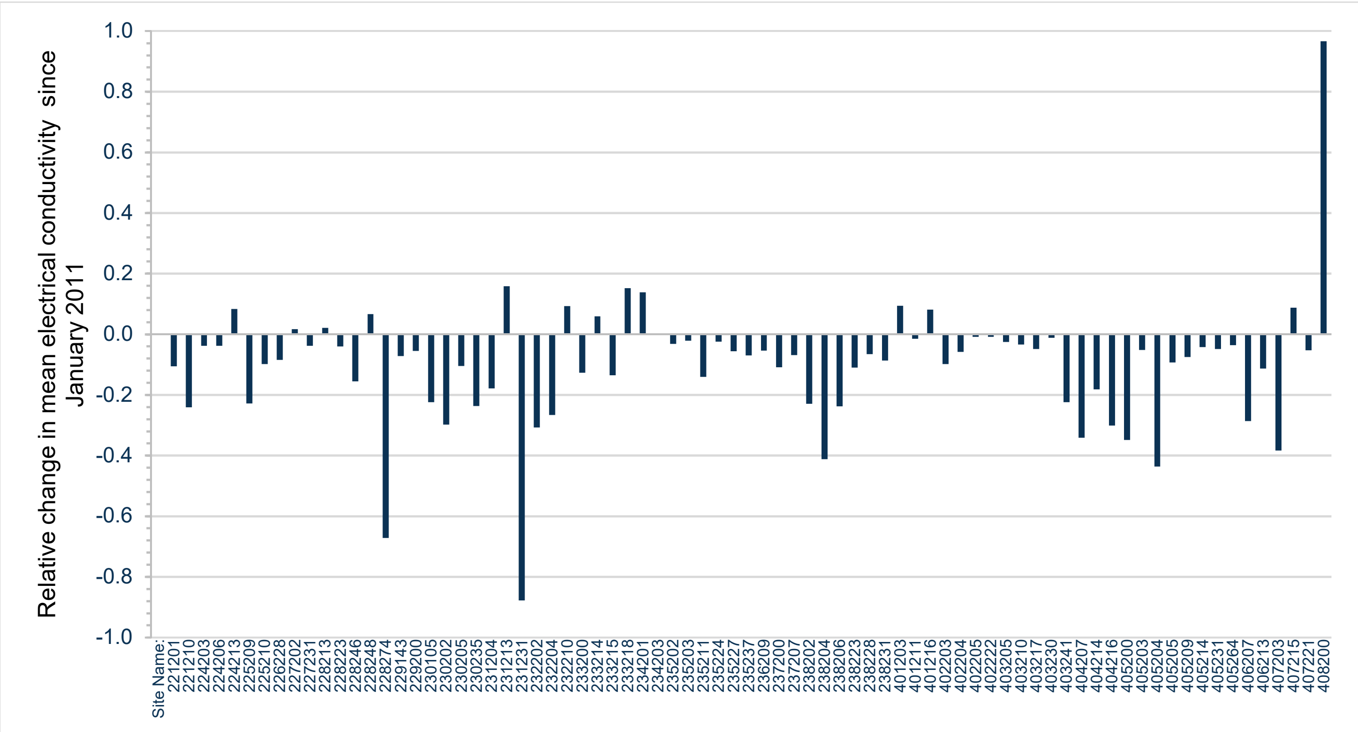


Figure 12: Relative change in mean electrical conductivity levels at 79 water monitoring sites since January 2011. Bars show difference in mean EC between the period January 2011 – December 2016 and the period January 1991 – December 2010 at each site divided by the historical mean for that site.

3.1.5.3 pH

Mean and median pH levels were generally slightly higher after January 2011 when compared to the historic period January 1991 – December 2010 (refer to Figure 13).

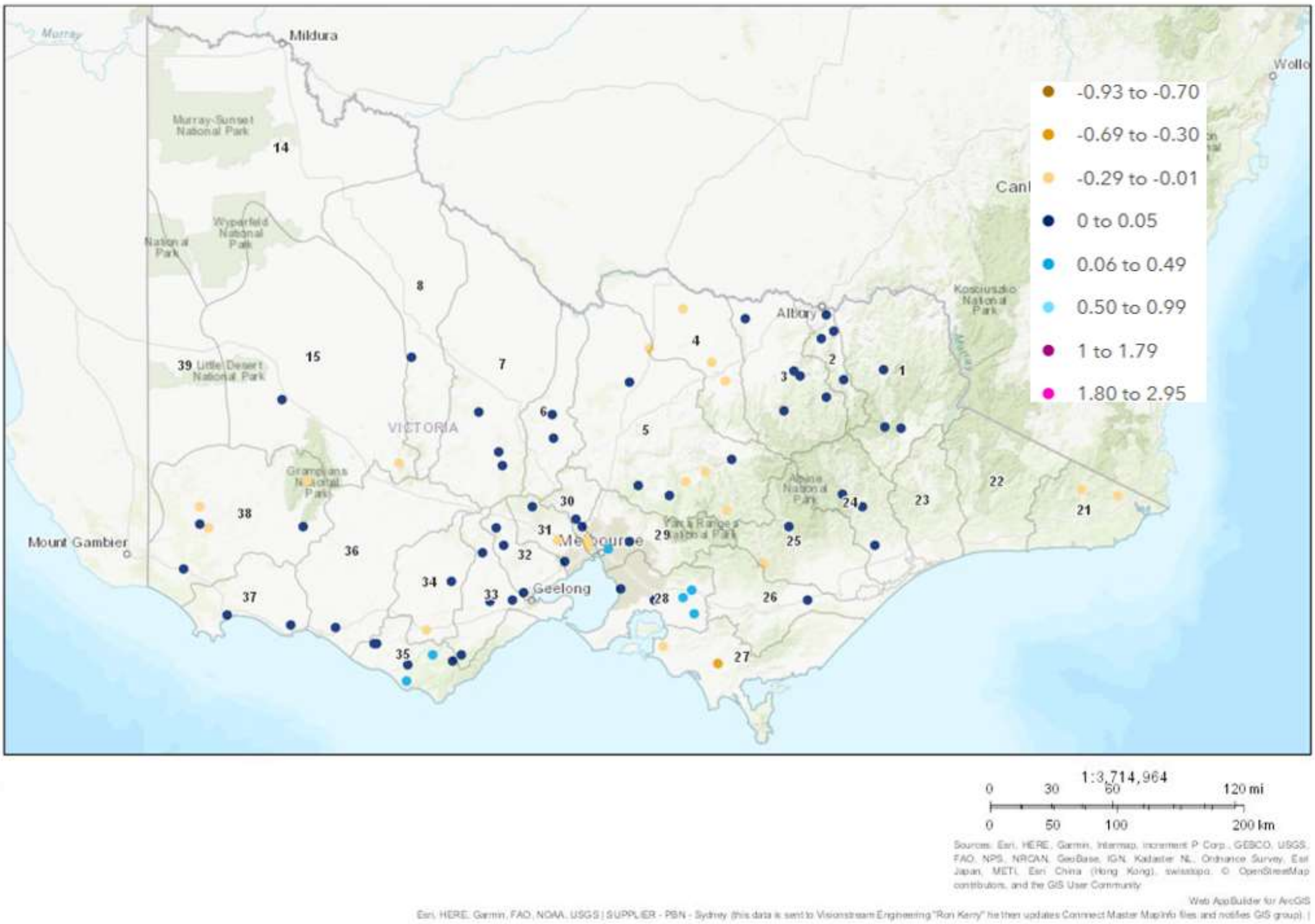


Figure 13: Change in pH data. The ranges represent the “current” period pH data median – “historical” period pH data median

Most sites in the east of the state (Upper Murray River (1), Kiewa River (2), Ovens River (3), Mitchell River (24), Thomson River (25) and Latrobe River (26)) all showed very minor increases in pH. Sites in basin 4 (Broken River) and some sites in basin 5 (Goulburn River) showed very minor decreases in pH.

Table 4 shows the top four sites with the largest increase or decrease in both median and mean pH values across the State.

Table 4: Top four sites showing largest increase or decrease in median and mean pH across the State

Site number	Site name	Magnitude of difference	Median Historical	Median current	Long term median	Standard deviation Historical	Standard deviation Current	Strength of trend in timeseries plot

227202	Tarwin River @ Meeniyan	-0.30	7.20	6.90	7.10	0.41	0.48	Very minimal decline when compared to the long term median
227231	Bass River @ Glen Forbes South	-0.20	7.20	7.0	7.20	0.39	0.37	Very minimal decline when compared to the long term median
228213	Bunyip Main Drain @ Little Road	0.20	7.00	7.20	7.10	0.48	0.25	Very minimal increase when compared to the long term median
228223	Lang Lang River u/s Drouin-Poowong Road, Athlone	0.10	7.30	7.40	7.30	0.43	0.24	Very minimal increase when compared to the long term median

Site number	Site name	Magnitude of difference	Mean Historical	Mean current	Long term mean	Standard deviation Historical	Standard deviation Current	Strength of trend in timeseries plot
238231	Glenelg River @ Big Cord	-0.08	5.89	5.43	5.78	0.84	0.27	Very minimal decline when compared to the long term mean
235227	Gellibrand River @ Bunkers Hill	0.08	6.81	7.32	6.93	0.36	0.58	Very minimal increase when compared to the long term mean
235202	Gellibrand River @ Upper Gellibrand	0.06	6.82	7.22	6.91	0.47	0.34	Very minimal increase when compared to the long term mean
406207	Campaspe River @ Eppalock	0.06	7.24	7.66	7.34	0.63	0.48	Very minimal increase when compared to the long term mean

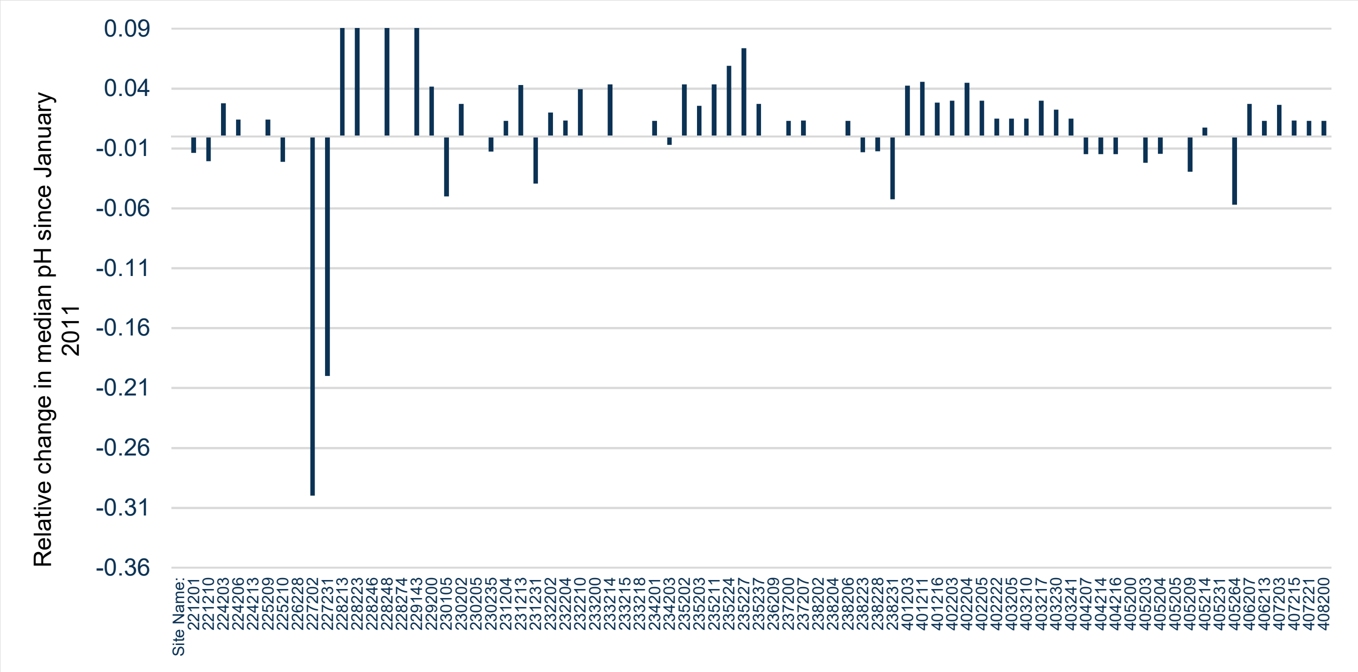


Figure 14: Relative change in median pH levels at 79 water monitoring sites since January 2011. Bars show difference in median pH between the period January 2011 – December 2016 and the period January 1991 – December 2010 at each site divided by the historical median for that site.

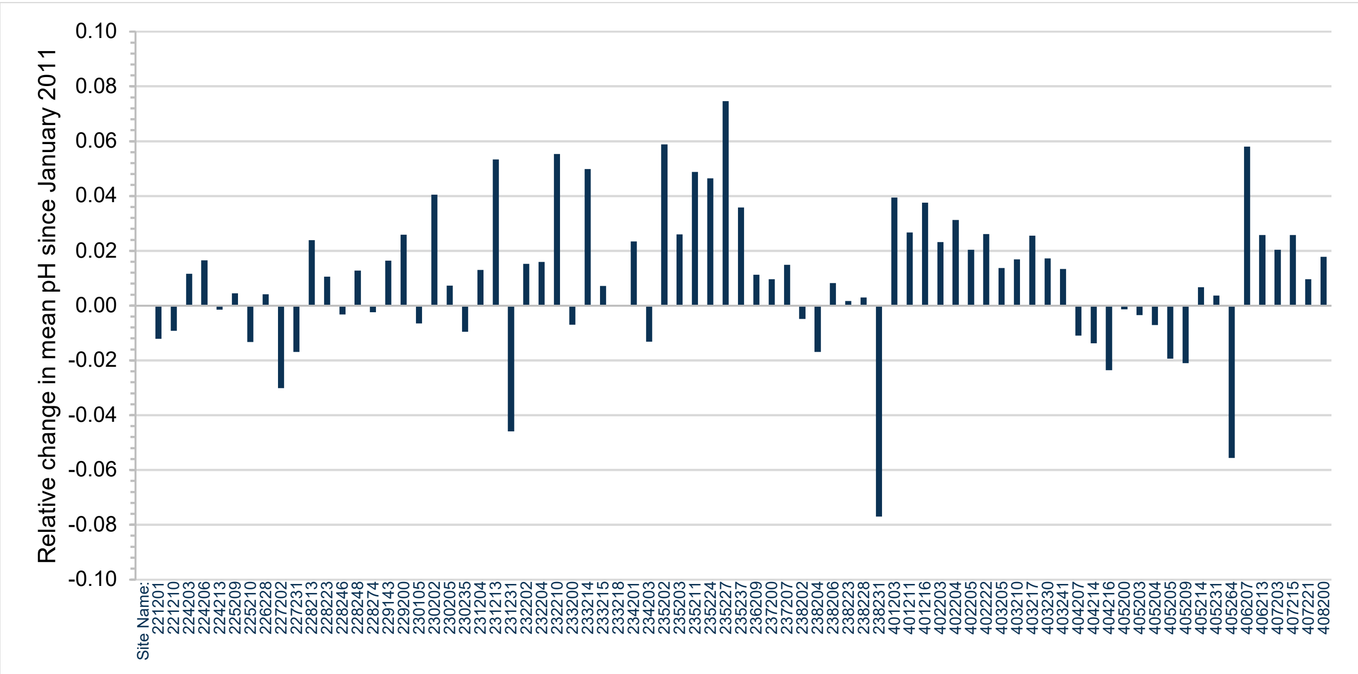


Figure 15: Relative change in mean pH levels at 79 water monitoring sites since January 2011. Bars show difference in mean pH between the period January 2011 – December 2016 and the period January 1991 – December 2010 at each site divided by the historical mean for that site.

3.1.5.4 Turbidity

Median and mean turbidity levels were generally higher at most of the 79 sites after January 2011 when compared to January 1991 – December 2010 data (refer to Figure 16).

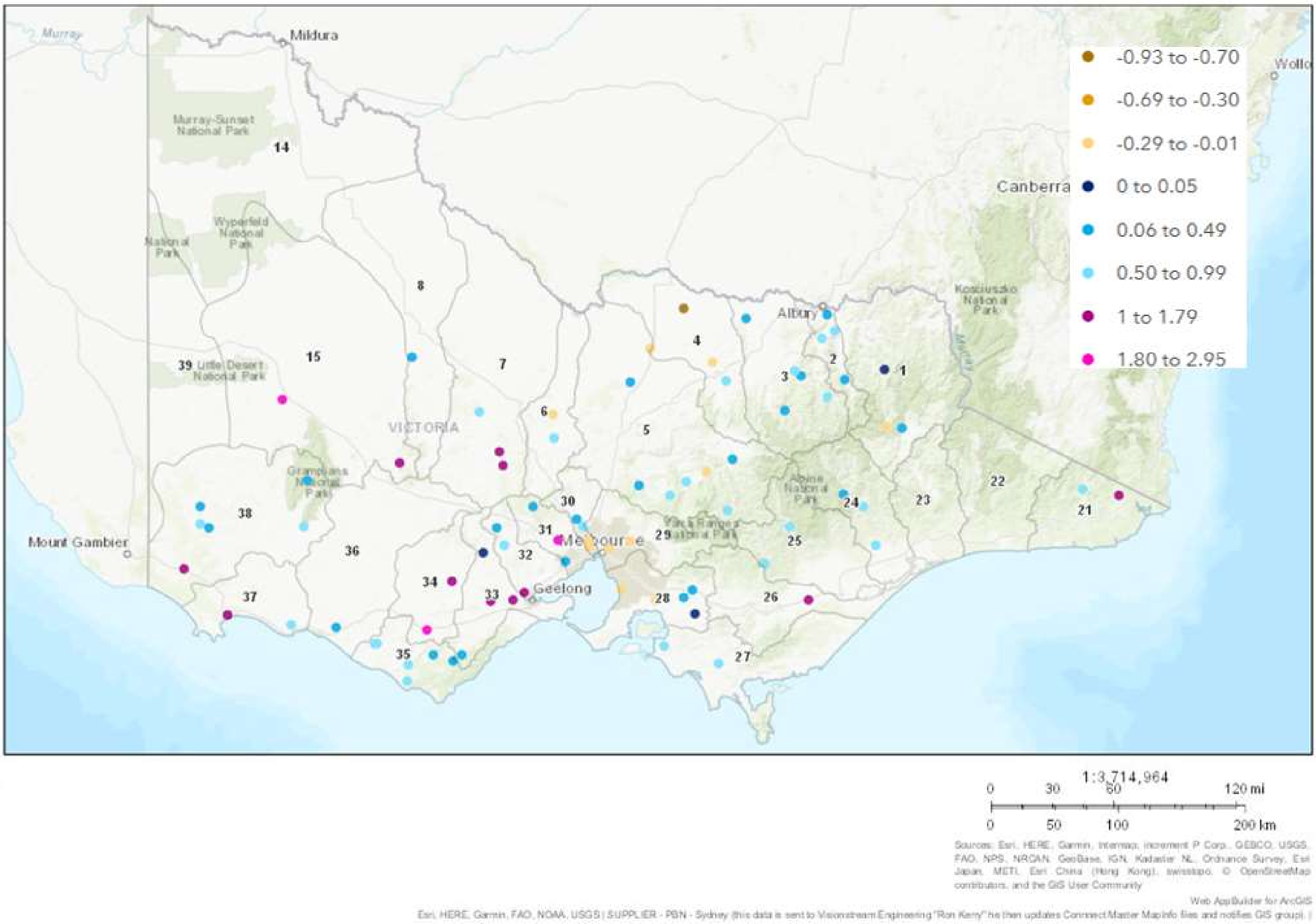


Figure 16: Change in turbidity data. The ranges represent the “current” period turbidity data median – “historical” period turbidity data median

Most of the turbidity peaks that influence the increasing trend across sites, are most likely in response to high flow events which increase catchment runoff. This is particularly evident in 2011 when flooding across the State heralded the breaking of the Millennium drought and subsequent period of regular rainfall.

One site in particular, Wannon River @ Dunkeld, 238204, has a very large mean magnitude of difference, which is due to a series of pool readings in the current period (April, May and June 2012 and July, August, September 2013) when the site ceased flowing.

The sites located in close proximity to Melbourne in basins 29 (Yarra River) and 30 (Maribyrnong River) showed a small decrease in turbidity. Some sites in basins to the west of the State showed a strong increase (Wimmera-Avon River (15) and Lake Corangamite (34)).

Table 5 shows the top four sites with the biggest increase or decrease in mean and median turbidity across the State.

Table 5: Top four sites showing largest increase or decrease in median and mean turbidity across the State

Site number	Site name	Magnitude of difference	Median Historical	Median current	Long term median	Standard deviation Historical	Standard deviation Current	Strength of trend in timeseries plot
415200	Wimmera River at Horsham	2.95	13.00	51.40	17.90	33.93	27.45	Moderate increase when compared to long term median
231231	Toolern Creek @ Melton South	2.86	4.95	19.1	7.15	25.74	41.97	Moderate increase when compared to long term median
234203	Pirron Yallock Creek @ Pirron Yallock	2.50	9.85	34.45	14.00	15.01	34.90	Moderate increase when compared to long term median
221210	Genoa River @ The Gorge	1.70	2.00	5.40	2.30	5.75	13.86	Minimal increase when compared to long term median
Site number	**Site name**	**Magnitude of difference**	**Mean Historical**	**Mean current**	**Long term mean**	**Standard deviation Historical**	**Standard deviation Current**	**Strength of trend in timeseries plot**
238204	Wannon River @ Dunkeld	12.00	25.54	332.04	83.98	47.21	763.56	Very large increase when compared to long term mean
403205	Ovens Rivers @ Bright	3.11	5.68	23.33	9.77	20.07	91.27	Moderate increase when compared to long term mean
224213	Dargo River @ Lower Dargo Road	3.00	4.38	6.14	4.81	11.79	12.98	Minimal increase when compared to long term mean
221210	Genoa River @ The Gorge	1.96	3.79	11.19	5.64	5.75	13.86	Minimal increase when compared to long term mean

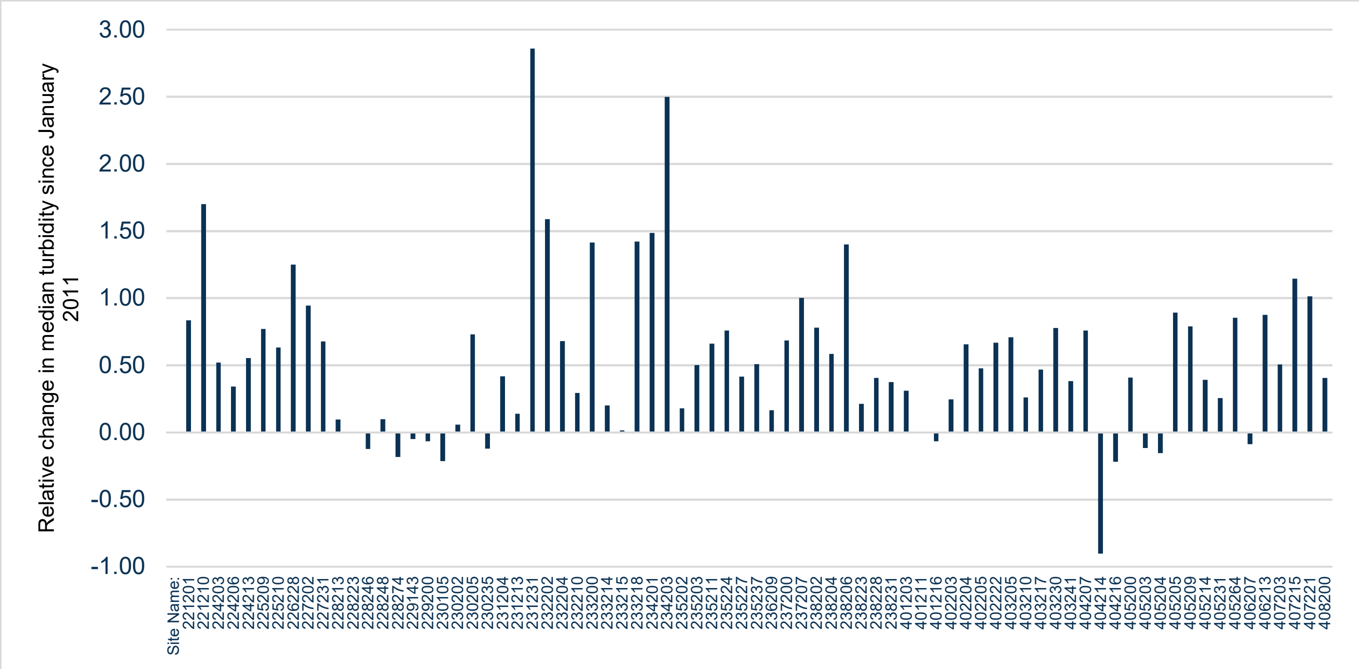


Figure 17: Relative change in median turbidity levels at 79 water monitoring sites since January 2011. Bars show difference in median turbidity between the period January 2011 – December 2016 and the period January 1991 – December 2010 at each site divided by the historical median for that site.

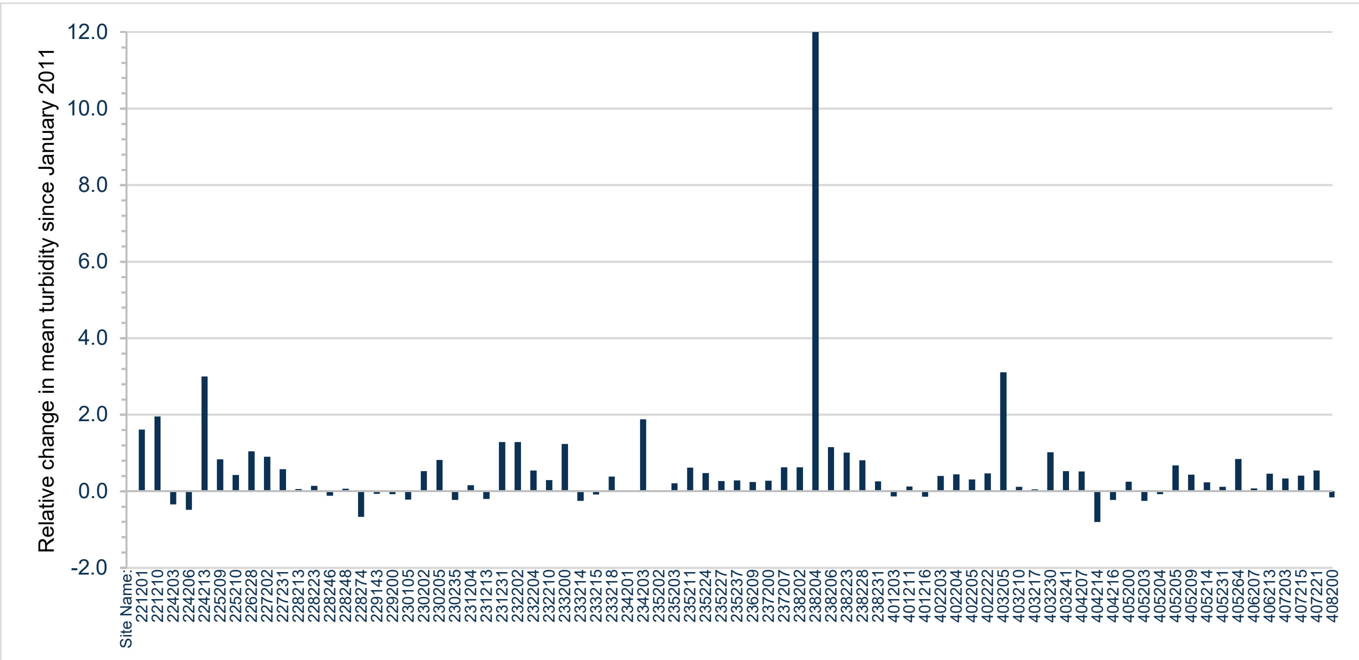


Figure 18: Relative change in mean turbidity levels at 79 water monitoring sites since January 2011. Bars show difference in mean turbidity between the period January 2011 – December 2016 and the period January 1991 – December 2010 at each site divided by the historical mean for that site.

3.1.5.5 Total Nitrogen

Mean and median Total Nitrogen (TN) levels were generally slightly higher at most of the 79 sites after January 2011 when compared to January 1991 – December 2010 data. This increase in nutrients at most sites is most likely due to higher catchment runoff post Millennium drought (refer to Figure 19).

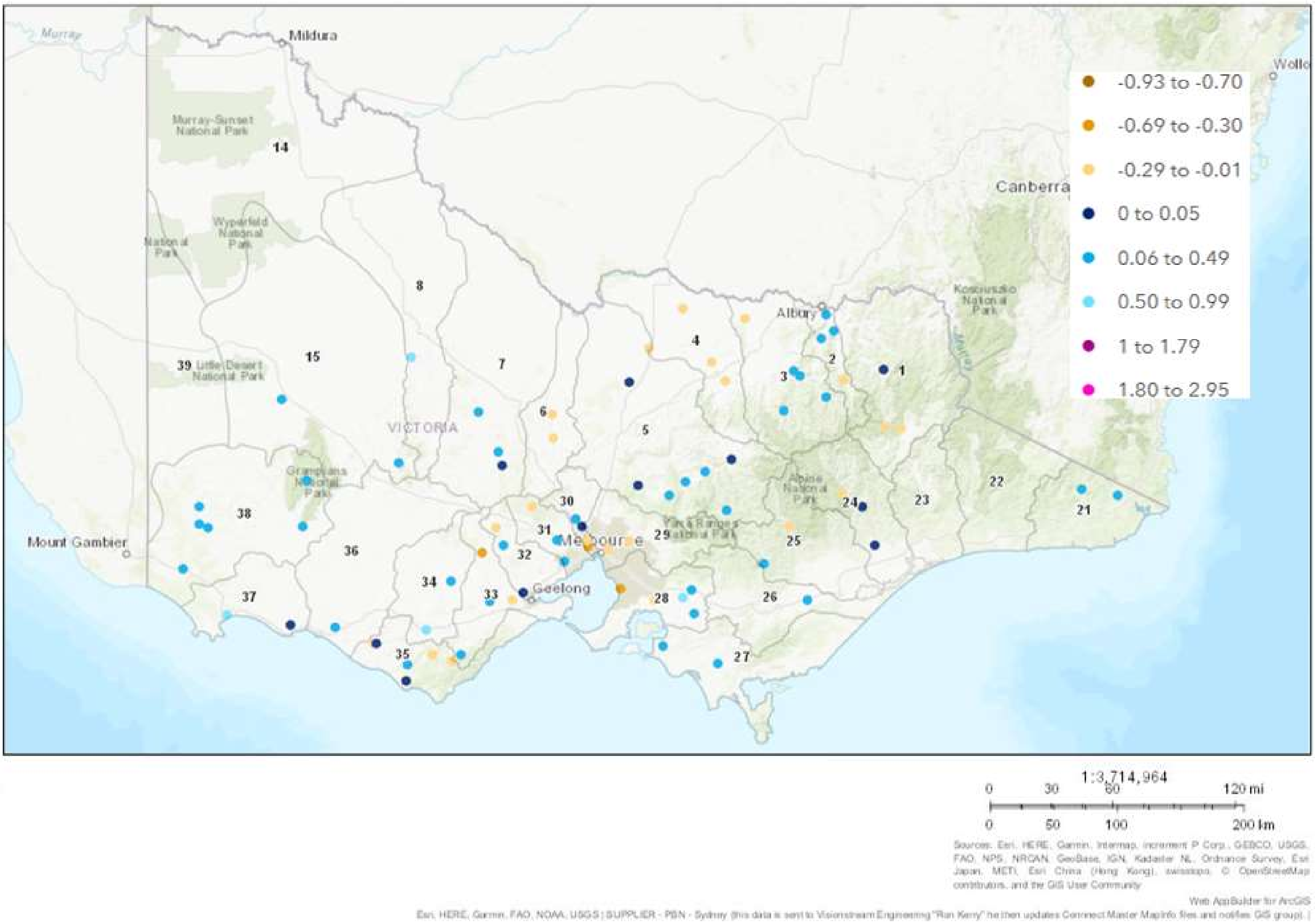


Figure 19: Change in TN data. The ranges represent the "current" period TN data median – "historical" period TN data median

Sites in basins close to Melbourne (Bunyip River (28), Yarra River (29) and Maribyrnong River (30)) showed a small increase in TN. Likewise basin 4, Broken River, and basin 6, Campaspe River, had small increases.

Table 6 shows the top four sites with the biggest increase or decrease in median and mean TN across the State. All top 4 sites for both median and mean values had a reduction in TN, with the exception of Macalister River @ Licola, which experienced a very minor decrease in TN levels. This could be due to the historic period being dominated by large floods in 2007.

Table 6: Top four sites showing largest increase or decrease in median and mean TN across the State

Site number	Site name	Magnitude of difference	Median Historical	Median current	Long term median	Standard deviation Historical	Standard deviation Current	Strength of trend in timeseries plot
228213	Bunyip Main Drain @ Little Road	0.98	0.68	1.08	0.60	0.49	0.62	Very minor increase when compared to long term median
237207	Surry River @ Heathmere	0.73	0.21	0.36	0.23	0.30	0.45	Very minor increase when compared to long term median
408200	Avoca River @ Coonooer	0.63	1.10	1.80	1.15	2.07	3.18	Very minor increase when compared to long term median
234203	Pirron Yallock Creek @ Pirron Yallock	0.57	1.83	2.83	1.91	1.07	1.48	Very minor increase when compared to long term median
Site number	**Site name**	**Magnitude of difference**	**Mean Historical**	**Mean current**	**Long term mean**	**Standard deviation Historical**	**Standard deviation Current**	**Strength of trend in timeseries plot**
228213	Bunyip Main Drain @ Little Road	0.83	0.83	1.14	0.71	0.49	0.62	Very minor increase when compared to long term mean
225209	Macalister River @ Licola	-0.756	0.22	0.16	0.21	0.22	0.10	Very minor decrease when compared to long term mean
408200	Avoca River @ Coonooer	0.681	1.42	2.38	1.61	2.07	3.18	Very minor increase when compared to long term mean
234203	Pirron Yallock Creek @ Pirron Yallock	0.546	1.97	3.04	2.17	1.07	1.48	Very minor increase when compared to long term mean

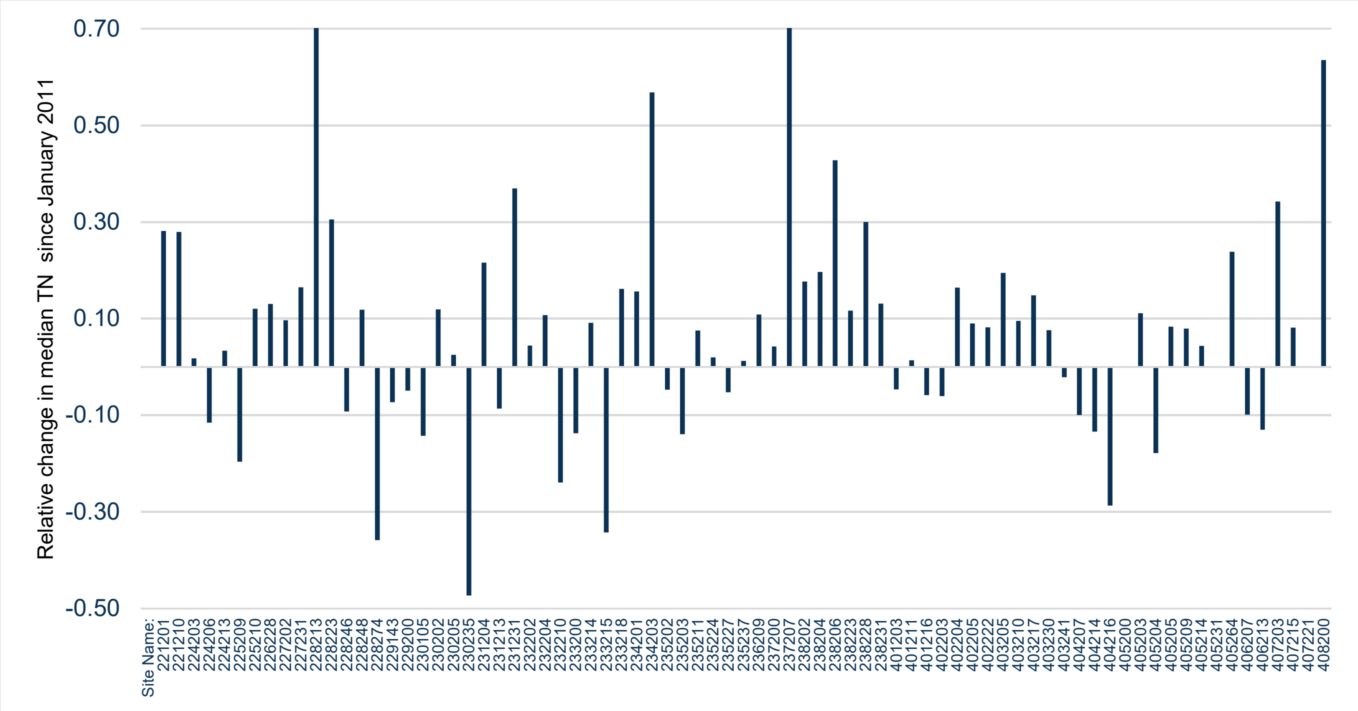


Figure 20: Relative change in median TN levels at 79 water monitoring sites since January 2011. Bars show difference in median TN between the period January 2011 – December 2016 and the period January 1991 – December 2010 at each site divided by the historical median for that site.

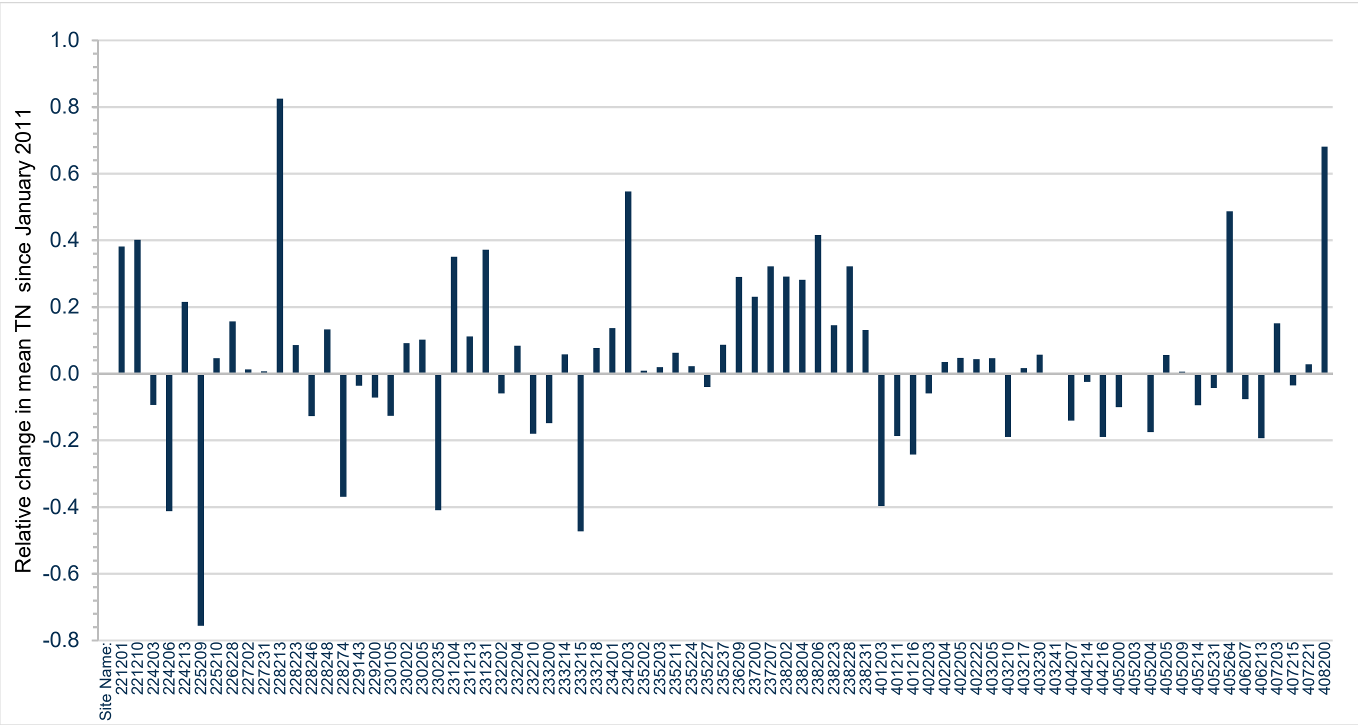


Figure 21: Relative change in mean TN levels at 79 water monitoring sites since January 2011. Bars show difference in mean TN between the period January 2011 – December 2016 and the period January 1991 – December 2010 at each site divided by the historical mean for that site.

3.1.5.6 Total Phosphorus

Median Total Phosphorus (TP) levels were higher at most of the 79 sites after January 2011 when compared to January 1991 – December 2010 data (refer to Figure 22).

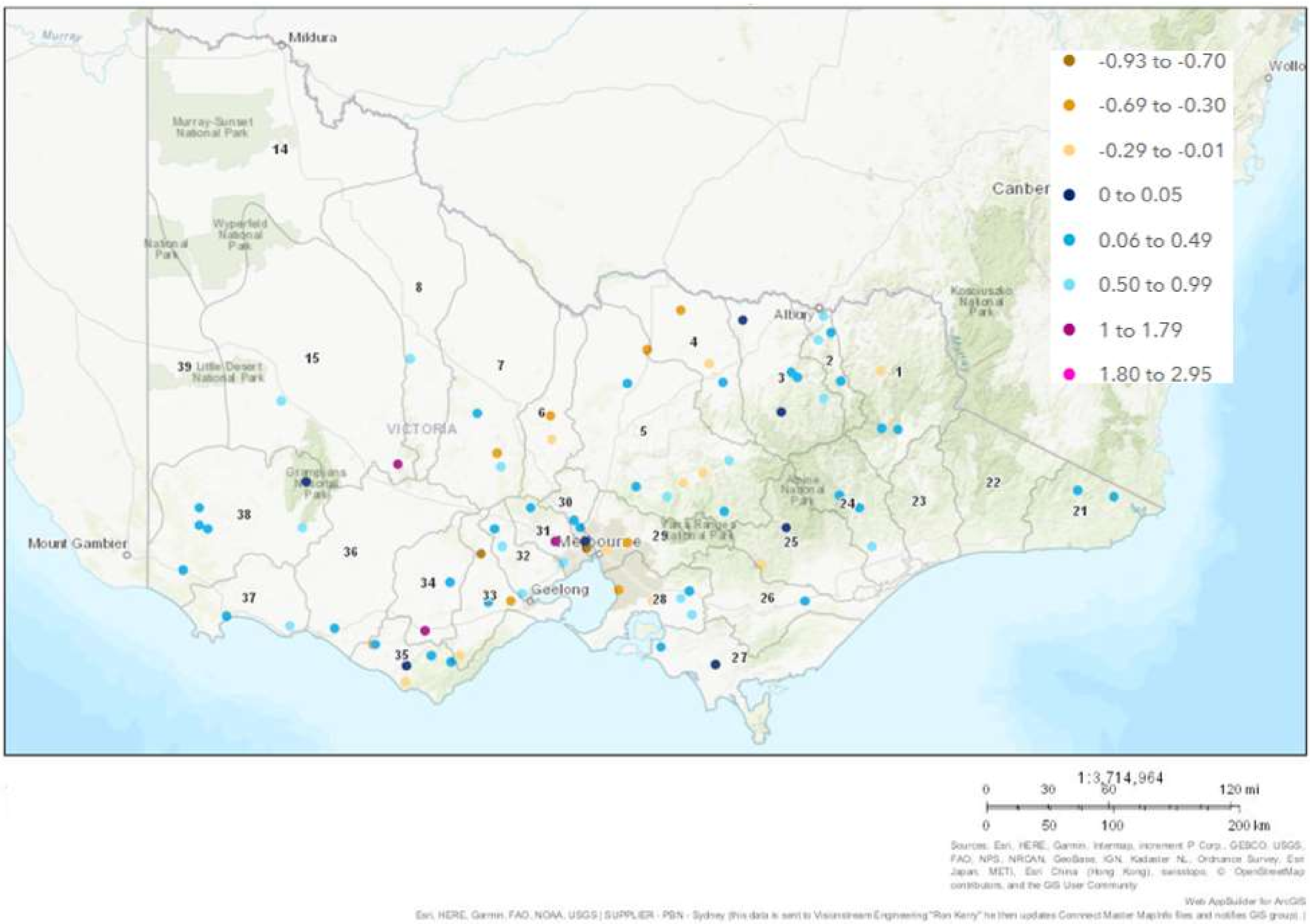


Figure 22: Change in TP data. The ranges represent the "current" period TP data median – "historical" period TP data median

The majority of sites in the east of the state showed increases in TP which may be due to increased runoff post Millennium drought.

Table 7 shows the top four sites with the biggest increase or decrease in median and mean TP across the State.

Table 7: Top four sites showing largest increase or decrease in median and mean TP across the State

Site number	Site name	Magnitude of difference	Median Historical	Median current	Long term median	Standard deviation Historical	Standard deviation Current	Strength of trend in timeseries plot
234203	Pirron Yallock Creek @ Pirron Yallock	1.57	0.07	0.18	0.09	0.11	0.19	Very minor increase when compared to long term median
231231	Toolern Creek @ Melton South	1	0.05	0.1	0.06	0.05	0.65	Very minor increase when compared to long term median
415207	Wimmera River @ Eversley	1	0.02	0.04	0.03	0.08	0.11	Very minor increase when compared to long term median
232204	Moorabool River @ Morrisons	0.95	0.01	0.02	0.010	0.02	0.02	Very minor increase when compared to long term median
Site number	**Site name**	**Magnitude of difference**	**Mean Historical**	**Mean current**	**Long term mean**	**Standard deviation Historical**	**Standard deviation Current**	**Strength of trend in timeseries plot**
231231	Toolern Creek @ Melton South	2.1	0.06	0.19	0.07	0.05	0.65	Very minor increase when compared to long term mean
224213	Dargo River @ Lower Dargo Road	1.52	0.02	0.04	0.02	0.01	0.17	Very minor increase when compared to long term mean
238204	Wannon River @ Dunkeld	1.46	0.10	0.25	0.13	0.09	0.33	Very minor increase when compared to long term mean
221210	Genoa River @ The Gorge	1.18	0.01	0.02	0.01	0.01	0.01	Very minor increase when compared to long term mean

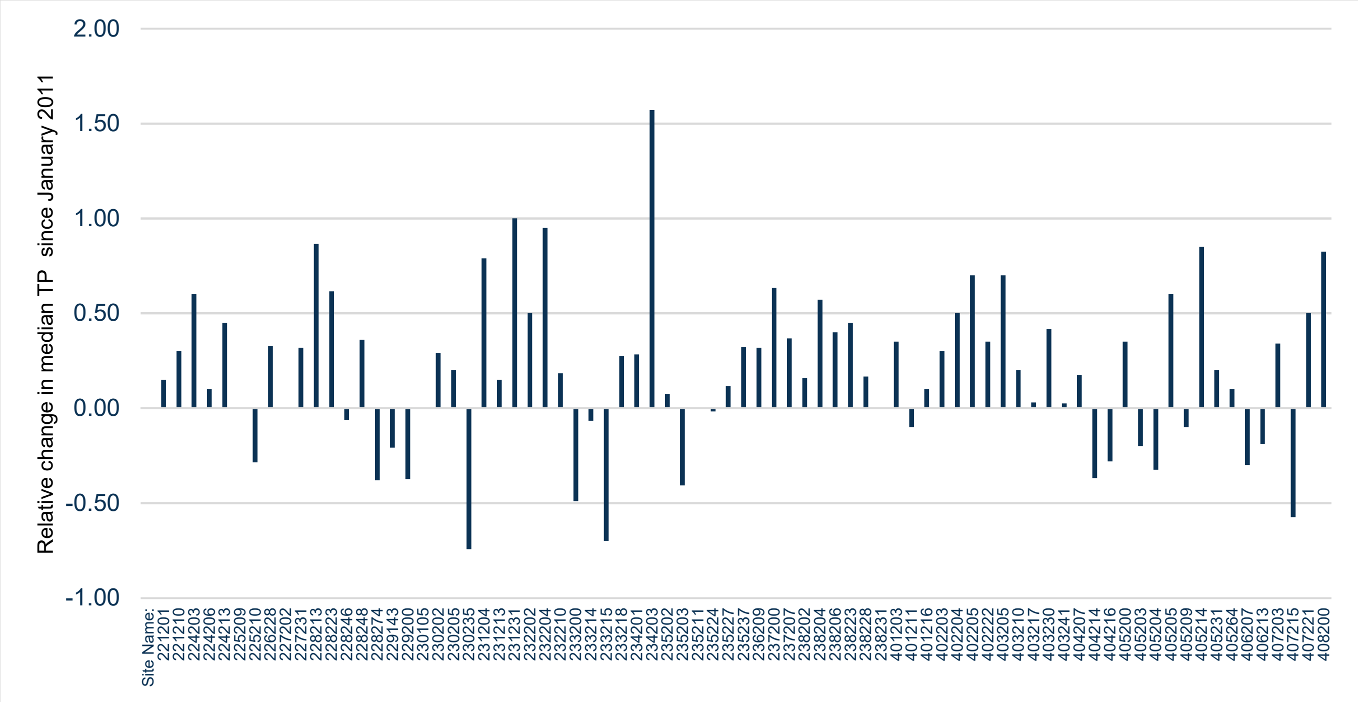


Figure 23: Relative change in median TP levels at 79 water monitoring sites since January 2011. Bars show difference in median TP between the period January 2011 – December 2016 and the period January 1991 – December 2010 at each site divided by the historical median for that site.

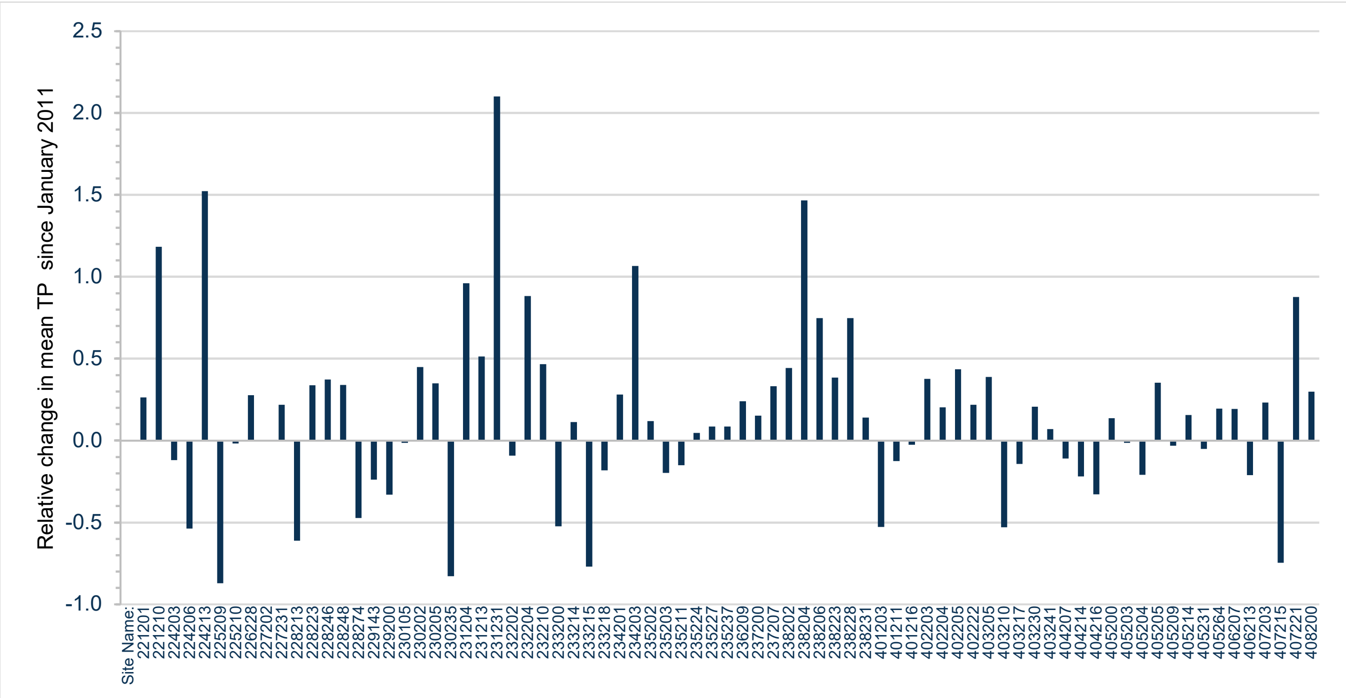


Figure 24: Relative change in mean TP levels at 79 water monitoring sites since January 2011. Bars show difference in mean TP between the period January 2011 – December 2016 and the period January 1991 – December 2010 at each site divided by the historical mean for that site.

3.2 Stage 2: In depth analysis of candidate sites

3.2.3 Site selection

3.2.3.1 Review of 2013 sites

The 2013 statewide water quality in-depth trend analysis (Jacobs 2013) developed control and run charts for six sites nominated by several catchment management authorities:

- Barwon River at Pollocksford (streamflow gauging station no. 233200)
- Gellibrand River at Bunkers Hill (streamflow gauging station no. 235227)
- Goulburn River at Shepparton (streamflow gauging station no. 405204)
- Broken River at Goorambat (streamflow gauging station no. 404216)
- Wimmera River at Eversley (streamflow gauging station no. 415207)
- Wimmera River at Horsham (streamflow gauging station no. 415200)

The Jacobs (2013) analysis showed that control charts are potentially an effective tool for assessing water quality trends over time and for assessing new data as they are collected. However, their effectiveness is closely linked to the fit of the predictive model that they are based on. Models that explain a large proportion of the historical variation will more accurately predict future observations and will therefore provide a more sensitive test of unexpected changes to water quality.

Variation in some of the water quality variables tested at certain sites (e.g. pH at most sites and electrical conductivity in the Wimmera River at Horsham) could not be reliably explained by the predictive variables that were available for analysis. The control charts for those variables were not very informative and unless more reliable predictor variables can be identified and measured, then there is little point investing time and effort in performing detailed assessments for those variables at certain sites. Given the time and effort required to develop models, it was recommended that detailed assessment with control charts should only be developed for selected variables at sites where a particular need has been identified or suspected. Pertaining to the poor pH results from the 2013 study, it was decided not to include pH in the analysis.

For the current study, a decision needed to be made on whether control and run chart analyses were repeated at the previously analysed sites or whether new sites should be included. Factors influencing the site-selection included the success of the 2013 analysis and the representativeness of the sites for various river types in Victoria and the specific issues that warrant testing (e.g. changes in management practices that might influence water quality, or for establishing a baseline for predication against future threats, such as urbanisation).

Table 7 provides a summary of sites previously analysed and justification for whether they should be re-analysed (retained) or not (replaced).

Table 8: Recommendations for sites analysed in the 2013 study

Site	Comment
Wimmera River at Eversley	**Retain** – Useful site for assessing impacts of drought. Data collected during the drought may be used to predict what will happen during future droughts (SKM 2011).
Broken River at Goorambat	**Retain** – Models provided good predictions, especially for turbidity. Continue to evaluate changes following decommissioning of Lake Mokoan. This site is a good candidate for testing updates to control charts (SKM 2011).
Barwon River at Pollocksford	**Retain –** Continue to assess water quality response to land management improvement in catchment.
Gellibrand River at Bunkers Hill	**Replace** – Models showed little change in historical data and exceedences not considered to be ecologically detrimental
Goulburn River at Shepparton	**Replace -** Models showed little change in historical data, most variables complied with SEPP objectives
Wimmera River at Horsham	**Replace** – model predictability generally low.

3.2.3.2 Additional candidate sites

Table 9 provides additional sites that were recommended to DELWP for inclusion in the analysis to increase the geographic spread of sites and the coverage of a range of waterway issues in Victoria. A brief comment on the justification for inclusion is included.

Table 9: Additional sites recommended for consideration for control and run chart analysis

Site	Comment
Oven River at Peechelba (403241)	Lowland site on Murray Plain – provides geographic spread
Jacksons Creek at Sunbury (230202)	Site in Melbourne region, experiencing landuse change – establish baseline for assessing impacts of urbanisation on water quality
La Trobe River at Rosedale (226228)	Lowland site on Gippsland Plain – provides geographic spread, establish baseline for assessing changes associated with coal mine rehabilitation
Moorabool River at Batesford (232202)	Flow stressed site with water quality issues related to flow stress.
Yarra River at Chandler Highway (229143)	Melbourne Water site that is located in the Melbourne region for assessing impacts of a range of catchment management decisions relating to water supply and urbanisation.
Maribyrnong River at Canning Street Ford (230235)	Melbourne Water site that is located in the Melbourne region assessing impacts of flow stress and urbanisation.

3.2.3.3 Final site list

In consultation with DELWP and Ventia Pty Ltd, the following list of six candidate sites were included in the 2017 statewide water quality analysis for in-depth trend analysis using control charts and run charts:

- Wimmera River at Eversley (415207)
- Broken River at Goorambat (404216)
- Barwon River at Pollocksford (233200)
- Oven River at Peechelba (403241A)
- La Trobe River at Rosedale (226228)
- Yarra River at Chandler Highway Kew (229143)

3.2.4 Methodology

The overall approach to the data analysis was as follows:

1) Summarise the availability and standard of water quality data. This included a visual inspection of the data to exclude any clearly anomalous data points;
2) Prepare other datasets, such as streamflow, water temperature, local rainfall and time since last rain event greater than 20 mm to support the analysis[1];
3) Fit a regression model over the reference period January 1991 to December 2010 to describe variation in each water quality variable;
4) Apply the regression model to estimate water quality beyond the reference period, i.e. to estimate water quality from January 2011 to December 2016;
5) Prepare a control chart using the regression model outputs to compare recorded data against predictions and to highlight instances where deviations exceeded defined control limits;
6) Prepare a run chart showing the number of consecutive records above or below the predicted value in the current data;
7) Provide some interpretation of the results where possible.

The method used at each of these steps is described in more detail below.

3.2.4.1 Method for assessing the availability and quality of data

In order to be included in the study, the data record for each parameter needed to contain at least 75% of all possible monthly measurements between January 1991 and December 2010 and have no more than 24 months of continuously missing data. The actual number of data points analysed for each parameter at each site is presented in the results chapter for each site. The quality of recorded water quality data was assumed to be good unless indicated otherwise through visual inspection of the data.

The water quality data were visually inspected to identify any clearly anomalous data points. Anomalous results were only considered to be outliers if they were isolated within the data record, differed by an order of magnitude from the rest of the dataset, and did not occur on days where other water quality variables also indicated similarly anomalous values. Any values identified as outliers by the above definition were excluded from the regression analyses to determine the best predictive models for each variable.

[1] Numerous other datasets including landuse change and fire history were considered as potential predictors of water quality during the method development phase of the project, but they were rejected because the data were generally not available in the relevant and/or appropriate time steps and hence were not useful for developing empirical predictive models.

3.2.4.2 Method for preparing other supporting datasets

Date, water temperature, streamflow, season and rainfall were most commonly used to predict water quality at each site. Some water quality variables were used as predictors for other water quality variables where a potential causal link could be identified. For example, turbidity was included in some nutrient models, because phosphorus and nitrogen can enter rivers when nutrient laden soil is washed into drains and rivers during rain events. Electrical conductivity was also trialled in turbidity models, because high salinity levels can cause fine suspended particles to precipitate out of solution. The treatment of different predictor variables is described below.

The date on which each sample was taken was converted to a continuous variable so that it could be readily used in multiple regression models. For the purposes of this project we used ExcelDate + 15000 to represent the sample date. 'ExcelDate' represents the standard daily integer applied by Microsoft Excel starting from the 31st of December 1899, with 01/01/1900 being 1. The addition of 15000 is arbitrary and is an artefact in the spreadsheet that was used for the calculation. The actual starting number is irrelevant for the current project as long as all numbers are positive. As an example, the date 01/01/2004 is represented by the Date Number 52987 in the current project.

Water temperature was in most cases measured at the same time as all other water quality data and water temperature on the day of sampling was used in the predictive models.

Streamflow data were based on the mean daily flow recorded on the day corresponding to the water quality reading. In some cases, flow in one or more major upstream tributaries was included as a separate variable to investigate whether inputs from a particular sub-catchment had a greater influence on the water quality variable of interest. Quality codes were provided with the streamflow data, and only data with a quality code of less than or equal to 150 were used in the analysis, which is generally regarded as a suitable threshold for reasonable quality data.

The season variable in the analysis was defined by a monthly sinusoidal function ($\sin(2\pi/n)$ where n is the month number from 1 to 12). This attempts to account for seasonal patterns that fluctuate throughout the year.

Rainfall from the nearest rainfall gauge was used to assess the effect of local catchment run-off, which may be particularly important in urban areas or catchments with intensive agriculture. Two measures of rainfall were used. Cumulative rainfall in the 72 hours preceding each water quality measurement was used to assess likely run-off. Time since the last major rainfall event (i.e. >20 mm) was used to assess any specific effects associated with a first flush event, because the first rain event after a prolonged dry period will often carry more nutrients and organic debris into a stream. The rainfall site used in each analysis is presented in the results section of this report.

3.2.4.3 Method for fitting and applying regression models

Standard multiple regression analyses were conducted to determine the suite of predictor variables and associated model that best explained variation in each water quality parameter at each site for the period 1991 to 2010. All models had the same generic form (see Equation 1), but different combinations of variables and different transformations were tested to find the best fit.

Equation 1: Generic model used as a starting point for each analysis

Water Quality = function of water temperature, season, date, flow in the river, local rainfall, time since last rainfall event and selected water quality variables

In most cases, water quality and flow variables were transformed to the power of 0.4 in order to ensure an unbiased model fit. The decision about whether to transform each independent variable was based on an examination of model residuals over the data range for each independent variable, as well as the dependent variable.

In some cases, flow was split into two variables representing different major tributaries close to the water quality measurement site to better account for the effect of run-off from different sources.

The regression models were developed using Jacobs' in-house data analysis tool (GetDat) and then applied in Excel. Variables with a p-statistic greater than 0.1 after transformation were considered to have little influence on the dependent variable of interest and were removed from the regression model. There were two exceptions to this rule. In both cases parameters with a p-statistic greater than 0.10 but less than 0.15 were retained because they improved the visually inspected distribution of model residuals.

The resulting Coefficient of determination (R^2) for each model was allocated a descriptor based on the value as per Table 10 below.

Table 10: R^2 descriptions

Terminology	R^2 Bounds
Well explained	0.75 – 1
Moderately well explained	0.6 – 0.74
Poorly explained	0.4 - 0.59
Very poorly explained	0 – 0.39

3.2.4.4 Method for preparing control charts and run charts

The control chart spreadsheet used in this study was developed by the Statistical Consulting Centre of the University of Melbourne based on method investigation and development by EPA Victoria. The owners of the spreadsheet tool are EPA Victoria and DELWP.

For the control charts, the historical data period over which the models were fitted was from 1 January 1991 to 31 December 2010 (grey data points for observed data and grey line for the fitted model on Figure 25). Observed data were applied to the control charts from 1 January 2011 to the end of December 2016, which was the six-year period of interest for these analyses (black data points on Figure 25). This was compared with the predicted concentration based on the model for the current period, which is shown as the black line on the chart. The multipliers for the upper and lower fences on the box plots were set at 1.5 times the inter-quartile range. The quartile coefficient of skewness was calculated from the historical data.

If the observed data in the current period followed the predicted concentration based on the model, then we concluded that the current period did not differ from historical trends. However, if the data for the current period was higher, lower or significantly more variable than the predicted concentrations, then we concluded that the trends in water quality were different from historical trends. Data was also compared to the SEPP (WoV) trigger values for all parameters.

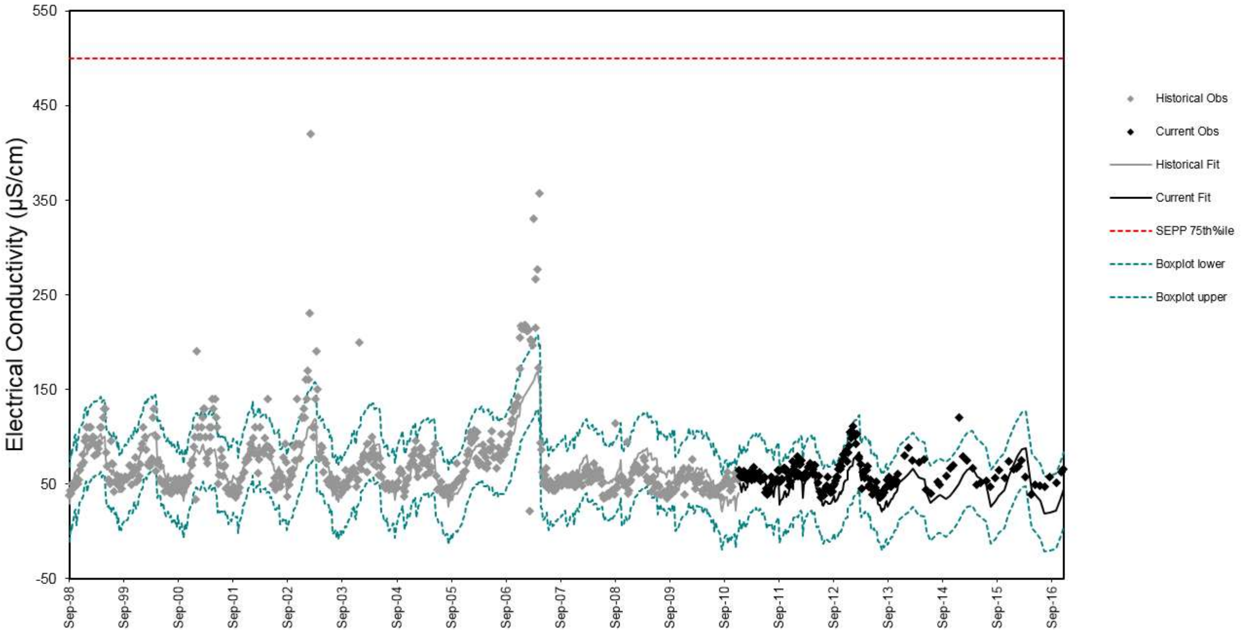


Figure 25: Example control chart for electrical conductivity (in µS/cm) in the Ovens River at Peechelba showing historical data (grey points), fitted model (grey line) current data (black points) and predicted concentrations based on the model (black line)

Run charts were prepared to display the number of consecutive data points above or below the modelled estimate (Figure 26). Under normal conditions, the number of consecutive data points above or below the modelled estimate would be relatively short. Long runs above or below the modelled estimate indicate a consistent deviation from anticipated conditions and may be interpreted as a trend for improving or worsening conditions, providing the model is a good fit. For example, electrical conductivity levels in the Ovens River had long runs of high EC in the current data compared to the model (Figure 26). Run chart limits were set at three standard deviations from the mean run length recorded during the historical data period (i.e. three standard deviations from the mean run length recorded for data collected between 1991 and 2010). Any runs in the new data period (i.e. 2011 to 2016) that exceeded the run chart limits were considered unusual and potentially indicate a more sustained change in the data at that particular site.

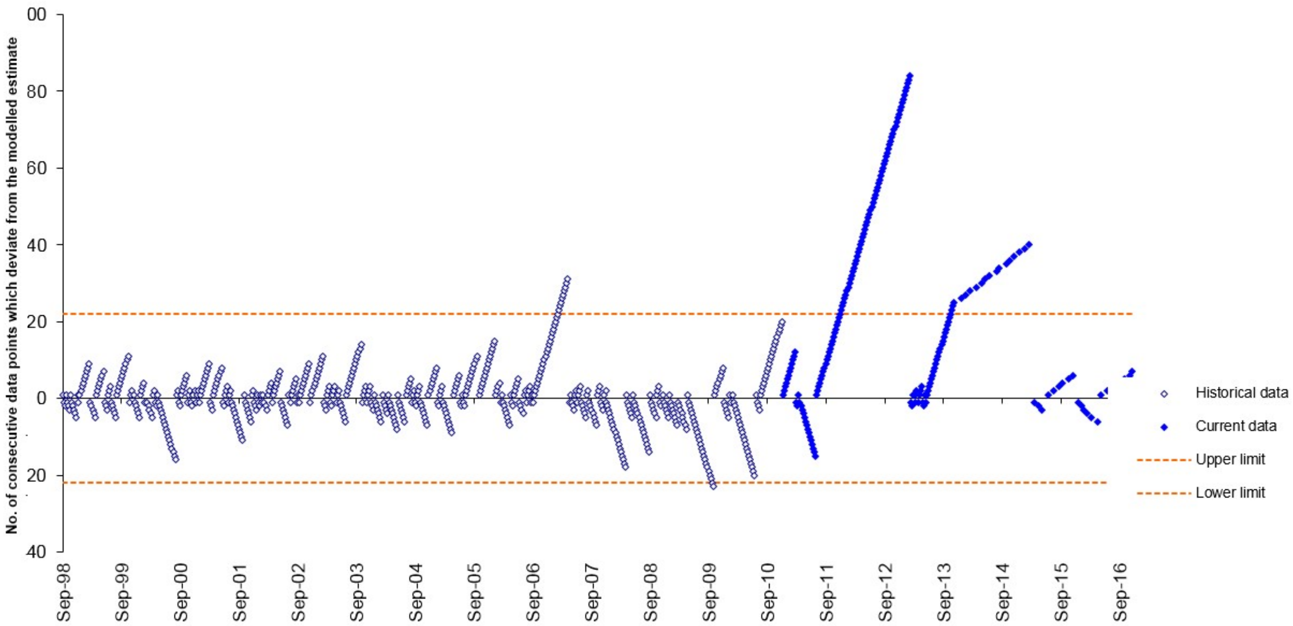


Figure 26: Example run chart for electrical conductivity (in µS/cm) in the Ovens River at Peechelba showing the historical data (blue outlined points), current data (blue filled points) and run chart limits set at three standard deviations from the mean run length (orange dashed lines)

Any runs in the new data period (i.e. 2011 to 2016) that exceeded the run chart limits were considered unusual and potentially indicate a more sustained change in the data at that particular site, as indicated above in Figure 26.

3.2.5 Presentation of results

The results of the analyses for the six detailed assessments sites are presented separately in the following chapters. Each chapter begins with a description and map of the monitoring site, followed by a summary of the data. Models that best describe the historical variation in each water quality variable are presented alongside the control charts, run charts and a discussion of results for each water quality variable in separate sub-chapters. In these interpretation sections, the regression models fit against the historical data (1991- 2010) is described and how well they predict conditions from 2011 to 2016. We compare the collected data against the relevant State Environment Protection Policy (Waters of Victoria) SEPP (WoV) (2003) objectives and describe any trends that are highlighted by the control charts or run charts. All goodness of fit statistics are presented in the arithmetic domain, even if the dependent variable was transformed.

4. Results for Wimmera River at Eversley (415207)

4.1 Site Location

The Wimmera River at Eversley (streamflow gauge number 415207) is located in the upper reaches of the Wimmera River, upstream of the junctions with Mount Cole and Spring Creeks (Figure 27). Eversley is located in Western Victoria approximately 30 kilometres north-east of Ararat and approximately 10 kilometres north of Langi Ghiran and Mount Buangor State Parks. The Wimmera River rises in the Great Dividing Range between Ararat and Avoca, flowing north and west, and joined by fourteen minor tributaries before reaching its mouth at Lake Hindmarsh. It is an intermittent, inland river - in most years, flow does not reach Lake Hindmarsh and the watercourse dries to a series of pools. On rare occasions, flow reaches Lake Hindmarsh and overflows through outlet creek and into Lake Albacutya. Water quality in the river is affected by saline groundwater inflows.

The Wimmera Catchment Management Authority (CMA) nominated the site as being of interest from a water quality perspective for the previous water quality trend analysis study. The upper reaches of the Wimmera River have very low flow during summer (and drought conditions) and the pool where water quality samples are recorded for this site becomes very shallow and often has high algal growth (M. Toomey, personal communication, 1/5/12).

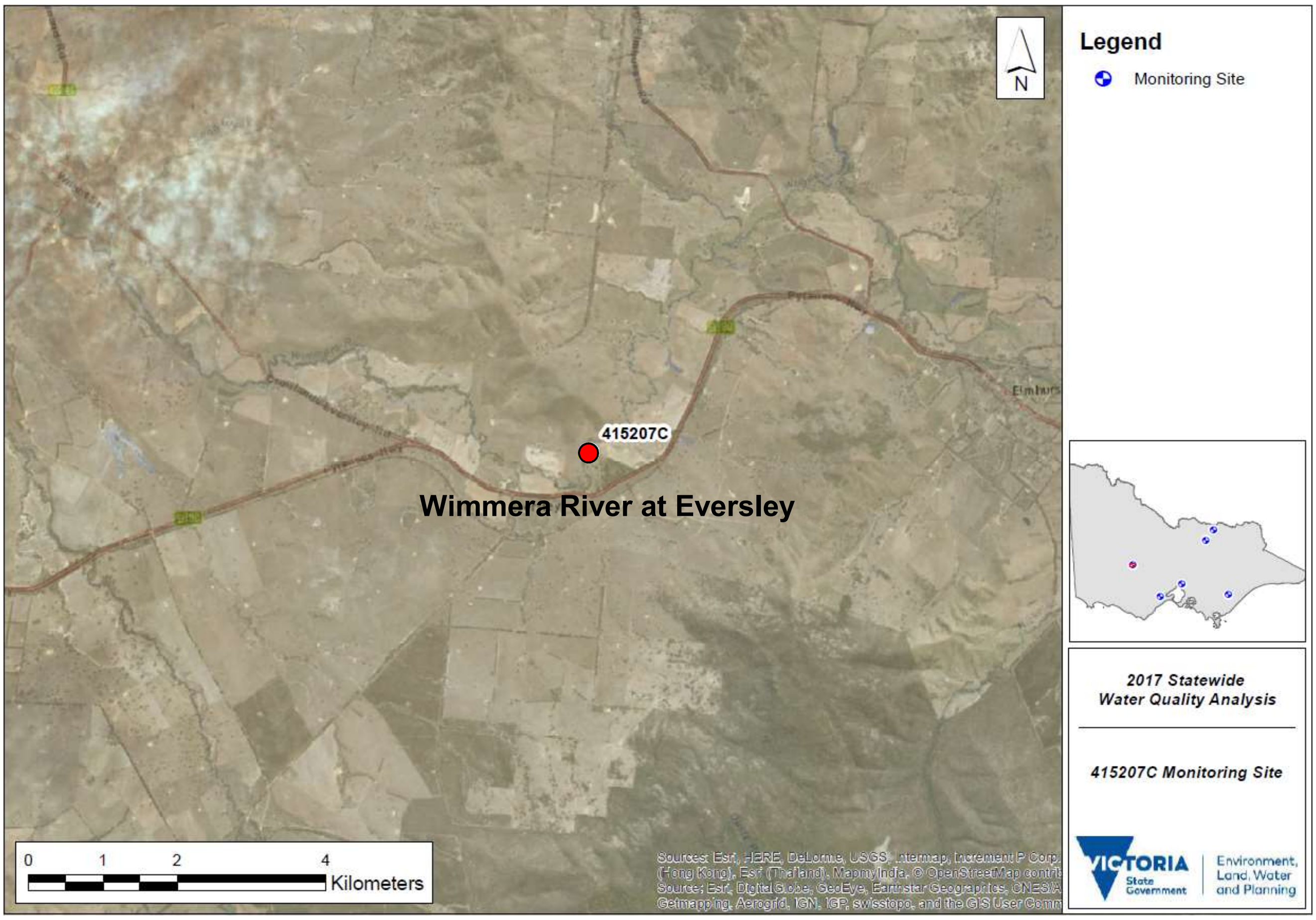


Figure 27: Locality map for Wimmera River at Eversley

4.2 Data availability and quality

Water quality was monitored at Eversley on 266 occasions between January 1991 and December 2010. Water quality data was generally available, however a number of data points had to be excluded from the analysis due to missing rainfall data (Table 11).

Table 11: Missing data over period of regression model fit (Jan 1991 – Dec 2010)

Missing data elements	Dissolved oxygen	Turbidity	Electrical conductivity	pH	Total nitrogen	Total phosphorus
No. of missing water quality readings on days when at least one other parameter was recorded	1	0	1	3	0	0
No. of data points removed as outliers	0	0	0	0	0	0
No. of data points not analysed due to missing water temperature data	0	0	-	0	0	0
No. of data points not analysed due to missing or zero flow data	-	0	0	0	0	0
No. of data points not analysed due to missing rainfall data	-	21	-	21	50	29
Sample size for regression analysis	231	208	236	208	208	237

Water quality was monitored on 107 occasions between January 2011 to December 2016. Whilst there were no days with 'zero flow' readings, there were a number of data points with missing water temperature and / or flow data which were excluded from the analysis (Table 12).

Table 12: Missing data over period of control chart application (2011-2016)

Missing data elements	Dissolved oxygen	Turbidity	Electrical conductivity	pH	Total nitrogen	Total phosphorus
No. of missing water quality readings on days when at least one other parameter was recorded	3	3	3	3	0	0
No. of data points removed as outliers	0	0	0	0	0	0
No. of data points not analysed due to missing water temperature data	2	2	-	2	2	2
No. of data points not analysed due to missing or zero flow data	-	33	33	33	33	33
No. of data points not analysed due to missing rainfall data	-	0	-	0	0	0
Sample size for control chart application	69	69	69	69	72	72

4.3 Results for each water quality variable

4.3.1 Dissolved oxygen

Variation in dissolved oxygen (mg/L) levels in the Wimmera River at Eversley between 1991 and 2005 was poorly explained ($R^2 = 0.42$) by a combination of season, temperature, date and flow (Table 13). The predictability of the model was similar to the previous model and did not improve by the inclusion of data from 2006 to 2010 (Table 13).

Average and median dissolved oxygen levels were lower in the current period (2011-2016) compared to the historical period (1991-2010) (Table 14). Median values dropped from 8.6 mg/L to 7.5 mg/L and from 85.85% saturation to 69.88 % saturation. The model fit for percentage saturation was very poorly explained for the percent saturation DO ($R^2 = 0.35$) compared to the fit for the absolute dissolved oxygen levels (in mg/L; $R^2 = 0.42$).

There was a clear seasonal pattern in the historical data, with higher dissolved oxygen levels recorded in winter and lower values recorded in summer, however the fitted model for both DO in mg/L and % saturation tended to underestimate the highest values and overestimate the lowest values (Figure 28, Figure 29). This over and underestimation pattern was more evident during the historical period than the current period.

The model failed to accurately predict DO in mg/L and % saturation in the Wimmera River post 2010 (post-drought), which may be because the models were developed under predominantly drought conditions. In particular, the models failed to predict the low dissolved oxygen conditions experienced from 2009 to 2012, which were likely to have be caused by the breakdown of large amounts of accumulated organic matter entrained in the river channel during heavy rainfall events. Record rainfall was experienced in the years 2010 and 2011 from a La Niña weather pattern that broke the Millennium Drought (1996 to mid-2010).

Table 13: Best fit regression models to describe variation in dissolved oxygen in the Wimmera River at Eversley between 1991 and 2010.

	Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Regression model between 1991 and 2005	Dissolved oxygen (DO) [mg/L]	DO = 23.926 – (1.137*Season) – (0.135*Temp) –(0.000255*Date) – (0.00211*Flow)	170	0.49	15%
	Dissolved oxygen (DO) [% saturation]	DO = $(9.647 – (0.315*Season) + (0.0126*Temp) –(0.0000762*Date) – (0.000581*Flow))^{(1/0.4)}$	170	0.24	16%
Regression model between 1991 and 2010	Dissolved oxygen (DO) [mg/L]	DO = 33.117 - 1.330*MonthSIN - 0.0781*Temp - 0.000455*JDate	231	0.42	22%
	Dissolved oxygen (DO) [% saturation]	DO% = 351.083 – 13.505*MonthSIN + 1.153*Temp – 0.00549*JDate – 0.253*Rain72	206	0.35	22%

Table 14: Summary statistics for historical (1991-2010) and current (2011 – 2016) dissolved oxygen data recorded in the Wimmera River at Eversley

Heading	Record	N	Mean	Median	Standard Deviation
Dissolved oxygen mg/L	Historical	236	8.3	8.6	2.3
	Current	69	7.3	7.5	2.1
	Overall	305	8.1	8.4	2.3
Dissolved oxygen % Sat	Historical	235	82	86	22
	Current	68	67	70	15
	Overall	303	78	81	21

Water temperature affects the maximum amount of DO that can be dissolved in water, which gives rise to the seasonal fluctuations in DO in mg/L. DO in % saturation adjusts for this effect and therefore trends in DO (% saturation) related to temperature are from temperature-dependent rates of primary production and community respiration. The control chart for the DO in % saturation shows a considerable number of points below the lower SEPP trigger level of 80%, but above the modelled control limits. The control chart and the run chart clearly show that the regression model did not predict the higher dissolved oxygen levels recorded after 2013 (Figure 28, Figure 29). This may be due to increased flow in the river, post-drought, which produced higher than expected DO levels in the Wimmera River at Eversley.

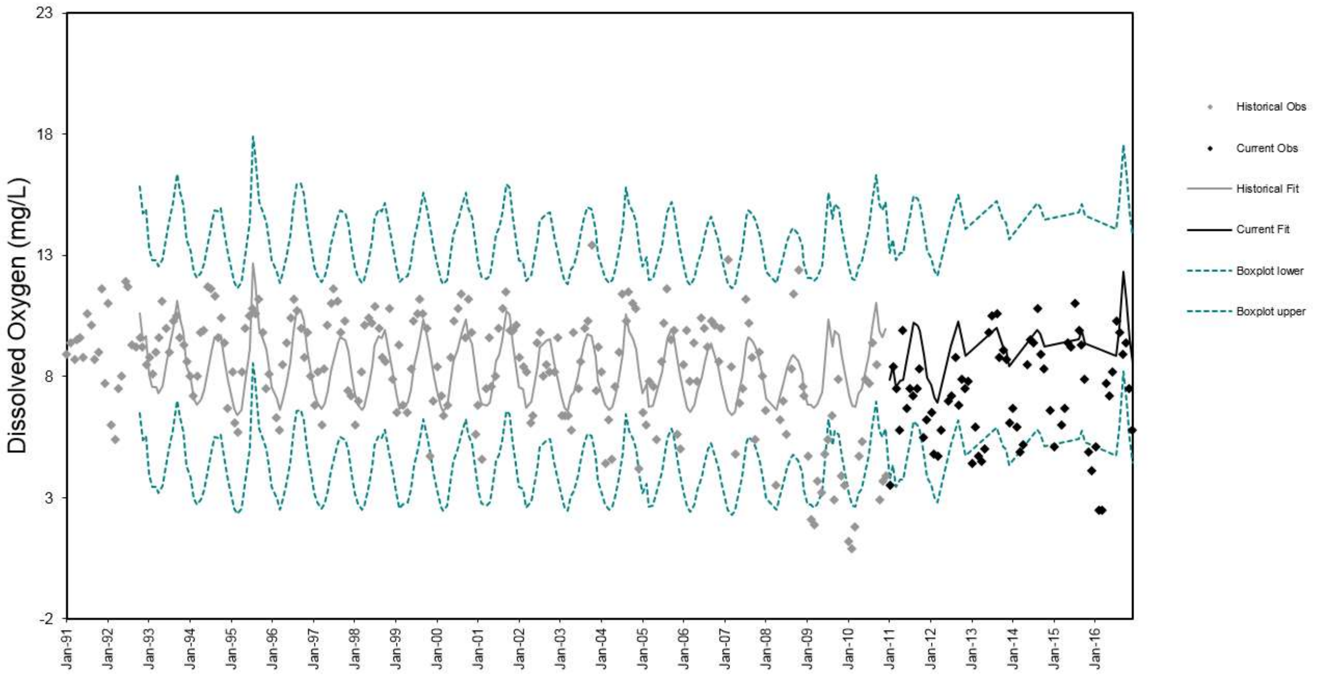


Figure 28: Control chart for dissolved oxygen (mg/L) in the Wimmera River at Eversley 1991 – 2016

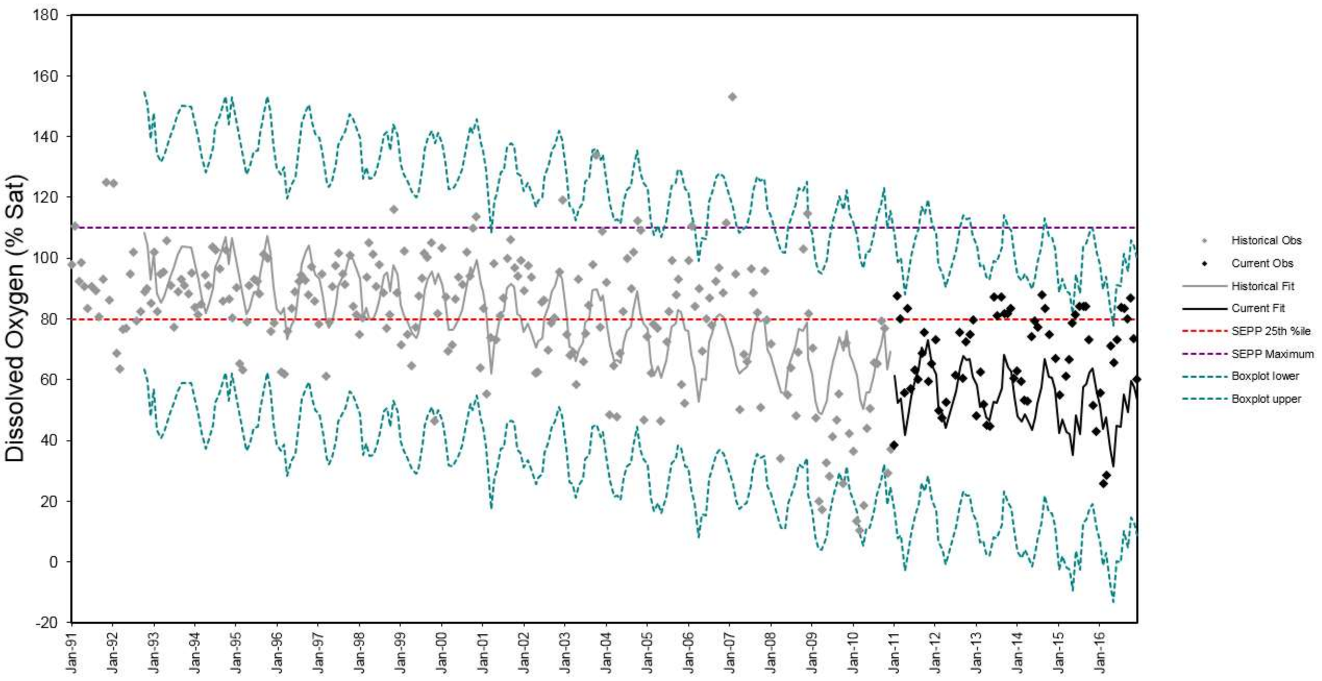


Figure 29: Control chart for percent saturation dissolved oxygen in the Wimmera River at Eversley 1991 – 2016

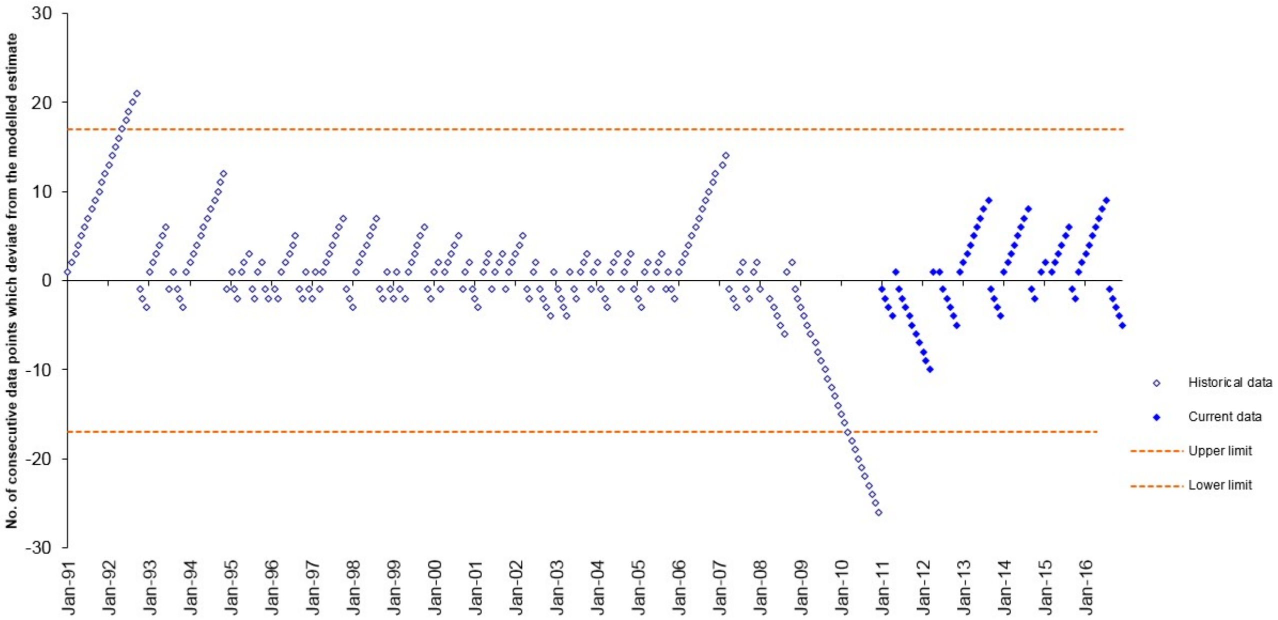


Figure 30: Run chart for dissolved oxygen (mg/L) in the Wimmera River at Eversley 1991 – 2016

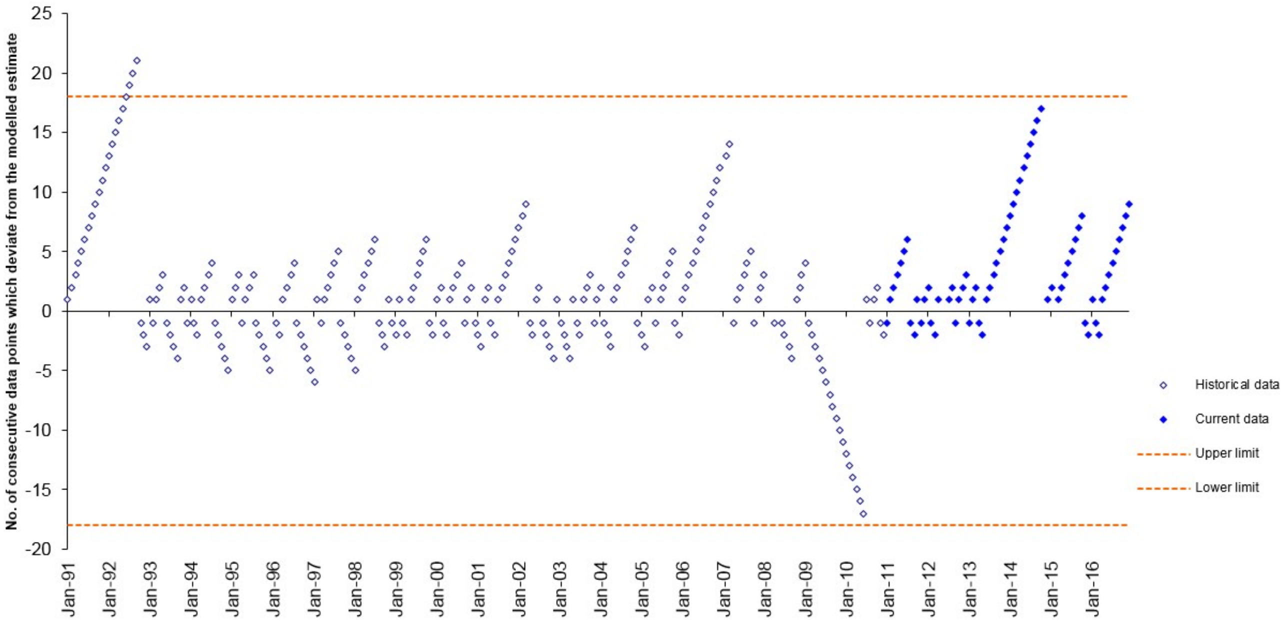


Figure 31: Run chart for percent saturation dissolved oxygen in the Wimmera River at Eversley 1991 - 2016

4.3.2 Turbidity

Variation in turbidity in the Wimmera River at Eversley between 2011 and 2016 was very poorly explained by the regression model, which considered season, date, temperature, flow and rainfall ($R^2 = 0.154$, Table 15). Rainfall data were taken from the Eversley rainfall gauge (Site # 079014) operated by the Bureau of Meteorology. Since 2011, average and median turbidity levels have been significantly higher than the historical record (Table 16). The model predicted an increase in turbidity and in many cases over-predicted turbidity levels, meaning that observed data was lower than the model prediction. There were a small number of very high turbidity levels recorded, which were not predicted by the model (Figure 32, Figure 33). In the current period since 2011, turbidity levels at this site have almost always exceeded the SEPP (WoV) water quality objective of 10 NTU and therefore observations outside of control may be a trigger for further investigation at the time of the observation. The general trend of increased turbidity after 2011 is likely to be as a result of increased flow and runoff from the catchment following the end of the Millennium Drought.

Table 15: Best fit regression models to describe variation in turbidity in the Wimmera River at Eversley between 1991 and 2005, and 1991 to 2010

Parameter		Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Regression model between 1991 and 2005	Turbidity (NTU)	Turbidity = 1.578 + (2.222*Flow$^{0.4}$) + (0.128*Rainfall)	171	0.41	87%
Regression model between 1991 and 2010	Turbidity (NTU)	Turbidity = -321.581 + 10.102*MonthSIN – 0.891*Temp + 0.0065*JDate + (4.572*Flow$^{0.4}$) - 0.345*Rain72	208	0.15	210%

Table 16: Summary statistics for historical (1991- 2010) and current (2011-2016) turbidity data recorded in the in the Wimmera River at Eversley

Heading	Record	N	Mean	Median	Standard Deviation
Turbidity (NTU)	Historical	237	14	6.6	30
	Current	69	31	14	88
	Overall	306	18	8	50

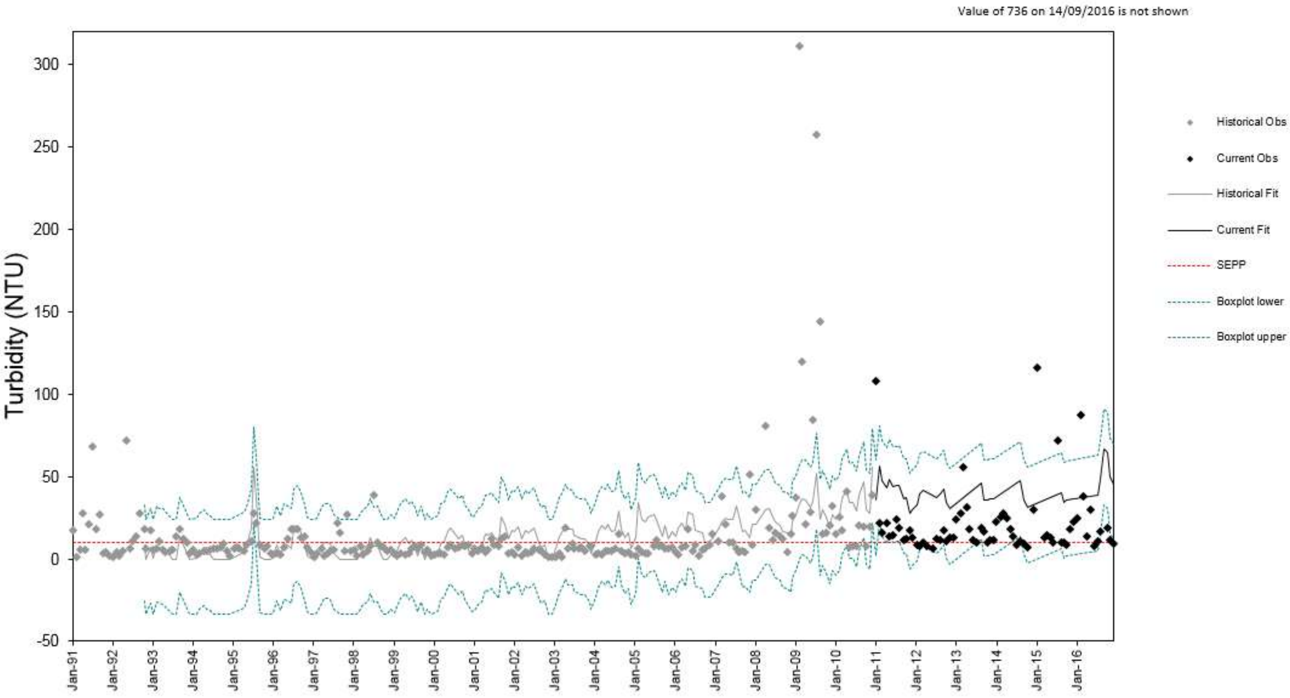


Figure 32: Control chart for turbidity (in NTU) in the Wimmera River at Eversley 1991 - 2016.

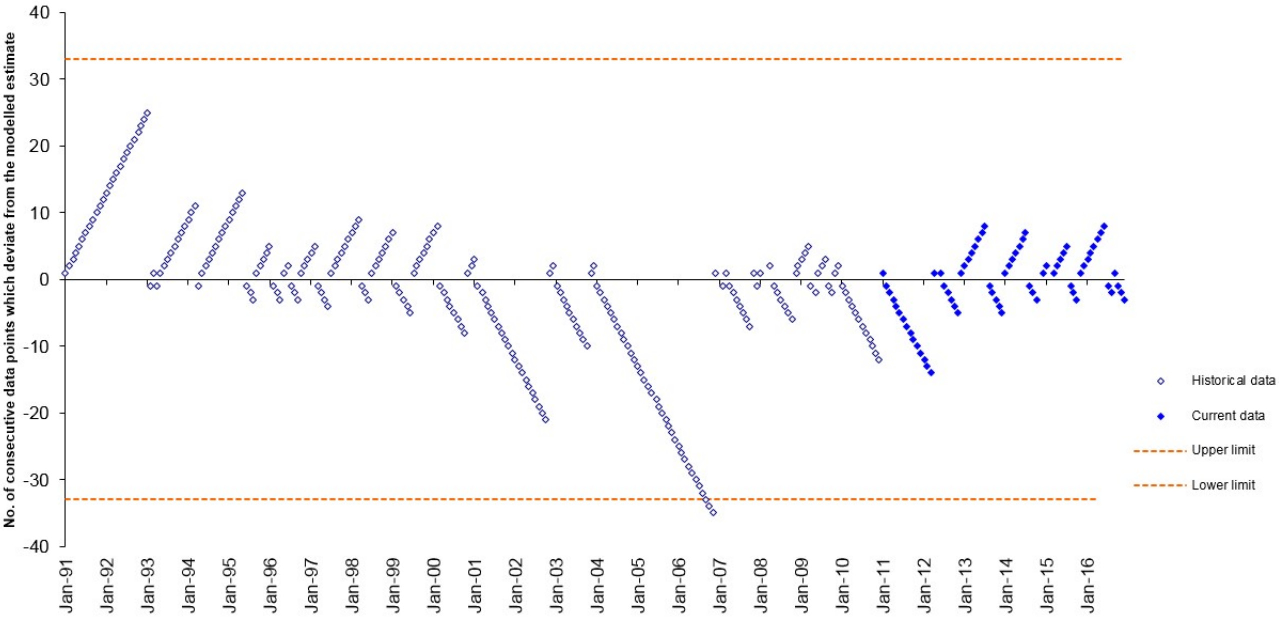


Figure 33: Run chart for turbidity (in NTU) in the Wimmera River at Eversley 1991 - 2016

4.3.3 Electrical conductivity

Variation in electrical conductivity in the Wimmera River at Eversley between 2011 and 2016 was moderately well explained by a combination of season and flow (R^2=0.66, Table 17). Average electrical conductivity levels for the current period (2011-2016) were quite similar to the historical period (Table 18). High electrical conductivity levels in the historical period, outside of the model bounds, correlate with cease-to-flow events in the Wimmera River during the drought. In the current period, the model more reliably predicted low EC values which typically occurred during winter and periods of flow. The highest EC values in the current period were under-predicted by the model, with several values recorded that were outside the upper control (Figure 34). The upper reaches of the Wimmera River have very low flow during summer (and drought conditions) and the pool where water quality samples are taken for this site becomes very shallow. The increase in EC in late summer and autumn may be because of evapo-concentration and/or increased groundwater intrusion from rising water tables post-drought.

The higher EC values at this site often exceeded the SEPP (WoV) trigger level of ≤1500 µS/cm for the protection of aquatic ecosystems and other beneficial uses of the waterway; while many of the lower values met the SEPP limits (Figure 34). There was significant variation in the EC values recorded during summer and winter, which is typical for EC in waterways with significant seasonal flow variations (current period median value 2370 and standard deviation of 1454). The high values recorded in the current period were within the range of the historical data, but outside the model predictions.

Table 17: Best fit regression models to describe variation in conductivity in the Wimmera River at Eversley between 1991 and 2005, and 1991 to 2010

Parameter		Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Regression model between 1991 and 2005	Electrical conductivity (EC)	$EC = (26.899 - (2.646 * Season) - (0.163 * Temp) - (1.253 * Flow^{0.4}))^{(1/0.4)}$	170	0.69	31%
Regression model between 1991 and 2010	Electrical conductivity (EC)	$EC = (25.737 + 1.807 * MonthSIN + (-1.687 * Flow^{0.4}))^{(1/0.4)}$	236	0.66	15%

Table 18: Summary statistics for historical (1991- 2010) and current (2011-2016) conductivity data recorded in the in the Wimmera River at Eversley

Heading	Record	N	Mean	Median	Standard Deviation
Electrical conductivity (µS/cm)	Historical	236	2551	2200	1501
	Current	69	2616	2370	1454
	Overall	305	2566	2200	1489

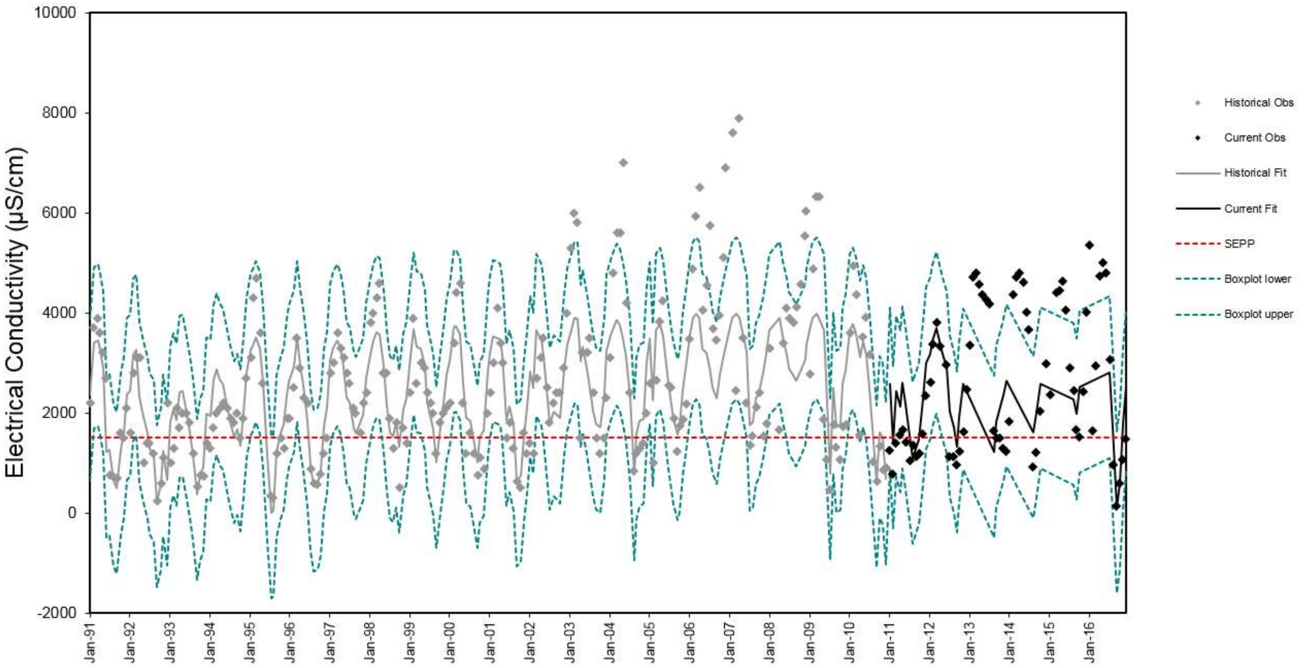


Figure 34: Control chart for electrical conductivity (in µS/cm) in the Wimmera River at Eversley 1991 – 2016

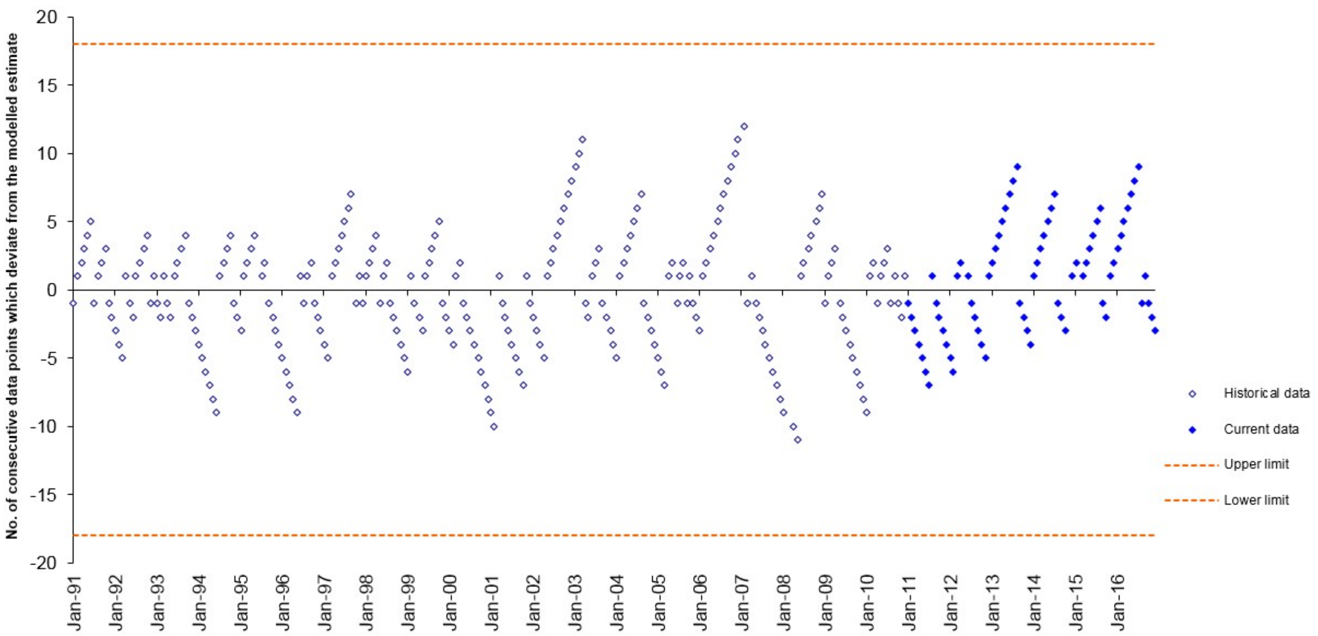


Figure 35: Run chart for electrical conductivity (in µS/cm) in the Wimmera River at Eversley 1991 – 2016

4.3.4 Total nitrogen

Variation in total nitrogen in the Wimmera River at Eversley was poorly explained by the regression model (R^2 = 0.56) which was based on season, date, flow, rainfall and turbidity (Table 19). Average and median total nitrogen levels increased in the current period compared to the historical period (Table 20). This increase was attributed to increased nutrient-laden catchment runoff in the wetter conditions experienced in the current period compared to the historical period that was dominated by drought.

The model tended to over-predict total nitrogen levels, with recorded data at the lower bounds of the model control range for a significant period after January 2011. This is also evident in the run chart (Figure 37). Total nitrogen concentrations at this site were typically below the SEPP (WoV) trigger levels of ≤0.900 mg/L, but some very high values did occur later in the current period (2014 to 2016) which tended to be under estimated by the model. These high values were within the historical range of total nitrogen values at the site, but they exceeded model controls and were well in excess of SEPP limits.

Table 19: Best fit regression models to describe variation in total nitrogen in the Wimmera River at Eversley between 1991 and 2005, and 1991 to 2010

Parameter		Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Regression model between 1991 and 2005	Nitrate + Nitrite (mg/L)	$NOx = (2.815 – (0.013*Temp) – (0.0000461*Date) +(0.0101*Flow^{0.4}) + (0.00476*Turbidity))^{(1/0.4)}$	171	0.44	125%
Regression model between 1991 and 2010	Total nitrogen (mg/L)	$TN = -2.188 + 0.200*MonthSIN + 0.0000436*JDate + 0.000566*Flow + 0.00238*Rain72 + 0.000413*RainDays + (0.2342*Turbidity^{0.5})$	208	0.56	55%

Table 20: Summary statistics for historical (1991- 2010) and current (2011-2016) total nitrogen data recorded in the in the Wimmera River at Eversley

Heading	Record	N	Mean	Median	Standard Deviation
Total nitrogen (mg/L)	Historical	238	0.88	0.66	0.72
	Current	72	1.06	0.88	0.61
	Overall	309	0.92	0.71	0.70

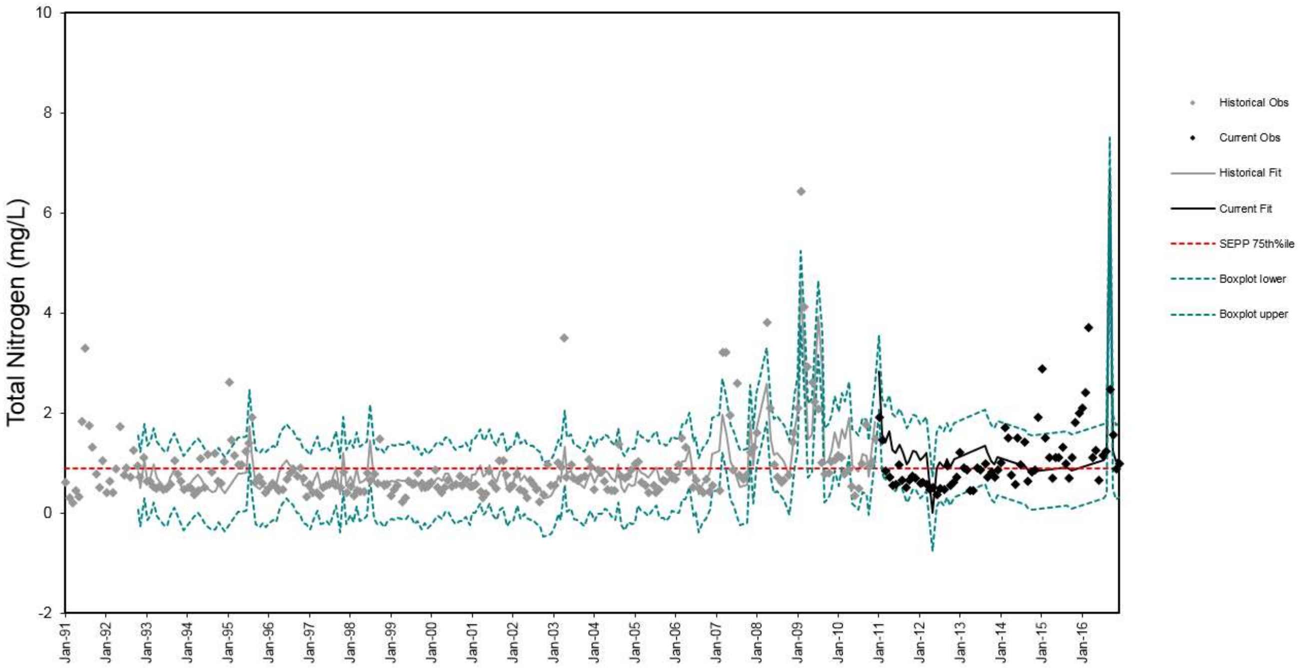


Figure 36: Control chart for total nitrogen (in mg/L) in the Wimmera River at Eversley 1991 - 2016.

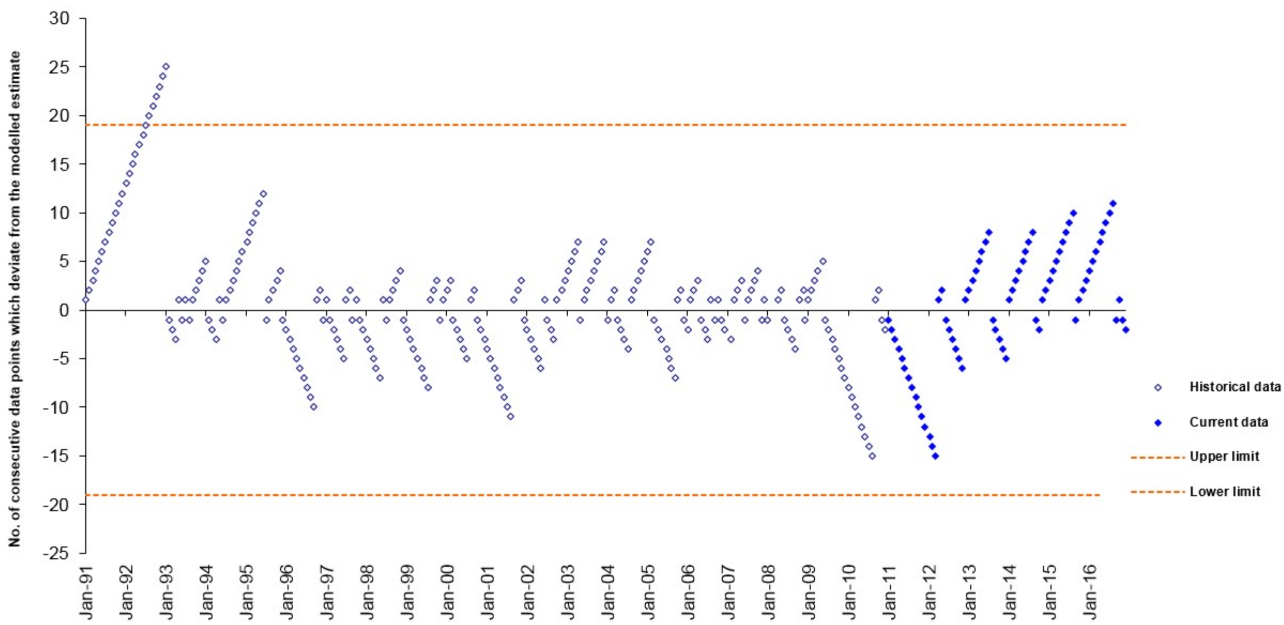


Figure 37: Run chart for total nitrogen (in mg/L) in the Wimmera River at Eversley 1991 - 2016.

4.3.5 Total phosphorus

Variation in total phosphorus concentration in the Wimmera River at Eversley in the current period was poorly explained by season, date, and turbidity (R^2= 0.55, Table 21). The recorded data after 2011 followed the shape of the model predictions reasonably well but values were lower than predicted. There were several very high values late in the current period that were not predicted by the model and were well above model bounds and SEPP limits. Average and median total phosphorus concentrations at this site were significantly higher and more variable in the current period compared to the historical record (Table 22). This correlates with the increase in total nitrogen concentration and turbidity observed over the same period (see Sections 4.3.4). The correlation with turbidity suggests that much of the phosphorus at this site may be bound to fine soil particles and could therefore be associated with erosion. However, there were still a few observations that were outside of the model controls that could trigger further investigation, especially since these values exceeded the SEPP (WoV) trigger level of ≤0.04 mg/L by as much as an order of magnitude.

Table 21: Best fit regression models to describe variation in total phosphorus in the Wimmera River at Eversley between 1991 and 2005, and 1991 to 2010

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Regression model between 1991 and 2005	$TP = (-0.800 + (0.00368*Temp) + (0.0000178*Date) + (0.00774*Flow^{0.4}) + (0.00373*Turbidity))^{(1/0.4)}$	171	0.43	77%
Regression model between 1991 and 2010	TP = -0.379 + 0.0198*MonthSIN + 0.00000771*JDate + 0.00167*Turbidity	237	0.55	120%

Table 22: Summary statistics for historical (1991- 2010) and current (2011-2016) total phosphorus data recorded in the in the Wimmera River at Eversley

Heading	Record	N	Mean	Median	Standard Deviation
Total phosphorus (mg/L)	Historical	237	0.043	0.02	0.077
	Current	72	0.078	0.04	0.113
	Overall	309	0.051	0.03	0.088

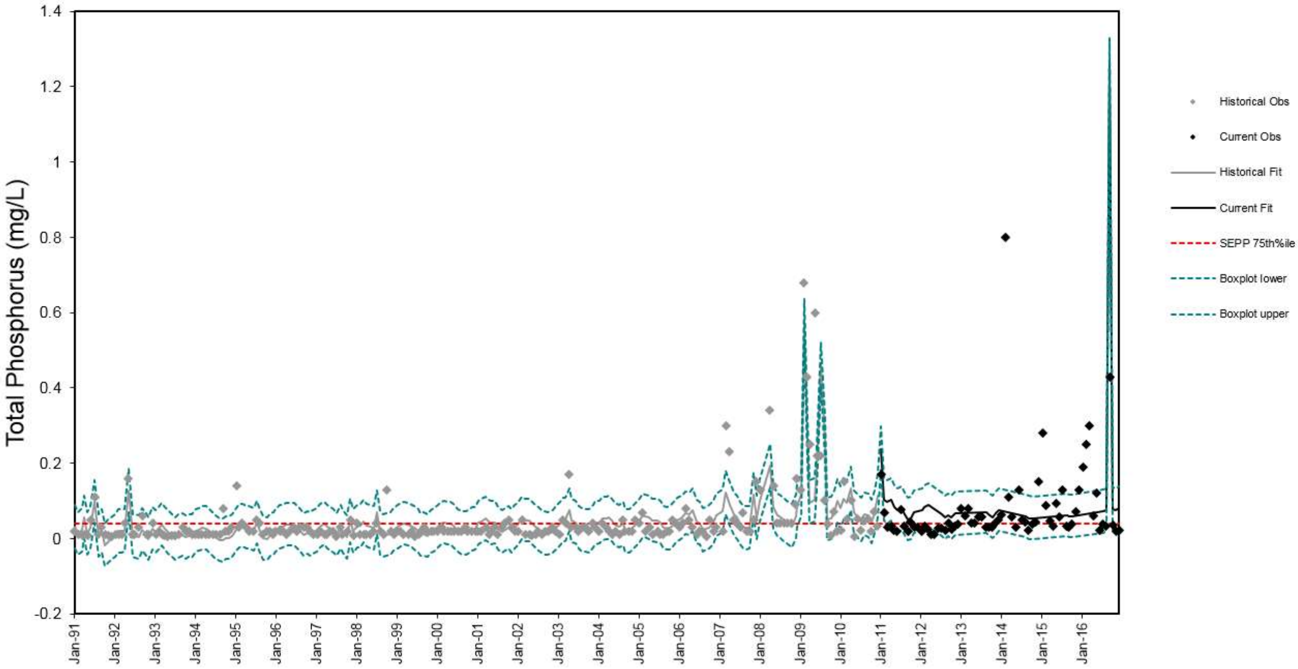


Figure 38: Control chart for total phosphorus (in mg/L) in the Wimmera River at Eversley 1991 - 2016.

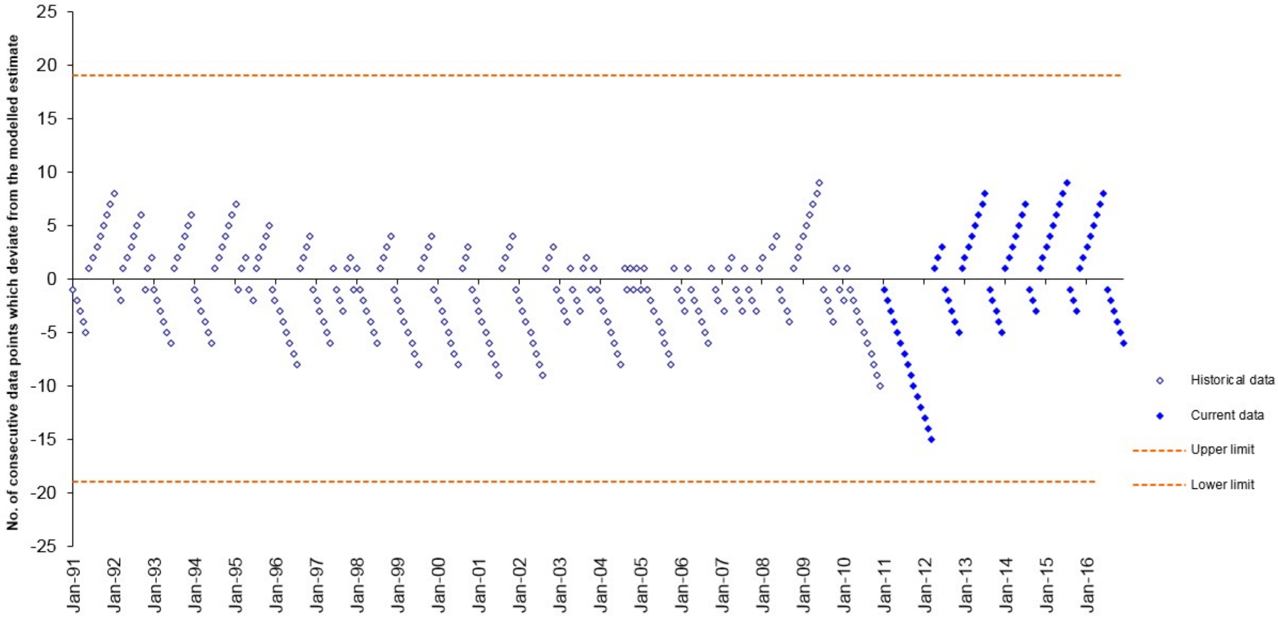


Figure 39: Run chart for total phosphorus (in mg/L) in the Wimmera River at Eversley 1991 - 2016.

5. Results for Broken River at Goorambat (404216)

5.1 Site Location

The Goorambat water quality monitoring site (streamflow gauge number 404216) is located midway along the Broken River, immediately downstream of Casey's Weir (Figure 40). Goorambat is located in Northern Victoria, approximately 15 kilometres north of Benalla. The Broken River is an inland, perennial river which is part of the Goulburn Broken catchment. It rises on the western slopes of the Victorian Alps, near Tolmie. It flows generally north and west and is joined by ten tributaries before its confluence with the Goulburn River near Shepparton.

Flow and water quality of the Broken River at Goorambat are influenced by upstream flow in the Broken River and outflow from Lake Mokoan/Winton Wetlands. Flow is also diverted into Broken Creek from Casey's Weir. Prior to 2009, Lake Mokoan was used to supply water for irrigation, stock and domestic use in the lower reaches of the Broken and Goulburn Rivers and parts of the Shepparton Irrigation District. Water was diverted from the Broken River into Lake Mokoan from Broken Weir when flow in the Broken River exceeded downstream demand, and outflows from Lake Mokoan returned to the Broken River at Casey's Weir. Lake Mokoan had a history of poor water quality, particularly high turbidity and frequent blue-green algae blooms. Outflow from Lake Mokoan therefore had a noticeable effect on water quality in the Broken River downstream of Casey's Weir. Lake Mokoan was decommissioned in late 2009 and the area is currently being rehabilitated to a wetland complex known as Winton Wetlands. Overflow from the Winton Wetlands still enters the Broken River at Casey's Weir, and many of the water quality issues associated with outflow water from Lake Mokoan are likely to still be relevant. However, the timing of outflows has changed. They are much less frequent and are likely to be associated with much greater flows throughout the whole catchment. These issues have been addressed in the analysis by using flow in the Broken River and flow from Lake Mokoan as separate predictor variables. Any models that use flow from Lake Mokoan / Winton Wetlands will set that variable to zero for any dates when there is no flow from that system.

The Goulburn Broken Catchment Management Authority nominated the Goorambat monitoring site on the Broken River as being of interest from a water quality perspective for the previous WQ trend analysis study.

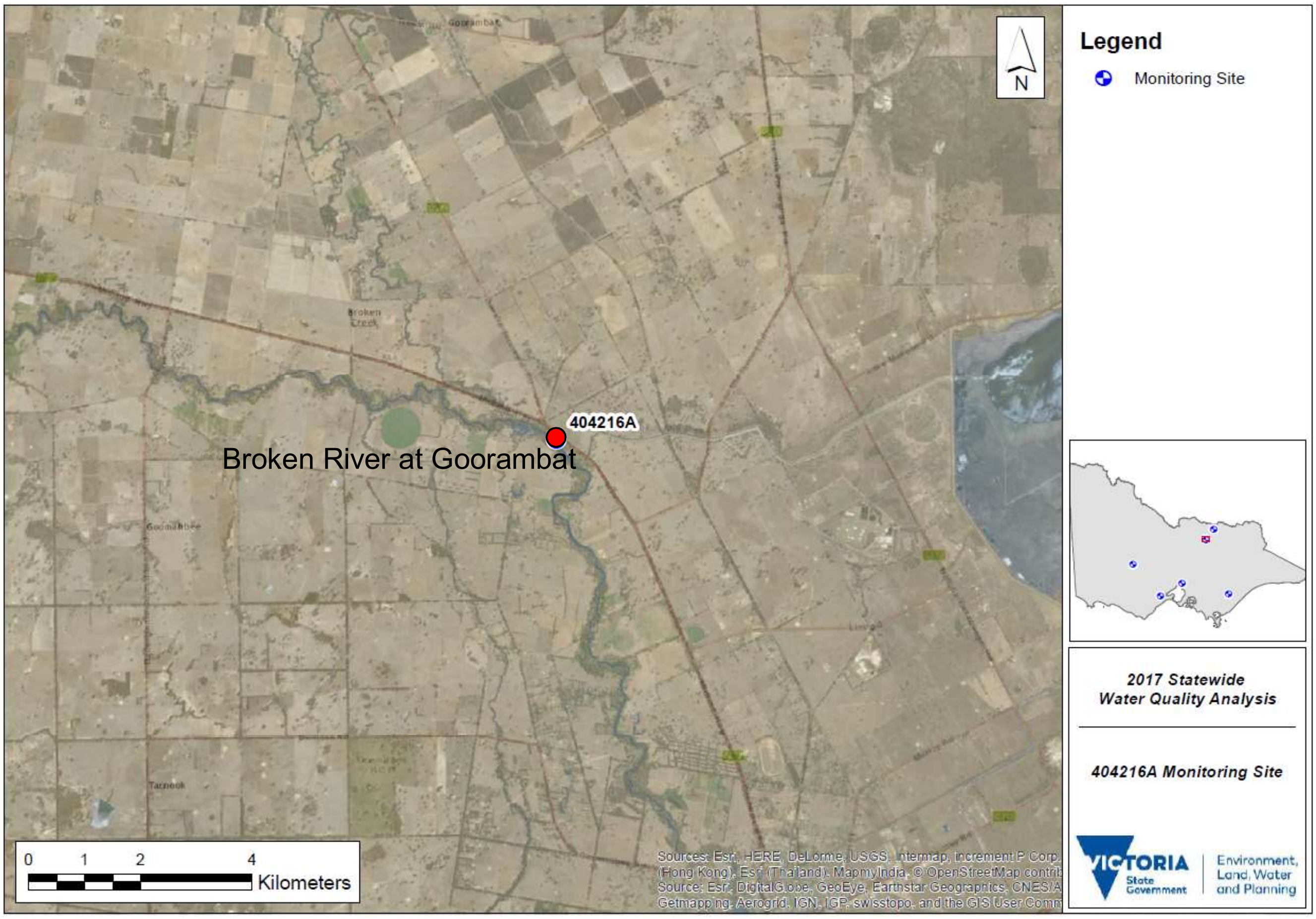


Figure 40: Locality map for Broken River at Goorambat

5.2 Data availability and quality

Water quality was monitored at Goorambat on 239 occasions between January 1991 and December 2010 (Table 23). Data was readily available, with only a small number of data points missing flow and / or rainfall data which had to be excluded from the analysis.

Table 23: Missing data over period of regression model fit (Jan 1991 – Dec 2010)

Missing data elements	Dissolved oxygen	Turbidity	Electrical conductivity	pH	Total nitrogen	Total phosphorus
No. of missing water quality readings on days when at least one other parameter was recorded	4	2	1	5	3	3
No. of data points removed as outliers	0	0	0	0	0	2
No. of data points not analysed due to missing water temperature data	0	0	0	0	0	0
No. of data points not analysed due to missing or zero flow data	-	1	1	1	1	1
No. of data points not analysed due to missing rainfall data	-	1	1	1	1	1
Sample size for regression analysis	236	237	237	233	235	232

Water quality was monitored on 79 occasions between January 2011 to December 2016. Whilst there were no days with 'zero flow' readings, there was a small number of data points with missing flow and / or rainfall data which were excluded from the analysis (Table 24).

Table 24: Missing data over period of control chart application (2011 – 2016)

Missing data elements	Dissolved oxygen	Turbidity	Electrical conductivity	pH	Total nitrogen	Total phosphorus
No. of missing water quality readings on days when at least one other parameter was recorded	0	0	1	1	0	0
No. of data points removed as outliers	0	0	0	0	0	0
No. of data points not analysed due to missing water temperature data	0	0	0	0	0	0
No. of data points not analysed due to missing or zero flow data	-	5	5	5	5	5

Missing data elements	Dissolved oxygen	Turbidity	Electrical conductivity	pH	Total nitrogen	Total phosphorus
No. of data points not analysed due to missing rainfall data	-	2	2	2	2	2
Sample size for control chart application	72	72	71	71	72	72

5.3 Results for each water quality variable

5.3.1 Dissolved oxygen

Variation in dissolved oxygen (mg/L) in the Broken River at Goorambat was moderately well explained by a combination of water temperature and date (R^2=0.61,

Table 25). Higher dissolved oxygen levels were observed during winter and lower dissolved oxygen levels during the summer, reflecting the temperature dependence of DO saturation in water. The model typically captured the low dissolved oxygen data well, while the higher dissolved oxygen values were under predicted by the model. The dissolved oxygen peaks were inside the upper control predictions in most cases. The model for absolute dissolved oxygen concentration (mg/L) predicted the data more accurately than the model for percentage saturation (R^2 = 0.34). As with the mg/L model, the percentage saturation data was a good fit with the seasonal variation, but the model underestimated the high DO peaks.

The average and median dissolved oxygen levels between the historical and current record were comparable, showing that median DO has not changed because of climatic and flow variability in the Broken River. However, the run chart shows that the current data is underestimated for longer periods of time than during the historic period by the model (Figure 43). This is because the historical data was showing a downward trajectory in DO during the drought. The control chart shows that the current DO levels in Broken Creek have improved compared to the historical trend. This trend was not evident by simply comparing the average and median levels, so it shows the strength of this method. This improvement is likely to be due to increased flow in the river post-drought. A number of data points remain below the lower SEPP (WoV) trigger level of 85% during summer which may warrant further investigation due to the threat to aquatic biota at this site (Figure 42).

Table 25: Best fit regression models to describe variation in dissolved oxygen in the Broken River at Goorambat

Parameter		Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Regression model between 1991 and 2005	**Dissolved Oxygen mg/L**	DO= 23.172 – (0.216*Temp) – (0.000243*Date) + (0.0544*FlowBroken$^{0.4}$) + (0.0485*FlowMokoan$^{0.4}$)	172	0.64	13%
	Dissolved Oxygen % Sat	DO= 212.177 – (0.573*Temp) – (0.00254*Date) + (0.442*FlowBroken$^{0.4}$) + (0.579*FlowMokoan$^{0.4}$)	172	0.31	12%
Regression model between 1991 and 2010	**Dissolved Oxygen mg/L**	DO = 25.956 - 0.231*Temp - 0.000281*JDate	236	0.61	15%
	Dissolved Oxygen % Sat	DO% = 203.621 – 0.729*Temp – 0.00232*JDate + (0.654*Flow$^{0.4}$)	235	0.34	11%

Table 26: Summary statistics for historical (1991-2010) and current (2011 – 2016) dissolved oxygen data

Heading	Record	N	Mean	Median	Standard Deviation
Dissolved oxygen mg/L	Historical	236	7.6	7.6	1.8
	Current	72	7.6	7.4	2.0
	Overall	308	7.6	7.6	1.9
Dissolved oxygen % Sat	Historical	236	76	78	14
	Current	72	77	79	13
	Overall	308	76	78	14

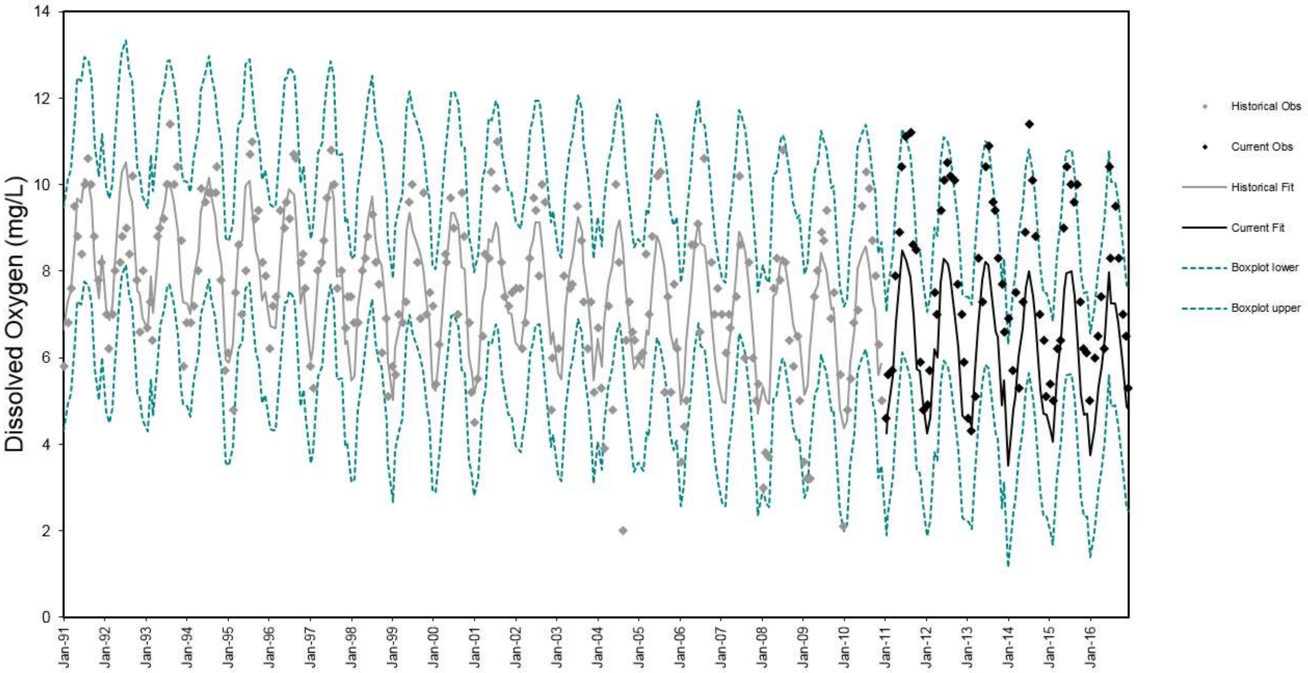


Figure 41: Control chart for dissolved oxygen (mg/L) in the Broken River at Goorambat 1991 – 2016

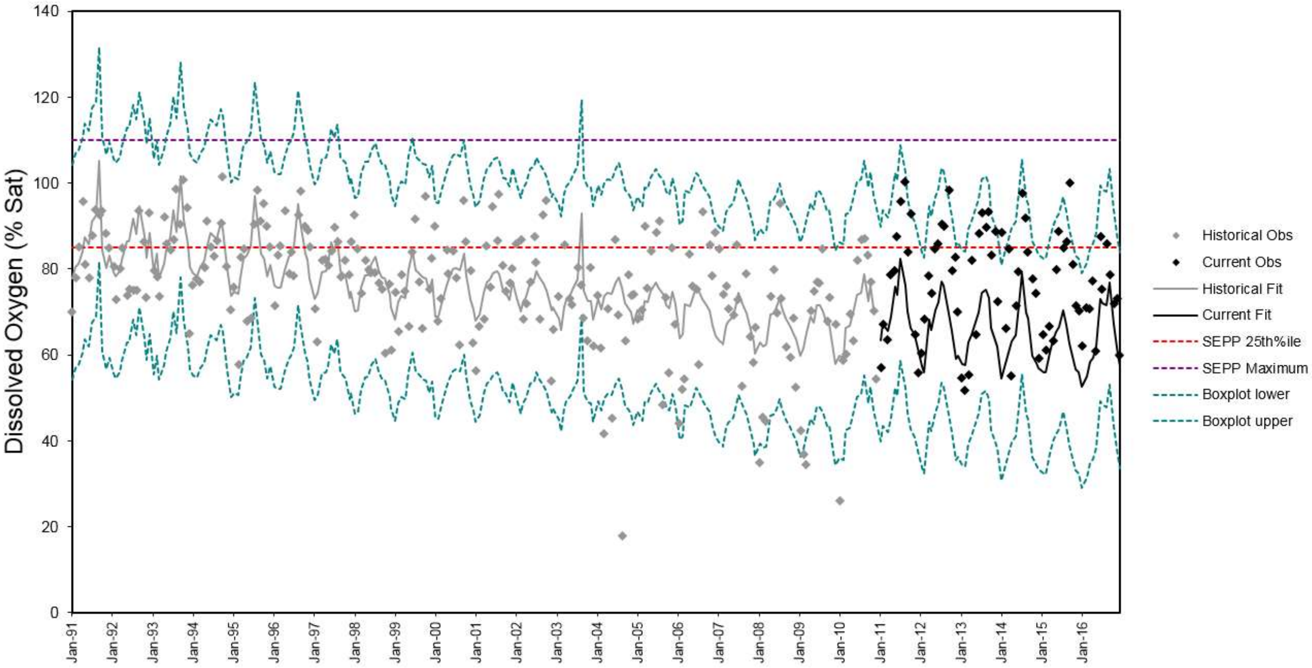


Figure 42: Control chart for percent saturation dissolved oxygen in the Broken River at Goorambat 1991 – 2016

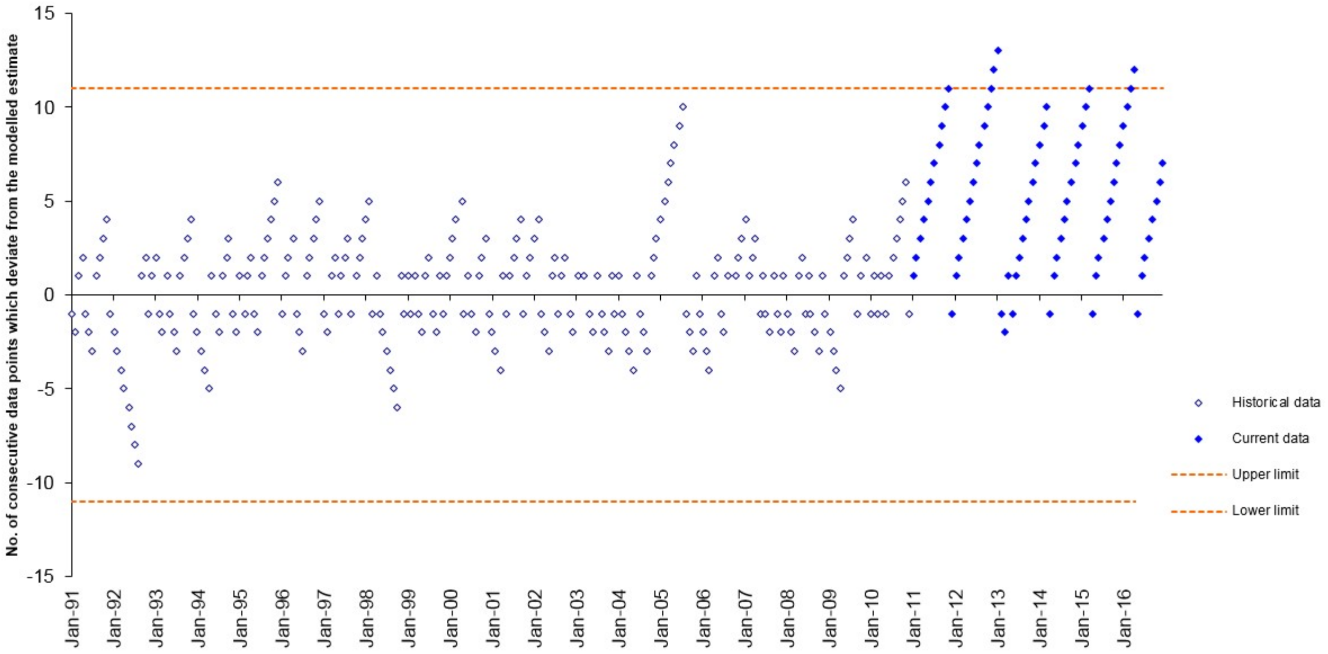


Figure 43: Run chart for dissolved oxygen (mg/L) in the Broken River at Goorambat 1991 – 2016

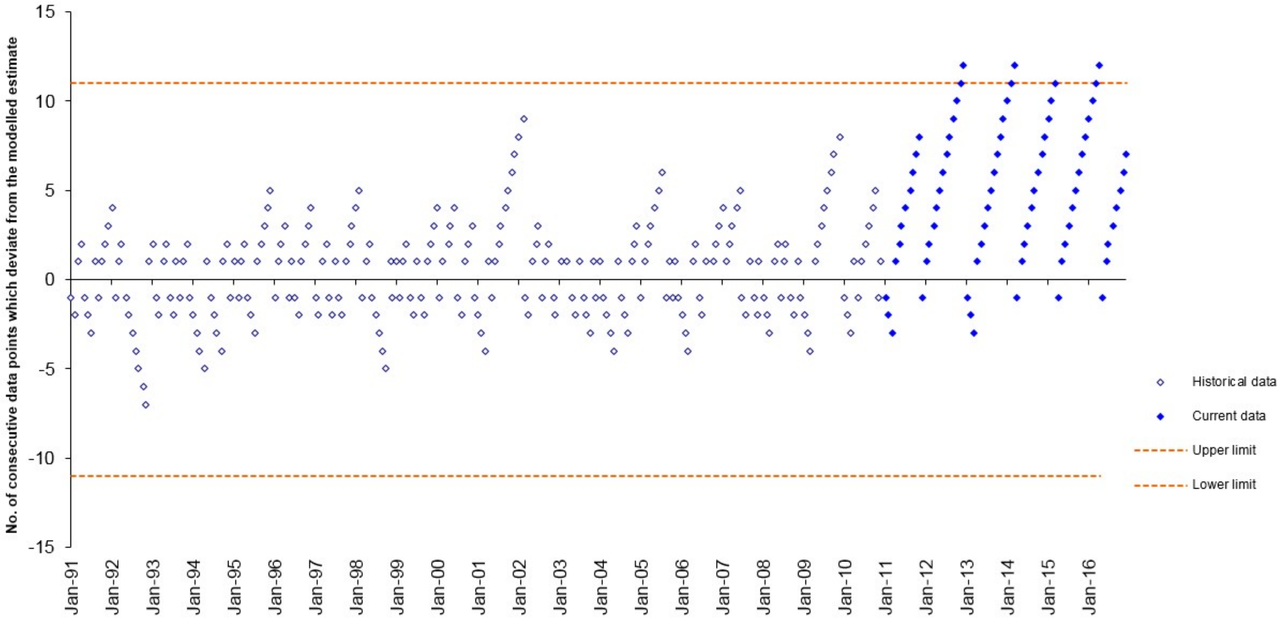


Figure 44: Run chart for percent saturation dissolved oxygen in the Broken River at Goorambat 1991 - 2016

5.3.2 Turbidity

Variation in turbidity in the Broken River at Goorambat (404216) was very poorly explained (R^2=0.18) by a combination of temperature, date, flow and number of rainy days (Table 27). A secondary regression model was fitted to explain turbidity in Broken River using a combination of season, date, rainfall, conductivity and flow data from Lake Mokoan pre-2009 (R^2=0.54, Table 27). The improvement in the regression attributes the historical turbidity trends in Broken River to inflows from Lake Mokoan.

A comparison of the current data (2011 to 2016) with historical data (1991 to 2010) showed that the decommissioning of Lake Mokoan in 2009 significantly reduced turbidity levels in the Broken River compared to the historical trends (Table 28). The mean and median turbidity for the current period were lower than for the historical period, whilst the standard deviation was higher.

The SEPP (WoV) trigger level of ≤30 NTU was exceeded on over 50% of occasions during the current period, but there was a general downward trend towards achieving this trigger level. Some very high values were recorded, including one value of over 600 NTU, but these and other very high values occur only on a small number of isolated occasions. The run chart shows that turbidity was evenly under predicted and over predicted by the model for the current period (Figure 47).

Table 27: Best fit regression models to describe variation in turbidity in the Broken River at Goorambat between 1991 and 2005, 1991 to 2010, as well as 1991 and 2009

Parameter		Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Regression model between 1991 and 2005	**Turbidity (NTU)**	Turbidity = –15.8494 + (0.005257*FlowBroken) + (0.2954*EC) + (3.9635*FlowMokoan$^{0.4}$)	171	0.75	36%
Regression model between 1991 and 2010	**Turbidity (NTU)**	TURBIDITY = -393.6905 + 3.0266*Temp + 0.0075*JDate + 0.0120*Flow + 0.0857*RainDays	237	0.18	89%
Regression model between 1991 and 2009 **(Mokon flow record ends prior to 2009)**	**Turbidity (NTU)**	Turbidity = -270.044 + 6.283*MonthSIN + 0.00542*JDate + 0.0947*RainDays + (5.578*FlowMokoan$^{0.4}$) + 0.1126*Conductivity	211	0.54	58%

Table 28: Summary statistics for historical (1991- 2010) and current (2011-2016) turbidity data recorded in the in the Broken River at Goorambat

Heading	Record	N	Mean	Median	Standard Deviation
Turbidity (NTU)	Historical	238	59	40	58
	Current	72	46	31	80
	Overall	310	56	37	63

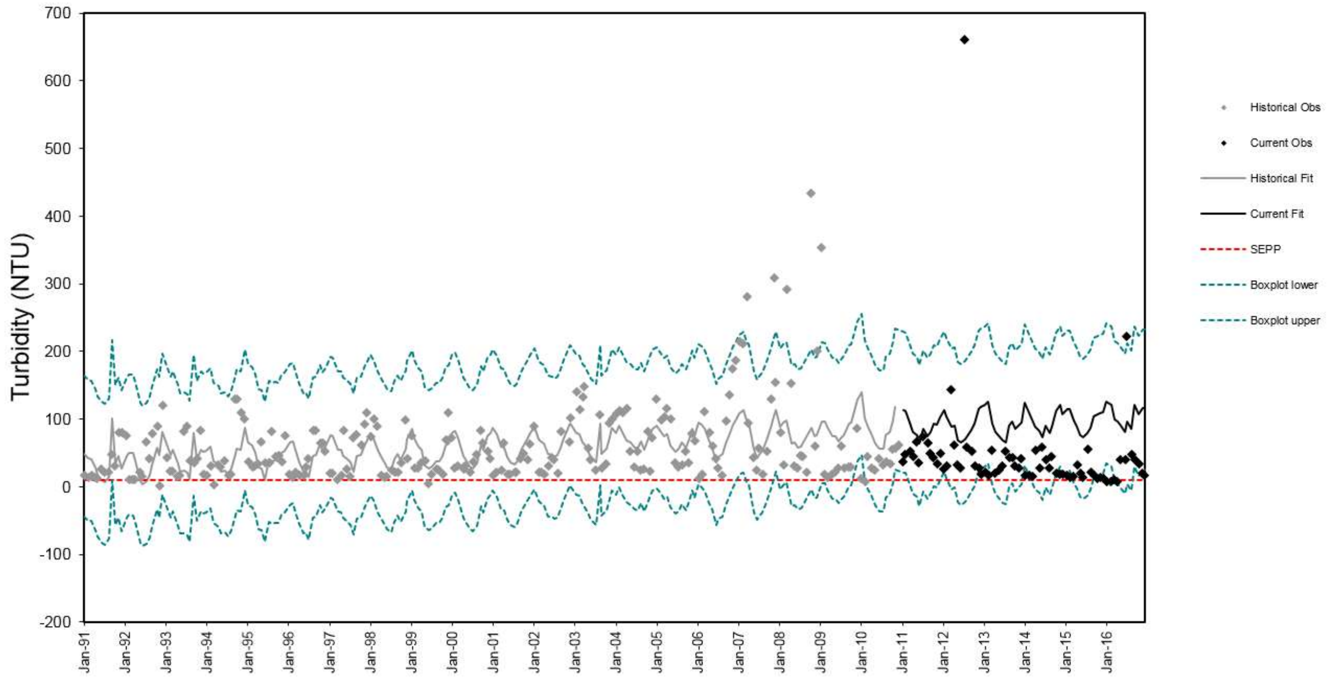


Figure 45: Control chart for turbidity (in NTU) in the Broken River at Goorambat 1991 - 2016.

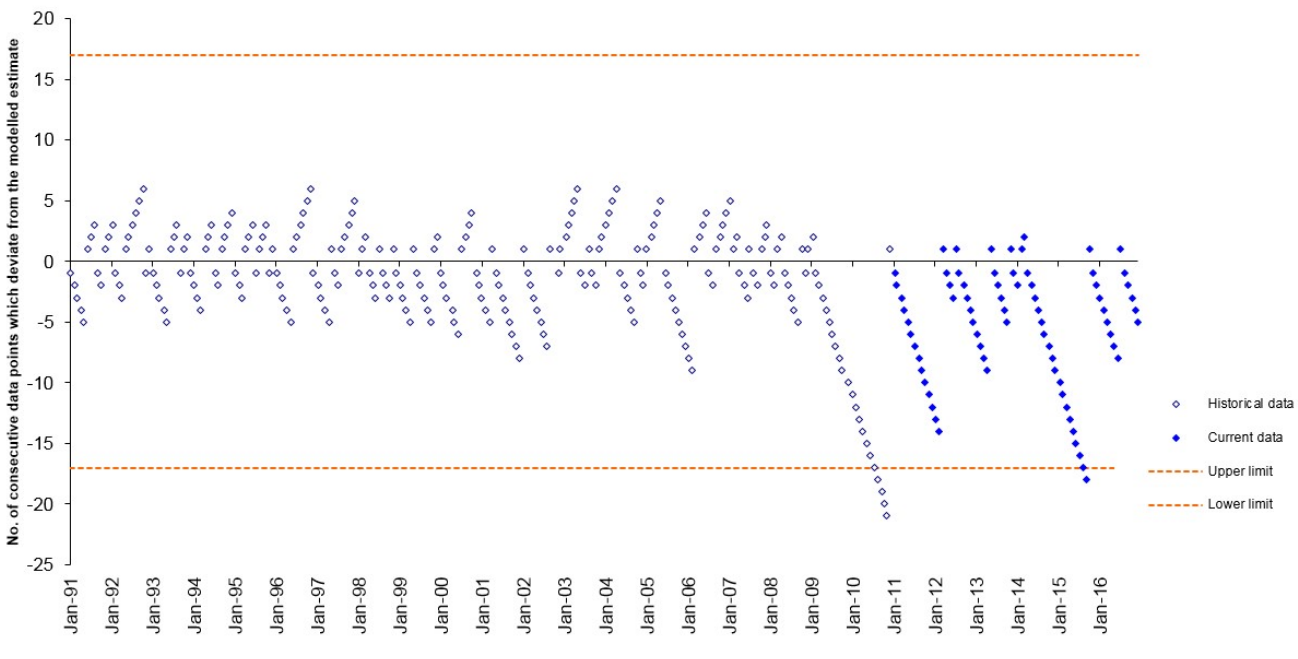


Figure 46: Control chart for turbidity (in NTU) in the Broken River at Goorambat 1991 – 2016 (regression model is limited by Mokoan flow record)

.

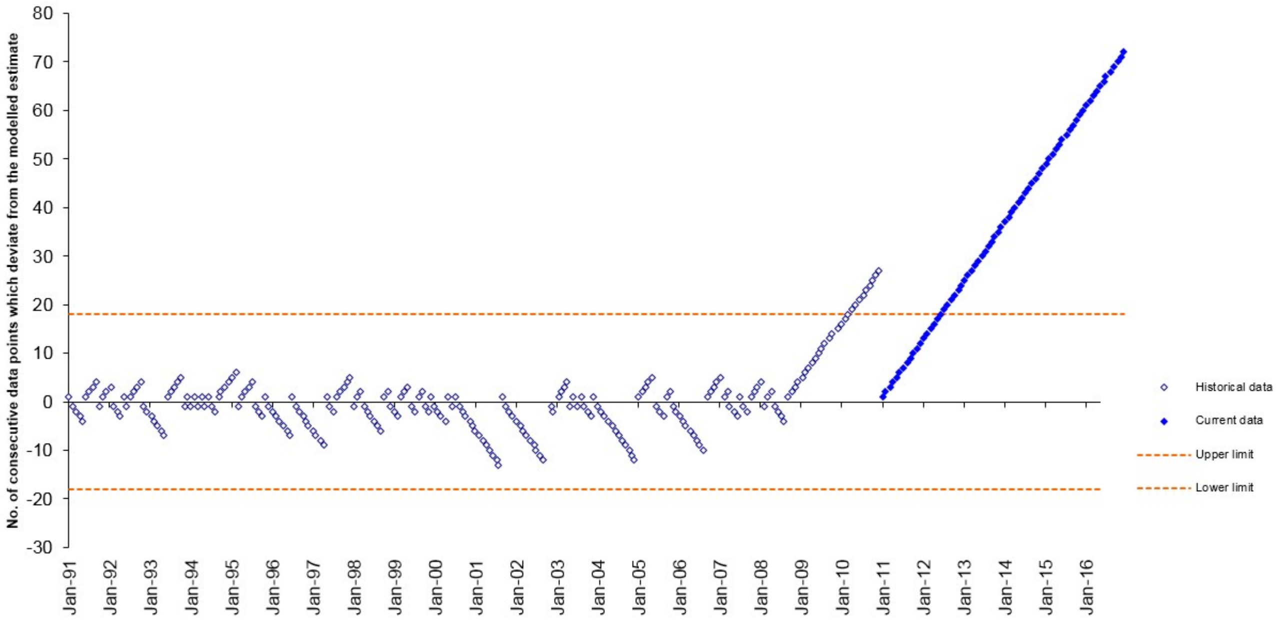


Figure 47: Run chart for turbidity (in NTU) in the Broken River at Goorambat 1991 - 2016

5.3.3 Electrical conductivity

Variation in EC in the Broken River at Goorambat was very poorly explained by a combination of temperature, date, flow and rainfall (R^2=0.105, Table 29). The average and median EC levels were significantly lower in the current (2011-2016) period than during the historical period (Table 30). The historical data period was dominated by the Millennium Drought (1996 to mid-2010) with associated increases in EC from evapo-concentration during very low flow conditions in the river. The current data shows that the EC levels dropped during 2010 and remained at that lower level (Figure 48). The recorded data is still within the control limits, however closer to the lower limit (Figure 48, Figure 49). The long run of consecutive data points that deviation from the estimate, as shown in Figure 49, are probably reflective of the poor model fit. There was significantly less variation in the EC data for the current period (standard deviation of 20) compared with the historical period (standard deviation of 104). The isolated, very high EC values recorded in the period between 2000 and 2010 (associated with drought conditions) were not recorded in the current period. The data is consistently well below the SEPP (WoV) trigger value of 500 µS/cm. The EC trend analysis shows a significant reduction in EC conditions in Broken Creek post-drought and post the decommissioning of Lake Mokoan. As both of these events occurred after the historical period used to determine the best regression fit for the models, the model was unable to accurately predict the decrease in levels, as shown in Figure 5-11 which indicates that the majority of observations were lower than the modelled estimate.

Table 29: Best fit regression models to describe variation in conductivity in the Broken River at Goorambat between 1991 and 2005, and 1991 to 2010

Parameter		Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Regression model between 1991 and 2005	**Electrical Conductivity (µS/cm)**	$EC^{0.4} = 8.375 - (0.0257*Temp) - (0.0856*FlowBroken^{0.4}) + (0.137*FlowMokoan^{0.4})$	172	0.45	22%
Regression model between 1991 and 2010	**Electrical Conductivity (µS/cm)**	$EC = (-0.261 + 0.0306*Temp + 0.000150*JDate - 0.000132*Flow - 0.0170*Rain72)^{(1/0.4)}$	237	0.105	17%

Table 30: Summary statistics for historical (1991- 2010) and current (2011-2016) conductivity data recorded in the in the Broken River at Goorambat

Heading	Record	N	Mean	Median	Standard Deviation
Electrical conductivity (µS/cm)	Historical	237	186	160	104
	Current	64	129	127	20
	Overall	301	174	150	95

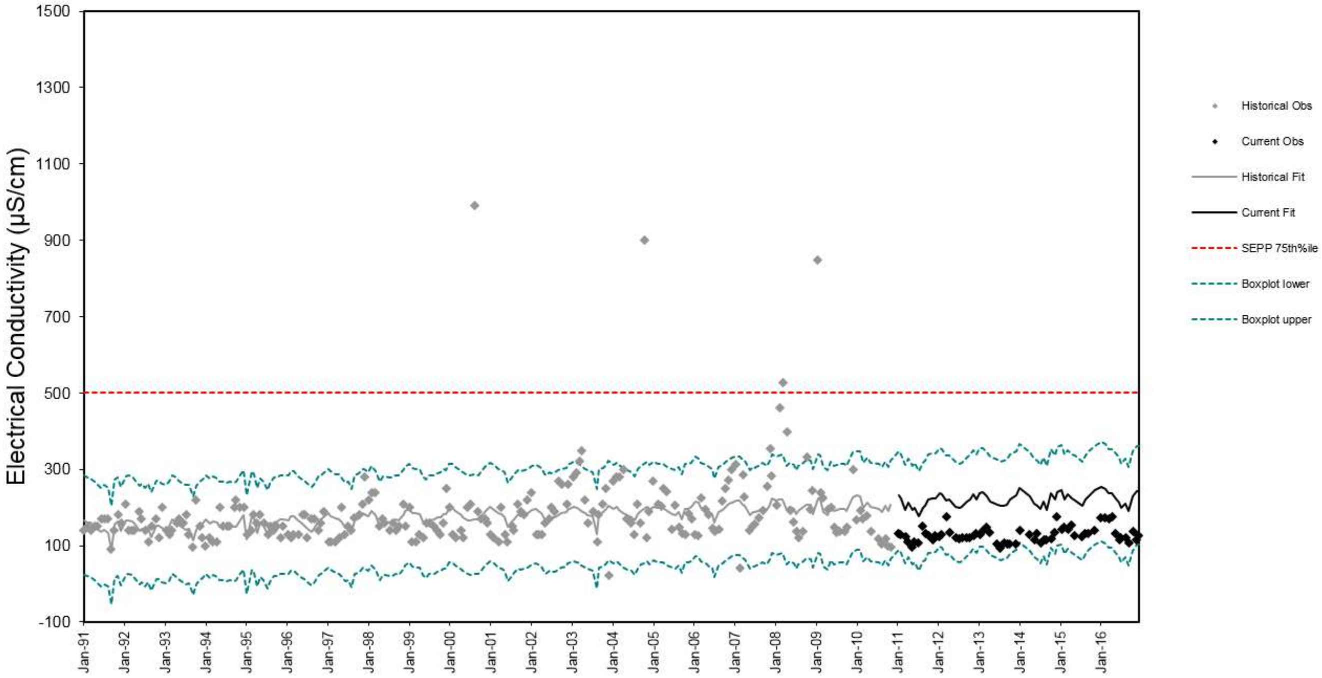


Figure 48: Control chart for electrical conductivity (in µS/cm) in the Broken River at Goorambat 1991 – 2016

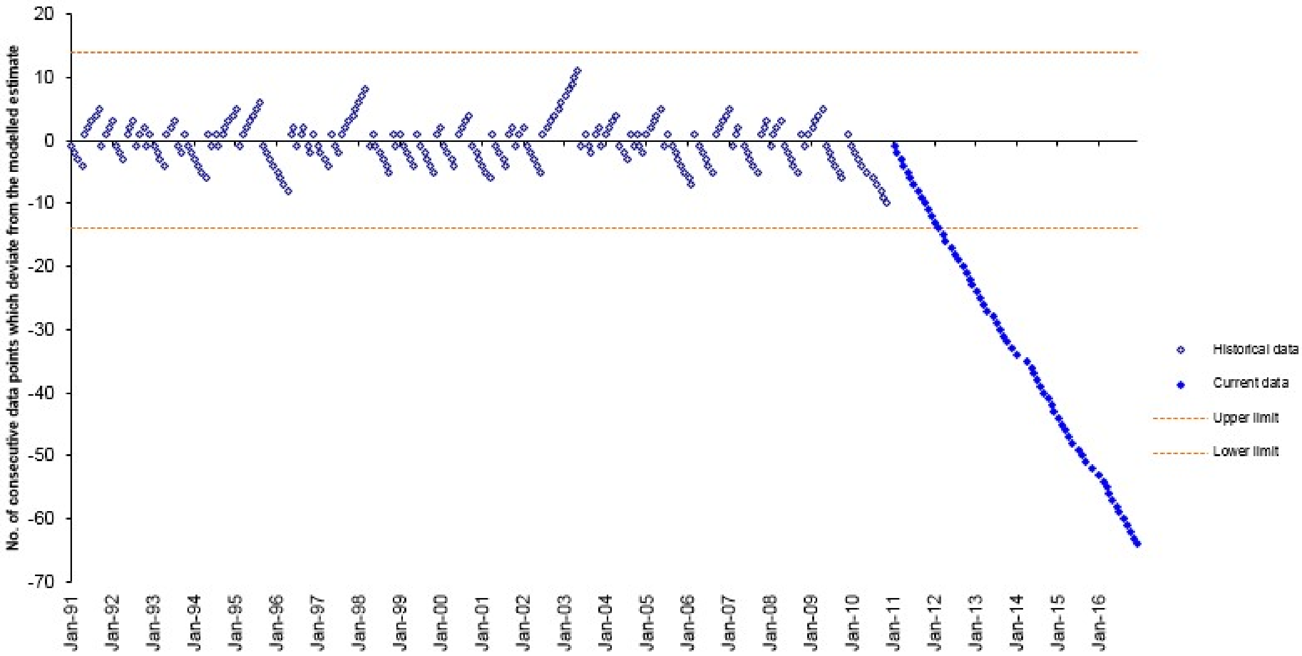


Figure 49: Run chart for electrical conductivity (in µS/cm) in the Broken River at Goorambat 1991 – 2016

5.3.4 Total nitrogen

Variation in total nitrogen in the Broken River at Goorambat was very poorly explained by a combination of season, date, rainy days and turbidity ($R^2 = 0.32$, Table 31). Table 32 shows that the mean and median for total nitrogen of the current period was lower and less variable than the historical period. Total nitrogen levels during the current period achieved the SEPP (WoV) trigger value of 0.9 mg/L more frequently than during the historic period (Figure 50). This analysis shows that nitrogen levels in Broken River have reduced from the decommissioning of Lake Mokoan in 2009 and correlated with a reduction in turbidity in the River.

Table 31: Best fit regression models to describe variation in total nitrogen in the Broken River at Goorambat between 1991 and 2005, and 1991 to 2010

Parameter		Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Regression model between 1991 and 2005	**Nitrate + Nitrite (mg/L)**	$NOx = 0.448 – (0.0777*Season)– (0.0118*Temp) + (0.00188*FlowBroken^{0.4})$	174	0.21	80%
Regression model between 1991 and 2010	**Total nitrogen (mg/L)**	$TN = (1.733 - 0.0953*MonthSIN - 0.0000151*JDate - 0.000331*RainDays + 0.00129*Turbidity)^{(1/0.4)}$	235	0.32	15%

Table 32: Summary statistics for historical (1991- 2010) and current (2011-2016) total nitrogen data recorded in the in the Broken River at Goorambat

Heading	Record	N	Mean	Median	Standard Deviation
Total nitrogen (mg/L)	Historical	237	1.05	0.97	0.51
	Current	72	0.85	0.69	0.44
	Overall	309	1.01	0.88	0.50

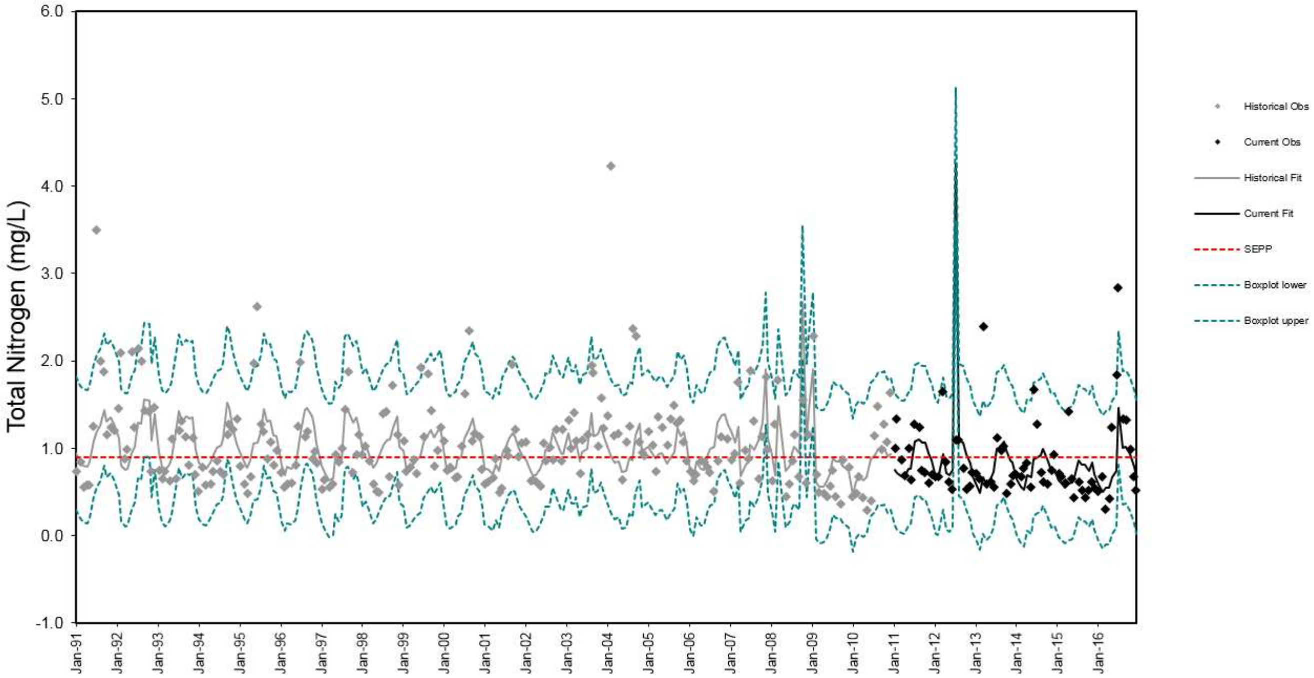


Figure 50: Control chart for total nitrogen (in mg/L) in the Broken River at Goorambat 1991 - 2016.

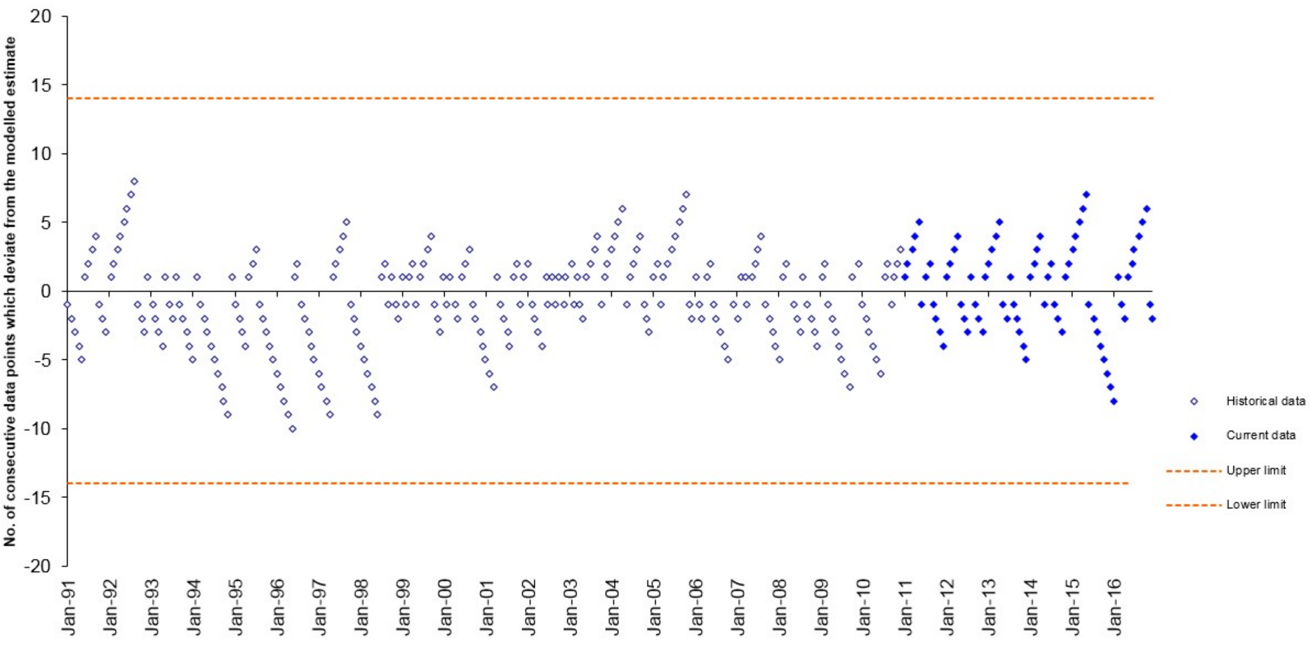


Figure 51: Run chart for total nitrogen (in mg/L) in the Broken River at Goorambat 1991 - 2016.

5.3.5 Total phosphorus

Variation in total phosphorus in the Broken River at Goorambat was very poorly explained by a combination of season, flow and turbidity (R^2=0.32, Table 33). The model consistently overestimated total phosphorus concentrations and predicted a cyclical pattern in TP levels which was not well matched by the data. Average and median total phosphorus levels at this site were lower during the current period than the historic period. This decline in total phosphorus levels was consistent with the decrease observed in turbidity levels and total nitrogen levels for 2010 to 2016. This underestimation of recorded data by the model occurs for considerable lengths of time, as shown in the run chart in Figure 53. This analysis shows that total phosphorus levels have reduced in Broken Creek most likely due to the decommissioning of Lake Mokoan in 2009, compared to the historical trajectory, but still frequently exceeded the SEPP WQO of 0.045 mg/L (Figure 52).

Table 33: Best fit regression models to describe variation in total phosphorus in the Broken River at Goorambat between 1991 and 2005, and 1991 to 2010

Parameter		Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Regression model between 1991 and 2005	Total phosphorus (mg/L)	$TP = (-0.1061 – (0.063*Season) + (0.00001014*Date) – (0.005752*FlowBroken^{0.4}) + (0.0009455*Turbidity))^{(1/0.4)}$	172	0.42	41%
Regression model between 1991 and 2010	Total phosphorus (mg/L)	TP = 0.0875 - 0.0351*MonthSIN - 0.0000132*Flow + 0.000528*Turbidity	232	0.32	50%

Table 34: Summary statistics for historical (1991- 2010) and current (2011-2016) total phosphorus data recorded in the in the Broken River at Goorambat

Heading	Record	N	Mean	Median	Standard Deviation
Total phosphorus (mg/L)	Historical	235	0.114	0.1	0.068
	Current	72	0.08	0.072	0.052
	Overall	307	0.106	0.09	0.066

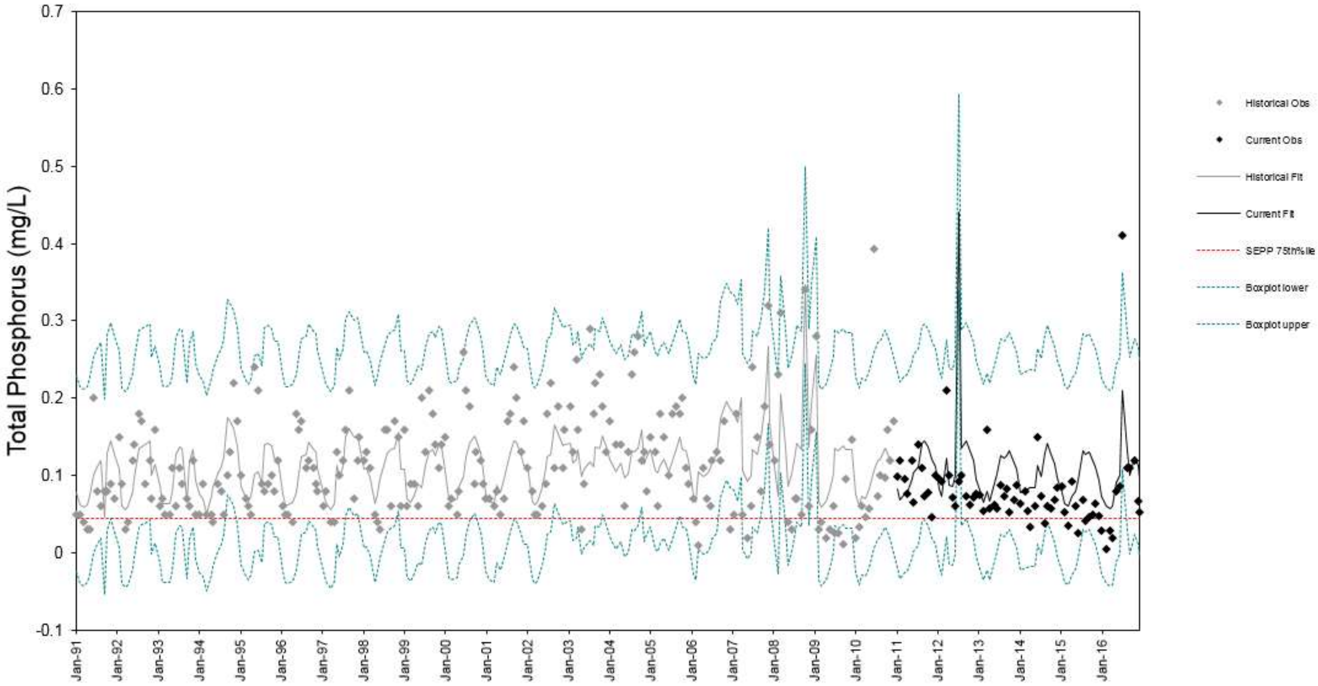


Figure 52: Control chart for total phosphorus (in mg/L) in the Broken River at Goorambat 1991 - 2016.

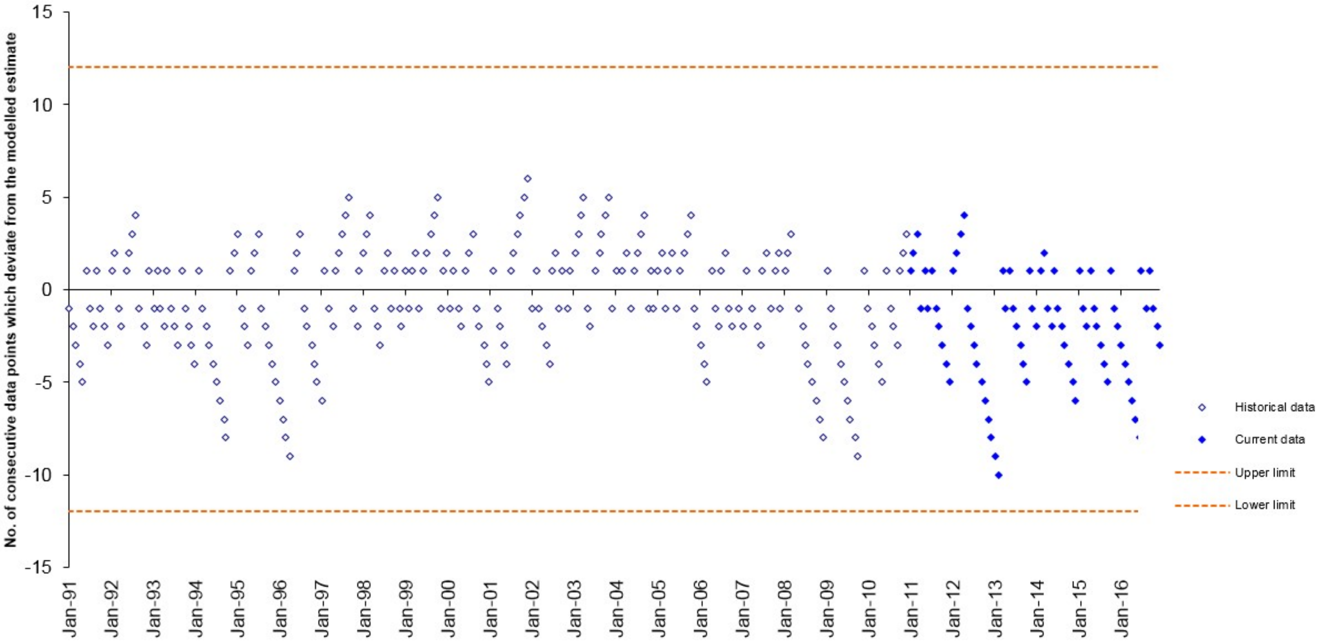


Figure 53: Run chart for total phosphorus (in mg/L) in the Broken River at Goorambat 1991 - 2016

6. Results for Barwon River at Pollocksford (233200)

6.1 Site Location

The Barwon River at Pollocksford (streamflow gauge number 233200) is located in the lower reaches of the Barwon River, downstream of the junction with the Leigh River, but upstream of the junction with the Moorabool River, as shown in Figure 54. The Barwon River rises in the Otway ranges and flows in a north-easterly direction, joined by 13 tributaries. The Barwon River flows through the greater Geelong area and Lake Connewarre before discharging into Bass Strait at Barwon Heads. Pollocksford is approximately 15 km west of central Geelong.

The Corangamite Catchment Management Authority (CMA) nominated the site as being of interest from a water quality perspective as it is in the lower part of the catchment and potentially integrates the effects on water quality across the whole Barwon River catchment

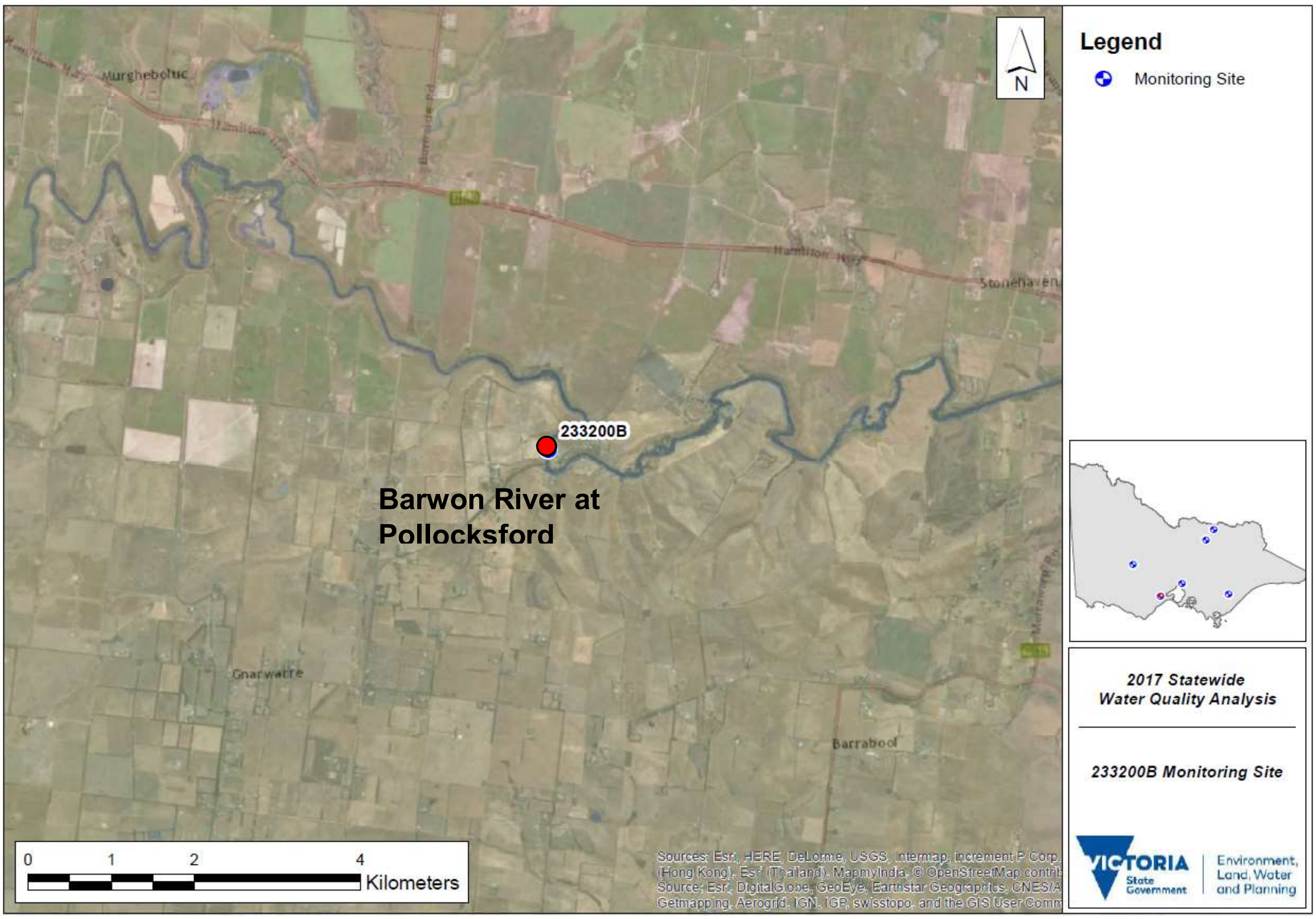


Figure 54: Locality map for Barwon River at Pollocksford

6.2 Data availability and quality

Water quality was monitored at Pollocksford on 245 occasions between January 1991 and December 2010 (Table 35). Data was readily available, with only a small number of data points missing flow and / or rainfall data which had to be excluded from the analysis.

Table 35: Missing data over period of regression model fit (Jan 1991 – Dec 2010)

Missing data elements	Dissolved oxygen	Turbidity	Electrical conductivity	pH	Total nitrogen	Total phosphorus
No. of missing water quality readings on days when at least one other parameter was recorded	252	248	248	251	246	246
No. of data points removed as outliers	0	0	0	0	0	0
No. of data points not analysed due to missing water temperature data	0	0	0	-	0	-
No. of data points not analysed due to missing or zero flow data	3	3	3	3	3	3
No. of data points not analysed due to missing rainfall data	-	-	-	11	11	11
Sample size for regression analysis	232	234	234	231	225	225

Water quality was monitored on 74 occasions between January 2011 to December 2016. Whilst there were no days with ‘zero flow’ readings, there was a small number of data points with missing flow data which were excluded from the analysis (Table 36).

Table 36: Missing data over period of control chart application (2011 – 2016)

Missing data elements	Dissolved oxygen	Turbidity	Electrical conductivity	pH	Total nitrogen	Total phosphorus
No. of missing water quality readings on days when at least one other parameter was recorded	0	0	0	0	1	1
No. of data points removed as outliers	0	0	0	0	0	0
No. of data points not analysed due to missing water temperature data	0	0	0	-	0	-
No. of data points not analysed due to missing or zero flow data	3	3	3	3	3	3
No. of data points not analysed due to missing rainfall data	-	-	-	0	-	0
Sample size for control chart application	71	71	71	71	70	70

6.3 Results for each water quality variable

6.3.1 Dissolved oxygen

The best fit regression model for DO in the Barwon River at Pollocksford (233200) used date and water temperature as explanatory factors. The R^2 value of 0.224 shows that the model was poorly explained and was not a strong predictor of DO data, due in part to the number of outlier data points that fell well outside the model predictions. A decline in mean and median DO values (mg/L and % sat) was noted between historical and current data (Table 38). Both the historic and current data shows some variability and included some outlying values that exceeded the lower and upper boundaries of the model (Figure 55). The standard deviation in the historical data was slightly higher than for the current data (Table 38). The low DO levels were low enough to threaten aquatic biota and warrant further investigation. The high DO levels are most likely due to super saturation from high levels of primary production associated with an algal bloom or prolific plant growth, which are more likely to occur during prolonged periods of low flow with warm temperatures. Low dissolved oxygen can also occur as a result of these algal blooms, either at night due to algal respiration causing dissolved oxygen depletion, or during the breakdown process.

The percentage saturation model very poorly explained variation in dissolved oxygen using a combination of season, water temperature, date, flow and rainfall data (R^2 = 0.064, Table 37). The model significantly underestimated the low dissolved oxygen peaks during the warmer months. A number of points were well below the lower SEPP (WoV) trigger level of 85%, including some observations, which were outside of the model limits (Figure 56).

Table 37: Best fit regression models to describe variation in dissolved oxygen in the Barwon River at Pollocksford between 1991 and 2005, and 1991 to 2010

Parameter		Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Regression model between 1991 and 2005	**Dissolved Oxygen mg/L**	DO = 26.977 – (0.000274*Date) – (0.201*Temp) – (0.0462*$Flow^{0.4}$)	168	0.37	13%
	Dissolved oxygen % Sat	DO% = 238.929 – (0.00278*Date) – (0.426*$Flow^{0.4}$)	168	0.10	14%
Regression model between 1991 and 2010	**Dissolved Oxygen mg/L**	DO = 17.283 - 0.171*Temp - 0.0001*JDate	232	0.224	16%
	Dissolved oxygen % Sat	DO% = 151.0233 – 4.658*MonthSIN + 0.644*Temp – 0.00123*JDate – 0.00337*Flow – 0.00979*RainDays	230	0.064	17%

Table 38: Summary statistics for historical (1991-2010) and current (2011 – 2016) dissolved oxygen data

Parameter	Record	N	Mean	Median	Standard Deviation
Dissolved oxygen mg/L	Historical	232	9.4	9.6	1.8
	Current	71	8.5	8.8	1.7
	Overall	303	9.2	9.4	1.8
Dissolved oxygen % Sat	Historical	232	94	94	17
	Current	71	86	90	15
	Overall	303	92	93	17

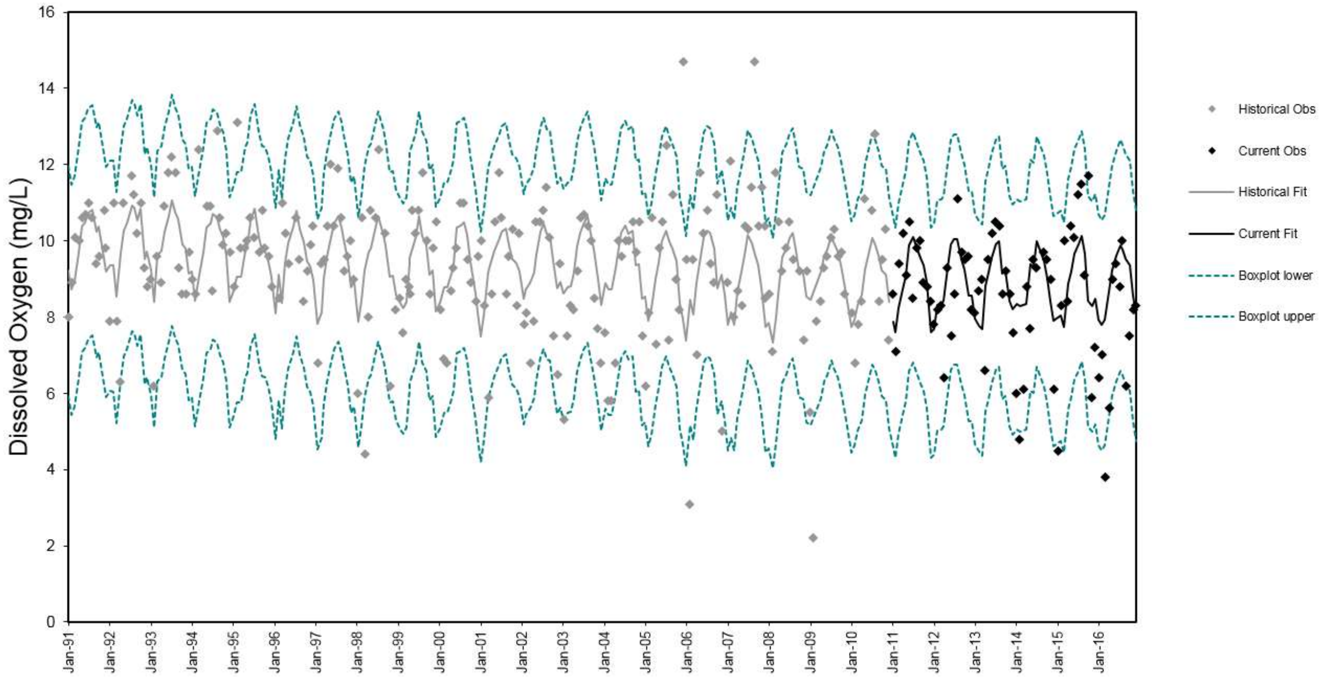


Figure 55: Control chart for dissolved oxygen (mg/L) in the Barwon River at Pollocksford 1991 – 2016

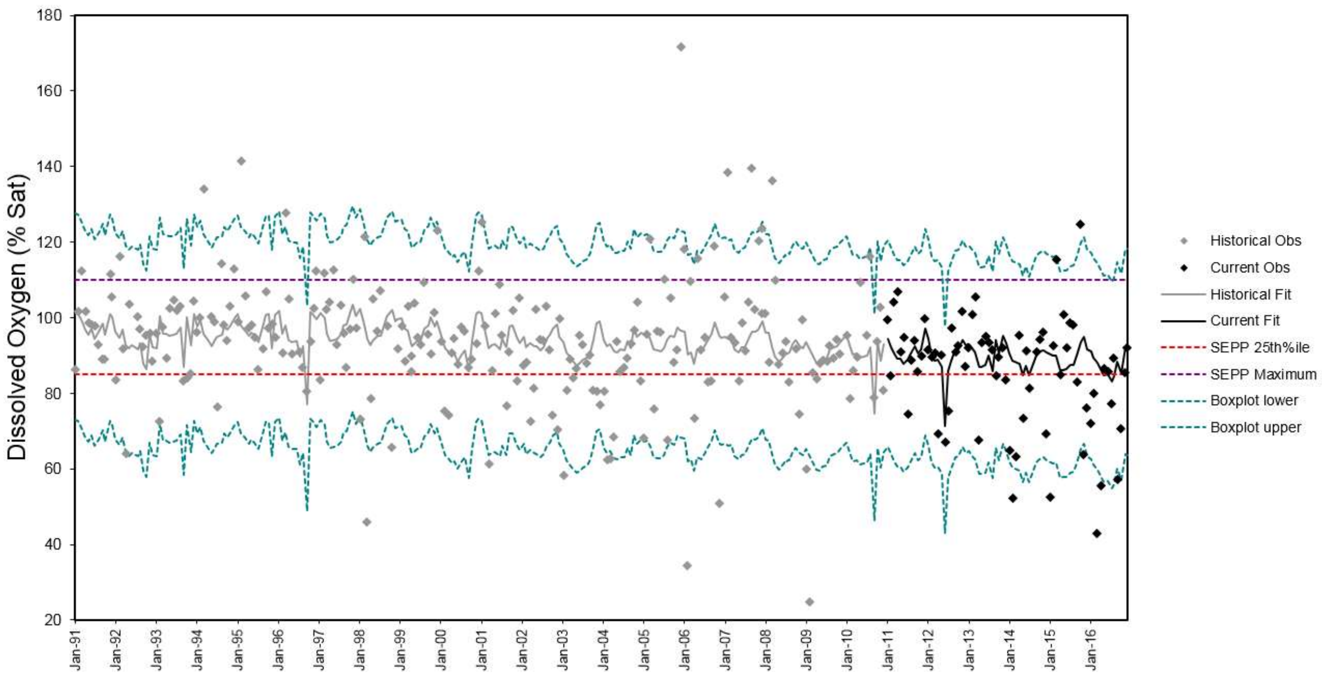


Figure 56: Control chart for percent saturation dissolved oxygen in the Barwon River at Pollocksford 1991 – 2016

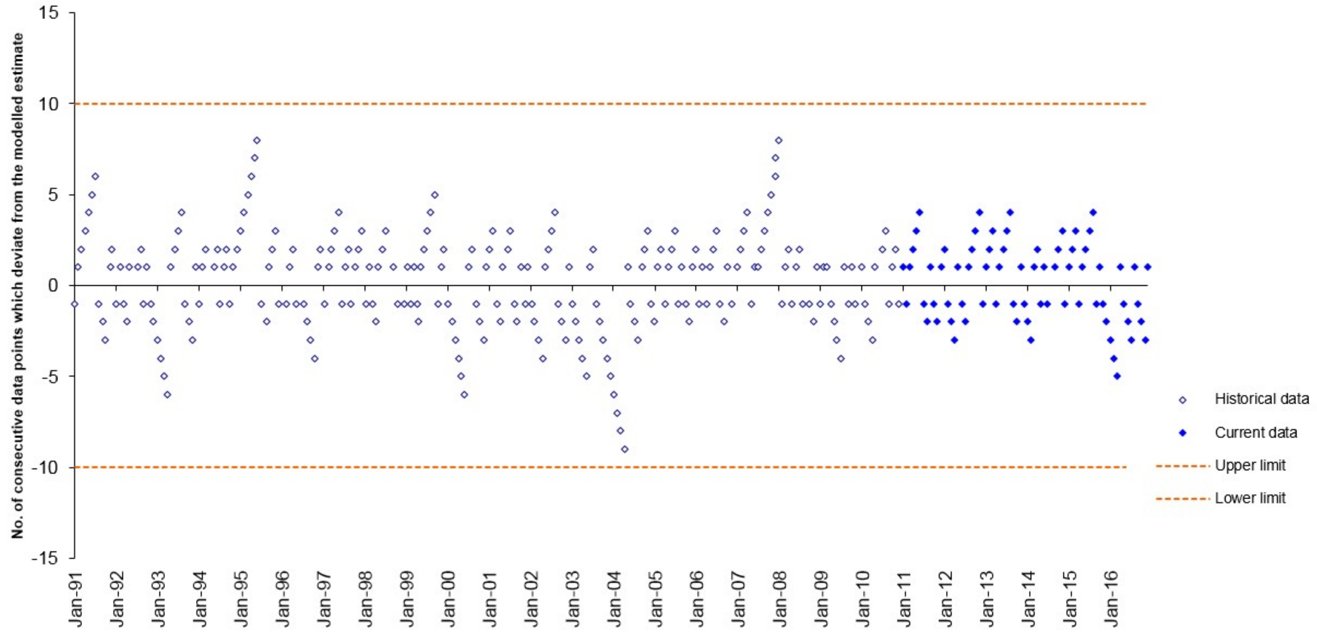


Figure 57: Run chart for dissolved oxygen (mg/L) in the Barwon River at Pollocksford 1991 – 2016

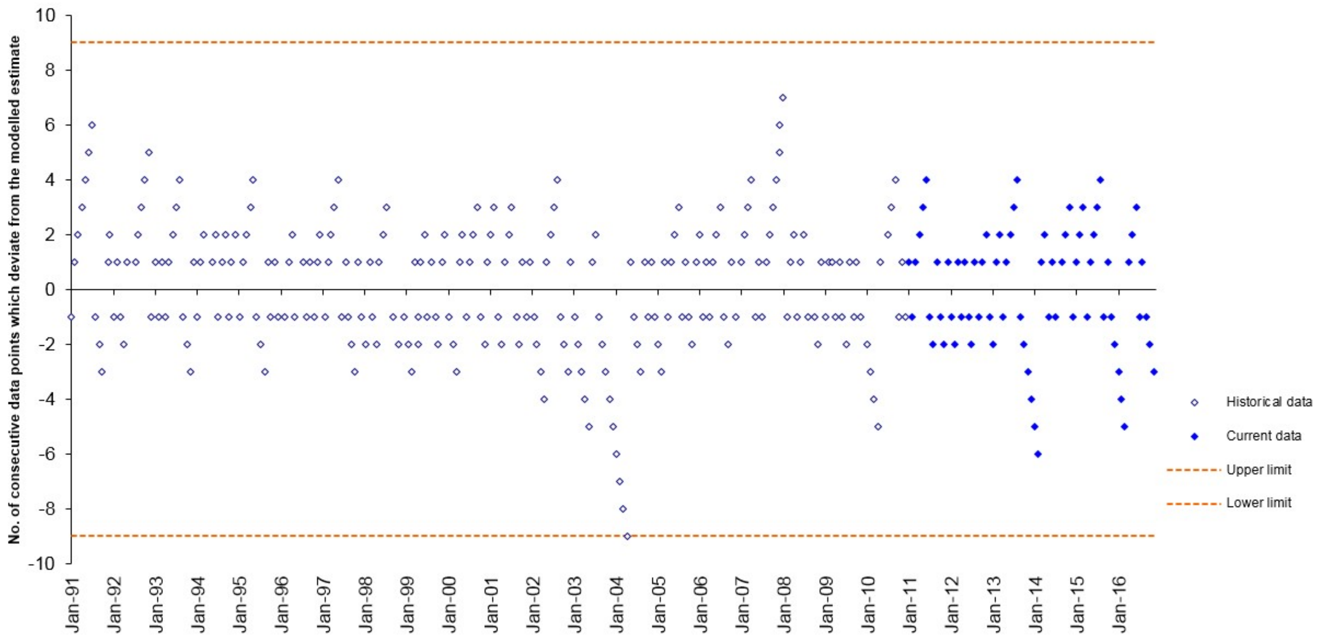


Figure 58: Run chart for percent saturation dissolved oxygen in the Barwon River at Pollocksford 1991 – 2016

6.3.2 Turbidity

At Barwon River at Pollocksford, variation in turbidity levels are moderately well explained (R^2=0.71) by the flow in the river (Table 39). The model fit of the historical data was good and able to successfully capture the peaks and overall trends of the data (Figure 59). However, with the return to wetter conditions, the historical data was not a good predictor of the current data.

The current data exceeded the SEPP (WoV) trigger value of 10 NTU at Barwon River at Pollocksford more frequently than over the historical record (Figure 59). The SEPP (WoV) objective for 75% of monthly readings to be below 10 NTU in any given twelve-month period was generally met during the historical period. However, after 2010 the data frequently exceeded this trigger value, with some data well in excess of the SEPP objective. This is reflected in the mean of 29 NTU over the current period (Table 40) as opposed to the historical period which had a mean value of 13 – less than half that of the current period. This is also shown in the jump in standard deviation of current data, implying an increase in distribution and variability of more recent data. This increase in turbidity coincided with the floods and heavy rainfall that occurred from 2011, causing an influx of sediment and runoff into the river. In contrast the data in the historic period was recorded during a period, which was characterised by significant spells of drought and low flows. These conditions are likely to result in lower turbidity due to lack of inflows and movement in the water. The run chart in Figure 60 highlights the increase and substantial changes in turbidity levels when comparing current and historic data.

Table 39: Best fit regression models to describe variation in turbidity in the Barwon River at Pollocksford between 1991 and 2005, and 1991 to 2010

Parameter		Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Regression model between 1991 and 2005	**Turbidity (NTU)**	Turbidity = 165.346 – (0.00247*Date) + (0.0129*Flow) – (0.0164*EC)	172	0.58	109%
Regression model between 1991 and 2010	**Turbidity (NTU)**	$TURBIDITY = (0.583 + (0.222*Flow^{0.4}))^{(1/0.4)}$	234	0.711	34%

Table 40: Summary statistics for historical (1991- 2010) and current (2011-2016) turbidity data recorded in the in the Barwon River at Pollocksford

Parameter	Record	N	Mean	Median	Standard Deviation
Turbidity (NTU)	Historical	236	13	3.2	27
	Current	71	29	7.6	68
	Overall	307	17	3.6	41

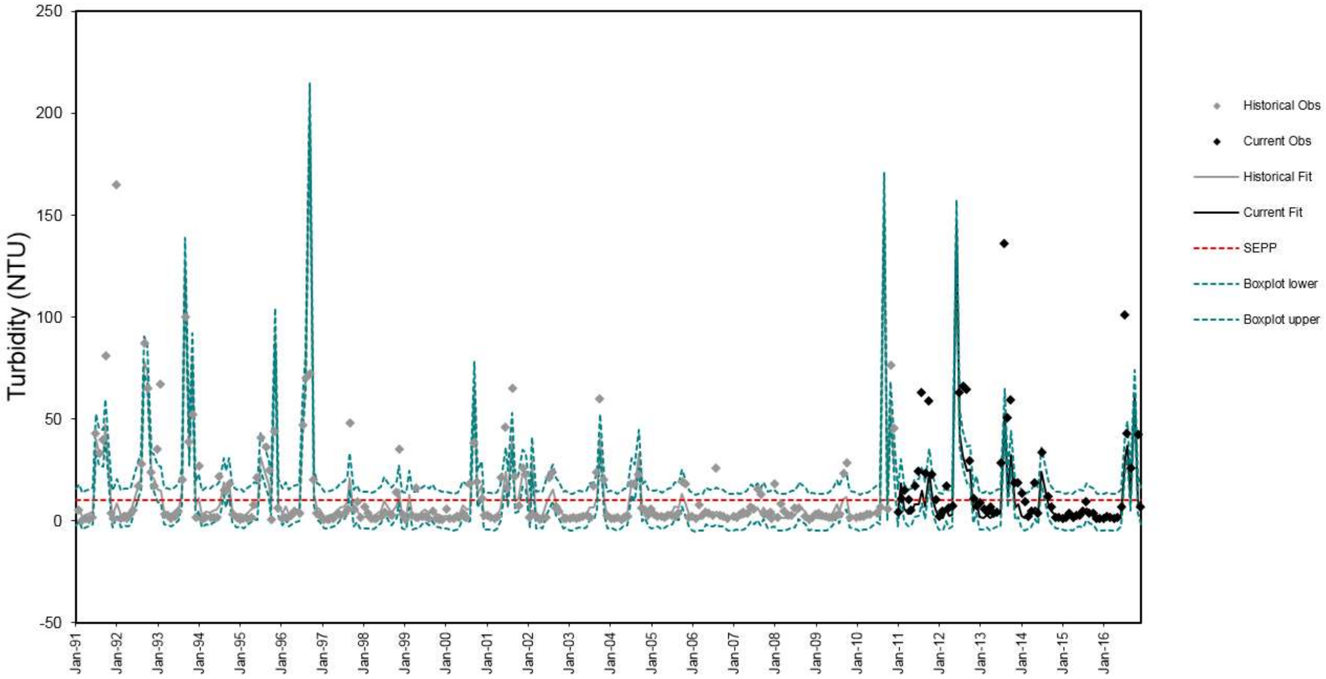


Figure 59: Control chart for turbidity (in NTU) in the Barwon River at Pollocksford 1991 - 2016

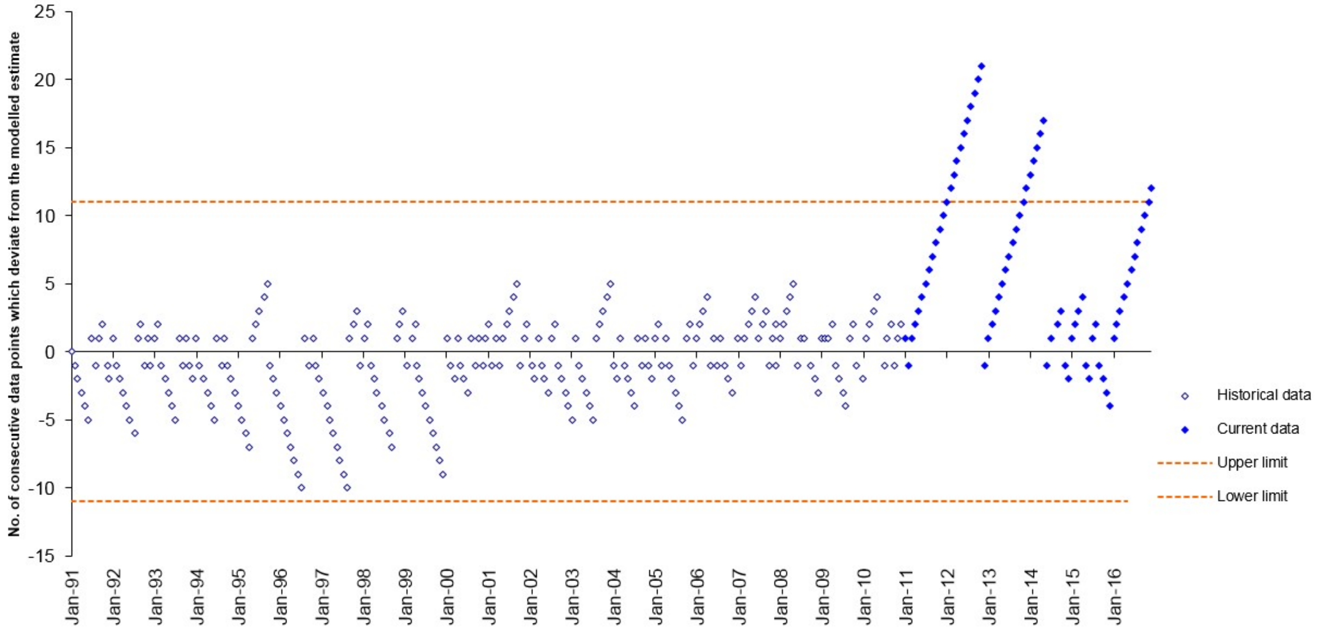


Figure 60: Run chart for turbidity (in NTU) in the Barwon River at Pollocksford 1991 - 2016.

6.3.3 Electrical conductivity

The regression model that best explains historical variation in EC at this site used season, water temperature and flow as predictor variables (Table 41). For the period of 1991 to 2016, the model had an R^2 value of 0.496. This indicates that the model predicted the data poorly and there was some variability outlying values outside model predictions.

Average electrical conductivity decreased in the current period compared to the historical data (Table 42) with less values exceeding the SEPP (WoV) trigger value of 1,500 µS/cm. The lower EC values recorded during the current period are likely a result of increased river flows compared the historic period which included the Millennium drought and was associated with higher EC values. This decrease is also shown in the run chart in Figure 52. Apart from a series of high values in 2009, the data is within the control boundaries. The long run of lower than expected EC levels in more recent years will likely have beneficial environmental outcomes in the system.

Table 41: Best fit regression models to describe variation in conductivity in the Barwon River at Pollocksford between 1991 and 2005, and 1991 to 2010

Parameter		Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Regression model between 1991 and 2005	**Electrical Conductivity (µS/cm)**	Turbidity = 165.346 – (0.00247*Date) + (0.0129*Flow) – (0.0164*EC)	172	0.58	109%
Regression model between 1991 and 2010	**Electrical Conductivity (µS/cm)**	$EC = (25.510 + 0.976*MonthSIN - 0.192*Temp + (-0.350*Flow^{0.4}))^{(1/0.4)}$	234	0.496	10%

Table 42: Summary statistics for historical (1991- 2010) and current (2011-2016) conductivity data recorded in the in the Barwon River at Pollocksford

Parameter	Record	N	Mean	Median	Standard Deviation
Electrical conductivity (µS/cm)	Historical	236	1871	1910	626
	Current	71	1633	1610	544
	Overall	307	1816	1900	615

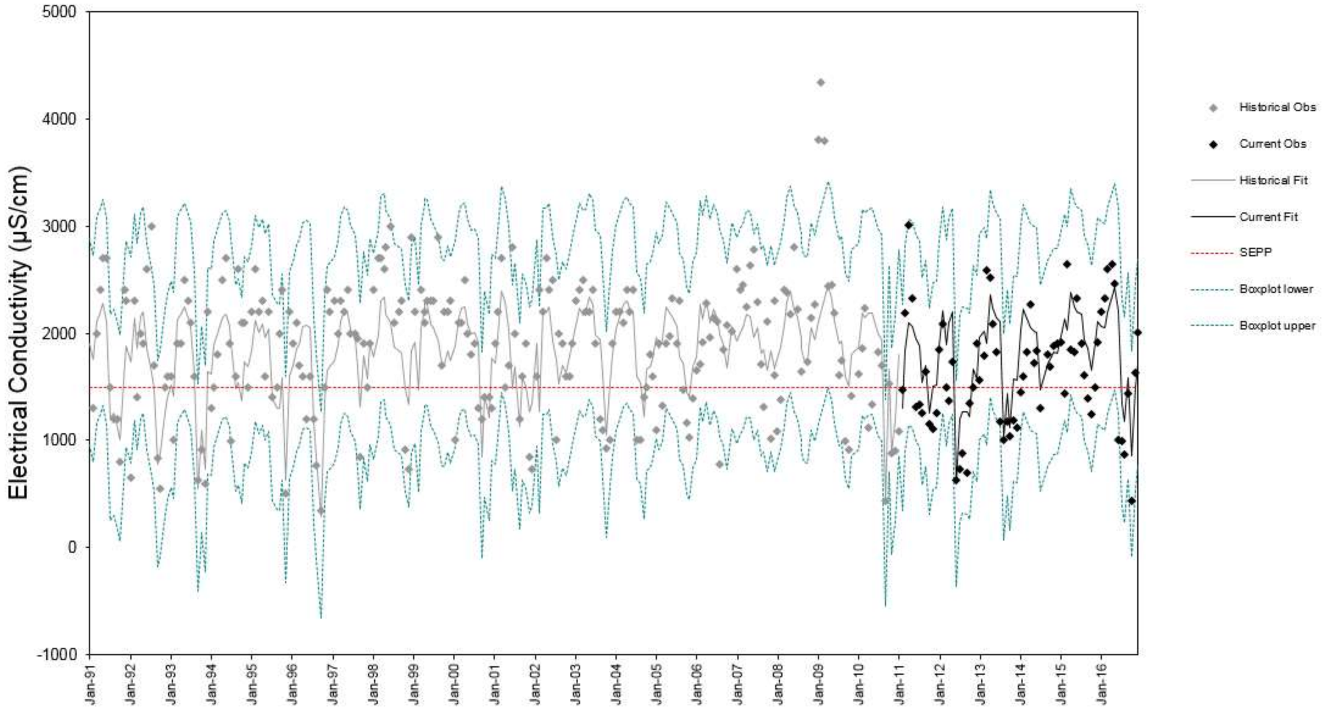


Figure 61: Control chart for electrical conductivity (in µS/cm) in the Barwon River at Pollocksford 1991 – 2016

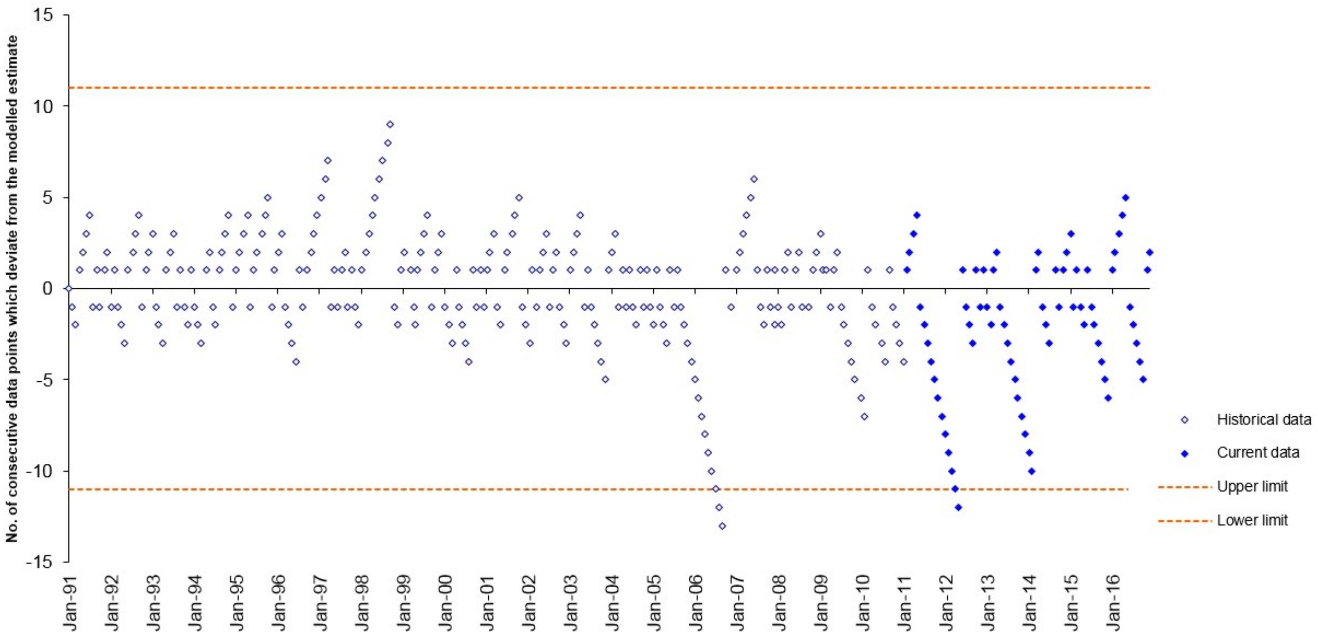


Figure 62: Run chart for electrical conductivity (in µS/cm) in the Barwon River at Pollocksford 1991 – 2016

6.3.4 Total nitrogen

Total nitrogen (TN) for the Barwon River at Pollocksford was very poorly explained using a combination of water temperature, date, flow and cumulative rainfall in the previous 72 hours (R^2 of 0.36, Table 43). Both the current and historic fits captured the peaks of the data well (Figure 63, Figure 64).

Total nitrogen was above the SEPP (WoV) trigger value of ≤0.60 mg/L for a majority of the model run period. However, total nitrogen levels continued the historical downward trend towards achieving the SEPP objective. There was a run of values above the predicted trajectory in 2015 and 2016, potentially triggering further investigation (Figure 63, Figure 64). The model successfully predicted the high nutrient load events from the post-drought floods in 2011 to 2016, with lower values during the drier years. Leigh River, a major tributary of the Barwon River that enters just upstream of the Polllocksford monitoring site, receives STP effluent from Ballarat, which may increase nitrogen levels in the Barwon River (Corangamite CMA 2005). Total nitrogen levels in the current period did not deviate significantly from the predicted trajectory from the historical period given the identified drivers of nitrogen levels in the Barwon River.

Table 43: Best fit regression models to describe variation in total nitrogen in the Barwon River at Pollocksford between 1991 and 2005, and 1991 to 2010

Parameter		Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Regression model between 1991 and 2005	**Nitrate + Nitrite (mg/L)**	$NOx = 6.904 - (0.0308*Temp) - (0.000117*Date) + (0.0197*Flow^{0.4})^{(1/0.4)}$	65	0.33	128%
Regression model between 1991 and 2010	**Total nitrogen (mg/L)**	$TN = (3.4242 - 0.0140*Temp - 0.0000430*JDate + (0.0153*Flow^{0.4}) + 0.00138*Rain72)^{(1/0.4)}$	225	0.36	21%

Table 44: Summary statistics for historical (1991- 2010) and current (2011-2016) total nitrogen data recorded in the in the Barwon River at Pollocksford

Parameter	Record	N	Mean	Median	Standard Deviation
Total nitrogen (mg/L)	Historical	238	1.40	1.06	1.01
	Current	70	1.19	0.91	0.72
	Overall	308	1.35	1.01	0.95

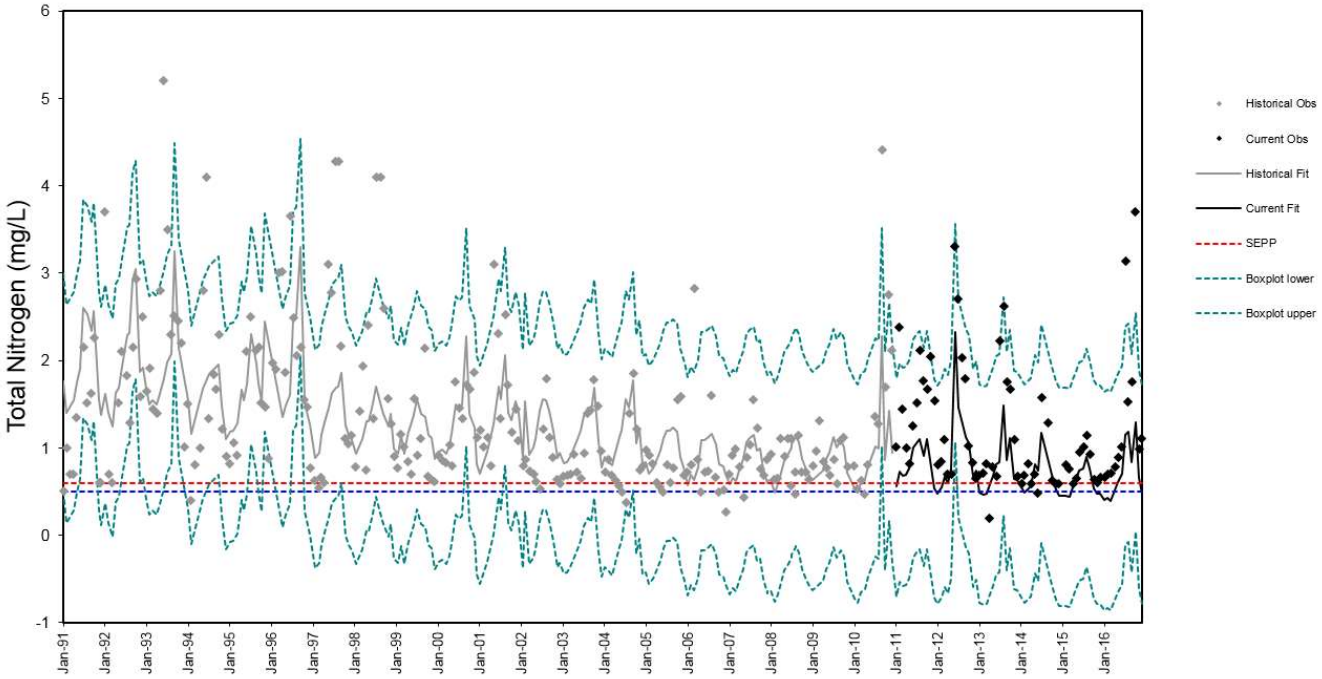


Figure 63: Control chart for total nitrogen (in mg/L) in the Barwon River at Pollocksford 1991 - 2016.

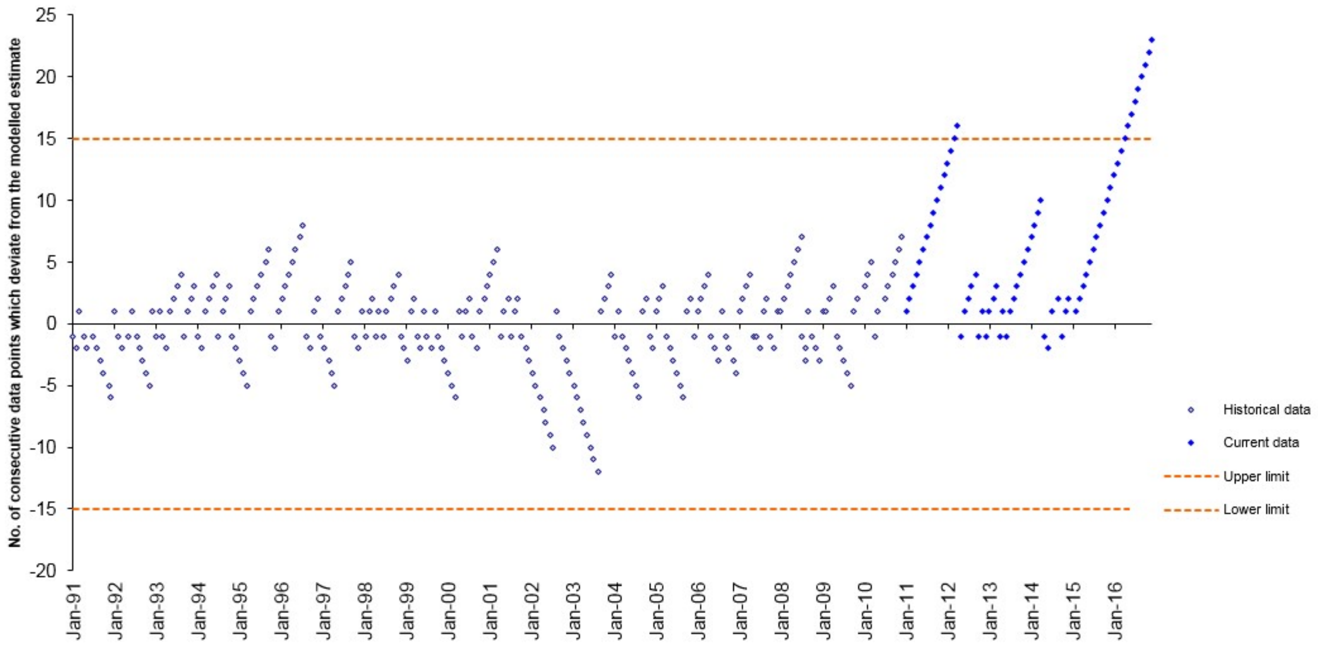


Figure 64: Run chart for total nitrogen (in mg/L) in the Barwon River at Pollocksford 1991 - 2016.

6.3.5 Total phosphorus

Variation in total phosphorus in the Barwon River at Pollocksford between 1991 and 2010 was very poorly explained by season, date, flow and cumulative rainfall in the preceding 72 hours (R^2= 0.264, Table 45).

Total phosphorus levels exhibited a decline from 1991 to 2010 (Figure 65, Figure 66). This trend continued as predicted after 2010, with average and median total phosphorus levels much lower compared to the historical period (Table 46), and less variable. Declining phosphorus levels, but increasing nitrogen levels, have been noted in the Leigh River, a major tributary of the Barwon River that enters just upstream of the Pollocksford monitoring site (Corangamite CMA 2005). Leigh River receives STP effluent from Ballarat, so the decline in total phosphorus may be due to a Biological Nutrient Removal (BNR) upgrade to the South Ballarat Treatment Plant in 1999. Also, farm management plans in the Colac region have been implemented to reduce nutrient-laden runoff.

There was one observation outside of the model controls at the end of the current monitoring period that could trigger further investigation (Figure 65).

Table 45: Best fit regression models to describe variation in total phosphorus in the Barwon River at Pollocksford between 1991 and 2005, and 1991 to 2010

Parameter		Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Regression model between 1991 and 2005	Total phosphorus (mg/L)	TP = $(0.321 + (0.0756*Season) + (0.00713*Flow^{0.4}) + (0.0000196*TimeSinceRain) + (0.00206*Turbidity))^{(1/0.4)}$	51	0.36	45%
Regression model between 1991 and 2010	Total phosphorus (mg/L)	TP = $(1.975 + 0.0756*MonthSIN - 0.0000289*JDate + 0.0000373*Flow + 0.00104*Rain72)^{(1/0.4)}$	225	0.264	29%

Table 46: Summary statistics for historical (1991- 2010) and current (2011-2016) total phosphorus data recorded in the in the Barwon River at Pollocksford

Parameter	Record	N	Mean	Median	Standard Deviation
Total phosphorus (mg/L)	Historical	238	0.198	0.14	0.176
	Current	70	0.094	0.0715	0.088
	Overall	308	0.174	0.12	0.166

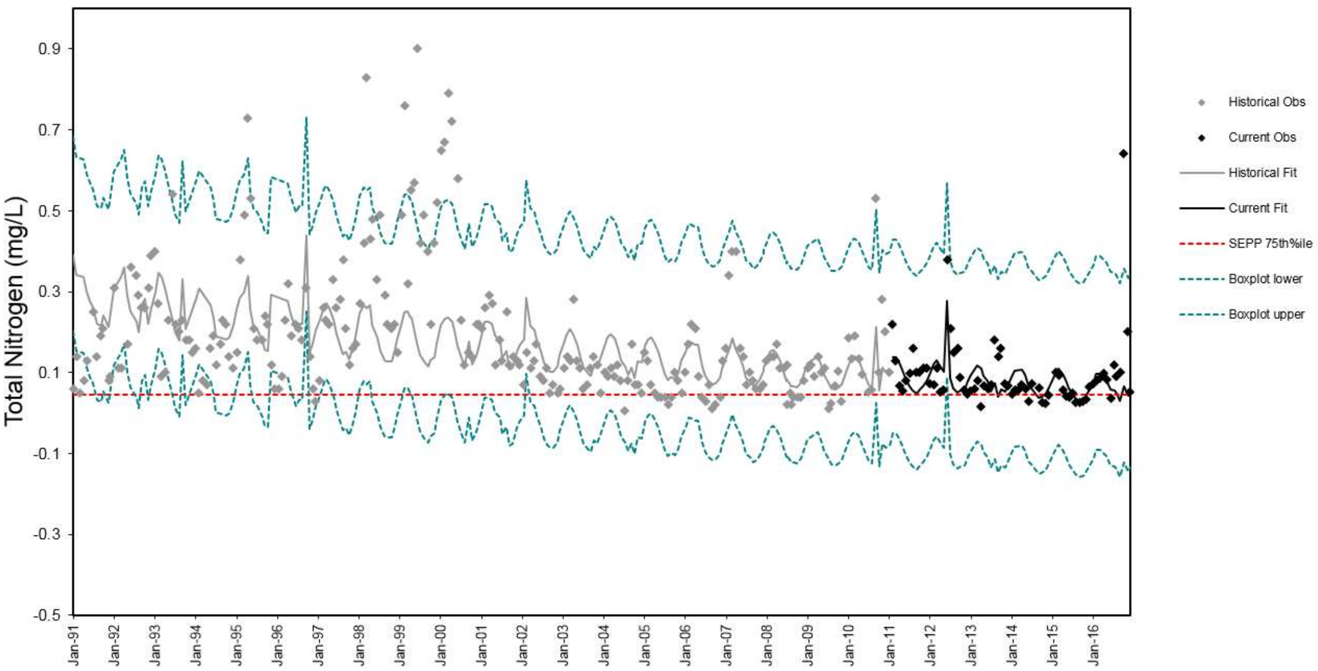


Figure 65: Control chart for total phosphorus (in mg/L) in the Barwon River at Pollocksford 1991 - 2016.

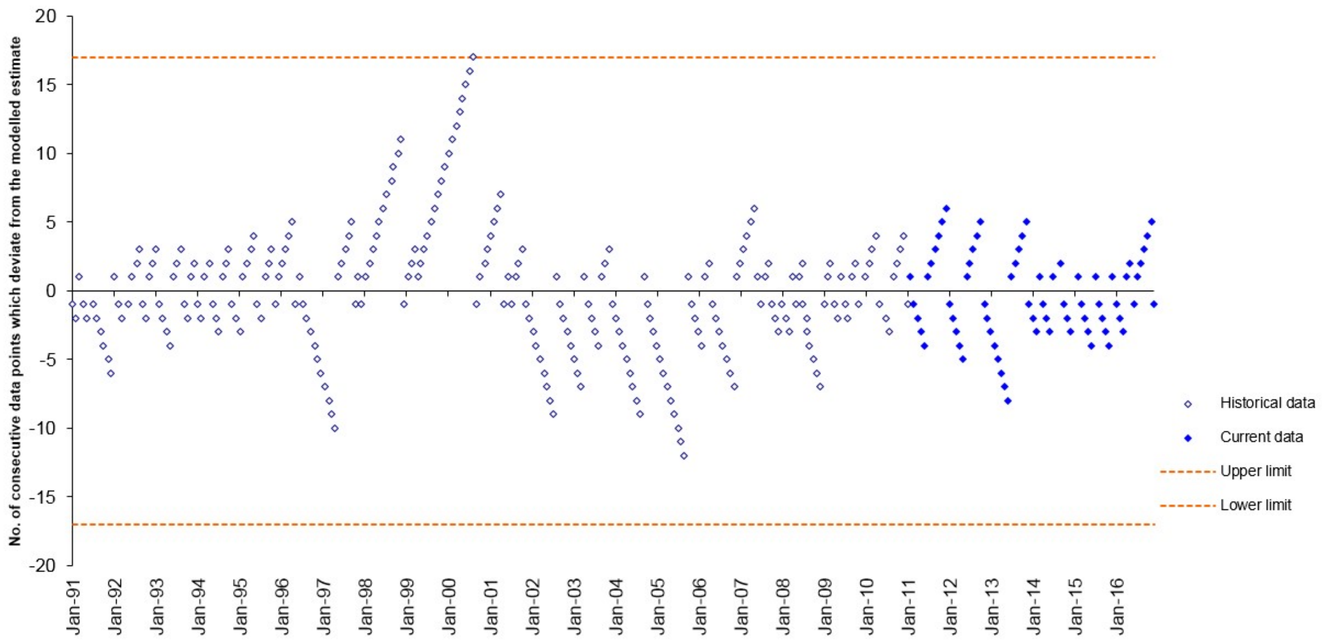


Figure 66: Run chart for total phosphorus (in mg/L) in the Barwon River at Pollocksford 1991 - 2016.

7. Results for Ovens River at Peechelba (403241)

7.1 Site Location

Peechelba is located on the Ovens River in north-east Victoria, between Wangaratta and Yarrawonga. The Ovens River rises in the Victorian Alps near Harrietville, sourced by runoff from high slopes in the Alpine and Mount Buffalo National Parks. It is a perennial river that is joined by eighteen tributaries which include Morses Creek, Buckland River, Buffalo River, and the King River. The river flows north west from its source and through the towns of Bright, Beechworth, Myrtleford and Wangaratta, and into the Murray River at Lake Mulwala. The river is approximately 191 kilometres long.

Grazing, viticulture, horticulture and fruit growing are popular land uses in the Ovens Valley, and tourism is important to the region. The river is largely unregulated; there are only two constructed dams in the system – Lake Buffalo (on the Buffalo River) and Lake William Hovell on the King River.

The river is the only lowland river nominated for environmental values under the Victorian Heritage Rivers Act and supports significant aquatic habitats and species. The Ovens River Wetlands are listed as nationally significant wetlands in the Directory of Important Wetlands.

Figure 67: Locality map for Ovens River at Peechelba

7.2 Data availability and quality

Water quality was monitored at Peechelba on 1044 occasions between January 1991 and December 2010 (Table 47). Whilst there were no days with 'zero flow' readings, there was a significant amount of flow data missing, as well as some missing rainfall data. These points were excluded from the analysis.

Table 47: Missing data over period of regression model fit (Jan 1991 – Dec 2010)

Missing data elements	DO	Turbidity	EC	pH	Total nitrogen	Total phosphorus
No. of missing water quality readings on days when at least one other parameter was recorded	160	18	9	34	11	10
No. of data points removed as outliers	0	0	0	0	0	0
No. of data points not analysed due to missing water temperature data	0	-	-	0	0	0
No. of data points not analysed due to missing or zero flow data	-	375	375	375	375	375
No. of data points not analysed due to missing rainfall data	-	11	11	11	0	11
Sample size for regression analysis	874	641	656	658	644	644

Water quality was monitored on 194 occasions between January 2011 to December 2016. Data was readily available; only a small number of points with missing rainfall data were excluded from the analysis (Table 48).

Table 48: Missing data over period of control chart application (2011 – 2016)

Missing data elements	DO	Turbidity	EC	pH	Total nitrogen	Total phosphorus
No. of missing water quality readings on days when at least one other parameter was recorded	0	0	0	0	2	2
No. of data points removed as outliers	0	0	0	0	0	0
No. of data points not analysed due to missing water temperature data	0	-	-	0	0	0
No. of data points not analysed due to missing or zero flow data	-	0	0	0	0	0
No. of data points not analysed due to missing rainfall data	-	4	4	4	4	4
Sample size for control chart application	190	190	190	190	188	188

7.3 Results for each water quality variable

7.3.1 Dissolved oxygen

Variation in dissolved oxygen (DO) (mg/L) levels in the Ovens River at Peechelba between 1991 and 2010 was moderately well explained by water temperature ($R^2 = 0.741$, Table 49). The best regression model for DO (% saturation) used season, water temperature, flow, cumulative rainfall in the preceding 72 hours and days since a 20mm rainfall event as the explanatory variables, but it only explained about 31% of the variation in DO percent saturation (Table 49). Rainfall data was obtained from Rutherglen Research rainfall gauge (site # 082039) operated by the Bureau of Meteorology.

DO levels (mg/L and % saturation) were very similar between historical and current data (Table 50). The SEPP trigger value for the Ovens River requires 75% of routine DO measurements in a given twelve-month period to be between 85 and 110 % saturation. That trigger value was broadly met between 2010 and 2016, but there were still a number of readings where dissolved oxygen levels were below these lower trigger levels on several occasions (Figure 69). Very low levels of dissolved oxygen are likely to be more of a threat to aquatic biota than very high DO levels, but very high levels of DO may be an indicator of other problems that could also warrant investigation.

Temporal fluctuation of DO has generally been well predicted in the models (mg/L and % saturation), with minor extended runs where the observed values do not match values predicted by the model (Figure 70, Figure 71) most likely as a result of changes in climatic conditions such as heavier rainfall in comparison to historical periods. In most cases, DO levels were higher than predicted during the cooler months between 2010 and 2016 (Figure 68 to Figure 71), in which low rainfall and warm weather was experienced in comparison to the historical period.

Table 49: Best fit regression models to describe variation in dissolved oxygen in the Ovens River at Peechelba between 1991 and 2010

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Dissolved Oxygen mg/L	DO = 12.757 - 0.266*Temp	874	0.741	8%
Dissolved oxygen % Sat	DO% = 101.387 – 3.744*MonthSIN – 0.872*Temp – 0.000477*Flow – 0.195*Rain72 – 0.0155*RainDays	619	0.310	3%

Table 50: Summary statistics for historical (1991-2010) and current (2011 – 2016) dissolved oxygen data recorded in the Ovens River at Peechelba

Parameter	Record	N	Mean	Median	Standard Deviation
Dissolved oxygen mg/L	Historical	874	8.5	8.6	1.9
	Current	190	8.6	8.6	1.9
	Overall	1064	8.5	8.6	1.9
Dissolved oxygen % Sat	Historical	865	84	86	11
	Current	190	86	87	10
	Overall	1055	84	86	11

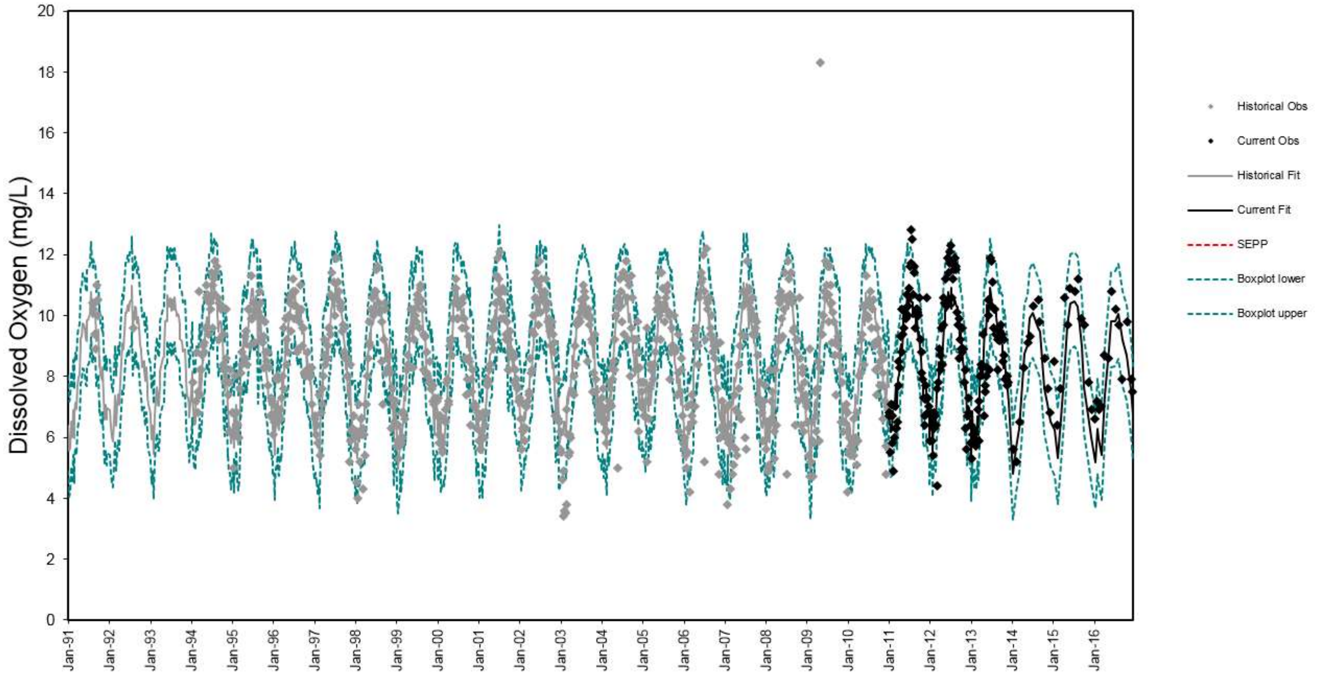


Figure 68: Control chart for dissolved oxygen (mg/L) in the Ovens River at Peechelba 1991 – 2016

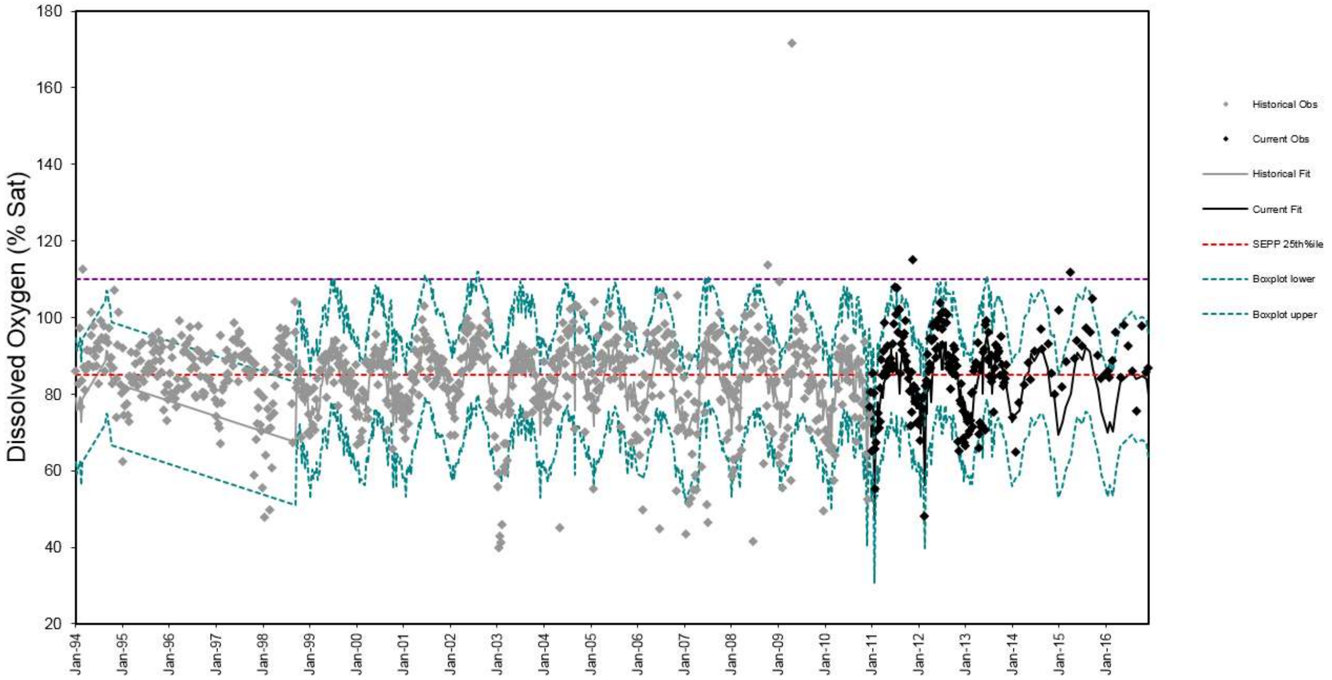


Figure 69: Control chart for percent saturation dissolved oxygen in the Ovens River at Peechelba 1991 – 2016

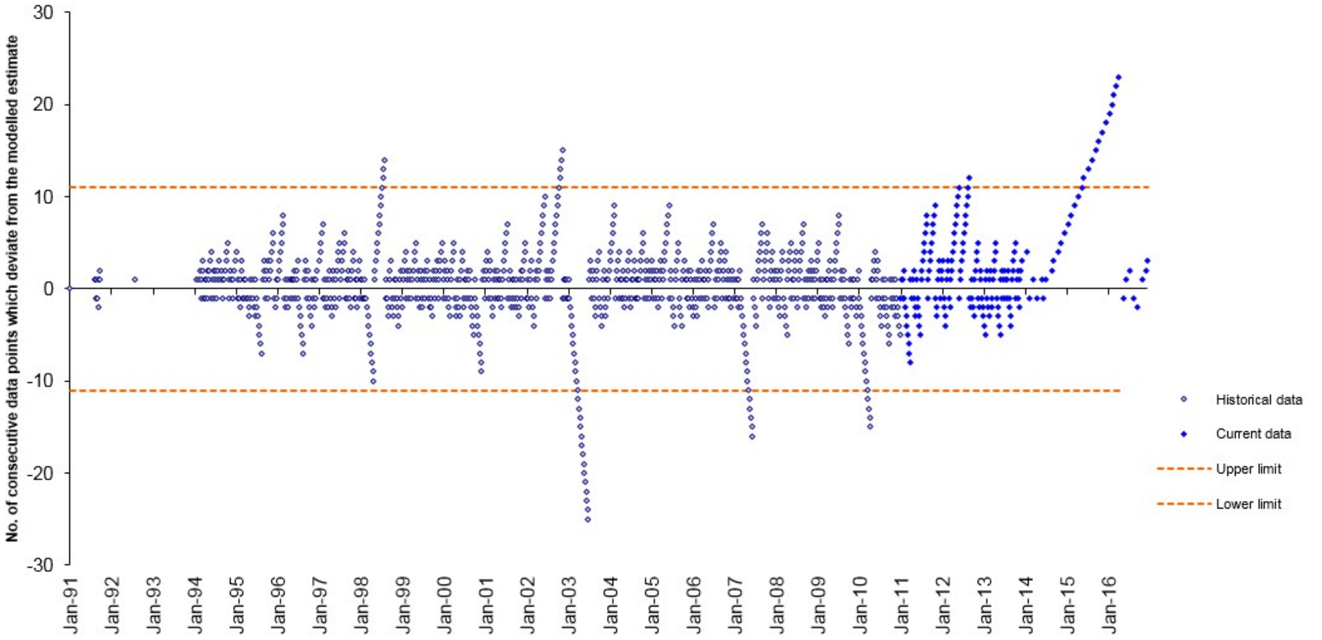


Figure 70: Run chart for dissolved oxygen (mg/L) in the Ovens River at Peechelba 1991 – 2016

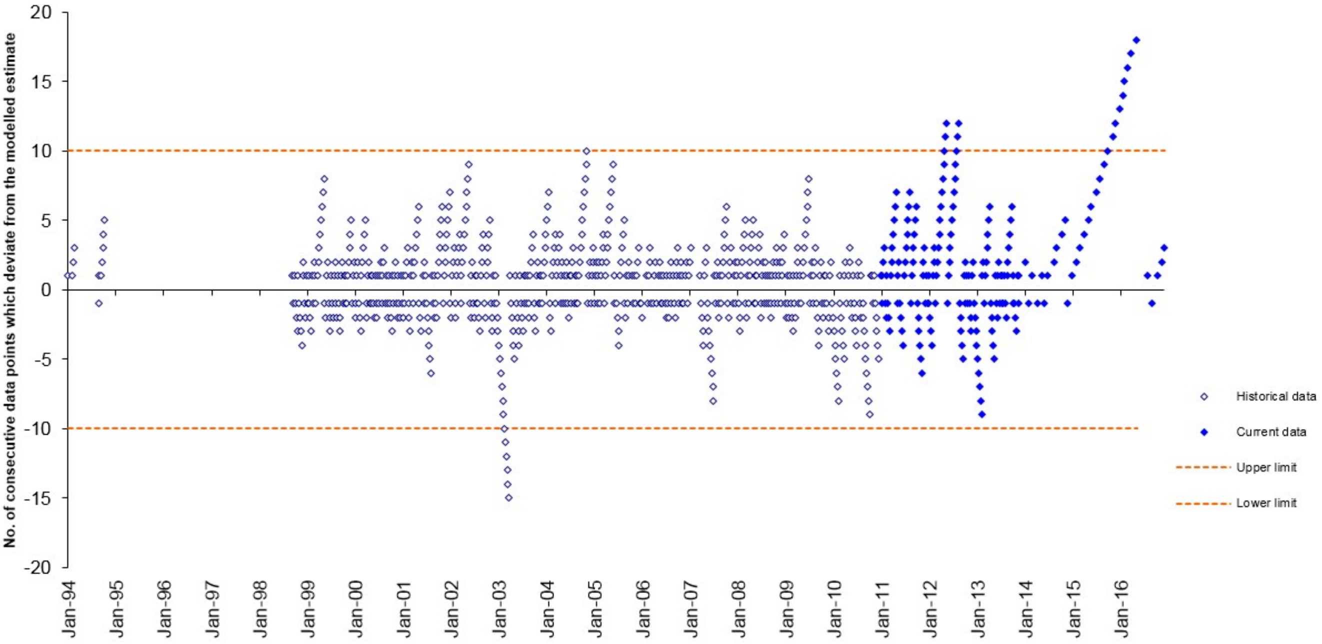


Figure 71: Run chart for percent saturation dissolved oxygen in the Ovens River at Peechelba 1991 – 2016

7.3.2 Turbidity

Variation in turbidity in the Ovens River at Peechelba between 1991 and 2010 was very poorly explained (R^2= 0.32, Table 51) by a combination of season, date, flow and cumulative rainfall in the preceding 72 hours. Rainfall data was obtained from Rutherglen Research rainfall gauge (site # 082039) operated by the Bureau of Meteorology.

Since 2010, average and median turbidity has been generally higher compared to historical observations and was more variable (Table 52). The model predicted turbidity after 2010 reasonably well, however there were a number of very high recorded values in 2011 and 2013 well outside the model limits (Figure 72, Figure 73). Interestingly, the model successfully predicted a spike in turbidity in early 2011, during which large scale flooding was experienced through much of Victoria. The spikes in turbidity in 2013, which were not successfully predicted by the model, also correlate with large, intense rainfall events. This is an indication of why cumulative rainfall was a significant predictor variable for the model. Turbidity levels at this site have frequency exceeded the SEPP (WoV) trigger level of ≤30 NTU since 2010. Observations outside of control may be a trigger for further investigation at the time of the observation.

Table 51: Best fit regression models to describe variation in turbidity in the Ovens River at Peechelba between 1991 and 2010

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Turbidity (NTU)	$TURBIDITY = (-3.923 + 0.182*MonthSIN + 0.000114*JDate + (0.0326*flow^{0.4}) + 0.0299*Rain72)^{(1/0.4)}$	641	0.323	18%

Table 52: Summary statistics for historical (1991- 2010) and current (2011-2016) turbidity data recorded in the in the Ovens River at Peechelba

Parameter	Record	N	Mean	Median	Standard Deviation
Turbidity (NTU)	Historical	630	18	13	25
	Current	190	26	18	49
	Overall	820	20	14	32

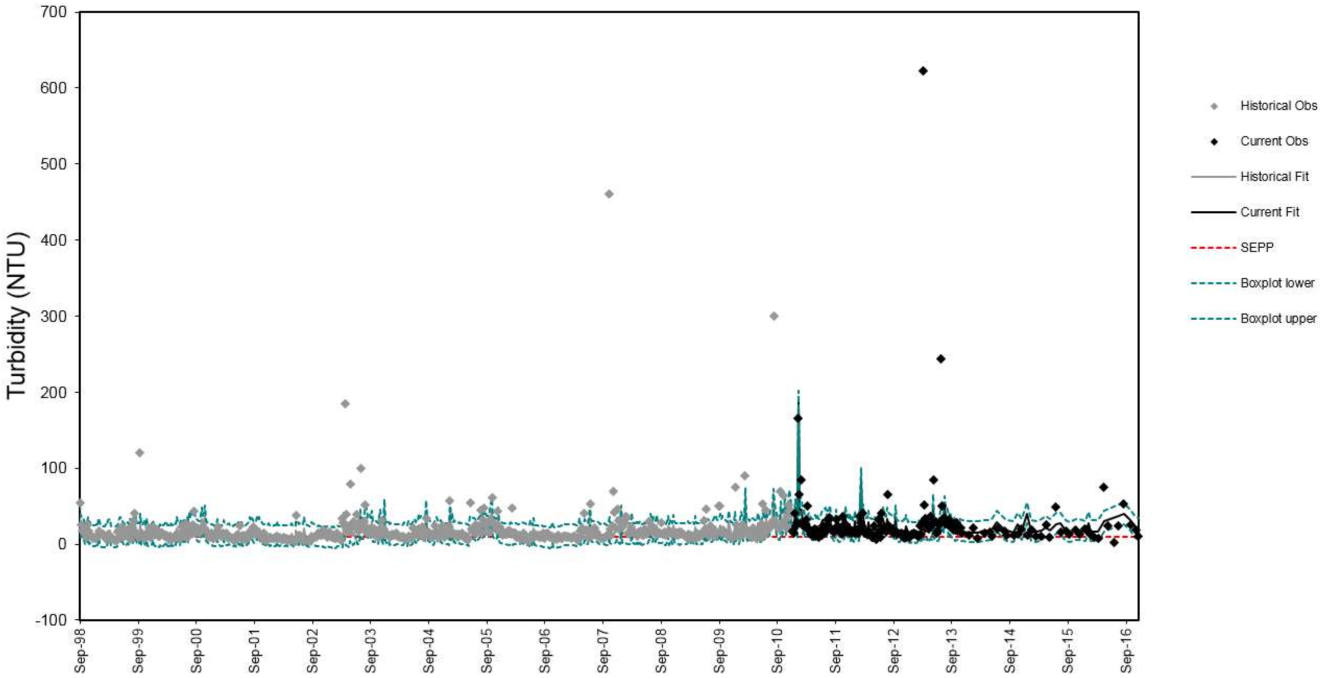


Figure 72: Control chart for turbidity (in NTU) in the Ovens River at Peechelba 1991 - 2016.

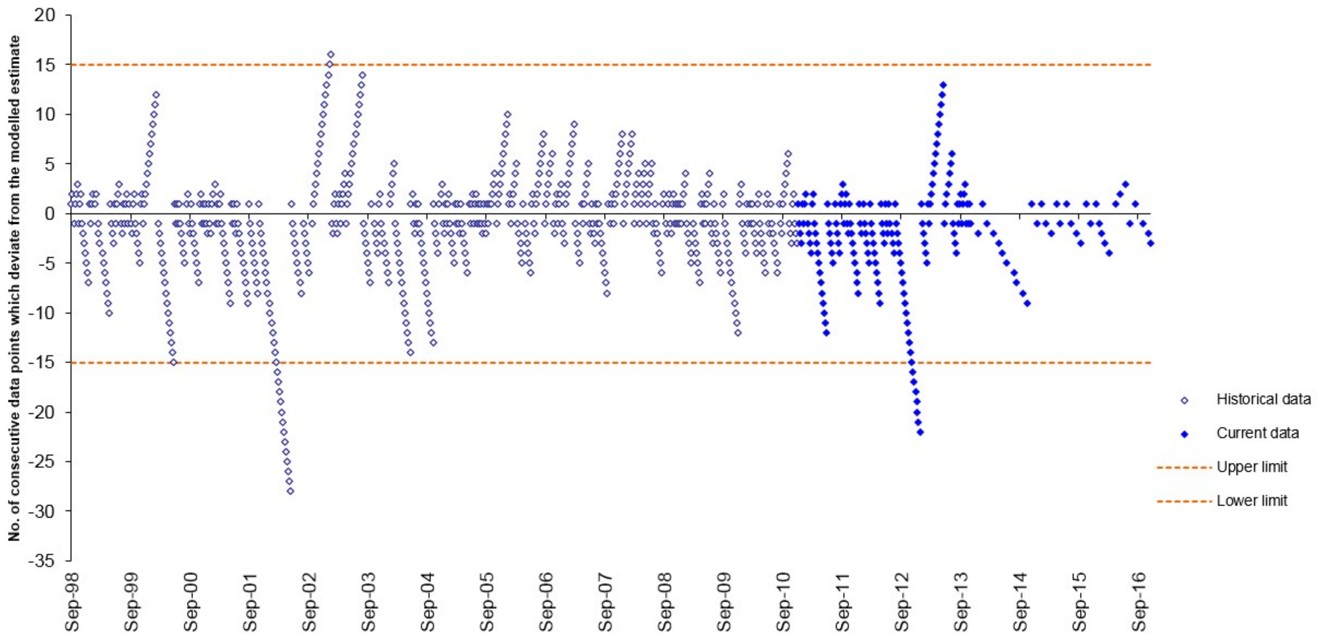


Figure 73: Run chart for turbidity (in NTU) in the Ovens River at Peechelba 1991 - 2016.

7.3.3 Electrical conductivity

Variation in electrical conductivity in the Ovens River at Peechelba between 1991 and 2010 was poorly explained by a combination of season, date, flow and cumulative rainfall in the preceding 72 hours (R^2 = 0.57, Table 53). Rainfall data was obtained from Rutherglen Research rainfall gauge (site # 082039) operated by the Bureau of Meteorology. The average and median electrical conductivity levels were lower after 2010 compared to the historical period, as well as less variable (Table 54). This is attributed to dilution from higher flows and snowmelt since the Millennium Drought. The model consistently underestimated conductivity levels after 2010 in comparison to the predicted values (Figure 75), with one observed value exceeding the model limits (Figure 74). The long runs of EC levels above the modelled estimate in 2011 and 2013 correlate with large, intense rainfall events. Electrical conductivity at this site was well below the SEPP (WoV) trigger value of 500 µS/cm (Figure 74). It is therefore not considered a threat to aquatic ecosystems or other beneficial uses of the waterway.

Table 53: Best fit regression models to describe variation in conductivity in the Ovens River at Peechelba between 1991 and 2010

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Electrical Conductivity (µS/cm)	$EC = (14.764 + 0.492*MonthSIN - 0.000175*JDate + (-0.0197*Flow^{0.4}) + 0.00423*RainDays)^{(1/0.4)}$	656	0.570	8%

Table 54: Summary statistics for historical (1991- 2010) and current (2011-2016) conductivity data recorded in the in the Ovens River at Peechelba

Parameter	Record	N	Mean	Median	Standard Deviation
Electrical conductivity (µS/cm)	Historical	635	73	60	41
	Current	190	60	58	15
	Overall	825	70	59	37

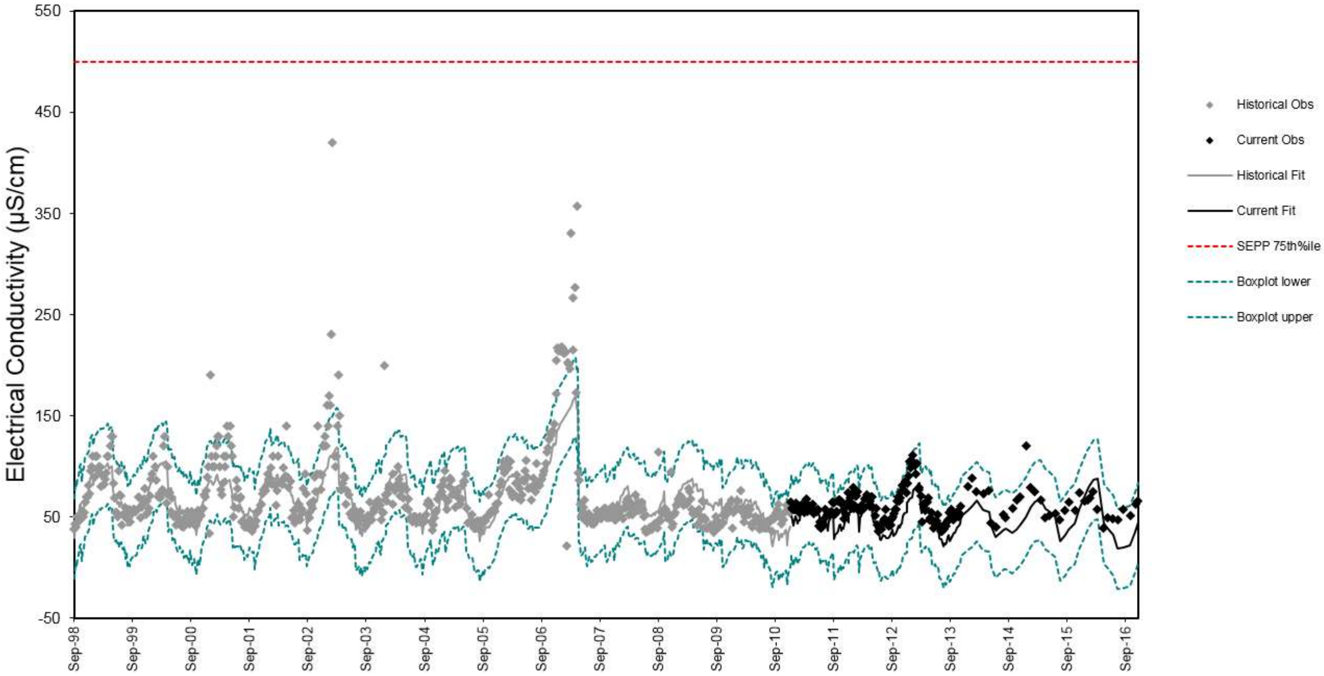


Figure 74: Control chart for electrical conductivity (in µS/cm) in the Ovens River at Peechelba 1991 – 2016

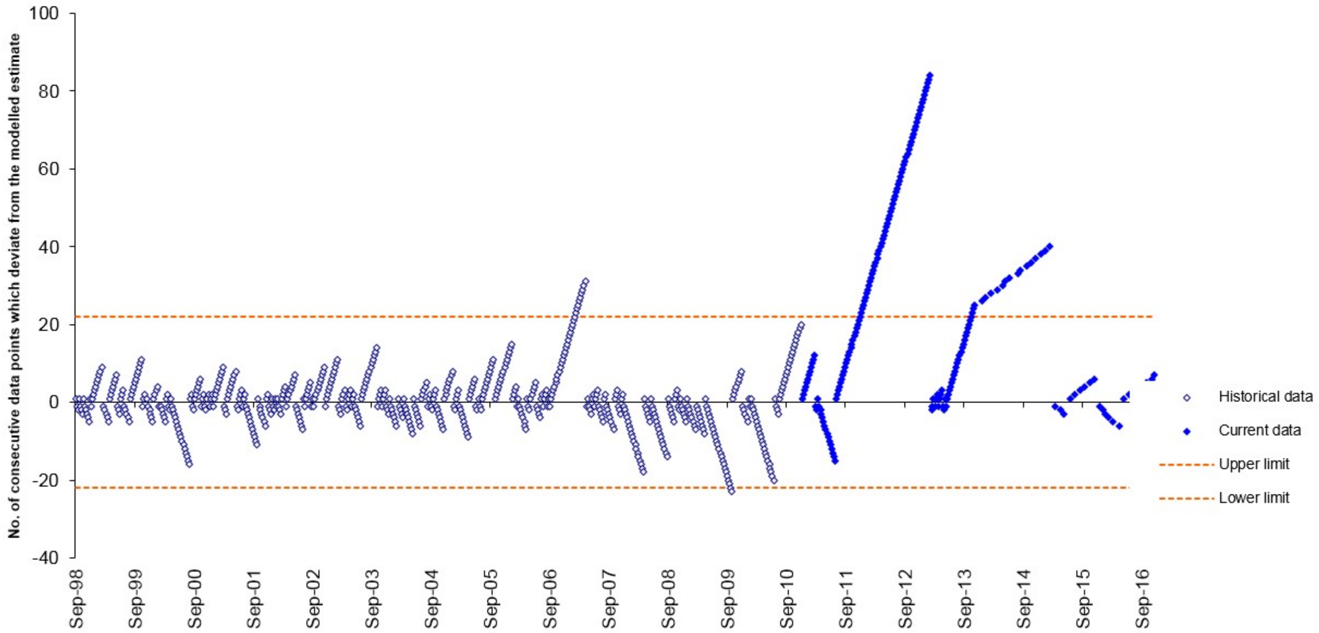


Figure 75: Run chart for electrical conductivity (in µS/cm) in the Ovens River at Peechelba 1991 – 2016

7.3.4 Total Nitrogen

Total Nitrogen for the Ovens River at Peechelba between 1991 and 2010 was very poorly explained using temperature, flow and turbidity (R^2 = 0.376, Table 55). Total nitrogen levels have been relatively stable since 2010, with only a slight increase in average and median levels and a decrease in variability (Table 56). The SEPP objective was achieved at this site during the current and historical period. The model accurately predicted a number of spikes in total nitrogen levels between 2010 and 2013, most likely due to high flow events from heavy rainfall in the catchment. However, there were a number of high, unexplained levels observed after 2010 outside of the model limits (Figure 76, Figure 77).

Table 55: Best fit regression models to describe variation in total nitrogen in the Ovens River at Peechelba between 1991 and 2010

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Total nitrogen (mg/L)	TN = 0.1166 - 0.00594*Temp + 0.00000697*Flow + (0.1278*Turbidity$^{0.4}$)	644	0.376	34%

Table 56: Summary statistics for historical (1991- 2010) and current (2011-2016) total nitrogen data recorded in the in the Ovens River at Peechelba

Parameter	Record	N	Mean	Median	Standard Deviation
Total nitrogen (mg/L)	Historical	634	0.29	0.25	0.18
	Current	188	0.31	0.27	0.16
	Overall	822	0.29	0.25	0.17

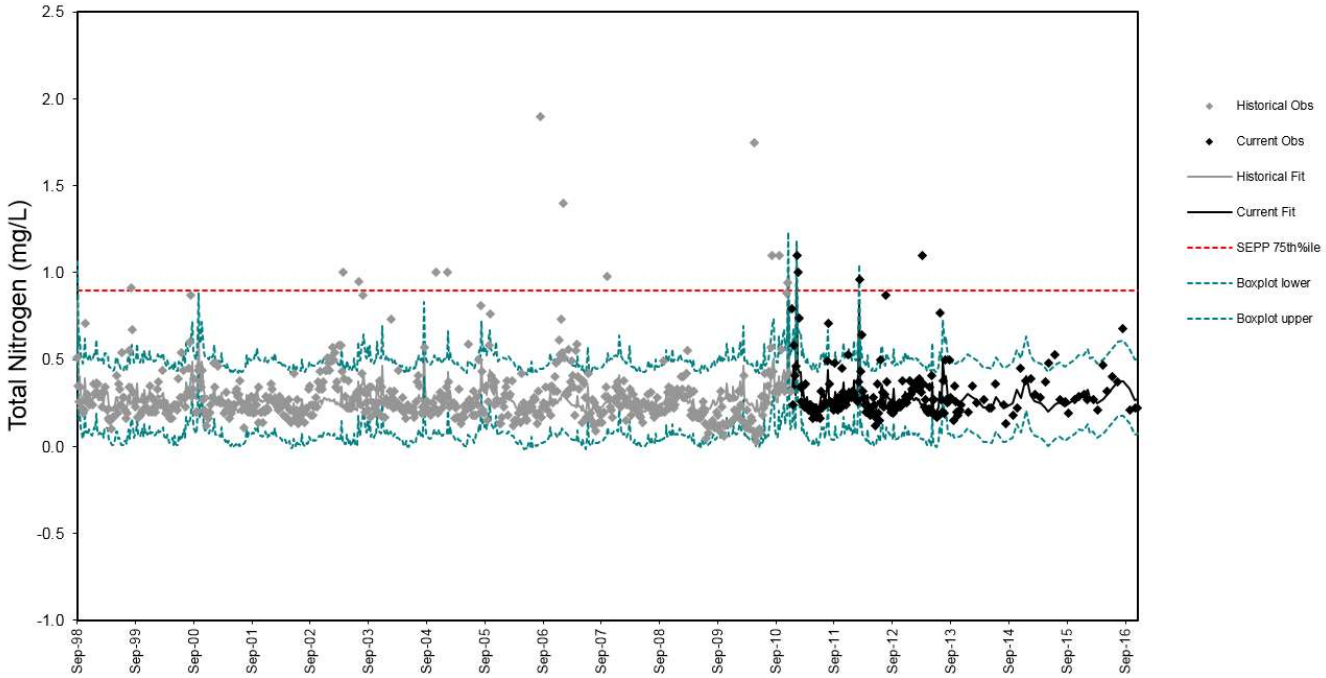


Figure 76: Control chart for total nitrogen (in mg/L) in the Ovens River at Peechelba 1991 - 2016.

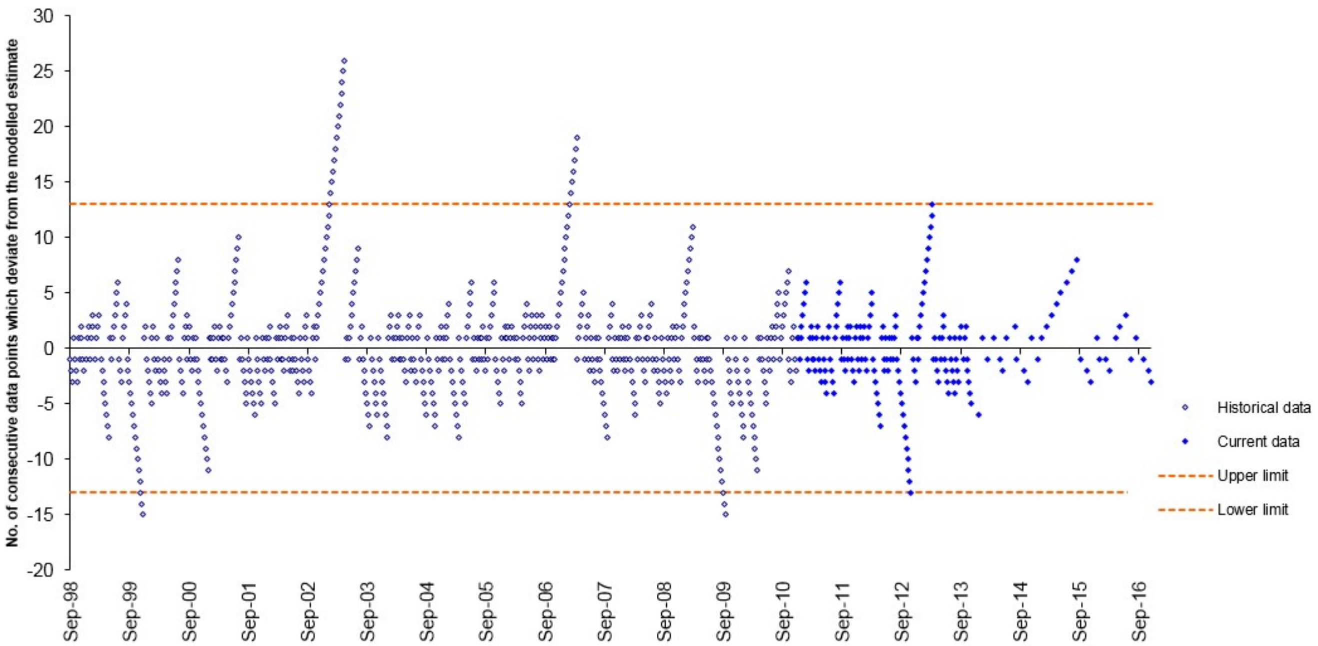


Figure 77: Run chart for total nitrogen (in mg/L) in the Ovens River at Peechelba 1991 - 2016.

7.3.5 Total phosphorus

Variation in total phosphorus concentration in the Ovens River at Peechelba between 1991 and 2010 was very poorly explained by water temperature, flow and cumulative rainfall in the preceding 72 hours (R^2= 0.147, Table 57). Average and median total phosphorus concentrations at this site were higher, but less variable since 2010 compared to the historical record (Table 58).

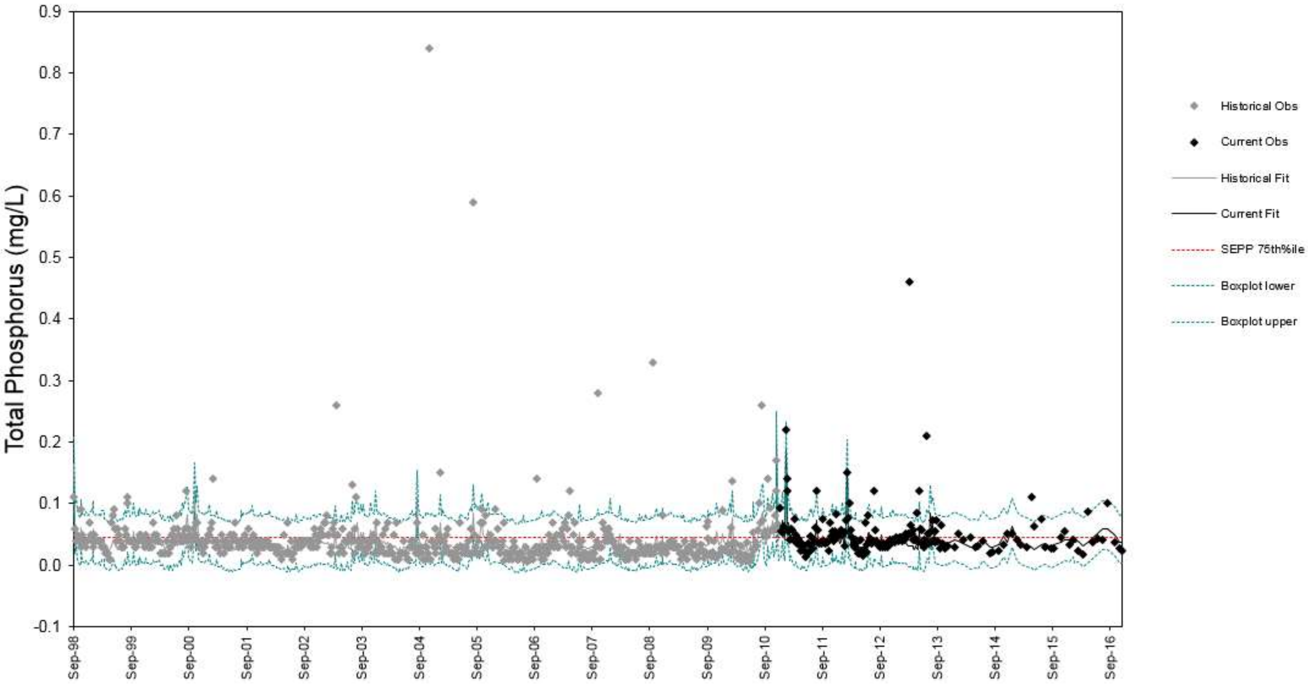
Comparing the patterns of observed values of phosphorus and turbidity since 2010, there appears to be a correlation with these two variables which may suggest that some of the phosphorus at this site may be bound to fine soil particles and could therefore be associated with erosion. The model appeared to have successfully predicted the spike in total phosphorus levels during the 2011 floods, however there were still a few observations outside of the model controls that could trigger further investigation, particularly where total phosphorus concentrations at this site exceeded the SEPP (WoV) trigger level of ≤0.045 mg/L (Figure 78, Figure 79). The spikes in total phosphorus in 2013, which were not successfully predicted by the model, also correlate with large, intense rainfall events. This is highlighted by the spike in the run chart in Figure 69 which indicates a long run of observations exceeded the modelled estimate.

Table 57: Best fit regression models to describe variation in total phosphorus in the Ovens River at Peechelba between 1991 and 2010

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Total Phosphorus (mg/L)	$TP = (0.196 + 0.00278*Temp + 0.00000487*Flow+0.00149*Rain72)^{(1/0.4)}$	644	0.147	19%

Table 58: Summary statistics for historical (1991- 2010) and current (2011-2016) total phosphorus data recorded in the in the Ovens River at Peechelba

Parameter	Record	N	Mean	Median	Standard Deviation
Total phosphorus (mg/L)	Historical	635	0.043	0.03	0.086
	Current	188	0.050	0.041	0.041
	Overall	823	0.045	0.036	0.078



Note: An extreme total phosphorus reading of 1.84 taken on 17th May 2010 was omitted to improve the resolution of the chart above

Figure 78: Control chart for total phosphorus (in mg/L) in the Ovens River at Peechelba 1991 - 2016.

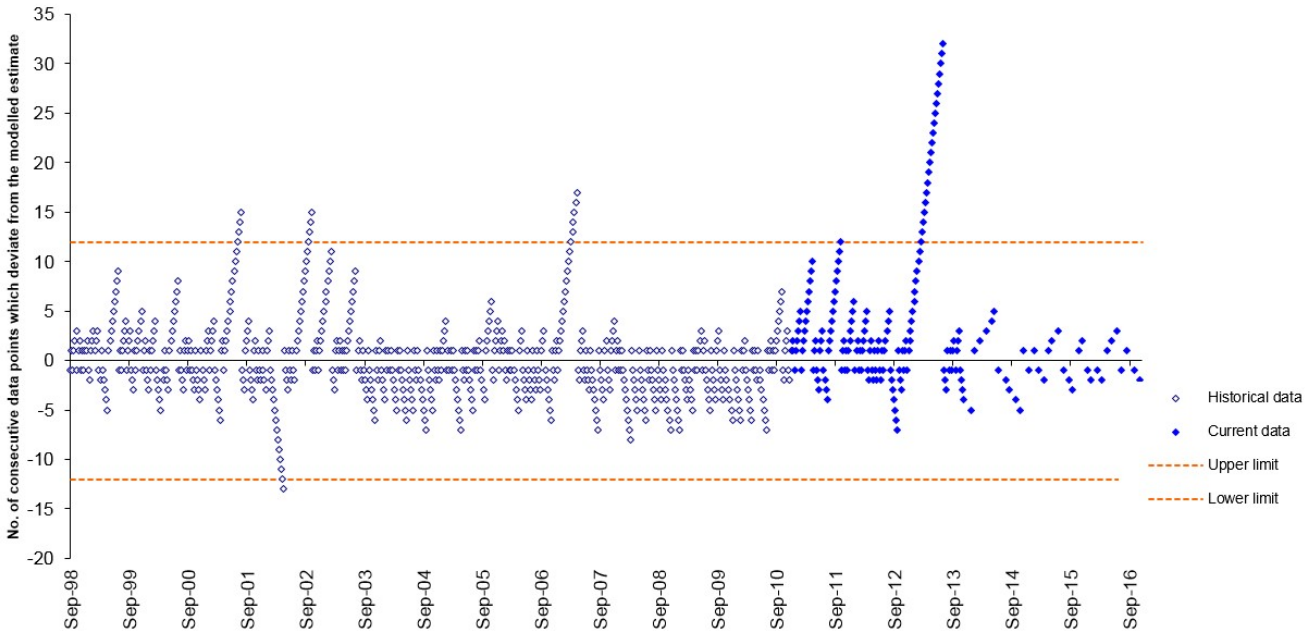


Figure 79: Run chart for total phosphorus (in mg/L) in the Ovens River at Peechelba 1991 - 2016.

8. Results for La Trobe River at Rosedale (226228)

8.1 Site Location

The La Trobe River is located in the West Gippsland region of Victoria. It flows 270 kilometres from the eastern and southern slopes of the Yarra Ranges to Lake Wellington, Gippsland Lakes. Major tributaries include the Loch River, Tooronga River, Tanjil River, Tyers River, Morwell River, Moe River, Traralgon Creek and the Thomson River. It passes through the urban areas of Moe, Morwell, Traralgon and Rosedale. The Rosedale monitoring site (226228) is located in the lower reach of the Latrobe River, downstream of all the major tributaries, except the Thomson River (Figure 80).

Agriculture, forestry and mining/industry are the main land uses in the catchment. La Trobe River is integral to the coal-fired power generation systems located in the Latrobe Valley. Lake Narracan is an on-stream storage, located upstream of the Yallourn Power station, built to specifically supply water for power generation. Blue Rock Reservoir and Moondarra Reservoir are two other major storages on tributaries of the La Trobe River that regulate the flows in the La Trobe River, delivering entitlements to electricity generators and irrigators. Environmental water is also supplied to the La Trobe River from Blue Rock Reservoir on the Tanjil River. The lower La Trobe River near Rosedale is ecologically disturbed due to desnagging, extensive clearing of riparian vegetation, artificial cut-offs and channel widening. Large-scale changes to the catchment have also occurred due to industry, urban growth and widespread clearing for agriculture. The Latrobe River downstream of the Thomson River is fringed by extensive, high value Ramsar wetlands.

Figure 80: Locality map for La Trobe River at Rosedale

8.2 Data availability and quality

Water quality was monitored at Rosedale on 244 occasions between January 1991 and December 2010 (Table 59). Data was readily available, with only a small number of points excluded from the regression analysis where rainfall data was missing.

Table 59: Missing data over period of regression model fit (Jan 1991 – Dec 2010)

Missing data elements	Dissolved oxygen	Turbidity	EC	pH	Total nitrogen	Total phosphorus
No. of missing water quality readings on days when at least one other parameter was recorded	5	13	8	5	7	2
No. of data points removed as outliers	0	0	0	0	0	0
No. of data points not analysed due to missing water temperature data	-	0	0	0	0	0
No. of data points not analysed due to missing or zero flow data	0	0	0	-	0	0
No. of data points not analysed due to missing rainfall data	-	1	-	0	-	1
Sample size for regression analysis	239	230	238	239	239	243

Water quality was monitored on 73 occasions between January 2011 to December 2016 (Table 60).

Table 60: Missing data over period of control chart application (2011 – 2016)

Missing data elements	Dissolved oxygen	Turbidity	EC	pH	Total nitrogen	Total phosphorus
No. of missing water quality readings on days when at least one other parameter was recorded	0	0	2	0	1	1
No. of data points removed as outliers	0	0	0	0	0	0
No. of data points not analysed due to missing water temp data	-	0	0	0	0	0
No. of data points not analysed due to missing or zero flow data	0	0	0	-	0	0

Missing data elements	Dissolved oxygen	Turbidity	EC	pH	Total nitrogen	Total phosphorus
No. of data points not analysed due to missing rainfall data	-	0	-	0	-	0
Sample size for control chart application	72	72	72	72	73	73

8.3 Results for each water quality variable

8.3.1 Dissolved oxygen (DO)

Variation in DO (mg/L) levels in the La Trobe River at Rosedale between 1991 and 2010 was moderately well explained by a combination of water temperature, date and flow in the La Trobe River ($R^2 = 0.699$, Table 61). DO levels exhibited a gradual decline from 1991 to 2010, which is an indication of why date was a significant predictor variable for the model (Figure 81). The current data showed an increase in DO levels compared with the historical trends (

Table 62). Whilst most DO levels were inside the model limits after 2010, there was one high value (recorded in 2015) that may be considered out of control and identifiable as a potential point of concern (Figure 81). Generally DO levels were within the model limits, however a long run of observations above the modelled estimate in Figure 83 and Figure 84 is potentially indicative of climatic conditions unanticipated by the model such as heavier rainfall in comparison to historical periods.

The increase in DO levels compared to the model is more pronounced in the percentage saturation model, which is partly explained using a combination of water temperature, date and flow (R^2 = 0.220, Table 61). This trend is evident despite the average and median DO levels being lower compared to the historical period, and less variable. Since 2010, the model significantly underestimated the DO peaks during the cooler months, with all data points above the lower SEPP (WoV) trigger level of 55%. Generally, DO levels (% saturated) were within the model limits with the exception of two observations in early 2015 which could be identified as a potential concern (Figure 82). The long positive run of observations above the modelled estimate in the later stages of the current period are likely to be reflective of unanticipated climatic conditions, as discussed above.

Table 61: Best fit regression models to describe variation in dissolved oxygen in the La Trobe River at Rosedale between 1991 and 2010

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Dissolved Oxygen mg/L	DO = 20.847 - 0.222*temp - 0.000154*JDate	239	0.699	8%
Dissolved oxygen % Sat	DO% = 194.344 – 0.321*Temp – 0.00182*JDate – 0.000897*Flow	239	0.220	8%

Table 62: Summary statistics for historical (1991-2010) and current (2011 – 2016) dissolved oxygen data recorded in the La Trobe River at Rosedale

Parameter	Record	N	Mean	Median	Standard Deviation
Dissolved oxygen mg/L	Historical	239	9.4	9.4	1.3
	Current	72	8.9	9.0	1.2
	Overall	311	9.3	9.4	1.3
Dissolved oxygen % Sat	Historical	239	93	94	8.2
	Current	72	89	89	7.4
	Overall	311	92	91	8.1

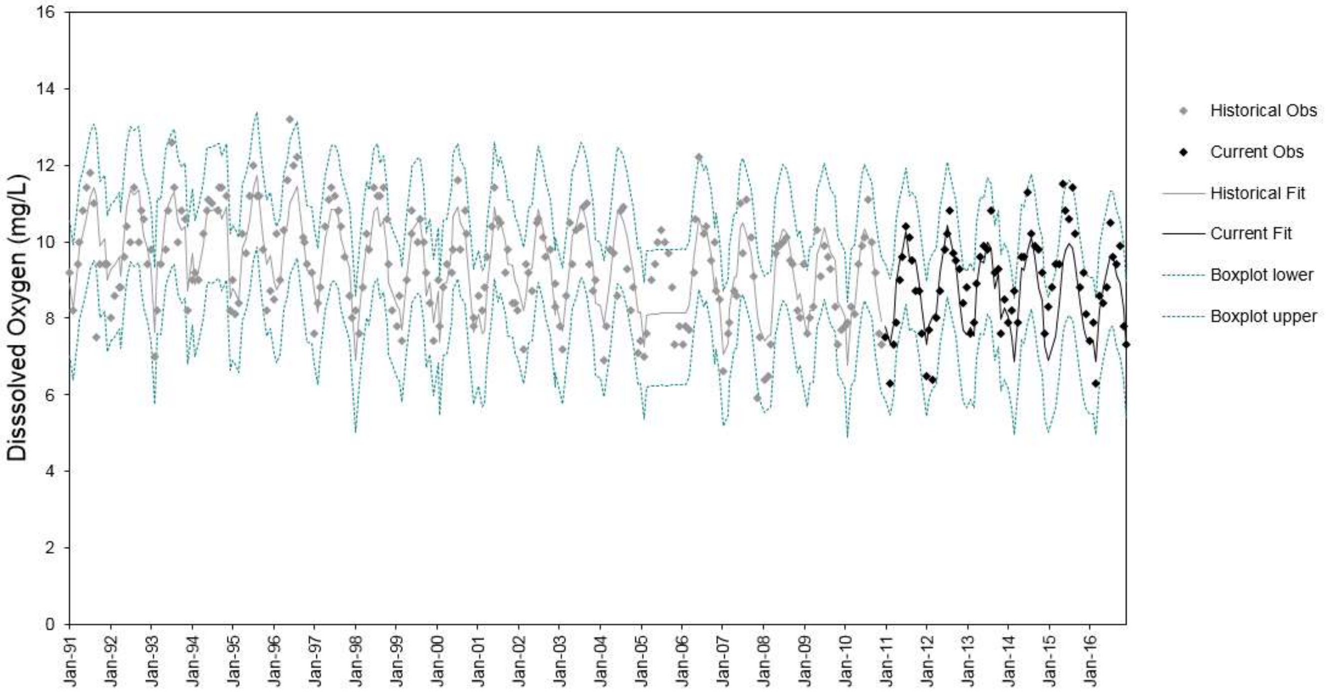


Figure 81: Control chart for dissolved oxygen (mg/L) in the La Trobe River at Rosedale 1991 – 2016

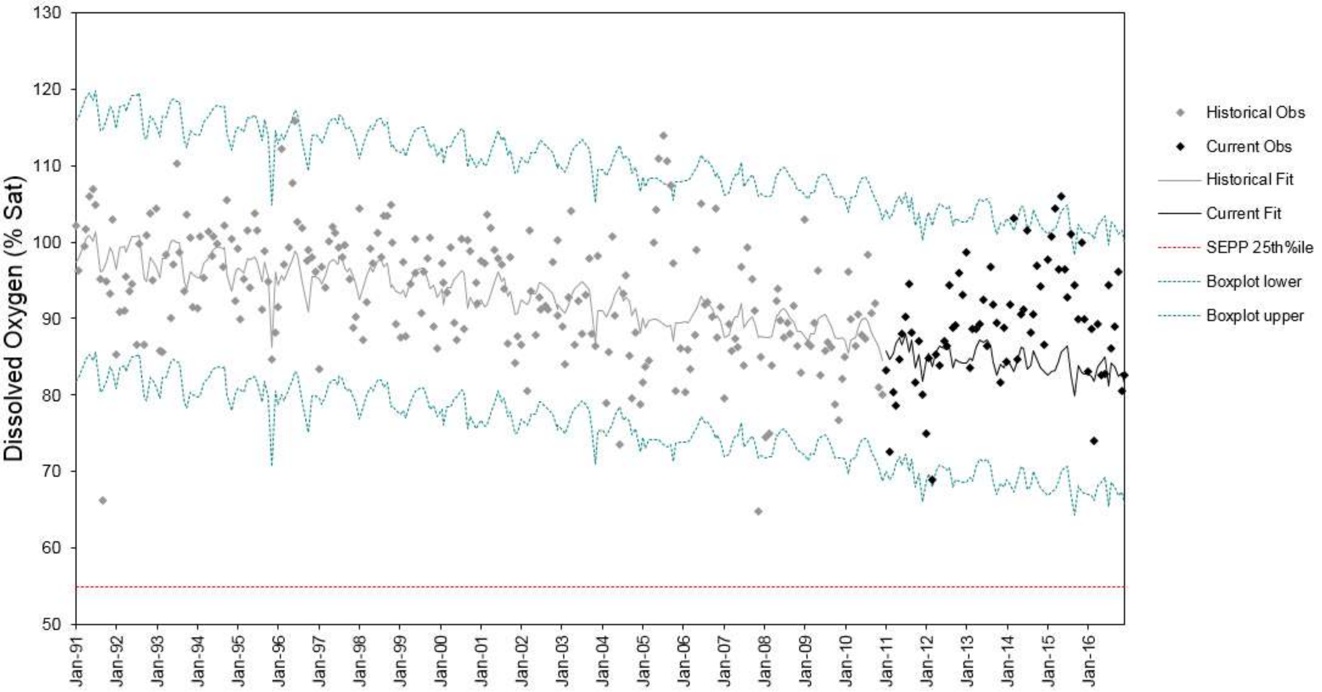


Figure 82: Control chart for percent saturation dissolved oxygen in the La Trobe River at Rosedale 1991 – 2016

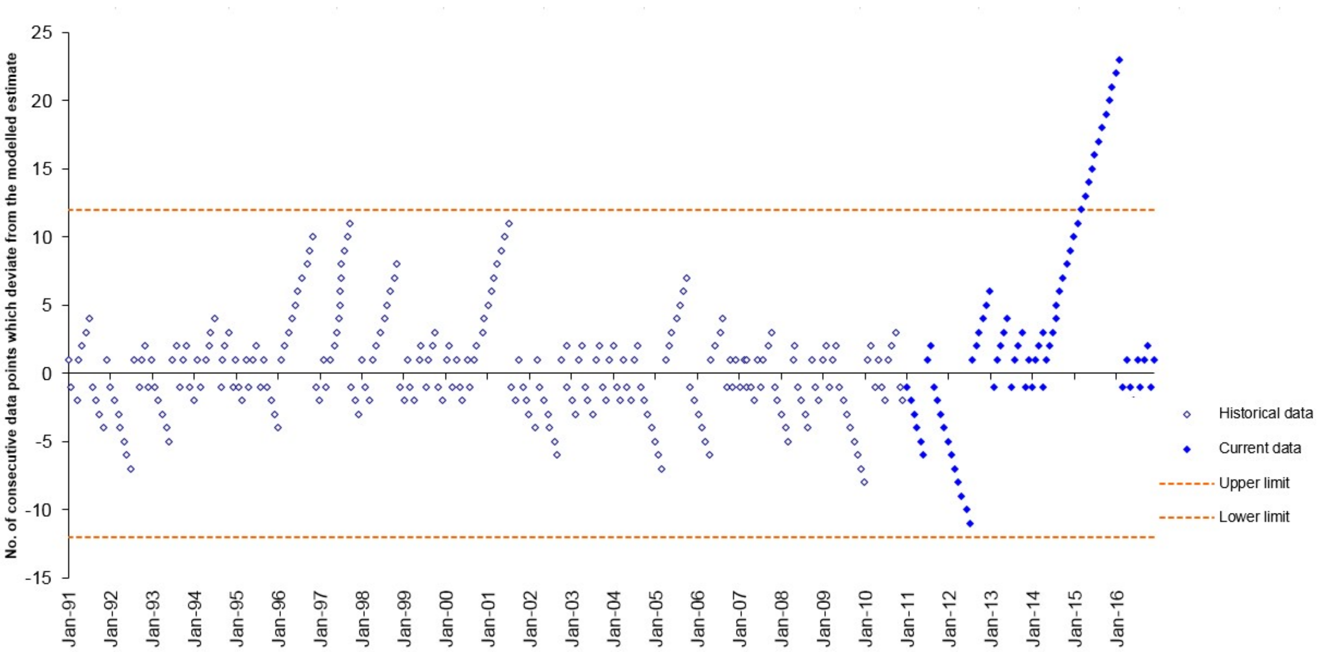


Figure 83: Run chart for dissolved oxygen (mg/L) in the La Trobe River at Rosedale 1991 – 2016

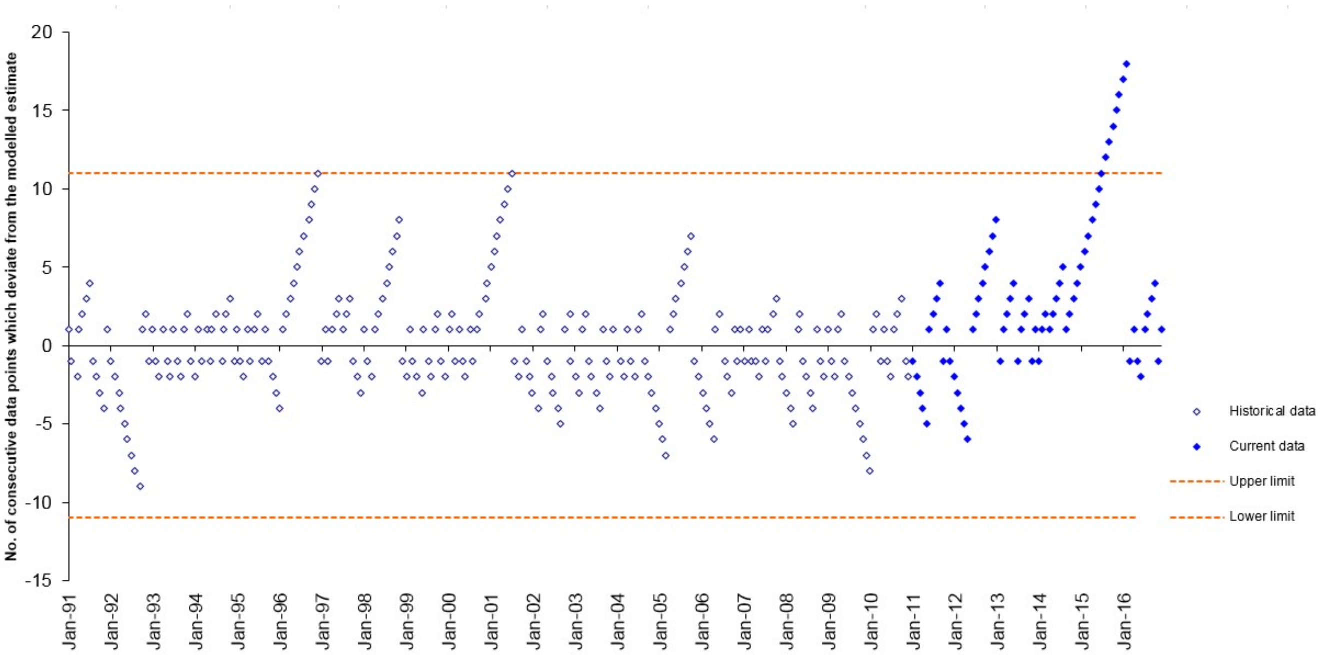


Figure 84: Run chart for percent saturation dissolved oxygen in the La Trobe River at Rosedale 1991 – 2016

8.3.2 Turbidity

Variation in turbidity in the La Trobe River at Rosedale between 1991 and 2010 was poorly explained ($R^2 = 0.58$, Table 63) by a combination of water temperature, date, flow and cumulative rainfall in the preceding 72 hours (Table 64). Rainfall data was obtained from East Sale rainfall gauge (site # 085072) operated by the Bureau of Meteorology.

Since 2010, average and median turbidity levels have been significantly higher than the historical record (Table 64). The model did not fully predict this increase and consequently the observed values were higher than those predicted by the model and commonly outside the model limits, particularly between 2010 and 2014 (Figure 85, Figure 86). For those observations identified as being outside the model limits during this period, there is a correlation with high flow events and prolonged duration rainfall. On June 6 2012, a failure of the Morwell River Diversion structure resulted in a large volume of water entering the Yallourn Coal Mine. In response to the flooding, TRUenergy applied for a temporary permit to discharge water into the Latrobe River under a provision of a Section 30A Approval of the Environment Protection Act, 1970. The discharge occurred for 5-6 months and raised turbidity levels in the river.

Since 2010, turbidity levels at this site have frequently exceeded the SEPP (WoV) trigger level of ≤25 NTU (50th percentile annual value). Turbidity was generally lower than predicted between 2014 and 2016, but was within the limits of the model (Figure 85, Figure 86).

Table 63: Best fit regression models to describe variation in turbidity in the La Trobe River at Rosedale between 1991 and 2010

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Turbidity (NTU)	TURBIDITY = -331.154 + 1.301*Temp + 0.00626*JDate + 0.00742*Flow + 1.084*Rain72	230	0.580	52%

Table 64: Summary statistics for historical (1991- 2010) and current (2011-2016) turbidity data recorded in the in the La Trobe River at Rosedale

Parameter	Record	N	Mean	Median	Standard Deviation
Turbidity (NTU)	Historical	231	30	25	24
	Current	72	61	56	25
	Overall	303	37	32	28

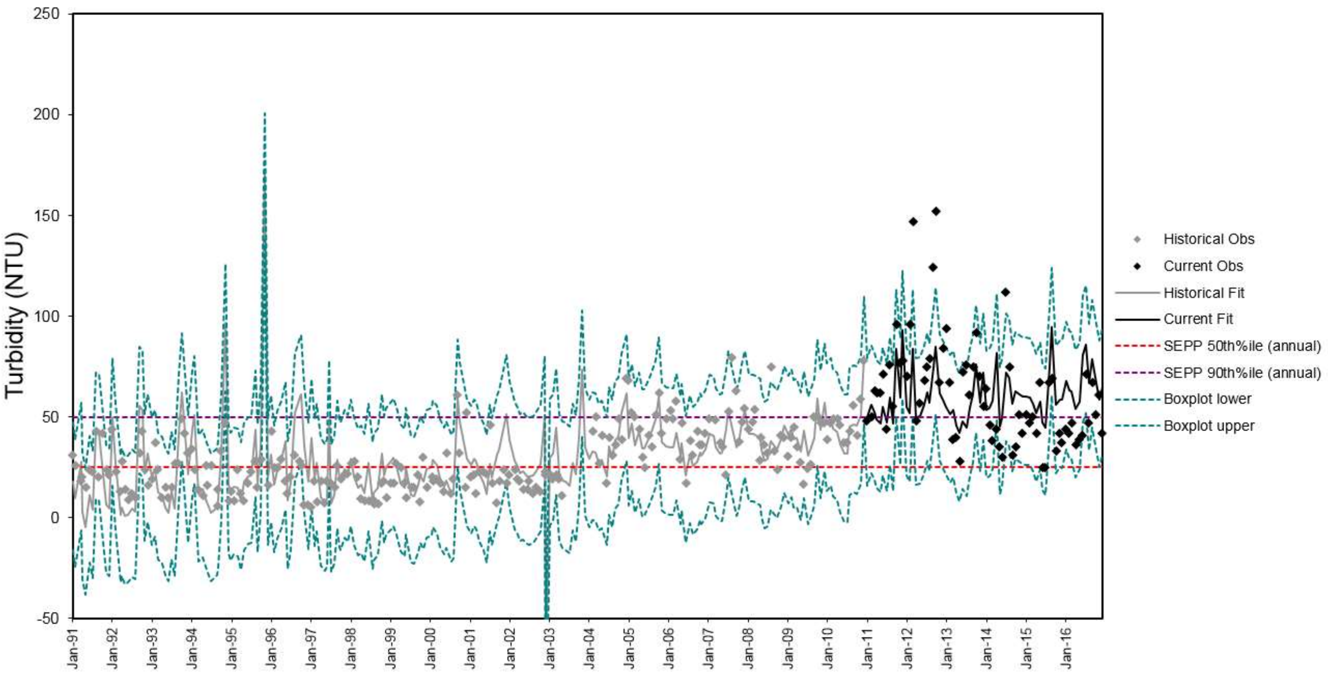


Figure 85: Control chart for turbidity (in NTU) in the La Trobe River at Rosedale 1991 - 2016.

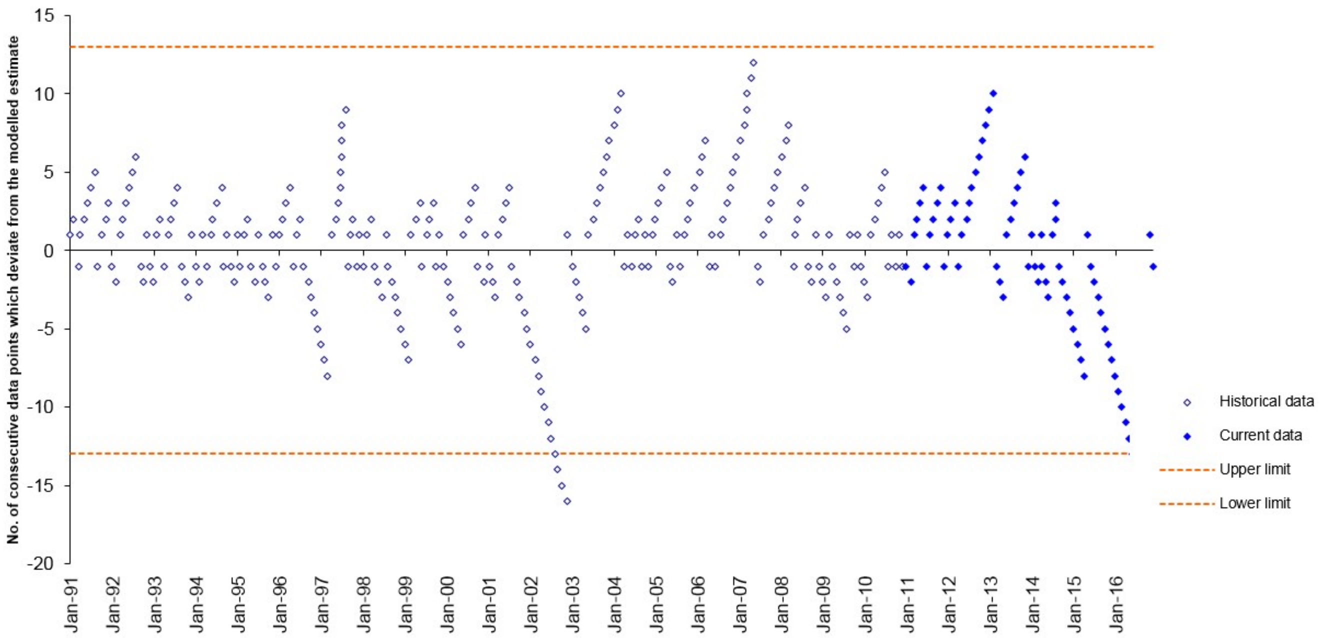


Figure 86: Run chart for turbidity (in NTU) in the La Trobe River at Rosedale 1991 - 2016.

8.3.3 Electrical conductivity

Variation in electrical conductivity in the La Trobe River at Rosedale between 1991 and 2010 was very poorly explained by a combination of water temperature and flow (R^2 = 0.36, Table 65). The average and median electrical conductivity levels were lower after 2010 compared to the historical period (Table 66). This is attributed to higher flows and dilution of industrial discharges. The model predicted a decline in electrical conductivity levels from 2010, however the observed data were generally further below the modelled fit (Figure 87, Figure 88).

Electrical conductivity at this site is within the control limits on the control chart and is below the ANZECC trigger value of 350 µS/cm (Figure 87). It is therefore not considered a threat to aquatic ecosystems or other beneficial uses of the waterway.

Table 65: Best fit regression models to describe variation in conductivity in the La Trobe River at Rosedale between 1991 and 2010

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Electrical Conductivity (µS/cm)	$EC = (12.639+(-0.0561*Temp) + (-0.0866*Flow^{0.4}))^{(1/0.4)}$	238	0.356	7%

Table 66: Summary statistics for historical (1991- 2010) and current (2011-2016) conductivity data recorded in the in the La Trobe River at Rosedale

Parameter	Record	N	Mean	Median	Standard Deviation
Electrical conductivity (µS/cm)	Historical	238	343	340	75
	Current	72	314	315	49
	Overall	310	337	330	71

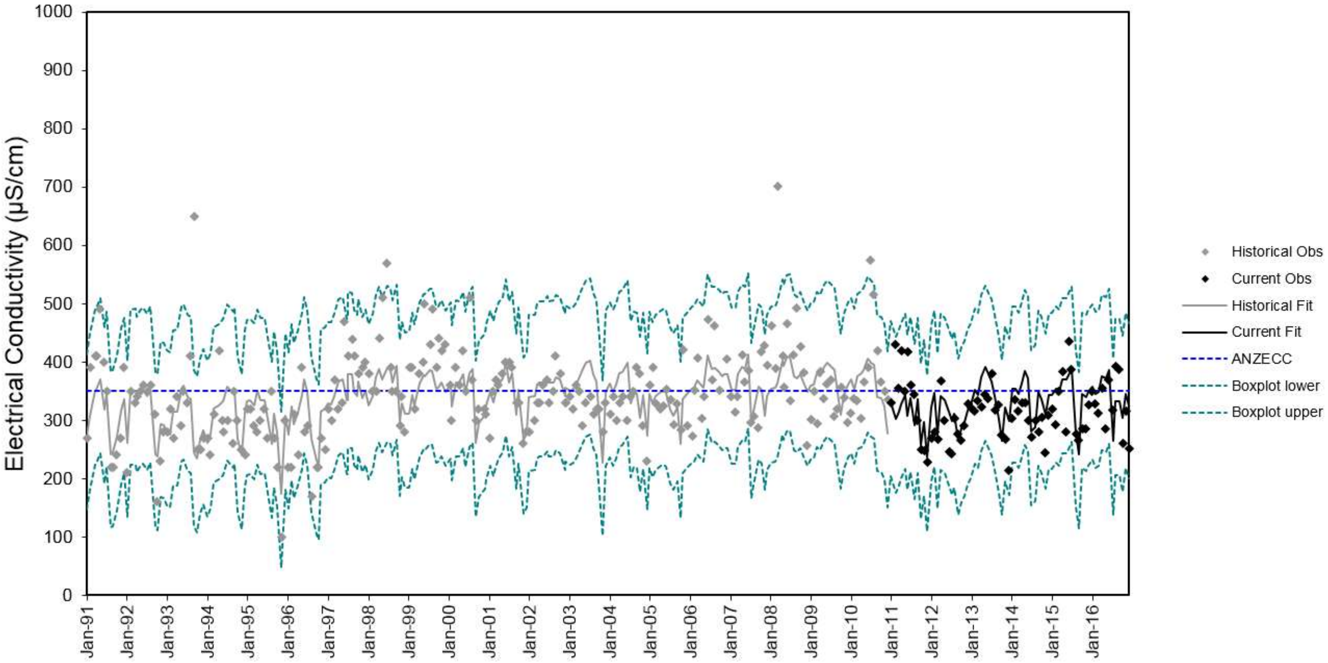


Figure 87: Control chart for electrical conductivity (in µS/cm) in the La Trobe River at Rosedale 1991 – 2016

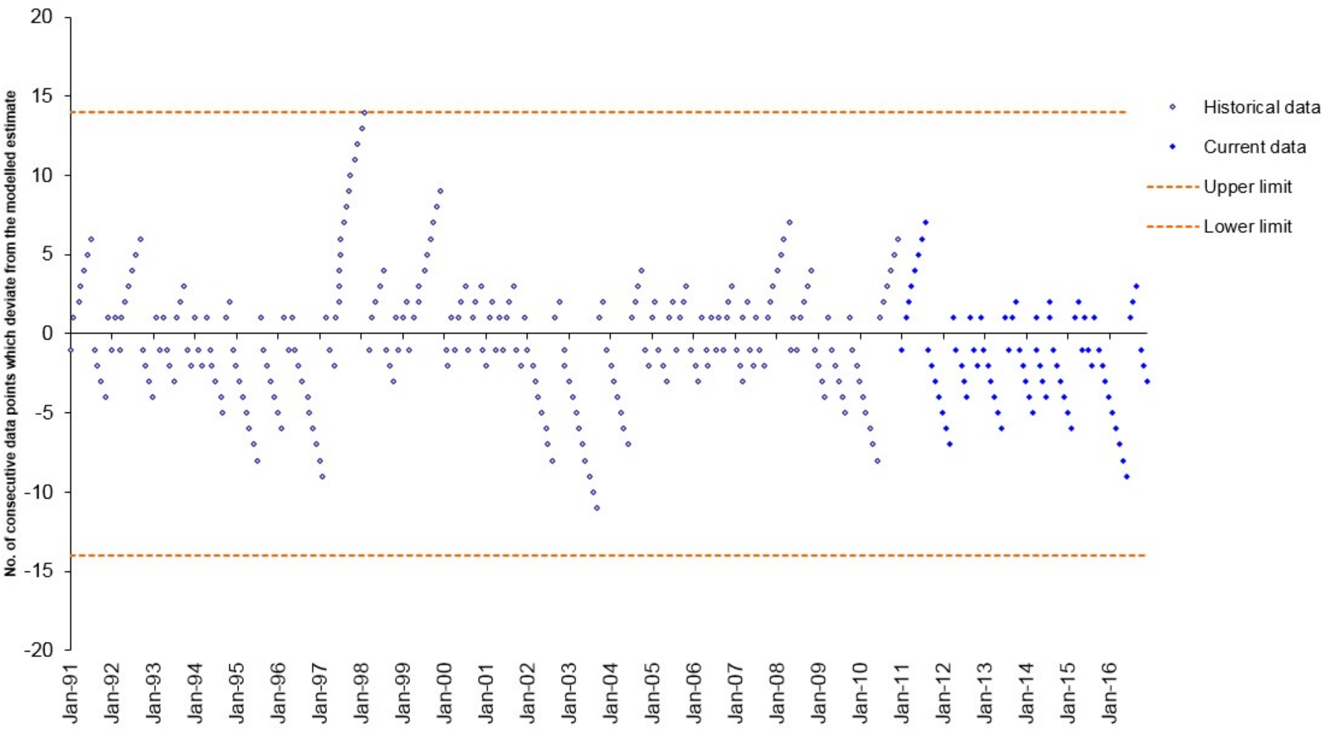


Figure 88: Run chart for electrical conductivity (in µS/cm) in the La Trobe River at Rosedale 1991 – 2016

8.3.4 Total nitrogen

Variation in total nitrogen in the La Trobe River at Rosedale between 1991 and 2010 was poorly explained by a combination season, water temperature and flow (R^2 = 0.58, Table 67). Average and median total nitrogen levels since 2010 have been generally higher compared to historical observations (Table 68) and exhibited higher variability.

Although there are no extended runs where the observed values exceed the predicted value (Figure 89), there were four occasions between 2011 and 2016 where total nitrogen levels were outside of the historical control limits (Figure 90). These high levels correlate with high rainfall and flooding events in the catchment. Since 2010, a number of total nitrogen observations have exceeded the SEPP (WoV) trigger value of 0.9 mg/L (75th percentile annual value) at this site. Generally, observations were found to be inside the model limits.

Table 67: Best fit regression models to describe variation in total nitrogen in the La Trobe River at Rosedale between 1991 and 2010

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Total nitrogen (mg/L)	TN = 0.620 – 0.144*MonthSIN – 0.012*Temp + (0.0345*$Flow^{0.4}$)	239	0.58	26%

Table 68: Summary statistics for historical (1991- 2010) and current (2011-2016) total nitrogen data recorded in the in the La Trobe River at Rosedale

Parameter	Record	N	Mean	Median	Standard Deviation
Total nitrogen (mg/L)	Historical	239	1.02	0.92	0.41
	Current	73	1.18	1.04	0.47
	Overall	312	1.06	0.93	0.43

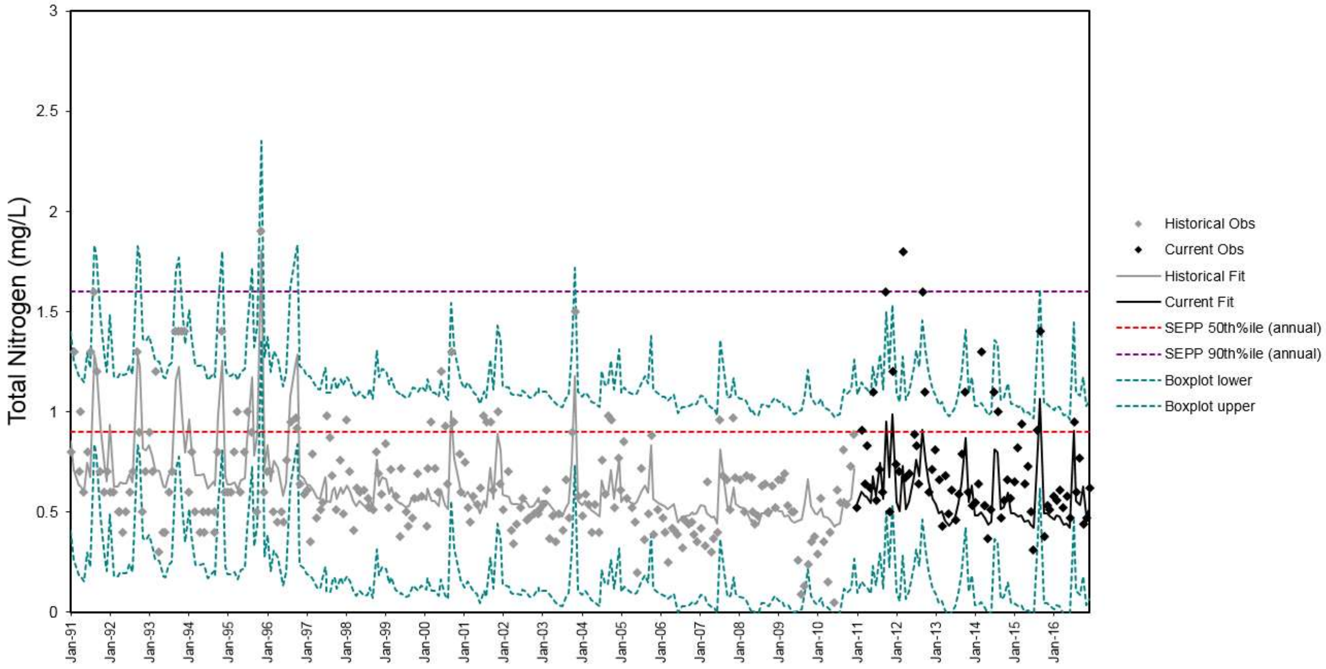


Figure 89: Control chart for total nitrogen (in mg/L) in the La Trobe River at Rosedale 1991 - 2016.

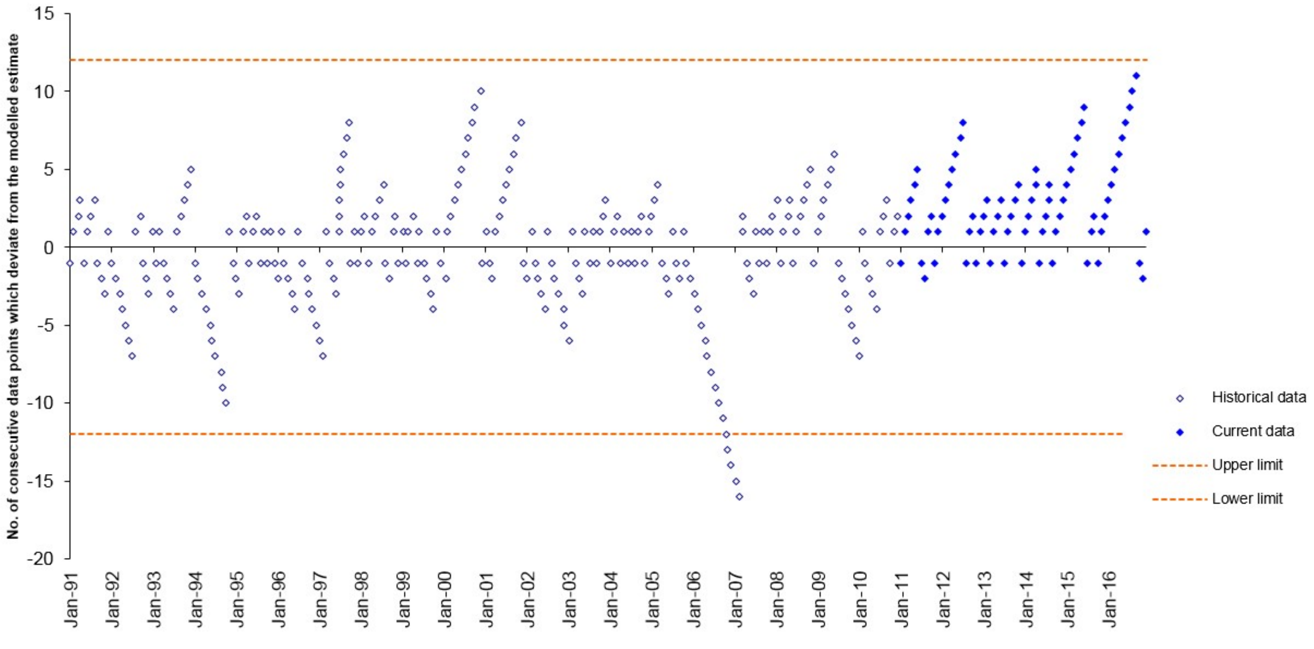


Figure 90: Run chart for total nitrogen (in mg/L) in the La Trobe River at Rosedale 1991 - 2016.

8.3.5 Total phosphorus

Variation in total phosphorus in the La Trobe River at Rosedale between 1991 and 2010 was poorly explained by a combination of water temperature, flow and cumulative rainfall in the preceding 72 hours (R^2 = 0.44, Table 69). Rainfall data was obtained from East Sale rainfall gauge (site # 085072) operated by the Bureau of Meteorology. Average and median total phosphorus levels at this site were higher after 2010 compared to the period 1991 to 2010 (Table 70). This increase in total phosphorus levels shows some correlation with the increase in turbidity between 2010 and 2016 (Section 8.3.2) which suggests that phosphorus at this site may be bound to fine soil particles and could therefore be associated with erosion or the mine collapse.

Total phosphorus data was quite scattered post 2010, in response to increased rainfall. There were only minor extended runs where the observed values differ from predicted values (Figure 92). There were four observations that were outside of the model controls that could trigger further investigation, especially since total phosphorus concentrations at this site frequently exceeded the annual 50th percentile SEPP (WoV) trigger level of ≤0.06 mg/L (Figure 91).

Table 69: Best fit regression models to describe variation in total phosphorus in the La Trobe River at Rosedale between 1991 and 2010

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Total Phosphorus (mg/L)	TP = 0.0136 + 0.00270*Temp + 0.0000138*Flow + 0.00112*Rain72	243	0.439	40%

Table 70: Summary statistics for historical (1991- 2010) and current (2011-2016) total phosphorus data recorded in the in the La Trobe River at Rosedale

Parameter	Record	N	Mean	Median	Standard Deviation
Total phosphorus (mg/L)	Historical	244	0.082	0.07	0.043
	Current	73	0.104	0.093	0.050
	Overall	317	0.087	0.08	0.046

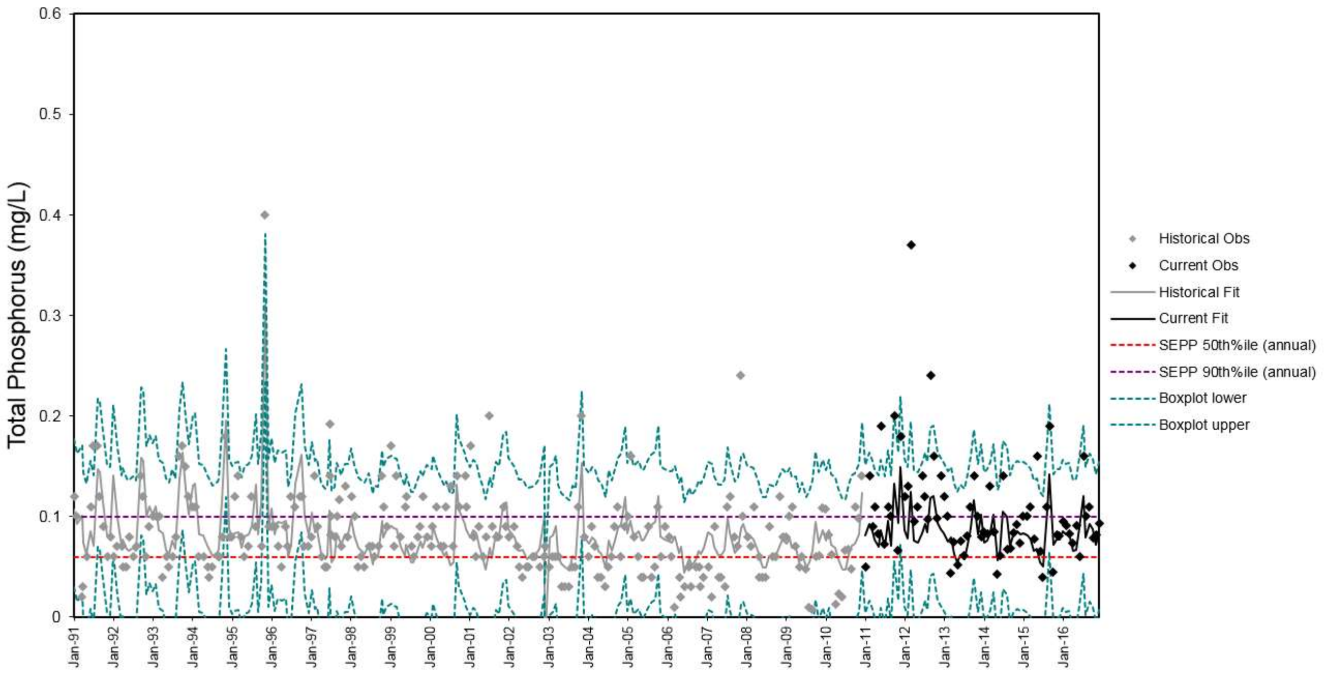


Figure 91: Control chart for total phosphorus (in mg/L) in the La Trobe River at Rosedale 1991 - 2016.

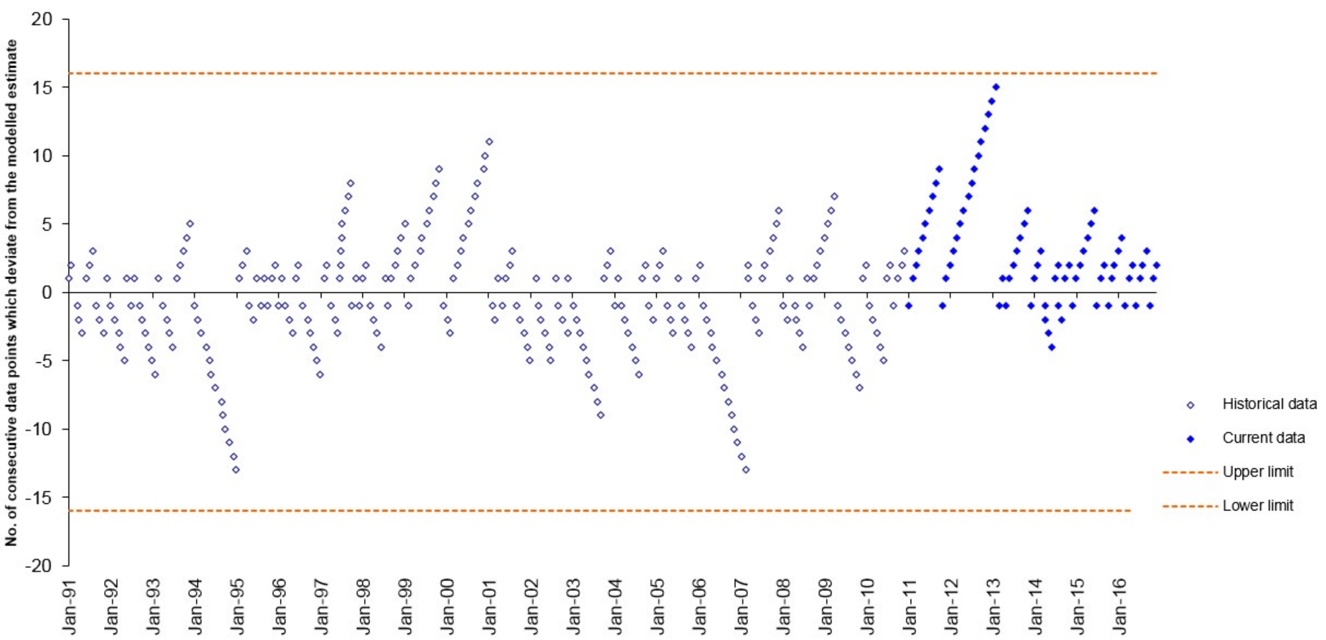


Figure 92: Run chart for total phosphorus (in mg/L) in the La Trobe River at Rosedale 1991 - 2016.

9. Results for Yarra River at Chandler Highway Kew (229143)

9.1 Site Location

The Yarra is a perennial river that flows for just under 245 kilometres from its source at Mount Baw Baw to its mouth at the top of Port Phillip Bay. Greater Melbourne dominates the lower reaches of the river, which is heavily impacted by urbanisation, altered hydrology and regulation. The upper Yarra is regulated by a series of dams and reservoirs, and is the source of much of Melbourne’s drinking water supply. The Yarra River at Chandler Highway site is located in an urban area of inner Melbourne, a short distance upstream of Dights Falls, beyond which the river becomes increasingly estuarine in nature (Figure 93). The river and its associated parklands are highly valued for recreational, cultural and amenity values.

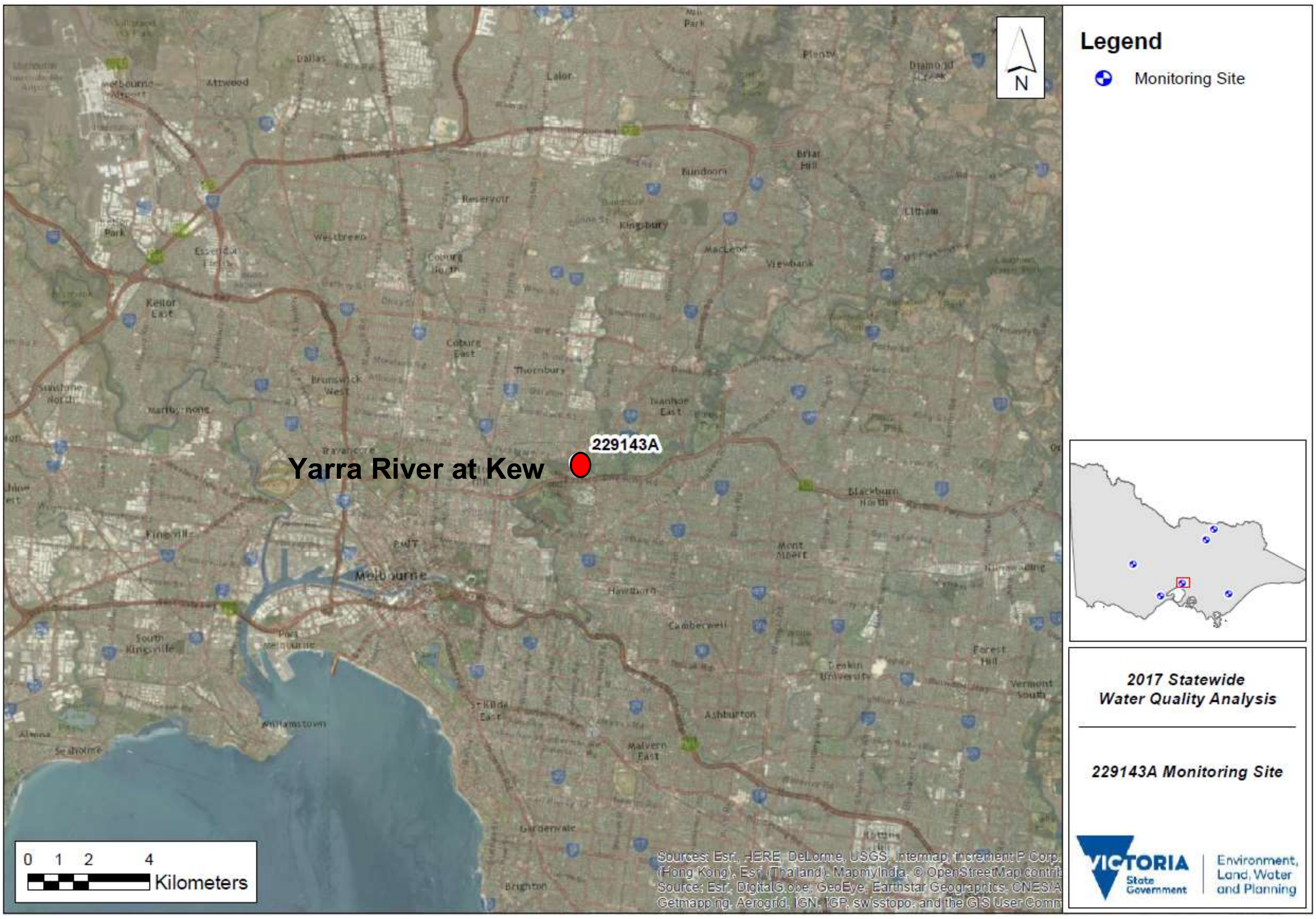


Figure 93: Locality map for Yarra River at Kew

9.2 Data availability and quality

Water quality was monitored at Chandler Highway Kew on 415 occasions between January 1991 and December 2010 (Table 71). Whilst there were no days with 'zero flow' readings, there was a significant amount of water temperature data missing, as well as some missing data for flow and rainfall. These points were excluded from the analysis.

Table 71: Missing data over period of regression model fit (Jan 1991 – Dec 2010)

Missing data elements	Dissolved oxygen	Turbidity	Electrical conductivity	pH	Total nitrogen	Total phosphorus
No. of missing water quality readings on days when at least one other parameter was recorded	65	113	65	68	84	78
No. of data points removed as outliers	0	0	0	0	0	0
No. of data points not analysed due to missing water temperature data	265	-	-	-	265	265
No. of data points not analysed due to missing or zero flow data	3	3	3	3	3	3
No. of data points not analysed due to missing rainfall data	-	4	4	-	-	4
Sample size for regression analysis	147	335	383	383	140	143

Water quality was monitored on 63 occasions between January 2011 to December 2016. Data was readily available; only a small number of points with missing rainfall data had to be excluded from the analysis (Table 72).

Table 72: Missing data over period of control chart application (2011 – 2016)

Missing data elements	Dissolved oxygen	Turbidity	Electrical conductivity	pH	Total nitrogen	Total phosphorus
No. of missing water quality readings on days when at least one other parameter was recorded	0	0	0	0	0	0
No. of data points removed as outliers	0	0	0	0	0	0
No. of data points not analysed due to missing water temperature data	0	-	-	-	0	0
No. of data points not analysed due to missing or zero flow data	0	0	0	0	0	0
No. of data points not analysed due to missing rainfall data	-	4	4	-	-	4
Sample size for control chart application	59	59	59	59	59	59

9.3 Results for each water quality variable

9.3.1 Dissolved oxygen

Variation in DO (mg/L) levels in the Yarra River at Chandler Highway Kew between 1991 and 2010 was poorly explained by water temperature ($R^2 = 0.50$, Table 73). Historical DO levels have been relatively consistent, with a clear seasonal pattern indicating higher DO levels during months with cooler water temperatures and lower DO levels during months with warmer water temperatures.

Since 2010, there has been an extended run of observed DO levels consistently above those predicted by the model, indicating an improvement in DO levels compared to the historical trends (Figure 94, Figure 95). Average and median DO levels were also higher after 2010 compared to the historical period (Table 74). The model predicted DO levels after 2010 reasonably well, with the exception of two observations which were outside the model limits (Figure 94). Dissolved oxygen levels at this site were mostly above the SEPP (WoV) trigger level of ≤6 mg/L.

The percentage saturation model also poorly explained the variation using a combination of season, water temperature, flow and rainfall data ($R^2 = 0.556$, Table 73). Similar to the dissolved oxygen model (mg/L), the percent saturation model consistently underestimated the dissolved oxygen peaks during the cooler months, with virtually all data achieving the lower SEPP (WoV) trigger level of 60% (Figure 96). Generally, observations agreed with predicted values reasonably well, with virtually all observations within the model controls.

Table 73: Best fit regression models to describe variation in dissolved oxygen in the Yarra River at Chandler Highway Kew between 1991 and 2010

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Dissolved Oxygen mg/L	DO = 13.015 -0.361*Temp	147	0.691	16%
Dissolved Oxygen % Sat	DO% = 97.497 - 3.261*MonthSIN – 2.069*Temp + (4.114*$Flow^{0.4}$) - 0.0689*Rain72	144	0.556	16%

Table 74: Summary statistics for historical (1991-2010) and current (2011 – 2016) dissolved oxygen data recorded in the Yarra River at Chandler Highway Kew

Parameter	Record	N	Mean	Median	Standard Deviation
Dissolved oxygen mg/L	Historical	147	7.4	7.6	2.2
	Current	59	8.7	8.8	1.6
	Overall	206	7.7	8.1	2.1
Dissolved oxygen % Sat	Historical	150	74	76	17
	Current	59	86	88	8.9
	Overall	209	78	82	16.3

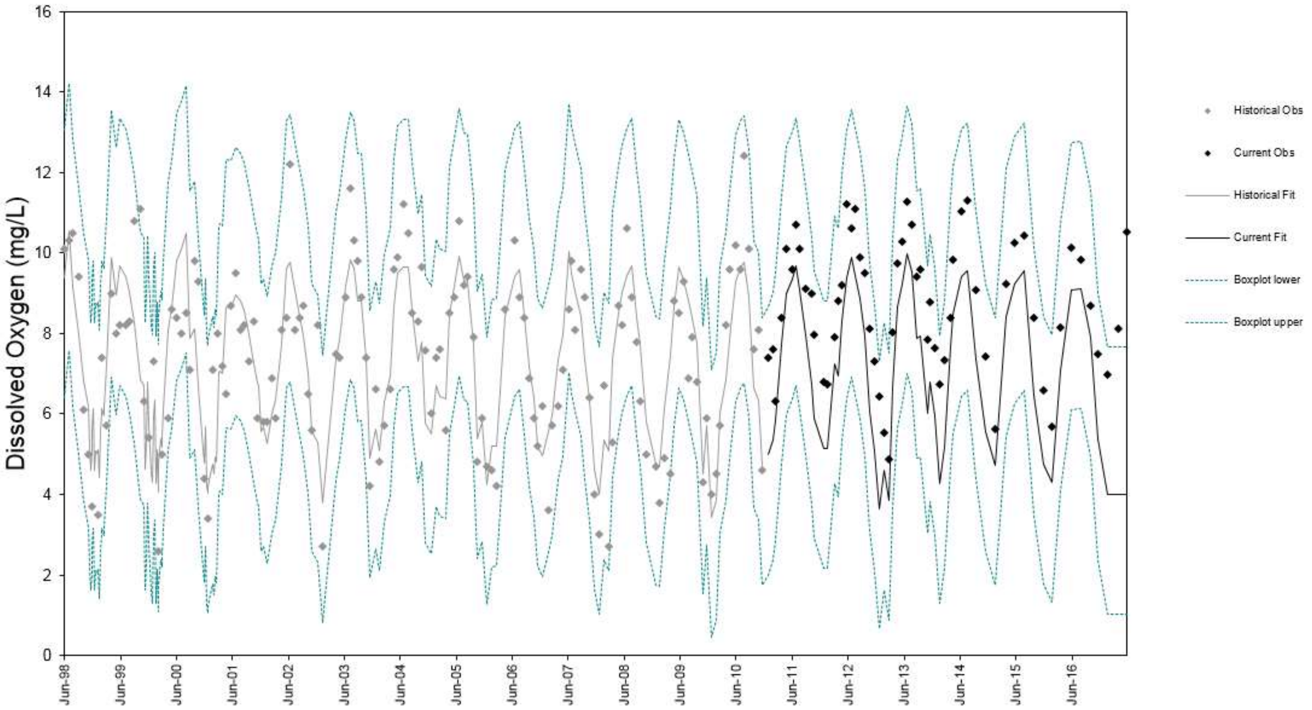


Figure 94: Control chart for dissolved oxygen (mg/L) in the Yarra River at Chandler Highway Kew 1991 – 2016

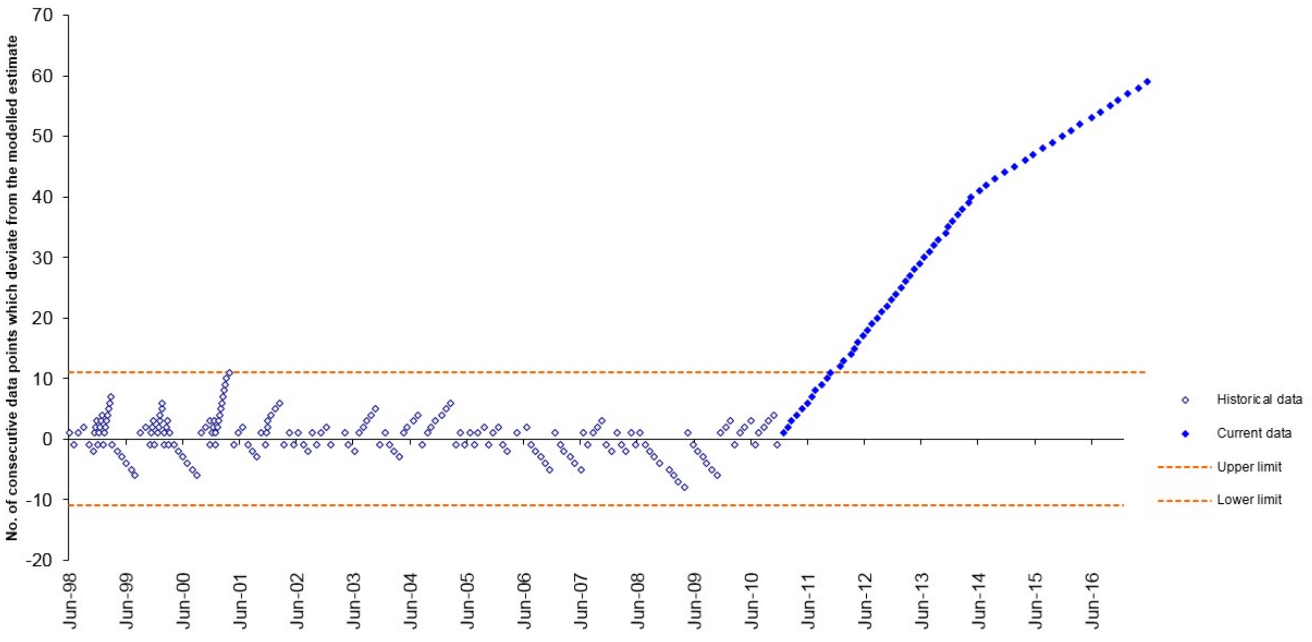


Figure 95: Run chart for dissolved oxygen (mg/L) in the Yarra River at Chandler Highway Kew 1991 – 2016

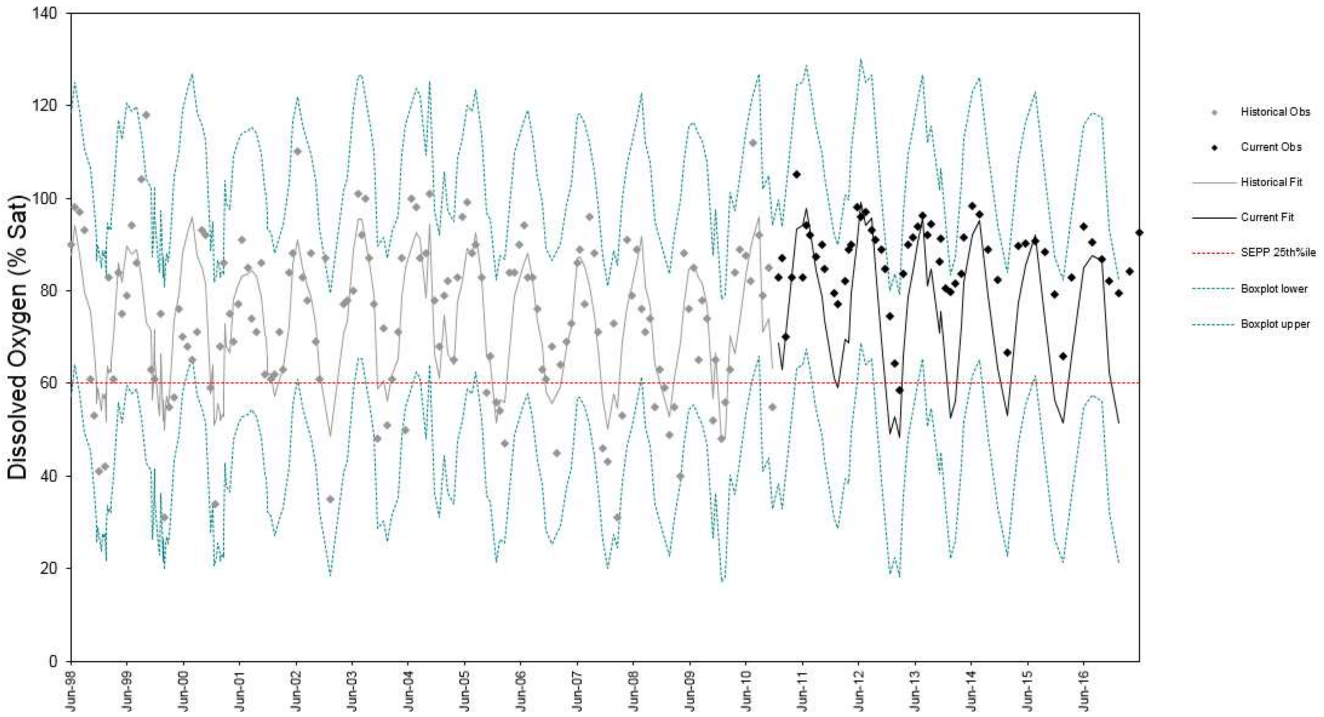


Figure 96: Control chart for percent saturation dissolved oxygen in the Yarra River at Chandler Highway Kew 1991 – 2016

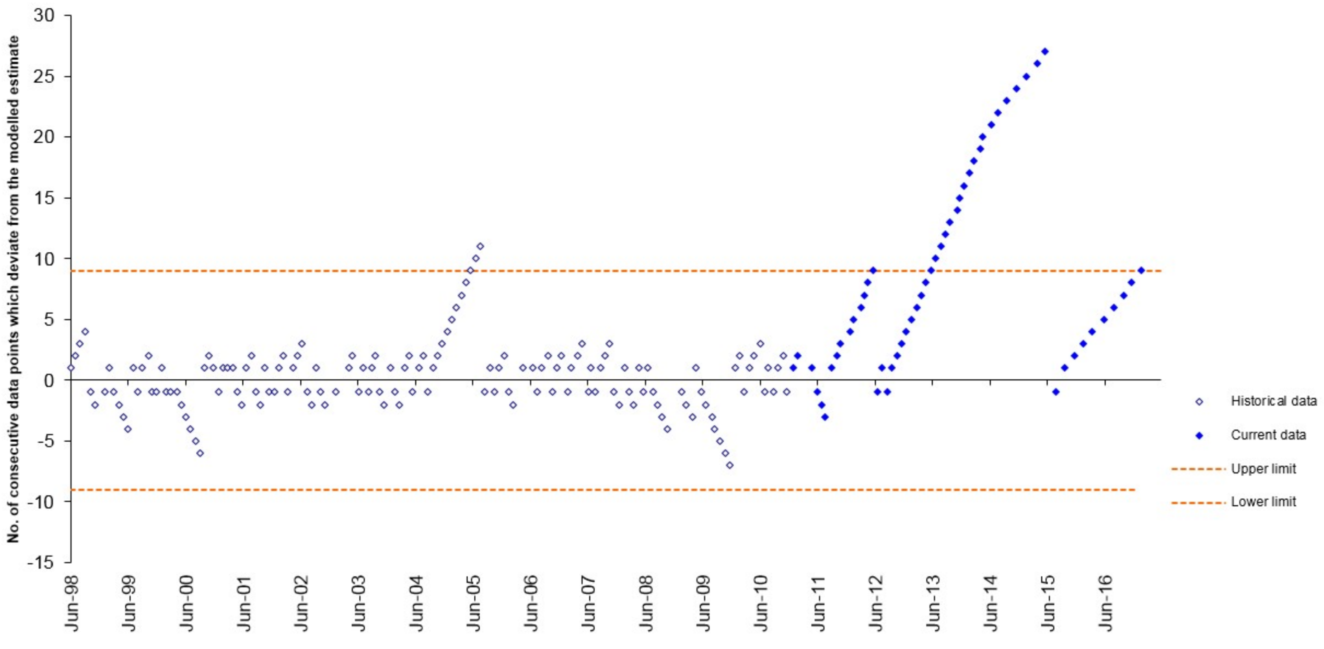


Figure 97: Run chart for percent saturation dissolved oxygen in the Yarra River at Chandler Highway Kew 1991 - 2016

9.3.2 Turbidity

Variation in turbidity in the Yarra River at Chandler Highway Kew between 1991 and 2010 was poorly explained (R^2= 0.45, Table 75) by a combination of flow and cumulative rainfall in the preceding 72 hours.

Since 2010, average turbidity levels have increased slightly from historical levels but with a large increased in variability (Table 76). The model exhibits a distinct seasonal pattern in that observed turbidity values were consistently higher than predicted values during warmer months, and consistently lower than predicted values during cooler months (Figure 98). The model predicted turbidity after 2010 reasonably well, with the exception of one very high recorded value in early 2011 outside the model limits (Figure 98). This correlates with an extensive state-wide flood event which would have entrained large amounts of organic debris into the river. Turbidity levels at this site have frequency exceeded the SEPP (WoV) trigger level of ≤30 NTU (50th percentile annual value) since 2010. Observations outside of control, particularly for those above the 90th percentile annual SEPP (WoV) trigger value of ≤80 NTU, may be a trigger for further investigation at the time of the observation.

Table 75: Best fit regression models to describe variation in turbidity in the Yarra River at Chandler Highway Kew between 1991 and 2010

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Turbidity (NTU)	$TURBIDITY = (2.693 + (0.475*Flow^{0.4}) + 0.0433*Rain72)^{(1/0.4)}$	335	0.453	23%

Table 76: Summary statistics for historical (1991- 2010) and current (2011-2016) turbidity data recorded in the in the Yarra River at Chandler Highway Kew

Parameter	Record	N	Mean	Median	Standard Deviation
Turbidity (NTU)	Historical	340	44	31	48
	Current	59	48	28	121
	Overall	399	45	30	64

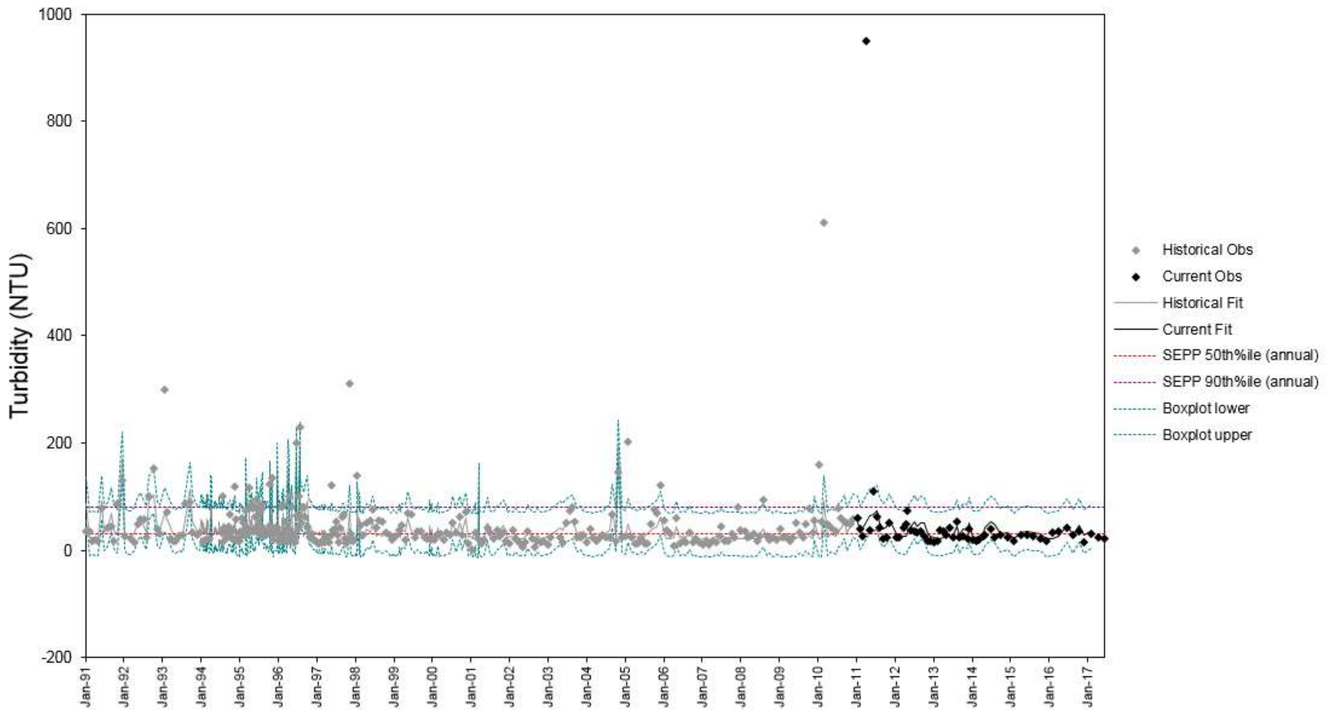


Figure 98: Control chart for turbidity (in NTU) in the Yarra River at Chandler Highway Kew 1991 - 2016.

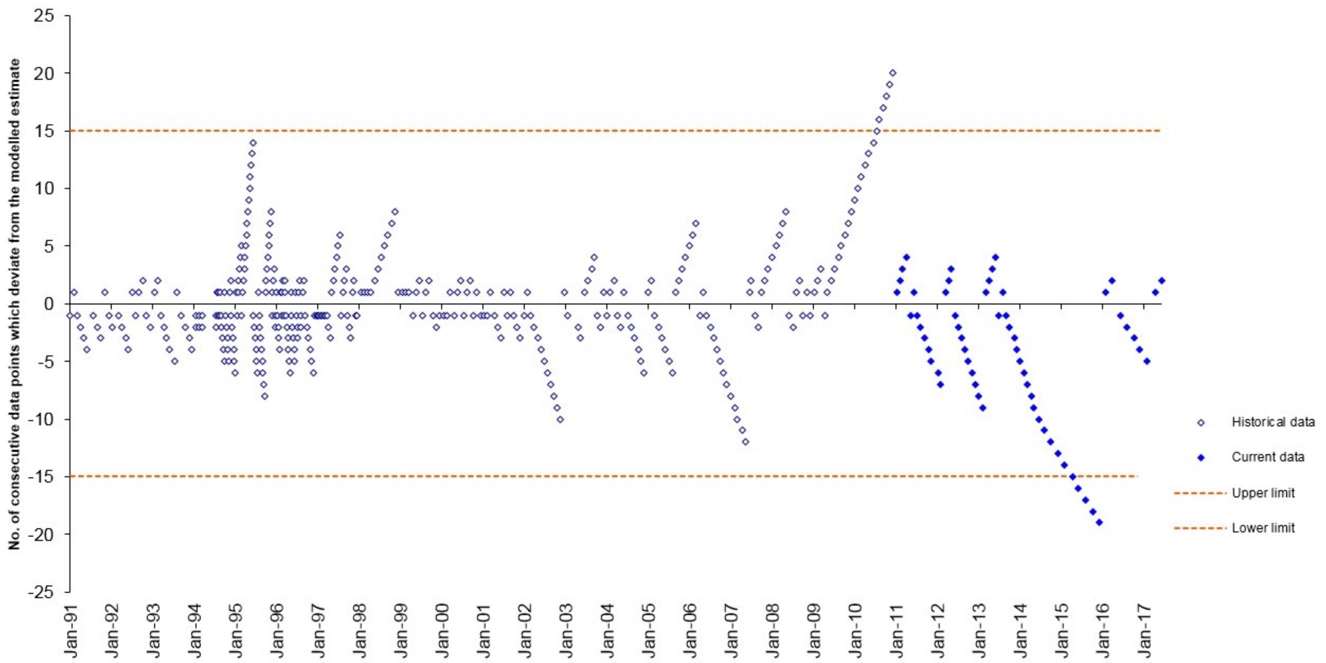


Figure 99: Run chart for turbidity (in NTU) in the Yarra River at Chandler Highway Kew 1991 - 2016.

9.3.3 Electrical conductivity

Variation in EC in the Yarra River at Chandler Highway Kew between 1991 and 2010 was very poorly explained by a combination of season, date, flow and cumulative rainfall in the preceding 72 hours (R^2= 0.28, Table 77).

Between 1991 and 2010, EC at this site generally increased as the drought increased in intensity from 1996 to mid-2010 (Figure 100), which is an indication of why date was a significant predictor variable for the model. Since 2010, there has been an extended run of observed EC levels consistently below those predicted by the model, indicating an improvement in EC levels compared to the historical trends.

As predicted by the model, the average and median electrical conductivity levels were lower after 2010 when compared to the historical period (Table 78), although observed data were further below the modelled fit (Figure 101). Besides a few points between 2010 and 2011, observed values were generally within the limits of the model. Electrical conductivity levels at this site were below the ANZECC trigger value of ≤350 µS/cm. It is therefore not considered a threat to aquatic ecosystems or other beneficial uses of the waterway.

Table 77: Best fit regression models to describe variation in conductivity in the Yarra River at Chandler Highway Kew between 1991 and 2010

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Electrical Conductivity (µS/cm)	$EC = (3.416 - 0.227*MonthSIN + 0.000112*JDate + (-0.350*Flow^{0.4}) + 0.0235*Rain72)^{(1/0.4)}$	383	0.284	9%

Table 78: Summary statistics for historical (1991- 2010) and current (2011-2016) conductivity data recorded in the in the Yarra River at Chandler Highway Kew

Parameter	Record	N	Mean	Median	Standard Deviation
Electrical conductivity (µS/cm)	Historical	388	207.32	200	68.68
	Current	59	190.68	180	36.67
	Overall	447	205.12	200	65.57

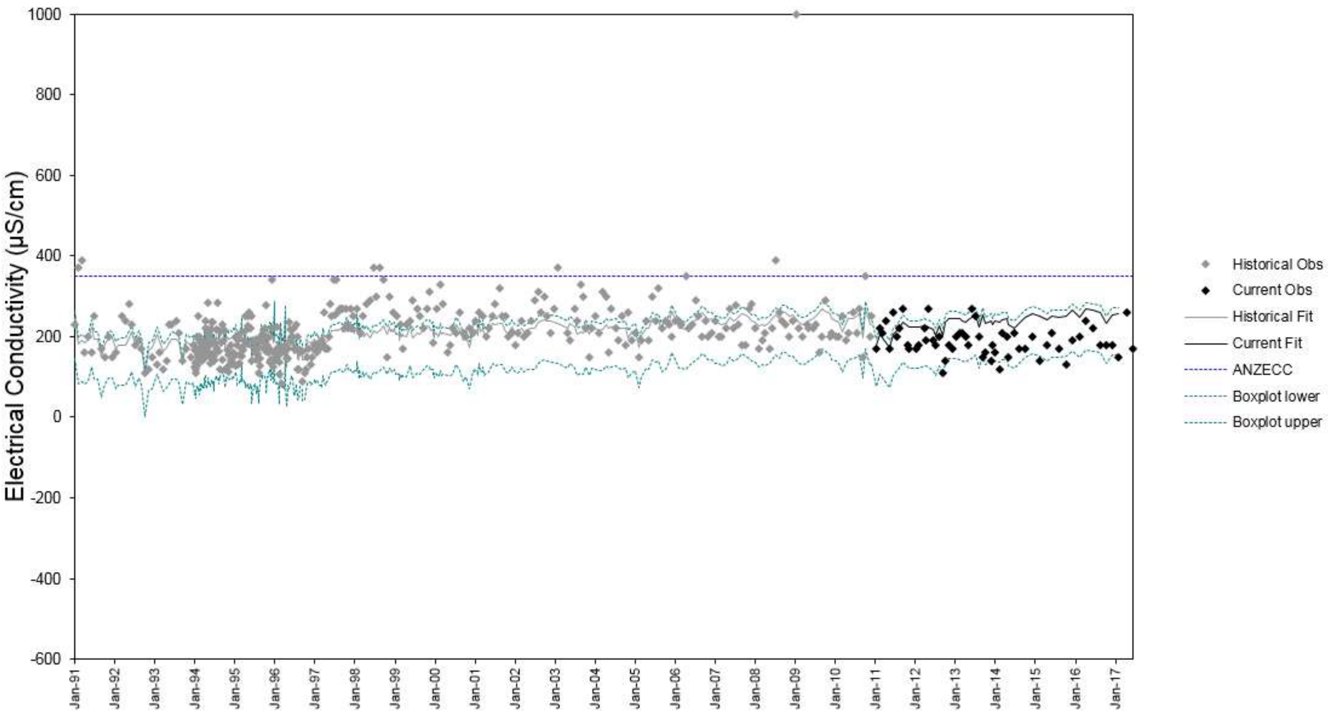


Figure 100: Control chart for electrical conductivity (in µS/cm) in the Yarra River at Chandler Highway Kew at Peechelba 1991 – 2016

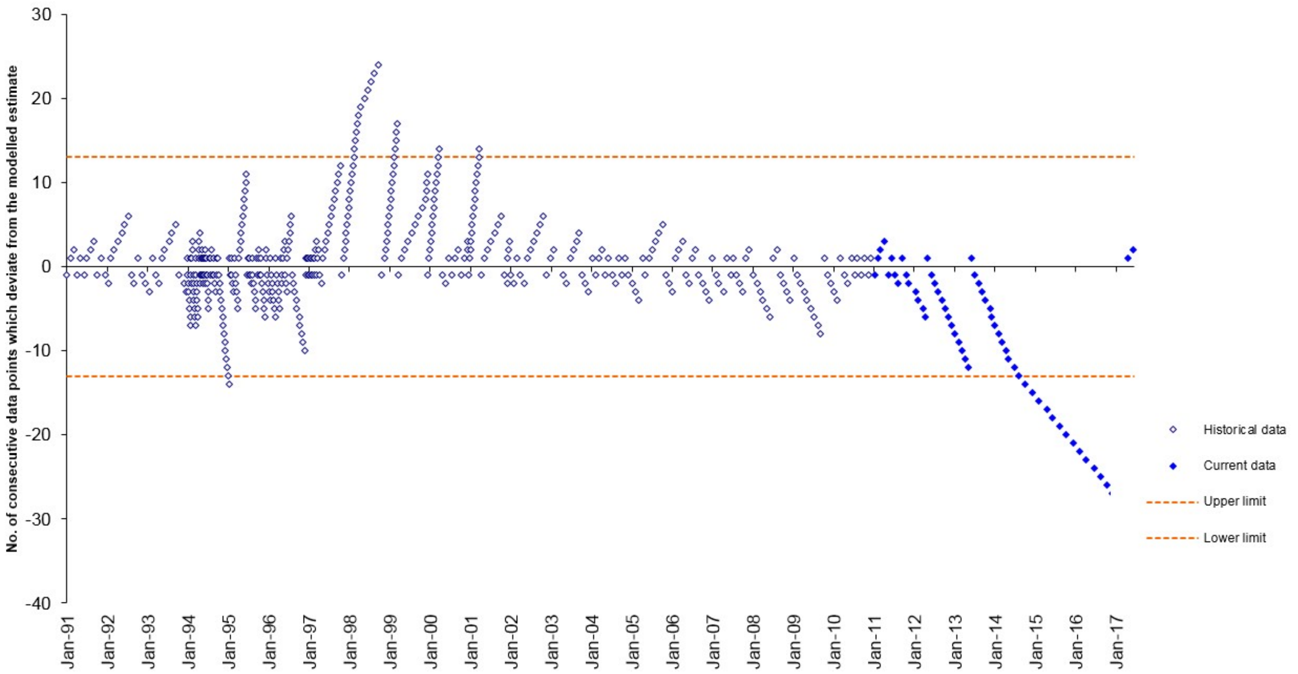


Figure 101: Run chart for electrical conductivity (in µS/cm) in the Yarra River at Chandler Highway Kew 1991 – 2016

9.3.4 Total nitrogen

Variation in total nitrogen in the Yarra River at Chandler Highway Kew between 1991 and 2010 was poorly explained ($R^2 = 0.47$) by a combination of water temperature and flow (Table 79). Since 2010, average and median total nitrogen levels have decreased in comparison to the historical period, but were more variable compared to the preceding years (Table 80).

It is interesting to note that the model successfully predicted a spike in total nitrogen levels between 2011 and 2012, during which the Yarra River would have experienced increased nutrient loading due to a strong La Niña event which caused widespread flooding and increases in stream flow (Figure 102). Whilst observed values were consistently within the limits of the model since 2010, observations were generally even further below predicted values (Figure 103). A number of total nitrogen concentrations exceeded the SEPP (WoV) trigger levels of ≤0.900 mg/L.

Table 79: Best fit regression models to describe variation in total nitrogen in the Yarra River at Chandler Highway Kew between 1991 and 2010

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Total nitrogen (mg/L)	TN = 0.847 - 0.0154*Temp+ (0.298*Flow$^{0.4}$)	140	0.469	24%

Table 80: Summary statistics for historical (1991- 2010) and current (2011-2016) total nitrogen data recorded in the in the Yarra River at Chandler Highway Kew

Parameter	Record	N	Mean	Median	Standard Deviation
Total nitrogen (mg/L)	Historical	140	1.25	1.24	0.41
	Current	59	1.08	0.98	0.39
	Overall	202	1.20	1.14	0.41

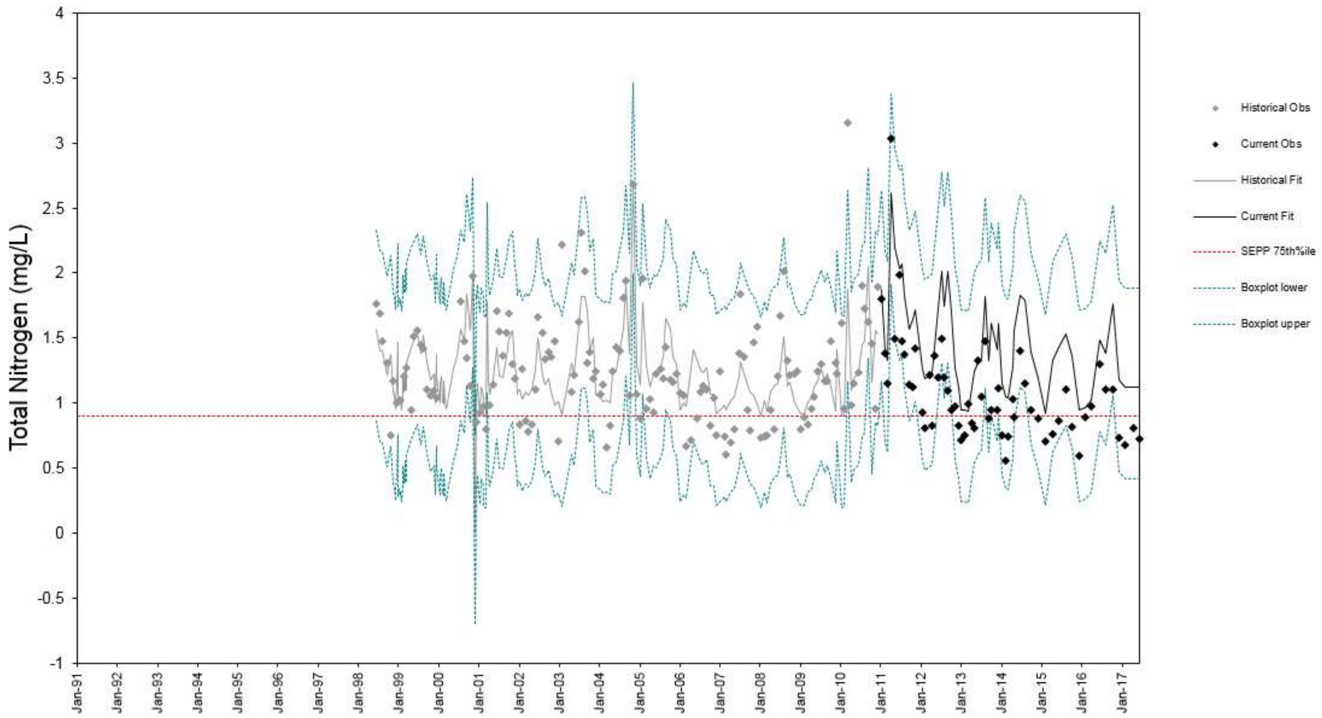


Figure 102: Control chart for total nitrogen (in mg/L) in the Yarra River at Chandler Highway Kew 1991 - 2016.

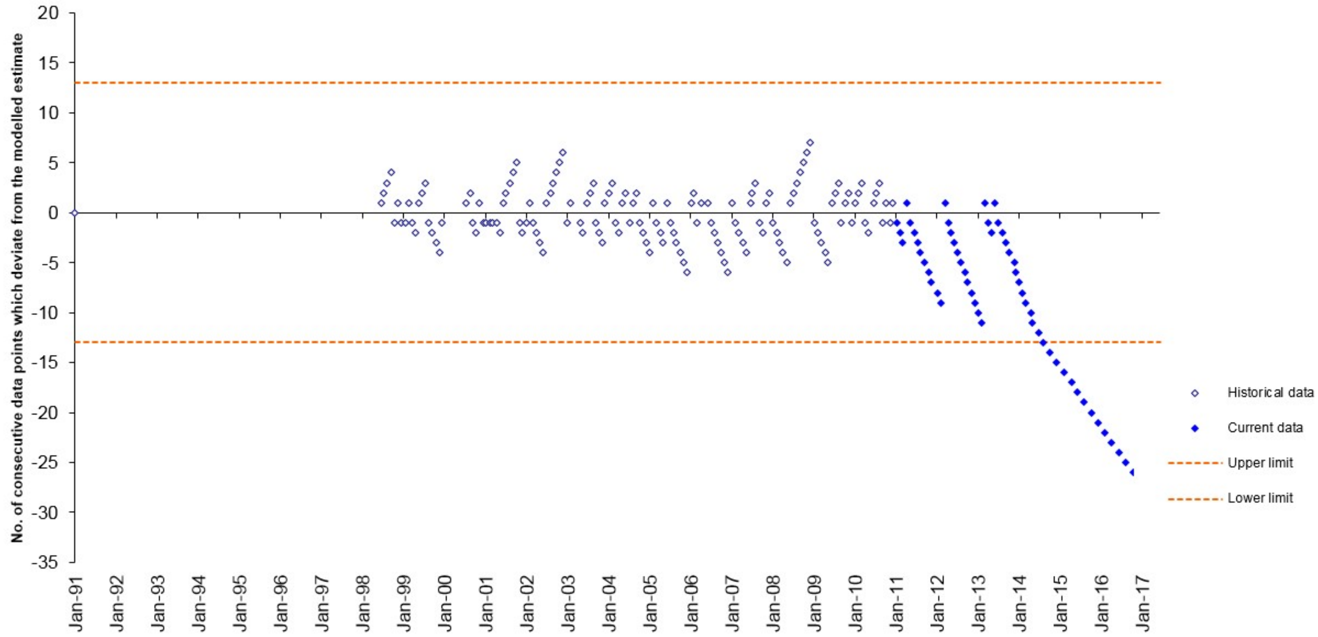


Figure 103: Run chart for total nitrogen (in mg/L) in the Yarra River at Chandler Highway Kew 1991 - 2016.

9.3.5 Total phosphorus

Variation in total phosphorus concentration in the Yarra River at Chandler Highway Kew between 1991 and 2010 was explained poorly by water temperature, flow and cumulative rainfall in the preceding 72 hours (R^2= 0.46, Table 81).

Average and median total phosphorus levels at this site have decreased since 2010 compared to the period 1991 to 2010 (Table 82). This correlates with an increase in dissolved oxygen with higher flows post-drought, which may be restricting the release of phosphorus from the sediment. Since 2010, total phosphorus concentrations were generally within the limits of the model, however the majority of observations were below predicted values (Figure 104). Whilst the model accurately predicted a spike in total phosphorus concentration associated with the 2011 floods, the magnitude of this concentration was higher than anticipated.

There were four observations that were outside of the model controls that could trigger further investigation, especially since a number of total phosphorus concentrations at this site exceeded the SEPP (WoV) trigger level of ≤0.08 mg/L (Figure 104).

Table 81: Best fit regression models to describe variation in total phosphorus in the Yarra River at Chandler Highway Kew between 1991 and 2010

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Total Phosphorus (mg/L)	$TP = (0.00390+0.00209*Temp+(0.0160*Flow^{0.4})+0.00195*Rain72$	143	0.464	34%

Table 82: Summary statistics for historical (1991- 2010) and current (2011-2016) total phosphorus data recorded in the in the Yarra River at Chandler Highway Kew

Parameter	Record	N	Mean	Median	Standard Deviation
Total phosphorus (mg/L)	Historical	143	0.080	0.074	0.036
	Current	59	0.069	0.061	0.038
	Overall	208	0.077	0.071	0.037

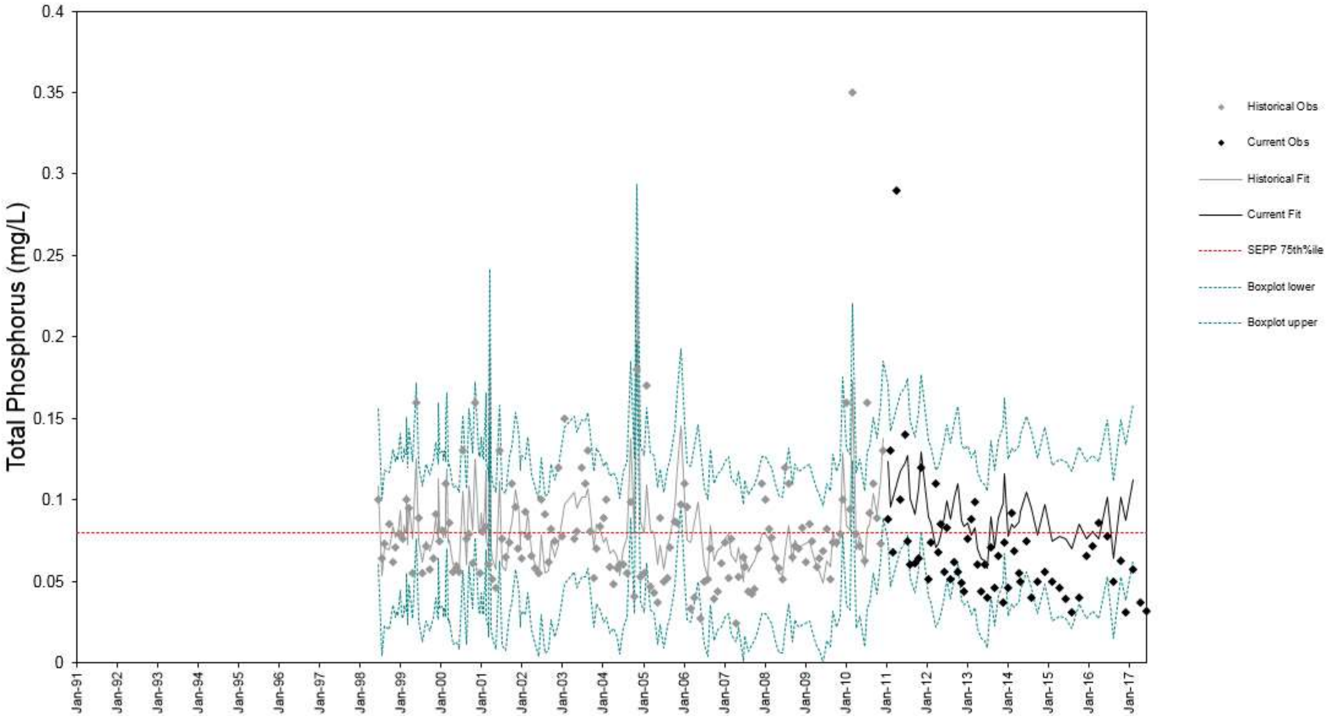


Figure 104: Control chart for total phosphorus (in mg/L) in the Yarra River at Chandler Highway Kew 1991 - 2016.

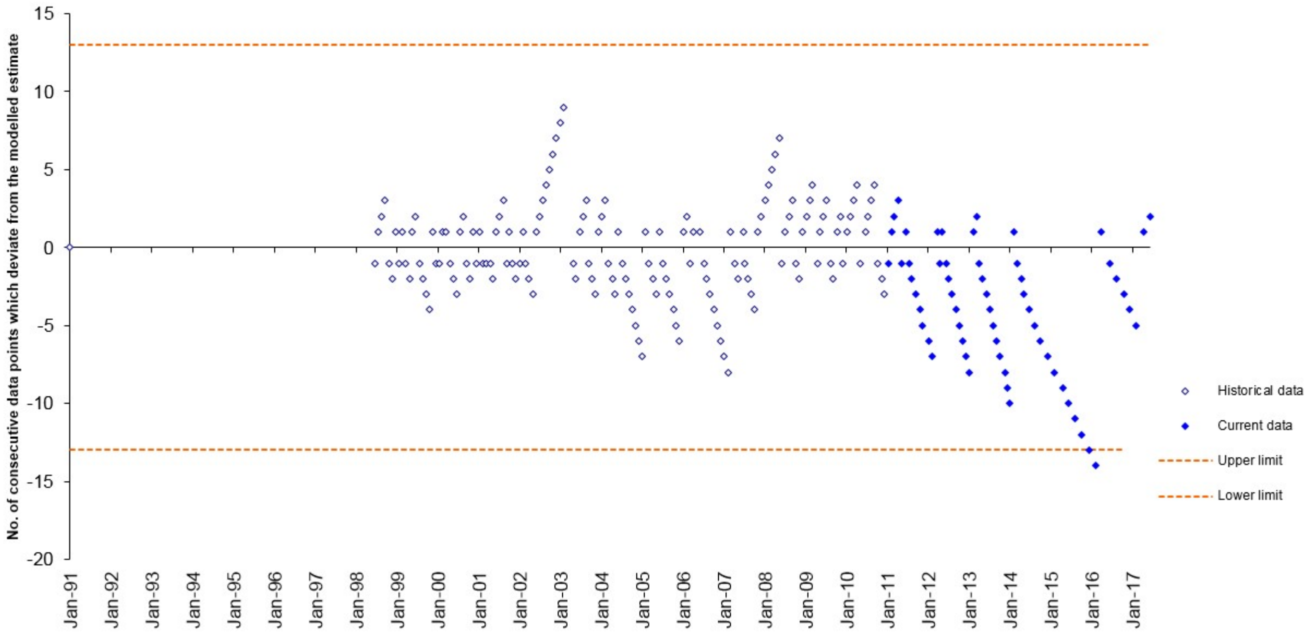


Figure 105: Run chart for total phosphorus (in mg/L) in the Yarra River at Chandler Highway Kew 1991 - 2016.

10. Conclusions

Trends in water quality from 2011 to 2016 were assessed at 79 water monitoring sites and in more detail at six Victorian monitoring sites. Current data (2011 to 2016) was compared to the historical record (1991 to 2010) using time series plots, statistical analysis, multiple regression analysis, control charts and run charts. The aim was to determine whether any statewide patterns were evident and whether water quality was as expected at sites including whether water quality changed relative to the expected historical trajectories. A summary of the individual site results per parameter are included in Appendix A and results for each of the water quality parameters for the six sites investigated in detail are summarised in Appendix C.

Overall, the effect of reduced rainfall and river flows during the Millennium drought (1996 to mid-2010) dominated the water quality trends over the historical record (1991 to 2010). Most sites, when site-specific factors were taken into account, showed trends of declining turbidity and nutrients from reduced runoff and declining dissolved oxygen levels and increasing electrical conductivity from prolonged periods of low flow conditions.

Record rainfall and flooding in late 2010 to 2012 from a La Niña weather pattern broke the Millennium Drought, signaling the return to average conditions post 2012. These climatic drivers caused a shift in water quality conditions in the current data (2011 to 2016) at most sites. Dissolved oxygen levels improved at most sites during the current period from increased flow in the rivers. However, turbidity and nutrient levels increased with higher catchment runoff, although site-specific factors were at play.

Given the large change in climate between the historical and current period, the historical models developed based on drought years were not good predictors of the current wet/average conditions. Despite flow and rainfall being included as predictor variables, this work shows that the scale of changes in these water quality drivers were not able to be effectively captured in the model and therefore the models were mostly non-transferable between wet and dry years. However, the outcome of this modelling has shown the rapid changes (mostly improvements) in water quality post-drought and the reversal in historical trajectories, which may not have been as obvious with basic water quality analysis.

Analysing specific catchment-based actions and their subsequent effect on water quality was not the primary purpose of this assessment. However, Table 83 contains some commentary around where further investigations could assist with determining if land use and or catchment management actions are having an impact on water quality or if flow is the primary trend driver for the six water quality parameters investigated.

Table 83: High level analysis of land use patterns

Site	Reason for inclusion	Comment
Wimmera River at Eversley (415207)	Used in previous trend report. Useful site for assessing impacts of drought. Data collected during the drought may be used to predict what will happen during future droughts.	The findings of this investigation may suggest that drought stressed rivers experience a decrease in water quality once wetter conditions are experienced. Further investigation is required to quantify and confirm this suggestion. If confirmed, identifying drought stressed rivers may allow river managers to identify where the biggest water quality impacts of flow might be experienced, for example in rivers that have historically experienced extended periods of reduced flow.
Broken River at Goorambat (404216)	Used in previous trend report. Models provided good predictions, especially for turbidity. Continue to evaluate changes following	It is difficult to identify if changes in water quality were a result of the drought breaking and a return to wetter conditions, or if the decommissioning of Lake Mokoan had an impact on water quality. Further investigation is recommended in this space.

Site	Reason for inclusion	Comment
	decommissioning of Lake Mokoan.	
Barwon River at Pollocksford (233200)	Used in previous trend report. Continue to assess water quality response to land management improvement in catchment.	Two of the water quality parameters assessed showed an improvement in the current period when compared to the historic period, with two parameters showing a decline and one parameter showing no change. These findings may be reflective of land management improvements, however, more detailed investigations into specific events is required to confirm.
Oven River at Peechelba (403241)	Lowland site on Murray Plain – provides geographic spread	This site was included for geographic spread. No clear patterns were observed that suggested any different water quality responses from sites in different parts of the State.
La Trobe River at Rosedale (226228)	Lowland site on Gippsland Plain – provides geographic spread, establish baseline for assessing changes associated with coal mine rehabilitation	Successful in establishing baseline for assessing changes in future years. No clear patterns were observed that suggested any different water quality responses from sites in different locations or in upland or lowland locations.
Yarra River at Chandler Highway (229143)	Melbourne Water site that is located in the Melbourne region for assessing impacts of a range of catchment management decisions relating to water supply and urbanisation.	Water quality improved at this site for both DO, EC, TN and TP which may have been a result of catchment management decisions relating to water supply and urbanization, however further investigation is recommended to quantify and identify these practices and their impact on water quality.

The importance of having a complete long-term records at water monitoring sites was evident during this assessment. Long term data provides a solid basis for comparisons of changes in water quality across the State and hence leads to better information about management practices and the potential to direct where funds could be best spent in terms of improving water quality. It was evident during this Study that not all catchments had a representative number of water monitoring sites with long term data and hence widescale catchment changes were difficult to assess. Any reduction in water quality data collection across the State should consider investigations such as these that rely on the long term record.

11. References

Department of Environment and Primary Industries (2013) Victorian Water Quality Trends 1991 - 2010.

EPA (2011) Western Port Condition Report, Publication 1371.

SEPP (2003) Variation of the State Environment Protection Policy (Waters of Victoria) Victorian Government Gazette No S107.

Appendix A Stage 1 Site List and Relative Change Summary Table

The relative change is the current median value minus the historical median value divided by the historical median value

Negative relative change (reduction in parameter)
Positive relative change (increase in parameter)
No relative change

Site number	Site name	DO	Turbidity	pH	EC	TN	TP
221201	Cann River (West Branch) @ Weeragua						
221210	Genoa River @ The Gorge						
224203	Mitchell River @ Glenaladale						
224206	Wonnangatta River @ Crooked River						
224213	Dargo River @ Lower Dargo Road						
225209	Macalister River @ Licola						
225210	Thomson River @ The Narrows						
226228	Latrobe River @ Rosedale (Main Stream)						
227202	Tarwin River @ Meeniyan						
227231	Bass River @ Glen Forbes South						
228213	Bunyip Main Drain @ Little Road, Iona						
228223	Lang Lang River U/S Drouin- Poowong Road, Athlone						
228246	Deep Creek @ Rythedale Ballarto Rd						
228248	Tarago River @ Longwarry North Morrisons Rd						
228274	Paterson River @ National Water Sports Centre						
229143	Yarra River @ Chandler Highway Kew						
229200	Yarra River @ Warrandyte						
230105	Maribyrnong River @ Brimbank Park U/S Taylors Creek						
230202	Jackson Creek @ Sunbury						
230205	Deep Creek @ Bulla (D/S Of Emu Creek Junct.)						
230235	Maribyrnong River @ Avondale Heights						
231204	Werribee River @ Werribee Diversion Weir						
231213	Lerderderg River @ Sardine Creek O'brien Crossing						
231231	Toolern Creek @ Melton South						
232202	Moorabool River @ Batesford						
232204	Moorabool River @ Morrisons						
232210	Moorabool River West Branch @ Lal Lal						
233200	Barwon Pollocksford						

Site number	Site name	DO	Turbidity	pH	EC	TN	TP
233214	Barwon River East Branch @ Forrest (Above Tunnel)						
233215	Leigh River @ Mount Mercer						
233218	Barwon River @ Inverleigh						
234201	Woady Yaloak@Cressy						
234203	Pirron Yallock Creek @ Pirron Yallock						
235202	Gellibrand River @ Upper Gellibrand						
235203	Curdies River @ Curdie						
235211	Kennedys Creek @ Kennedys Creek						
235224	Gellibrand River @ Burrupa						
235227	Gellibrand River @ Bunkers Hill						
235237	Scotts Creek @ Curdie (Digneys Bridge)						
236209	Hopkins River @ Hopkins Falls						
237200	Moyne River @ Toolong						
237207	Surry River @ Heathmere						
238202	Glenelg River @ Sandford						
238204	Wannon River @ Dunkeld						
238206	Glenelg River @ Dartmoor						
238223	Wando River @ Wando Vale						
238228	Wannon River @ Henty						
238231	Glenelg River @ Big Cord						
401203	Mitta Mitta River @ Hinnomunjie						
401211	Mitta Mitta River @ Colemans						
401216	Big River @ Jokers Creek						
402203	Kiewa River @ Mongans Bridge						
402204	Yackandandah Creek @ Osbornes Flat						
402205	Kiewa River @ Bandiana						
402222	Kiewa River @ Kiewa (Main Stream)						
403205	Ovens Rivers @ Bright						
403210	Ovens River @ Myrtleford						
403217	Rose River @ Matong North						
403230	Ovens River @ Rocky Point						
403241	Ovens River @ Peechelba						
404207	Holland Creek @ Kelfeera						
404214	Broken Creek @ Katamatite						
404216	Broken River @ Goorambat (Casey Weir H. Gauge)						
405200	Goulburn River @ Murchison						
405203	Goulburn River @ Eildon						
405204	Goulburn River @ Shepparton						
405205	Murrindindi River @ Murrindindi Above Colwells						
405209	Acheron River @ Taggerty						

Site number	Site name	DO	Turbidity	pH	EC	TN	TP
405214	Delatite River @ Tonga Bridge						
405231	King Parrot Creek @ Flowerdale						
405264	Big River @ D/S Of Frenchman Creek Junction						
406207	Campaspe River @ Eppalock						
406213	Campaspe River @ Redesdale						
407203	Loddon River @ Laanecoorie						
407215	Loddon River @ Newstead						
407221	Jim Crow Creek @ Yandoit						
408200	Avoca River @ Coonooer						
415200	Wimmera River @ Horsham						
415207	Wimmera River @ Eversley						

Appendix B Basin List

Basin number	Basin
1	Upper Murray River
2	Kiewa River
3	Ovens River
4	Broken River
5	Goulburn River
6	Campaspe River
7	Loddon River
8	Avoca River
14	Mallee River
15	Wimmera-Avon Rivers
21	East Gippsland River
22	Snowy River
23	Tambo River
24	Mitchell River
25	Thomson River
26	Latrobe River
27	South Gippsland River
28	Bunyip River
29	Yarra River
30	Maribyrnong River
31	Werribee River
32	Moorabool River
33	Barwon River
34	Lake Corangamite
35	Otway Coast
36	Hopkins
37	Portland Coast
38	Glenelg River
39	Millicent Coast

Appendix C Stage 2 Summary Table

Terminology	R^2 Bounds
Well explained	0.75 – 1
Moderately well explained	0.6 – 0.74
Poorly explained	0.4 - 0.59
Very poorly explained	0 – 0.39

Site	Variable	Predictor variables	Regression model fit to historical data	Detectable trend since 2011	No. of current observations out of control	Comment
Wimmera River at Eversley	Dissolved oxygen (mg/L)	Season, Water temperature, Date	$R^2 = 0.42$	Slightly lower than predicted	>10 values below lower limit	The model failed to accurately predict DO in mg/L and % saturation after 2010 (post-drought). This may be because the models were developed under predominantly drought conditions. Low dissolved oxygen conditions experienced from 2009 to 2012 were likely caused by the breakdown of large amounts of accumulated organic matter entrained in the river channel during heavy rainfall events. The control chart for the DO in % saturation shows a considerable number of points below the SEPP trigger level of 80%.
	Dissolved oxygen (% sat)	Season, Water temperature, Date, 72 hour rainfall total	$R^2 = 0.35$	Slightly higher than predicted	0 values out of control	
	Turbidity (NTU)	Season, Water temperature, Date, Flow, 72 hour rainfall total	$R^2 = 0.15$	Lower than predicted	4 values above the higher limit	Turbidity levels increased after 2010, but not to the same degree the model predicted. The increased turbidity is likely to be a result of increased flows and runoff in the catchment following the end of the Millennium Drought. The majority of observations exceed the SEPP trigger level, which may be of potential concern.
	Electrical conductivity (µS/cm)	Season, Flow	$R^2 = 0.66$	Higher than predicted	>10 values above higher limit	High electrical conductivity levels in the historical period, outside of control, correlate with cease-to-flow events in the Wimmera River during the drought. Post 2010, the model more reliably predicted low EC values which typically

Site	Variable	Predictor variables	Regression model fit to historical data	Detectable trend since 2011	No. of current observations out of control	Comment
						occurred during winter and periods of flow. The increase in EC in late summer and autumn may be because of evapo-concentration and/or increased groundwater intrusion from rising water tables post-drought.
Wimmera River at Eversley	Total nitrogen (mg/L)	Season, Date, 72 hour rainfall total, Days since a >20mm rainfall event, Turbidity	$R^2 = 0.54$	Lower than predicted 2010 – 2014, generally as predicted 2014 – 2016.	2 values above the higher limit	An increase in total nitrogen levels during the current period was attributed to increased nutrient-laden catchment runoff in the wetter conditions experienced compared to the historical period that was dominated by drought. In some instances, total nitrogen concentrations exceeded the SEPP (WoV) trigger level of ≤0.900 mg/L.
	Total phosphorus (mg/L)	Season, Date, Turbidity	$R^2 = 0.55$	Lower than predicted 2010 – 2014, higher than predicted 2014 – 2016.	9 values above the higher limit	Total phosphorus concentrations have increased since the historical period. This correlates with the increase in total nitrogen concentration and turbidity observed over the same period. This suggests that much of the phosphorus at this site could therefore be associated with erosion. Values exceeded the SEPP (WoV) trigger level of ≤0.04 mg/L by as much as an order of magnitude.
Broken River at Goorambat	Dissolved oxygen (mg/L)	Water temperature, Date	$R^2 = 0.61$	Higher than predicted	2 values above the higher limit	Current data is underestimated by the model for longer periods of time compared to the historic period. This is because the historical data was showing a downward trajectory in DO during the drought. The percent saturated model shows current DO levels in Broken Creek have improved. This improvement is likely due to increased flow in the river post-drought. A number of data points remain below the lower SEPP (WoV) trigger level of 85% during summer which may warrant further investigation.
	Dissolved oxygen (% sat)	Water temperature, Date, Flow	$R^2 = 0.34$	Higher than predicted	1 value above the higher limit	
	Turbidity (NTU)	Water temperature, Date, Flow, Days since a >20mm rainfall event	$R^2 = 0.18$	Generally as predicted	3 values above the higher limit	The decommissioning of Lake Mokoan in 2009 significantly reduced turbidity levels in the Broken River compared to the historical trends. The historical model was a poor predictor of the current turbidity levels.

Site	Variable	Predictor variables	Regression model fit to historical data	Detectable trend since 2011	No. of current observations out of control	Comment
	Electrical conductivity (µS/cm)	Water temperature, Date, Flow, 72 hour rainfall total	$R^2 = 0.11$	Lower than predicted	0 values out of control	The average and median EC levels were lower in the current period compared to the historical period. The lower EC values recorded during the current period align with increased river flows compared to the historic period which included the Millennium drought. The data is consistently well below the SEPP (WoV) trigger value. A significant reduction in EC conditions in Broken Creek occurs post-drought and post the decommissioning of Lake Mokoan.
	Total nitrogen (mg/L)	Season, Water temperature, Flow, Days since a >20mm rainfall event	$R^2 = 0.11$	Lower than predicted	2 values above the higher limit	Compared to the historic period, the current period achieves the SEPP (WoV) trigger value of 0.9 mg/L more frequently. This analysis shows that nitrogen levels in Broken River have reduced from the decommissioning of Lake Mokoan in 2009 compared to the historical trajectory.
	Total phosphorus (mg/L)	Season, Flow, Turbidity	$R^2 = 0.32$	Slightly lower than predicted	1 value above the higher limit	This decline in total phosphorus levels was consistent with the decrease observed in turbidity levels and total nitrogen levels for 2010 to 2016. The analysis showed that total phosphorus levels have reduced in Broken Creek most likely due to the decommissioning of Lake Mokoan in 2009, compared to the historical trajectory, but still frequently exceeded the SEPP trigger level.
	Dissolved oxygen (mg/L)	Water temperature, Date	$R^2 = 0.22$	Lower than predicted in Summer, higher than predicted in Winter	3 values below the lower limit	Continued decline as predicted, particularly for the percent saturation model. Percent saturation results are consistently below SEPP trigger level and are a potential cause for concern.
	Dissolved oxygen (% sat)	Season, Water temperature, Date, Flow, Days since a >20mm rainfall event	$R^2 = 0.064$	Lower than predicted in Summer, higher than predicted in Winter	1 value above the higher limit; 5 values below the lower limit	

Site	Variable	Predictor variables	Regression model fit to historical data	Detectable trend since 2011	No. of current observations out of control	Comment
Barwon River at Pollocksford	Turbidity (NTU)	Flow	$R^2 = 0.71$	Slightly higher than predicted	8 values above the higher limit	Spikes in turbidity correlate with large floods and/or rainfall events. Turbidity levels have frequently exceeded the SEPP trigger level and are a potential cause for concern.
	Electrical conductivity (µS/cm)	Season, Water temperature, Flow	$R^2 = 0.50$	Slightly lower than predicted	0 values out of control	Electrical conductivity levels decreased between 2010 and 2011 but generally increased as predicted by the model after this period. The lower EC values recorded during the current period align with increased river flows compared to the historic period which included the Millennium drought.
	Total nitrogen (mg/L)	Water temperature, Flow	$R^2 = 0.50$	Slightly lower than predicted	2 value above the higher limit; 1 value below the lower limit	The model successfully predicted the high nutrient load events from the post-drought floods in 2011 to 2016, with lower values during the drier years. Nitrogen levels may be increased due to STP effluent from Ballarat which discharges into one of Barwon's major tributaries. Total nitrogen levels in the current period aligned with the predicted trajectory from the historical period. There were a series of very high values, potentially triggering further investigation.
	Total phosphorus (mg/L)	Season, Date, Flow, 72 hour rainfall total	$R^2 = 0.26$	Generally as predicted	1 value above the higher limit	Continued decline in total phosphorus levels as predicted, but observations consistently exceeded SEPP trigger level and are a potential cause for concern.
	Dissolved oxygen (mg/L)	Temp	$R^2 = 0.74$	Generally as predicted	2 values above the higher limit; 1 value below the lower limit	Dissolved oxygen levels (mg/L and % saturation) were very similar to the historical period. Dissolved oxygen levels were typically underestimated during cooler months, in which low rainfall and warm weather was experienced in comparison to the historical period. A number of low dissolved oxygen levels (% saturation) were below the SEPP trigger level and are a potential cause for concern.
	Dissolved oxygen (% sat)	Season, Water temperature, Flow, 72 hour rainfall total, Days since a >20mm rainfall event	$R^2 = 0.31$	Generally as predicted 2010 – 2014, slightly higher than predicted 2014 – 2016.	3 values above the higher limit	

Site	Variable	Predictor variables	Regression model fit to historical data	Detectable trend since 2011	No. of current observations out of control	Comment
Ovens River at Peechelba	Turbidity (NTU)	Season, Date, Flow, 72 hour rainfall total	$R^2 = 0.32$	Generally as predicted 2010 – 2013, slightly lower than predicted 2013 – 2016.	7 values above the higher limit	The model generally agrees well with observations. Spikes in turbidity correlate with large floods and/or rainfall events. Turbidity levels have frequently exceeded the SEPP trigger level and the model higher limit and may require further investigation.
	Electrical conductivity (µS/cm)	Season, Date, Flow, Days since a >20mm rainfall event	$R^2 = 0.57$	Slightly higher than predicted	1 value above the higher limit	EC levels declined compared to the historical period, but levels were slightly higher than predicted. Levels were well below the SEPP trigger value and not of concern.
	Total nitrogen (mg/L)	Water temperature, Flow, 72 hour rainfall total	$R^2 = 0.20$	Generally as predicted	5 values above the higher limit	Spikes in total nitrogen correlated with high flow events from heavy rainfall in the catchment from 2011 to 2016. Total nitrogen levels were generally below the SEPP trigger level for the model run period.
	Total phosphorus (mg/L)	Water temperature, Flow, 72 hour rainfall total	$R^2 = 0.15$	Slightly higher than predicted	3 values above the higher limit	There is correlation with variation in turbidity and total phosphorus which may be associated with erosion. Spikes in total phosphorous correlated with large, intense rain events. Total phosphorus levels frequently exceeded the SEPP trigger level and the model higher limit.
La Trobe River at Rosedale	Dissolved oxygen (mg/L)	Water temperature, Date	$R^2 = 0.70$	Generally as predicted	1 value above the higher limit	Dissolved oxygen levels increased compared to the historical trend most likely due to increased flows.
	Dissolved oxygen (% sat)	Water temperature, Date, Flow	$R^2 = 0.22$	Higher than predicted	>10 values above upper limit	
	Turbidity (NTU)	Water temperature, Date, Flow, 72 hour rainfall total	$R^2 = 0.58$	Higher than predicted 2010 – 2014, slightly lower than predicted 2014 – 2016.	5 values above the higher limit	The historical trend of increasing turbidity levels has continued. An increase in turbidity between 2012 and 2013 is attributable to temporary discharge from the Yallourn Coal Mine. Turbidity at this site has been consistently exceeding the SEPP trigger level since 2003 and is a potential cause for concern.

Site	Variable	Predictor variables	Regression model fit to historical data	Detectable trend since 2011	No. of current observations out of control	Comment
La Trobe River at Rosedale	Electrical conductivity (µS/cm)	Water temperature, Flow	$R^2 = 0.36$	Slightly lower than predicted	0 values out of control	Electrical conductivity was lower than expected potentially due to increased river flows and snowmelt following the Millennium Drought. The slight peak in 2011 correlates with a large scale flood event.
	Total nitrogen (mg/L)	Water temperature, Date, Flow	$R^2 = 0.49$	Slightly higher than predicted	3 values above the higher limit	Spikes in total nitrogen align with high rainfall events and flooding in the catchment. Generally, observations are well below the SEPP trigger value(s), however there are some points that may be cause for concern.
	Total phosphorus (mg/L)	Water temperature, Flow, 72 hour rainfall total	$R^2 = 0.44$	Slightly higher than predicted	4 values above the higher limit	Spikes in total phosphorous correlated with large, intense rain events. There is correlation with variation in turbidity and total phosphorus which may be associated with erosion. Total phosphorus levels frequently exceeded the SEPP trigger level and may require further investigation.
Yarra River at Chandler Highway	Dissolved oxygen (mg/L)	Water temperature	$R^2 = 0.69$	Slightly higher than predicted	2 values above the higher limit	Dissolved oxygen levels (mg/L and % saturation) generally exceeded predicted values, and may be a result of recovery in the river system following the Millennium Drought. Levels were consistently above the SEPP trigger level.
	Dissolved oxygen (% sat)	Season, Water temperature, Flow, 72 hour rainfall total	$R^2 = 0.56$	Slightly higher than predicted	2 values above the higher limit	
	Turbidity (NTU)	Flow, 72 hour rainfall total	$R^2 = 0.45$	Slightly lower than predicted	0 values out of control	Observed turbidity values were consistently higher than predicted values during warmer months, and consistently lower than predicted values during cooler months. Spikes in turbidity can be explained by large rainfall events. A number of readings exceeded SEPP trigger levels and may be cause for concern.
	Electrical conductivity (µS/cm)	Season, Date, Flow, 72 hour rainfall total	$R^2 = 0.28$	Lower than predicted	6 values above the higher limit; 5 values below the lower limit	Conductivity levels exhibited a decline in comparison to the historical period, which did not agree with the predicted values. This may be attributable to dilution from increased rainfall post Millennium Drought.

Site	Variable	Predictor variables	Regression model fit to historical data	Detectable trend since 2011	No. of current observations out of control	Comment
	Total nitrogen (mg/L)	Water temperature, Flow	$R^2 = 0.47$	Lower than predicted	0 values out of control	Total nitrogen concentrations exhibited a decline in comparison to the historical period, which did not agree with the predicted values. A large fraction of observations exceeded the site specific SEPP trigger level and may be a potential cause for concern.
	Total phosphorus (mg/L)	Water temperature, Flow, 72 hour rainfall total	$R^2 = 0.46$	Lower than predicted	3 values below the lower limit	There was a correlation in the decline of total phosphorus and total nitrogen concentrations in comparison to the historical period. The increase in total phosphorus also correlates with an increase in dissolved oxygen post-drought which may be restricting the release of phosphorus from the sediment. A smaller number of observations exceeded the site specific SEPP trigger level and may be a potential cause for concern.

ventia