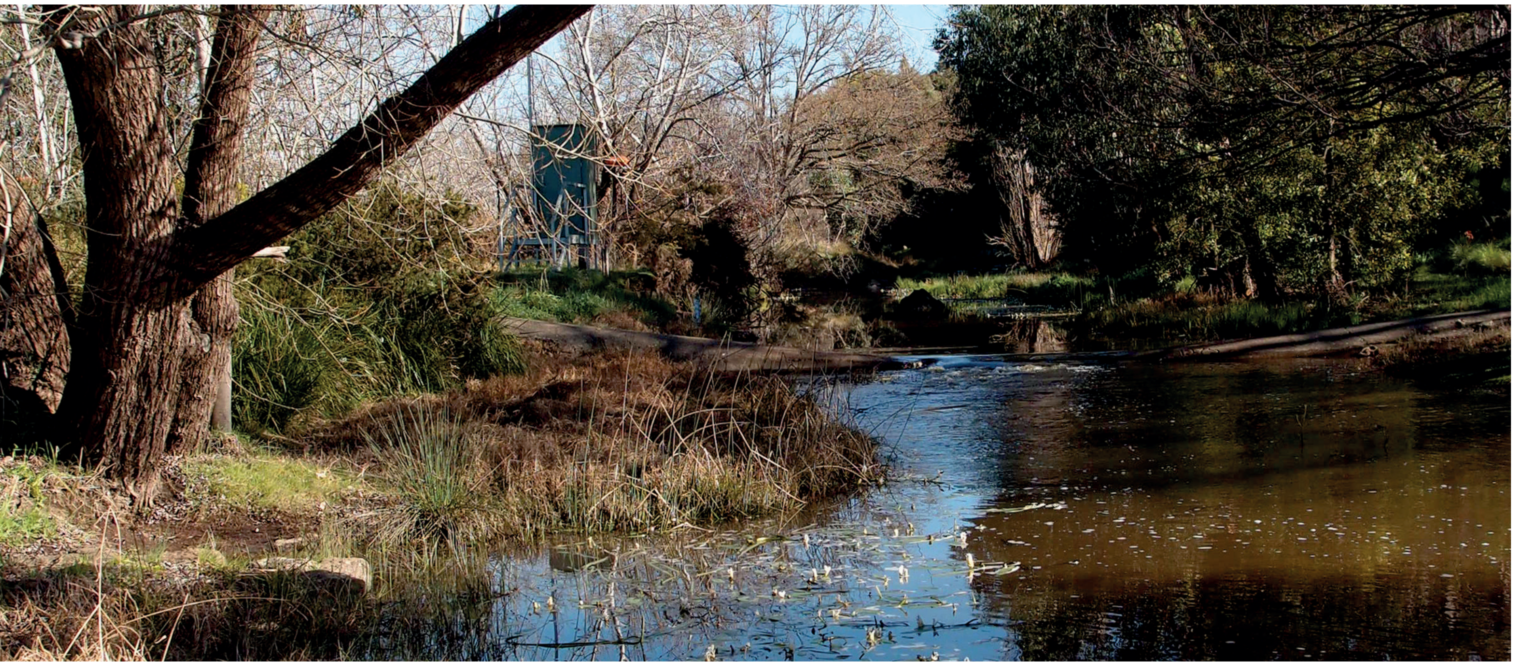
Victorian Water Quality Trends 1991–2010



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Executive summary

Regular water quality monitoring has occurred at river sites throughout Victoria since 1975. The number of monitoring sites has changed over that time due to sites being added or decommissioned. The suite of water quality variables measured at each site, and the frequency of that monitoring, has also varied over time. The Victorian Regional Water Monitoring Partnership (RWMP) currently collects water quality data from 314 river sites throughout Victoria, with spot measurements being taken at least monthly at most sites.

Water quality is an important indicator of river health and river managers have a keen interest in monitoring changes in water quality and in implementing management actions to maintain or improve water quality. The Victorian *Water Act 1989* requires long-term water resource assessments to assess changes to either the availability of surface water and groundwater, as well as changes to the health of waterways. To date, there have been two studies that have analysed long-term trends in river water quality across the state. Trends in the available data for pH, turbidity, electrical conductivity, total phosphorus and total nitrogen were analysed at 280 sites across Victoria by SKM in 1998. In 2007 SKM extended that analysis to include data up until the end of 2005.

This report presents the results of the third state-wide assessment of trends in water quality over the period 2005 to 2010 against trends prior to 2005. In addition, the report trials a tool for tracking water quality data and trends as new data are collected. This tool is part of the approach outlined by the Victorian EPA (2011) in the *Environmental Water Quality Guidelines for Victorian Riverine Estuaries*. The tool uses two types of analyses, control charts and run charts, for assessing 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. Such assessments can assist catchment managers because they facilitate understanding of whether any observed change in a new water quality measurement is within expectations at that site. This allows problems that are outside of expectations to be identified as they arise despite the inherent variability and dynamic nature of the site.

Broad trends in dissolved oxygen, pH, turbidity, electrical conductivity, total nitrogen and total phosphorus are described for 75 Regional Water Monitoring Partnership sites that have relatively complete records for all six water quality variables dating back to January 1991. These trends are based on visual inspection of time-series plots of all data collected between January 1991 and December 2010, and on comparisons of mean and median statistics for the period January 1991 – June 2005 against mean and median statistics for the period July 2005 – December 2010.

The second part of the report presents six case studies that use control chart and run chart analyses to more comprehensively assess trends for dissolved oxygen, pH, turbidity, electrical conductivity, total nitrogen and total phosphorus. The sites used for the case studies were nominated by the relevant Catchment Management Authorities.

The control chart and run chart analyses developed for this report were applied in a three step process. The first step used multiple regression techniques to identify a combination of predictor variables that best described variation in the water quality variable of interest between January 1991 and June 2005 at each of the six case study sites. Separate models were developed for each water quality variable at each site. In the second step, the regression model that best described historical variation in each dataset was used to predict the value for that water quality variable on each sampling occasion between July 2005 and December 2010. In the third step, water quality data collected between July 2005 and December 2010 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 warrant closer inspection. Data were also compared against State environment Protection Policy (Waters of Victoria) trigger levels to determine whether particular water quality variables were likely to pose risks to, for example, aquatic biota.

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 indicate a deviation from historical patterns.

General trends across 75 sites

The outcomes of the state-wide investigation are specific to each individual site, however some general patterns were observed:

- Dissolved oxygen levels declined at many sites throughout Victoria after June 2005. The biggest decreases were recorded in rivers in the western part of the state that had severely reduced flows , or were dry for extended periods during the drought.

- Electrical conductivity generally increased across Victoria after June 2005, with the greatest increases recorded at sites in the Werribee River, Jacksons Creek, Moorabool River, Broken River, Broken Creek and the Wimmera River.

- pH levels either did not change or slightly increased at most sites across Victoria since June 2005. However, the biggest recorded change was a large decline in pH in the Glenelg River @ Big Cord.

- Turbidity levels in most rivers throughout Victoria generally increased after June 2005, but the increases at most sites are not likely to be environmentally significant. The largest increases were recorded in the Macalister River @ Licola and the Avoca River @ Coonooer. Individual instances of high turbidity were recorded at sites in several Gippsland rivers during or soon after large floods.

- There have been no consistent state-wide trends for total nitrogen concentrations across Victoria since June 2005, but there have been some clear trends within individual river basins. Total nitrogen concentrations generally decreased in the Werribee River and Broken River basins and generally increased in the Mitchell River, Thomson River, Portland and Glenelg River basins. The biggest increases were recorded in the Macalister River after large floods in 2007.

- There have been no consistent state-wide trends for total phosphorus concentrations across Victoria since June 2005, but there have been some clear trends within individual river basins. Total phosphorus generally increased in the Corangamite, Portland and Wimmera River basins and decreased in the South Gippsland and Barwon River basins. The most consistent increases were recorded at sites in the Moorabool River, Hopkins River, Avoca River and Wimmera River. Very high total phosphorus concentrations were recorded during or soon after large floods at several other sites.

Detailed observations at six selected sites

In addition to the data analysis above, control charts were developed and analysed at the following six sites, with summary comments on each site provided below.

233200 Barwon River @ Pollocksford

Dissolved oxygen in the Barwon River @ Pollocksford, after June 2005, was higher and more variable than expected based on historical patterns. In particular, there were many records of very high dissolved oxygen during the drought, which may be due to increased photosynthesis associated with increased algal growth. pH levels at the site were higher than expected between July 2005 and December 2007 and were lower than expected after January 2008. However, there was no change in electrical conductivity or turbidity levels compared to historical patterns.

The most noticeable change at this site related to nutrient concentrations. Concentrations of total nitrogen and total phosphorus were very high on occasions at this site in the Barwon River in the early and mid-1990s. Much lower peaks were recorded after 1999 and the regression models based on the historical patterns consistently over-estimated results after July 2005. Discussions with staff from Central Highlands Water and the Corangamite Catchment Management Authority identified the implementation of a nutrient management plan for dairy farms in the Colac region and a Biological Nutrient Removal (BNR) upgrade to the South Ballarat Treatment Plant as likely causes for reduced nutrient levels after 1999. The changed management conditions within the Barwon River catchment meant that it was not appropriate to use all of the historical data record to predict nutrient concentrations after June 2005. New models were developed to describe variation in total nitrogen and total phosphorus concentrations between January 2000 and June 2005 and those models were used to predict nutrient concentrations after June 2005. These new models demonstrated that total nitrogen levels in the Barwon River @ Pollocksford after June 2005 were slightly higher than expected, but there was no change in total phosphorus concentrations compared to the previous five year period.

235227 Gellibrand River @ Bunkers Hill

Dissolved oxygen in the Gellibrand River at Bunkers Hill was lower than expected after June 2005, with some very low concentrations recorded during the worst years of the drought. There was little change in electrical conductivity compared to historical patterns but turbidity levels were higher than expected. In particular, there were several records of very high turbidity between 2005 and 2008. pH levels at this site between 2005 and 2007 were higher than previously recorded, but pH levels after 2008 were consistent with those recorded between 1991 and 2005.

Total nitrogen concentrations in the Gellibrand River @ Bunkers Hill were higher and more variable after June 2005 compared to the previous 15 years. The increase since 2005 is mainly due to more frequent very high total nutrient concentrations, which were recorded between 2006 and 2009. Total phosphorus concentrations at this site were slightly lower after June 2005 compared to historical patterns.

405204 Goulburn River @ Shepparton

Dissolved oxygen levels in the Goulburn River @ Shepparton generally declined between 1991 and June 2005. That decline was arrested in recent years and dissolved oxygen levels at the site after June 2005 were similar to those recorded between 2003 and 2005. Electrical conductivity and total phosphorus concentration both declined after June 2005 compared to historical patterns and observed results were generally lower than predicted by the models used in the control charts. These declines may be partly due to increased inter-valley transfer releases from Lake Eildon to meet downstream demand. Historical data shows a slow but steady increase in pH at this site between January 1991 and June 2005. That trend increased after June 2005 as predicted. Turbidity and total nitrogen concentration at this site after June 2005 were unchanged compared to historical patterns.

404216 Broken River @ Goorambat

Water quality in the Broken River @ Goorambat has historically been influenced by flow in the upstream reaches of the Broken River and outflows from Lake Mokoan. Outflow from Lake Mokoan declined substantially towards the end of the drought and after the lake was decommissioned in 2010. The full effects of decommissioning Lake Mokoan on water quality in the Broken River are not known and the current models used in the control charts may need to be revised as new data become available.

Dissolved oxygen in the Broken River @ Goorambat generally declined between January 1991 and June 2005. That decline continued as predicted after June 2005 and some very low dissolved oxygen levels were recorded during the drought that were outside the historical patterns observed at this site. These patterns could be worth closer examination as part of any future environmental drought response planning.

Turbidity in the Broken River @ Goorambat was higher and more variable after June 2005 compared to the previous 15 years. Very high turbidity levels were recorded on 11 occasions between 2006 and 2009. Those records were associated with high flow events, but were out of control compared to historical patterns. The very high records occurred after the 2006 bushfires, which burnt the upper reaches of the Broken Creek, and it is likely that ash and fine sediment that washed into the river continued to be mobilised during each subsequent high flow event. The decommissioning of Lake Mokoan is also likely to affect turbidity levels at this site and therefore relationships between turbidity and the predictor variables highlighted in this report are likely to change.

Electrical conductivity at this site increased after June 2005, with very high levels that were out of control in 2007 and 2008. However, the model based on historical patterns accurately predicted the decline in electrical conductivity in 2009 and 2010 due to reduced inflows from Lake Mokoan.

Total nitrogen concentrations in the Broken River @ Goorambat declined after June 2005 and recorded concentrations were generally lower than predicted. Mean and median total phosphorus concentrations also declined after June 2005, but some very high total phosphorus concentrations were recorded in 2007 and 2008. Those very high concentrations were probably due to ash and sediment that was washed into the river after the 2006 bushfires and, while the concentrations were higher than expected, they did coincide with high flow events and were not out of control compared to historical patterns. The decline in total phosphorus concentrations in 2009 and 2010 was probably due to reduced outflows from Lake Mokoan.

415207 Wimmera River @ Eversley

The Wimmera River @ Eversley ceased-to-flow for extended periods during the drought and also experienced a large flood in September 2009. Both of these climatic conditions affected water quality at the site.

Dissolved oxygen levels in the Wimmera River @ Eversley were consistently lower than predicted after 2005 and were frequently out of control after 2008 compared to historical patterns. The very low dissolved oxygen levels coincided with very low, or cease-to-flow events during summer up until the start of 2009. The low dissolved oxygen levels recorded after the September 2009 floods are possibly due to the breakdown of organic material that was washed into the river during those floods.

Turbidity in the Wimmera River @ Eversley was much higher than predicted after June 2005 and was frequently out of control compared to historical patterns. The very high turbidity levels recorded between 2007 and 2009 may be due to increased growth of planktonic algae during the drought and the high turbidity levels after 2009 are probably due to high sediment loads that were washed into the river during the floods.

Electrical conductivity was much higher after June 2005 and was frequently out of control compared to historical patterns when the river ceased to flow. The model used in the control chart accurately predicted electrical conductivity levels in the cooler months after June 2005 when the river was flowing. This result highlights the fact that the predictive models used in the control charts are only likely to be reliable for describing expected water quality conditions if the underlying hydrologic conditions are within the range of those used historically to fit the model.

pH increased in the Wimmera River @ Eversley between July 2005 and September 2009, but then decreased markedly. The highest pH levels recorded between 2005 and 2009 coincided with cease-to-flow events and may be associated with high photosynthesis rates from planktonic algae. Similarly, the decrease in pH after September 2009 may be due to the floods flushing the algae through the system and increased carbon dioxide released as organic material washed into the river by the floods was broken down.

Total nitrogen concentrations in the Wimmera River @ Eversley decreased after June 2005, but there were at least five occasions between 2006 and 2010 when total nitrogen concentrations were very high and out of control compared to historical patterns. Total phosphorus concentrations were much higher and more variable after June 2005. Total phosphorus concentration was correlated with turbidity and the very high concentrations recorded in 2009 were reasonably well predicted by the model even though the actual values were several times higher than the highest records from the historical period.

415200 Wimmera River @ Horsham

The Wimmera River site @ Horsham is located downstream of the Horsham weir pool. It experienced very low and cease-to-flow events during the drought and large floods in September 2009. Stormwater run-off from Horsham possibly represented a higher than normal proportion of flow at this site during the drought and may have affected the ability of historical models to accurately predict water quality on some occasions.

Dissolved oxygen in the Wimmera River @ Horsham was lower than predicted after June 2005. The low levels between July 2005 and August 2009 are explained by the low, stable flows. The low dissolved oxygen levels that were recorded after the 2009 floods may be due to the decomposition of organic material that was washed into the river during the floods.

Turbidity in the Wimmera River @ Horsham was lower than predicted between July 2005 and March 2008, but was frequently higher than predicted after that time. Several readings taken after March 2008 were very high and were out of control compared to historical patterns. The high turbidity levels recorded in 2009 and 2010 are associated with sediment being washed into the Wimmera River during floods, but the high turbidity levels recorded during 2008 are possibly due to increased growth of planktonic algae.

Electrical conductivity in the Wimmera River @ Horsham generally decreased after June 2005. However, these patterns were not well explained by the model used in the control chart. Variation in pH at this site was also not well explained by any of the tested predictor variables. The very high pH levels were recorded between 2007 and 2009 may be due to high rates of photosynthesis by planktonic algae and the slight drop in pH after 2009 is probably due to the floods.

Total nitrogen concentration was more variable after June 2005 compared to historical patterns. The frequent high concentrations recorded in 2006 and 2008 were much higher than predicted and were higher than most of the historical record.

Total phosphorus concentrations in the Wimmera River @ Horsham increased markedly from 2007. The highest concentrations were recorded in the driest years, and many of those were out of control compared to historical patterns. Total phosphorus concentrations decreased slightly after the 2009 floods, but did not drop back to the levels recorded between 2000 and 2006.

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.

Variation in some of the water quality variables tested at certain sites in this project (e.g. pH at most sites and electrical conductivity in the Wimmera River @ 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 is 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.

In developing the control charts it is also important to consider any significant changes to catchment management practices over the period of model fitting. As the example of nutrient concentrations in the Barwon River @ Pollocksford demonstrates, the models used in control charts will not reliably predict future water quality conditions if they are based on historical data that were collected at a time when different management strategies applied. It is critical to talk to relevant stakeholders to fully understand management history at each site.

The results of this study demonstrated that water quality at any given site is very strongly influenced by local factors and conditions. This means that predictive models need to be developed independently for each water quality variable at each site. It also raises questions about the extent to which results and trends at individual sites can be extrapolated to other sites or to make general statements about conditions or trends at regional or state-wide scales.

Conclusions and recommendations

Control charts and run charts are potentially effective tools for assessing water quality trends over time and for assessing new data as they are collected. They will allow CMAs and other interested stakeholders to immediately compare a single water quality result against the prediction based on prevailing conditions at the time and decide whether the result is in keeping with historical patterns. Any recorded value that is very different to the predicted value, allowing for reasonable confidence limits, can be immediately identified and may trigger further investigation into potential causes.

The ability to rigorously evaluate individual water quality results as they are collected may help CMAs and other relevant agencies detect environmental stressors when they first occur, which means they may be able to implement appropriate mitigation actions before too much damage is done. Armed with these tools, CMA staff will be able to more actively review water quality data as they are collected and use those data in their operational management decisions, as well as in longer term strategic planning. Implementing mitigation measures as soon as potential problems arise and monitoring the effect of those actions is likely to accelerate and improve our understanding of specific relationships between water quality, ambient conditions and operational activities. Such information can be readily shared between different agencies and used in operational and strategic planning.

Surface water monitoring, including both flow and water quality parameters, represents a substantial investment by the Victorian Government and its agencies. The previous two water quality trend reports highlighted long-term patterns across the state. The next step will be to use the collected data to relate changes in a particular variable to other changes in the catchment. Such applications will enable agencies to better assess the effectiveness of management actions and to decide what particular management actions are needed and when they should be implemented. Moreover, it will highlight when conditions at a particular site are getting better or worse, which will allow the State Environment Protection Policy (Waters of Victoria) to be used more effectively.

Control charts and run charts are tools that have the potential to significantly increase the use of water quality data throughout Victoria. Most importantly, these two tools have the potential to assist CMA staff in managing their catchments by increasing the utility of the state-wide surface water data set collected under Victoria's Regional Water Monitoring Partnerships.

Contents

1. Introduction

1.1. Background

In 1998 and 2005 SKM was engaged by the Department of Sustainability and Environment to analyse historical trends in water quality data collected from sites in the Victorian Water Quality Monitoring Network (VWQMN) and the Regional Water Monitoring Partnerships (RWMP). SKM (1998) used Generalised Additive Models (GAM) to identify trends in pH, turbidity, electrical conductivity, total phosphorus and total nitrogen at up to 280 sites across Victoria over the preceding 10 to 20 years, depending on the length of the available data record. SKM (2007) extended the analysis to include data up until 2005. It described water quality trends from the start of the recorded period until 2005, rather than specifically considered changes in trend since 1998. Both assessments looked broadly at patterns across the state and identified particular sites and particular regions where trends were more pronounced.

The Regional Water Monitoring Partnerships continue to collect water quality data every month (and in some cases more frequently) at sites throughout the State. Data collected since 2005 is likely to be particularly interesting at some sites because it records water quality conditions during the last years of the Millennium Drought and water quality changes associated with the some drought breaking floods. The current project has two main aims. First, to compare water quality trends at Regional Water Monitoring Partnership sites over the period 2005 to 2010 against trends prior to 2005. Second, to test and evaluate a new approach to assess water quality data and trends in a more timely manner. Finally, the current project analyses dissolved oxygen data in addition to the five water quality parameters considered in the previous two trend assessments.

Water quality is inherently variable over short time periods, which makes it difficult to detect and interpret long-term temporal trends with confidence. The Victorian EPA (2011) recommended that control charts and run charts could be used to assess whether water quality measurements taken at a particular site of interest were within or outside an expected range, given other prevailing conditions, such as flow or weather conditions. Such assessments can assist catchment managers because they indicate whether a new water quality measurement is within expectations, given both the inherent variability and dynamic nature of the site. This allows problems that are outside of expectations to be identified as they arise.

The expected range for a particular water quality variable can be estimated or predicted by establishing relationships between various predictor variables and the response variable of interest. The predictive models may take any statistical form, but models that reliably predict the measurement of interest at a specific site will be of most use because they will produce the most sensitive control charts for that location.

The level of effort required to establish predictive models for the water quality parameters of interest for each of the sites where water quality parameters are sampled across Victoria is high. Equally, the level of effort required to derive meaningful information about water quality behaviour will vary between sites. Any data analysis approach should therefore consider the potential to analyse datasets in stages, with more complex analysis only applied to sites that are of particular management relevance and where the analysis will significantly improve understanding and predictive capability.

The objective of the overall project is to deliver a report that helps policy makers and resource managers evaluate the efficiency and effectiveness of existing management regimes and programs in order to determine whether new policies and strategies are required to drive change.

1.2. Introduction to control charts and run charts

1.2.1. Control charts

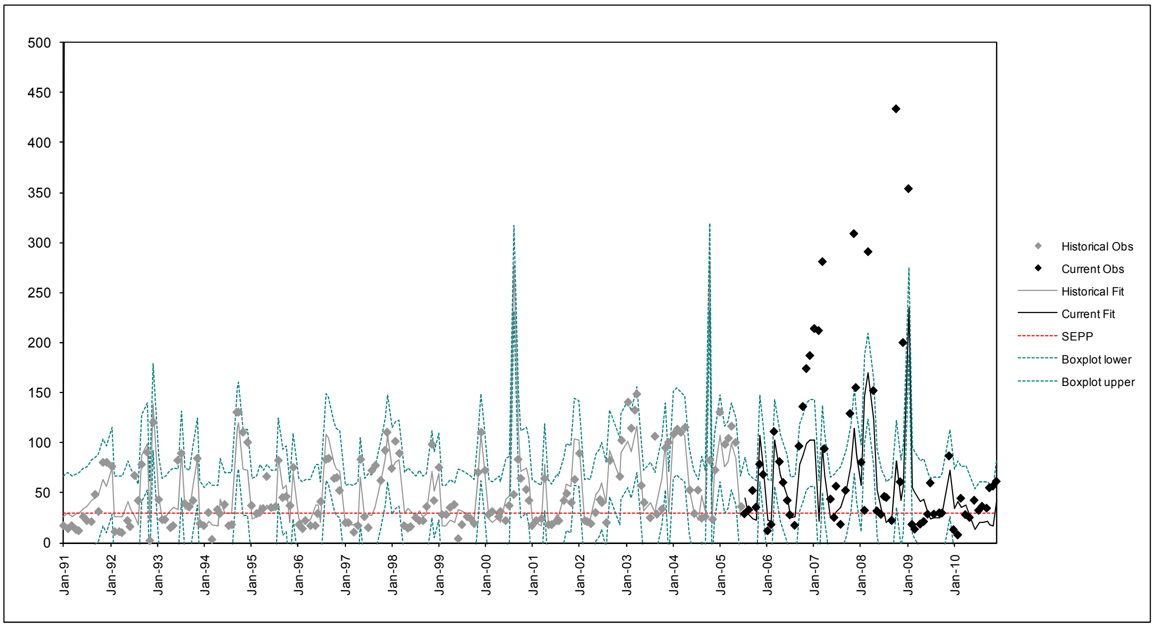
Control charts are a graphical tool that allows users to detect whether an observed value is within expected limits given an understanding of the factors that influence natural variation in the parameter of interest and historical patterns. Historical and/or reference data are used to quantify the effect that various factors have on natural variation. These relationships are used to develop a model, which can be used to predict values for the parameter of interest given prevailing conditions. Confidence limits can be attached to each prediction and any observed values that lie outside of those limits may be considered out of control due to environmental or human induced change.

The example control chart in Figure 1-1 shows turbidity in the Broken River @ Goorambat between 1991 and 2010. In that example, data collected between January 1991 and June 2005 (shown as grey points) were used to quantify the relationship between turbidity and various predictor variables measured at the site. That analysis indicated that variation in turbidity between January 1991 and June 2005 was best explained by flow in the Broken River. This relationship is shown by the grey fitted line and highlights regular fluctuations in turbidity levels in most years and particularly high spikes in 2000 and 2004 (Figure 1-1). The same relationship was used to predict turbidity levels after June 2005 and is shown as the black fitted line in the chart. The upper and lower confidence limits associated with the modelling results are shown by the green broken line, which follows the same pattern as the solid grey and black lines (Figure 1-1). All turbidity data recorded after June 2005 are shown as black points in the control chart. Each of these observations can be compared against the predicted value (i.e. the solid black line) to determine whether they are consistent with what would be expected given prevailing conditions for flow and electrical conductivity. All of the observations made between June 2005 and September 2006 and after January 2009 are close to the predicted line and within the specified confidence limits (see Figure 1-1), and we would therefore conclude that turbidity levels at those times were within expectations. However, turbidity levels recorded between October 2006 and January 2009 were often well above the predicted value and above the upper confidence limit (Figure 1-1), which suggests that something in the catchment has affected turbidity in an unexpected way. Such a result would most likely trigger further investigation by the relevant river manager.

The example described here shows how all of the data collected since June 2005 can be compared against the predicted values. However, once a model is developed to predict turbidity levels based on other factors such as flow and electrical conductivity, then any new observation can be assessed immediately. If the model used in Figure 1-1 was developed immediately after the June 2005 observation became available then any subsequent observations could be evaluated as they were recorded. In that situation a river manager would be satisfied that turbidity levels were within expectations up until September 2006. That manager may be concerned by the subsequent observations from October to December 2006, which are identified as lying outside of the control limits, and indicate that something unusual was occurring. The manager would then be in a position to investigate the potential cause of the change and take action if necessary.

Figure 1-1 also shows the State Environment Protection Policy (SEPP) trigger level for turbidity in the lowlands of the Kiewa, Ovens Goulburn and Broken Catchments within the Murray and Western Plains segment. As can be seen, turbidity levels in the Broken River @ Goorambat frequently exceed the SEPP threshold, even when turbidity levels may be considered to be ‘in control’. The control chart is likely to assist river managers in assessing the importance of compliance against SEPP, or any other relevant guidelines, by highlighting when non-compliance can be readily explained by prevailing conditions. Observed values that exceed the SEPP trigger level and are deemed to be ‘out of control’, are likely to be more concerning than values that exceed the SEPP trigger level and are ‘in control’, because high values that are ‘in control’ can be readily explained by known factors.

Figure: 1-1 Control chart for turbidity (measured in NTU) in the Broken River @ Goorambat



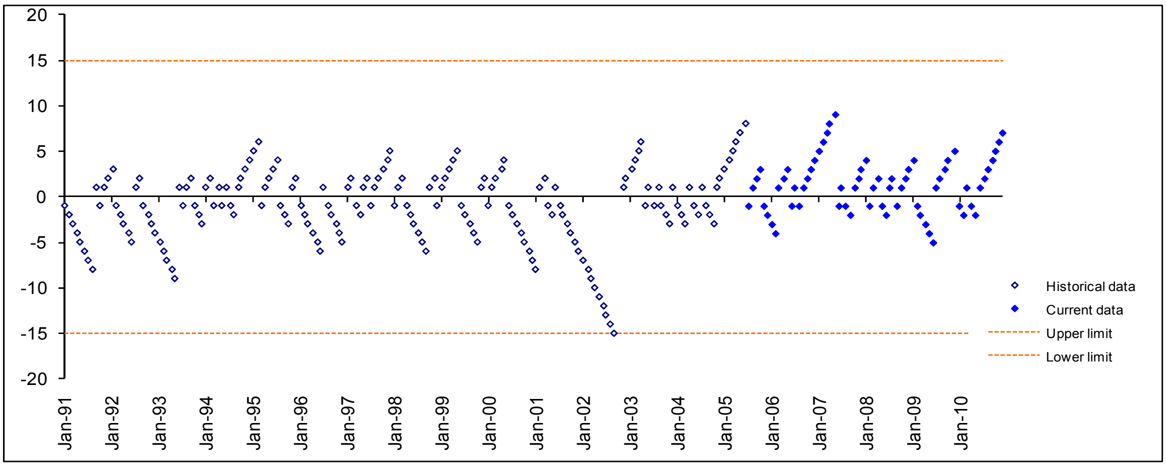
1.2.2. Run charts

Run charts use the same models developed for control charts to predict values for a parameter of interest based on prevailing conditions. While control charts primarily compare the magnitude of the difference between observed and predicted values, run charts plot the number of consecutive observations that are all above or all below their respective predicted values. The Y-axis of run charts describes the number of consecutive observations that are either above (a positive value) or below (a negative value) the predicted value. The example run chart in Figure 1-2 shows that there were rarely more than six consecutive turbidity observations that were above the predicted value and rarely more than eight consecutive turbidity observations that were less than the predicted value. It also shows that the longest run occurred between June 2001 and October 2003 when 15 consecutive monthly readings were below their predicted value.

If a particular water quality parameter is following a predictable pattern, we would not expect to see a long run of consecutive observations above the predicted value or a long run of consecutive observations below the predicted value. Nor would we expect to see a big difference in the length of runs above and below the predicted value. When a parameter is following a predictable pattern the run chart should look like the skeleton of a fish, with relatively short runs above the line alternating with relatively short runs below the line. Upper and lower limits can be specified to help highlight when particular runs are too long. Run charts are particularly useful for trend analyses because they can highlight when observed values are consistently above or below the predicted value, and therefore may indicate the start of a departure from previous patterns, even if the magnitude of the difference is relatively small.

It is interesting to note that the very high turbidity levels recorded in the Broken River @ Goorambat between October 2006 and January 2009, (which stood out clearly in the control chart in Figure 1-1), are not very pronounced in the run chart because some of the very high readings are punctuated by three readings in the middle of 2007 that were below the predicted value (Figure 1-2). Such contrasts between the run chart and control chart are important, and in this case may suggest that the very high turbidity readings are related to specific events rather than a chronic effect.

Figure 1-2: Run chart for Turbidity (in NTU) in the Broken River @ Goorambat



2. Project Stages

The project was divided into stages so that the method of applying control charts could be appropriately tested, the effort required to conduct each analysis could be evaluated, and so that sites where more complex analyses should be applied could be selected. It was agreed at the outset that detailed analyses would be conducted at sites that have particular management relevance from a water quality perspective and where the analysis would be likely to significantly improve understanding of water quality issues and predictive capability.

The five project stages included:

- Development of the method of analysis. The method development tested a range of alternative regression models and applied control charts for salinity and turbidity only at two sites. The results of those analyses were presented in a working document that was reviewed by the project steering committee and used to confirm a basic level of analysis that would be applied across a majority of Regional Water Monitoring Partnership sites that have relevant data and a more complex analysis that would be applied to a smaller sub-set of selected sites.

- Selection of sites currently sampled under the Regional Water Monitoring Partnership contracts with adequate data series for all six selected water quality parameters: dissolved oxygen, electrical conductivity, pH, turbidity, total nitrogen and total phosphorus.

- Preparation of time series plots and run charts for dissolved oxygen, electrical conductivity, pH, turbidity, total nitrogen and total phosphorus at 75 sites for the period from 1st January 1991 to 30th December 2010. These plots and associated analyses were used to broadly describe recent trends in water quality at each site and to identify individual sites for further analysis.

- Consultation by DSE with Catchment Management Authorities to identify a further subset of sites for using predictive models in control chart analysis from the candidate list that are of particular interest for management purposes.Development and application of site specific predictive models to prepare control charts and run charts to assess water quality trends at six selected sites. More details about the methods used to select sites for preliminary trend analysis, the methods used in those analyses and the results are presented in Chapter 3 of this report. The methods used for detailed assessments at six selected sites are presented in Chapter 4. The results of detailed analyses at each of the six selected sites are presented in Chapters 5 to 10. Overall conclusions and recommendations are presented in Chapter 11.

3. Preliminary analysis of water quality trends at Regional Water Monitoring Partnership sites with adequate data records

3.1. Site selection method

The 1998 Victorian Water Quality Monitoring Network (VWQMN) Trend Analysis described trends for electrical conductivity, pH, turbidity, total nitrogen and total phosphorus at 280 sites where at least one of these parameters was measured and where the period of record was at least 10 years (SKM, 1998). The 2005 water quality trend analysis described trends at 199 VWQMN sites where additional data had been collected since January 1998 (SKM, 2007). In both previous studies analyses were conducted over the entire period of the available record, which usually varied between 10 and 20 years depending on the site. The current analysis includes dissolved oxygen in addition to the five parameters considered in the previous trend analyses and only includes sites from the previous two studies where all of the six target water quality parameters are collected. Moreover, the current analysis only uses data collected after January 1991, because some of the target parameters were not routinely monitored at a large number of Regional Water Monitoring Partnership sites prior to that date. Restricting the data period from January 1991 to December 2010 ensures that analyses at all sites include the same broad climatic conditions (e.g. drought and floods) and are therefore comparable.

The current analysis differs from the previous two trend analysis in that the most recent data (i.e. those collected between June 2005 and December 2010) are compared directly against historical patterns that were determined by analysing data collected between January 1991 and June 2005. In order for the comparisons between recent and historical data to be reliable it is important that relatively complete data records are available for each group. Therefore the frequency and consistency of data collection was used to further refine the list of sites that were included in the current analysis.

Sites that were missing more than 25% of all potential monthly samples, or that had more than two years of continuous missing data were excluded. All six targeted water quality parameters were monitored for some of the time between January 1991 and December 2010 at 155 Regional Water Monitoring Partnership sites, but only 75 of those sites had adequate data records that matched the specified criteria. The trend analyses described in this report apply to those 75 sites.

3.2. Data presentation and analysis methods

Detailed models were not developed to describe historical variation for each parameter at each site, which meant that predictive control charts and run charts could not be developed for these sites.

Instead of predictive control charts, basic time series plots were prepared for dissolved oxygen, electrical conductivity, pH, turbidity, total nitrogen and total phosphorus over the period 1st January 1991 to 30 December 2010 at each site. These plots show changes in each parameter over the entire period, but they do not include any predicted values based on prevailing conditions. Data collected between January 1991 and June 2005 were plotted in a separate colour to data collected between July 2005 and December 2010 to highlight differences since the last trend analysis. The relevant State Environment Protection Policy (Waters of Victoria) (SEPP(WoV)) trigger levels were also shown on each time series plot to highlight any instances where particular water quality parameters were close to, or exceeded, levels that would generally be considered undesirable.

Run charts were prepared to show the number of consecutive observations above and below the median value for that parameter recorded during the period 1991 – 2005. As with the time series plots, the run charts did not use prevailing conditions to predict values for each parameter on each sampling occasion. However, the historical median is a useful reference for assessing consistent changes and trends since June 2005.

The time series plots and run charts were used to evaluate water quality conditions and trends at each site and to identify sites where more detailed modelling and analysis may be warranted.

3.2.1. Regional assessment of water quality trends

The 1998 and 2005 trend analyses used Generalised Additive Models to statistically test for trends at each assessment site. Formal statistical tests of trend were not undertaken for all 75 sites in the current project and therefore more subjective measures were used to describe trends at each site and to compare the direction and magnitude of trends across different sites.

As a first step, each time series plot was inspected and patterns after June 2005 were visually compared against temporal patterns between January 1991 and June 2005. Plots where there was an obvious increase or decrease in the particular water quality parameter after June 2005 were noted. Summary statistics were also derived for each water quality parameter at each site over the whole period of record, for the historical period (i.e. January 1991 – June 2005) and for the current period (i.e. July 2005 to December 2010) (see Table 3-1). Nine separate statistics were derived for each of the 75 water quality sites. This equates to over twelve thousand statistics, so the calculation method was automated to save on time and to reduce the potential for error.

Table: 3-1 Description of the summary statistics calculated for each water quality parameter and the three time periods that were analysed

Water quality parameter	Period of analysis	Statistics calculated
Dissolved oxygen (mg/L, % saturation)	Whole record Jan 1991 – Dec 2010	Mean of parameter
Electrical conductivity (µS/cm)	Historical period Jan 1991 – June 2005	Median of parameter
pH	Current period July 2005 – Dec 2010	Standard deviation of parameter
Turbidity (NTU)		Mean run length above the historical median
Total nitrogen (mg/L)		Median run length above the historical median
Total phosphorus (mg/L)		Standard deviation of the run length above the historical median
		Mean run length below the historical median
		Median run length below the historical median
		Standard deviation of the run length below the historical median

Each parameter was assessed by plotting the test statistic for the historical period at each site against the same test statistic for the current period to assess broad state-wide changes (see Figure 3-1). The example comparing mean electrical conductivity levels under historical and current periods at each site shows that average electrical conductivity levels at most of the 75 assessed sites were either the same or slightly higher after June 2005 compared to the period January 1991 to June 2005 (Figure 3-1). Differences between median and standard deviation statistics for data collected before and after June 2005 were compared in the same way. These plots are useful for describing overall trends, but they do not clearly show which sites have the largest trends and which sites have little or no trend. For simplicity, these plots have not been reproduced in the final report.

To highlight changes in water quality at individual sites we prepared plots showing the relative change in dissolved oxygen, electrical conductivity, pH, turbidity, total nitrogen and total phosphorus. For each site we calculated the change in the mean value for each water quality parameter between the current and historical periods (i.e. change in mean = mean for the current period – mean for the historical period). We then divided the change in mean by the historical mean to ensure that sites with very high or very low levels for a particular water quality parameter did not bias the results. The results for each water quality parameter were plotted as a bar graph, with each bar representing a separate site. Sites were presented in order according to their site number to highlight any patterns within or between individual basins. An example plot for electrical conductivity is shown in Figure 3-2. That plot shows that mean electrical conductivity levels increased at most of the 75 sites after June 2005, although changes at most sites are unlikely to be statistically significant. Moreover, it shows that the biggest increases occurred at sites 231204, 232202 and 232204 (Figure 3-2), where the relative change greater than 1.0 indicates that the mean value at these sites has more than doubled. Similar plots were prepared to show the change in median values for each water quality parameter at each site after June 2005.

Figure 3-1: Plot of the mean level of electrical conductivity (EC) (in µS/cm) at each site for the historical period (i.e. Jan 1991 – June 2005) against the mean level of electrical conductivity at each site for the current period (i.e. July 2005 – Dec 2010).

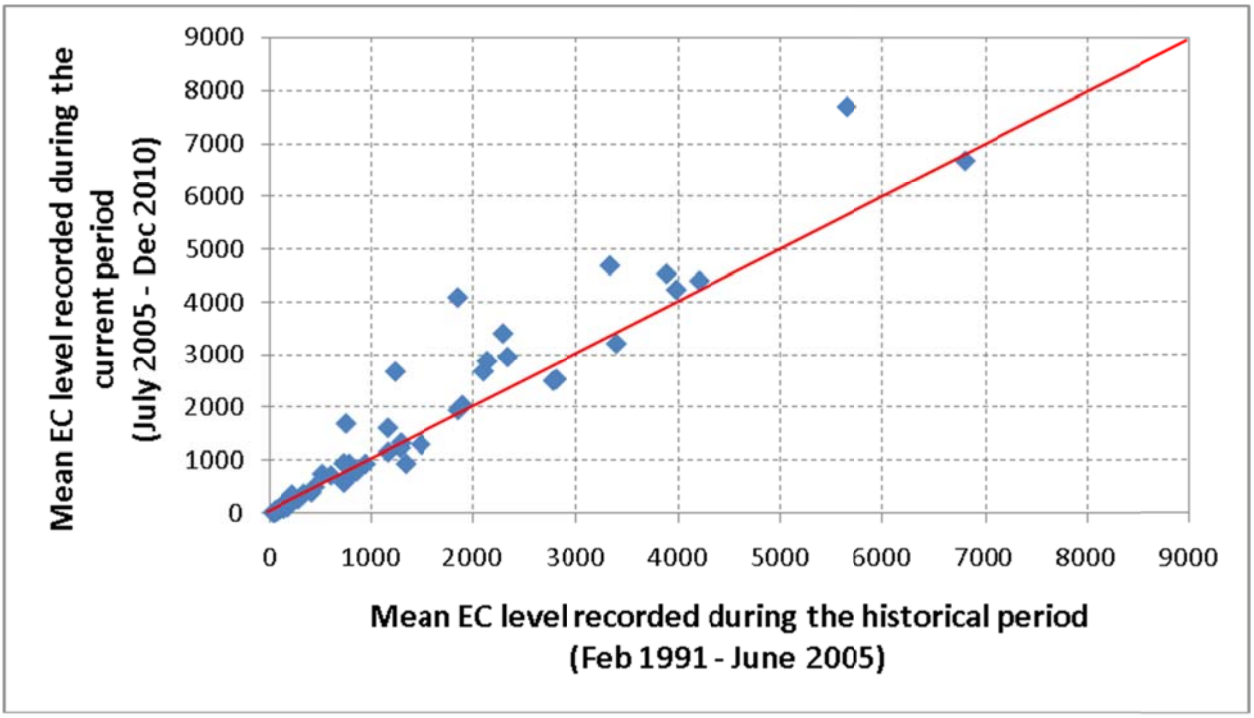
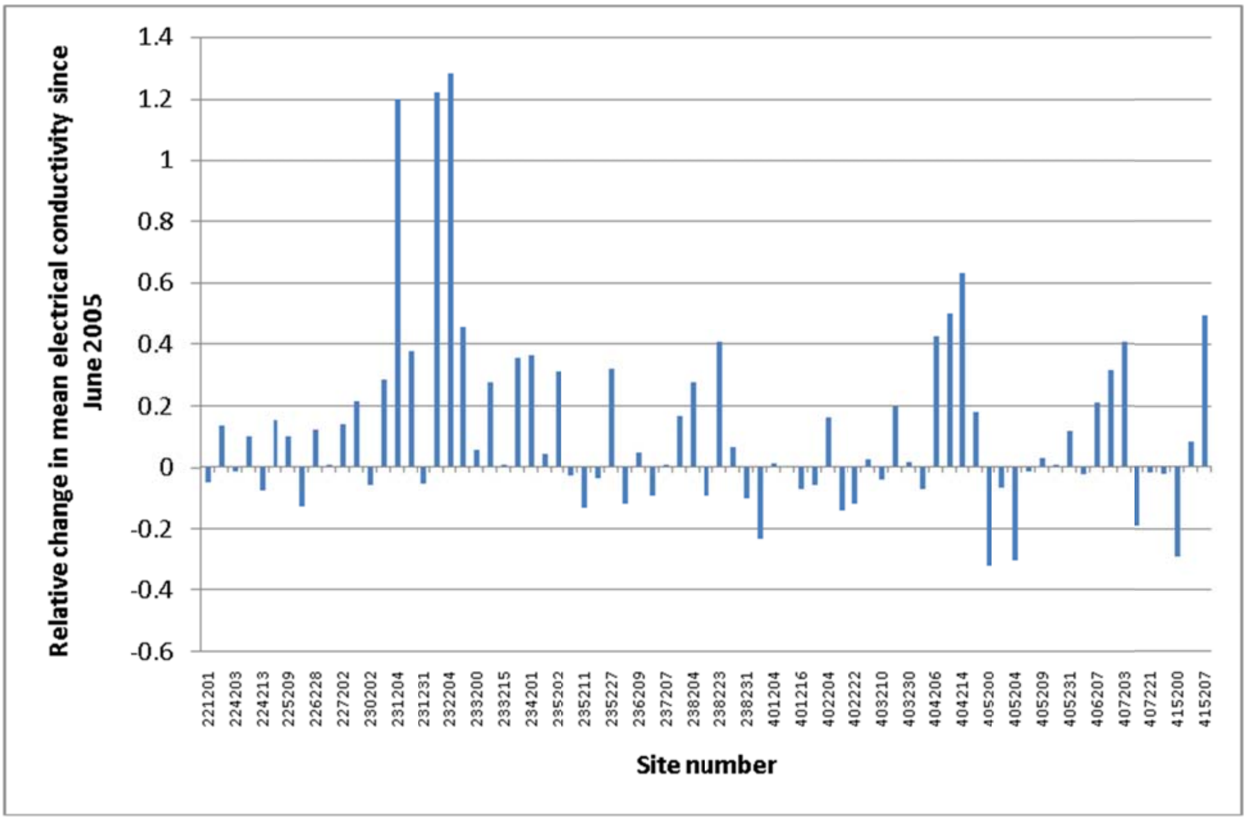


Figure 3-2: Relative change in mean electrical conductivity at 75 Regional Water Monitoring Partnership sites since June 2005. Bars show the difference in mean EC between the period July 2005 – December 2010 and the period January 1991 – June 2005 at each site, divided by the historical mean for that site.



3.2.2. Evaluation of sites for more detailed analysis

Sites where large changes in particular water quality parameters were considered as potential candidates for more detailed analyses. Other candidate sites for further analysis included:

1. Sites where the maximum run of consecutive values above or below the historical median after June 2005 was much greater than the maximum run length prior to June 2005; and
2. Sites where the mean value for any period was within two standard deviations from the relevant State Environment Protection Policy (Waters of Victoria) (SEPP (WoV)) trigger values (SEPP, 2003). This second point highlights sites that are likely to get close to or exceed the SEPP trigger values for a particular parameter and therefore may be of concern from a management perspective. The exact number of standard deviations between the mean and the SEPP trigger value is not critical for the assessment, rather the analysis aimed to identify those sites where the number of standard deviations between the mean and the SEPP was lowest.

3.3. Results for 75 selected sites

Individual time series plots and run charts for each parameter at each of the 75 selected sites are presented in a companion results report (Victorian Water Quality Trends: 1991-2010 Summary Tables and Plots). The following sections summarise state-wide patterns for each water quality parameter.

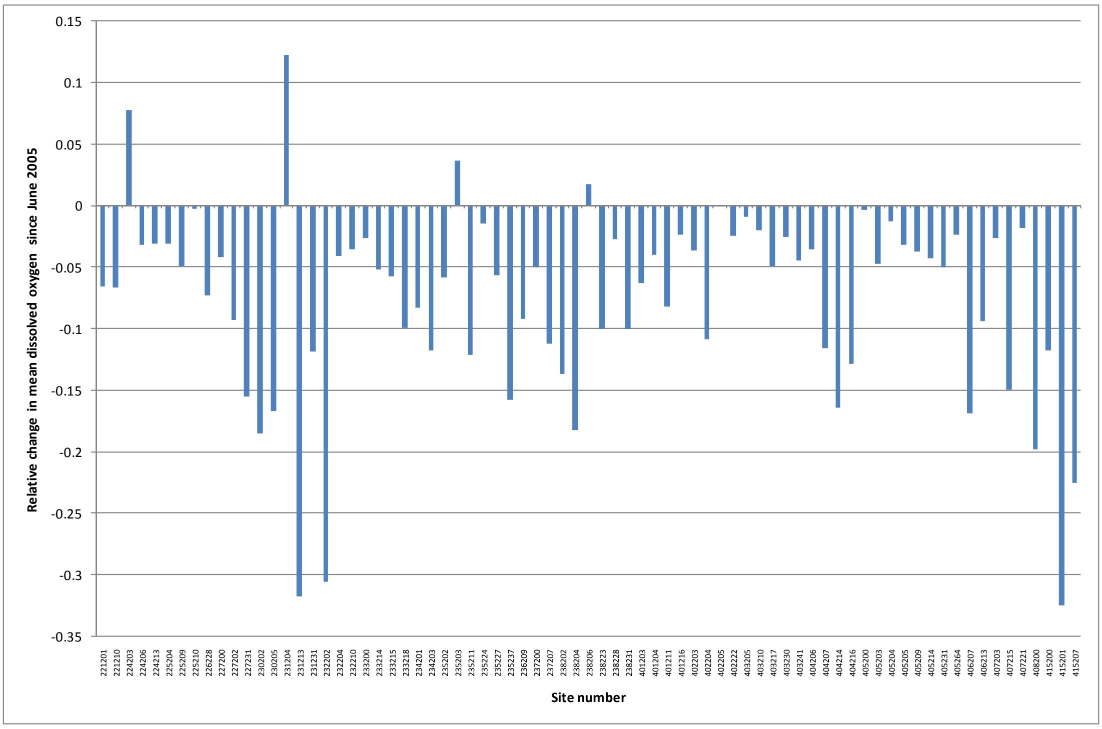
3.3.1. Dissolved oxygen

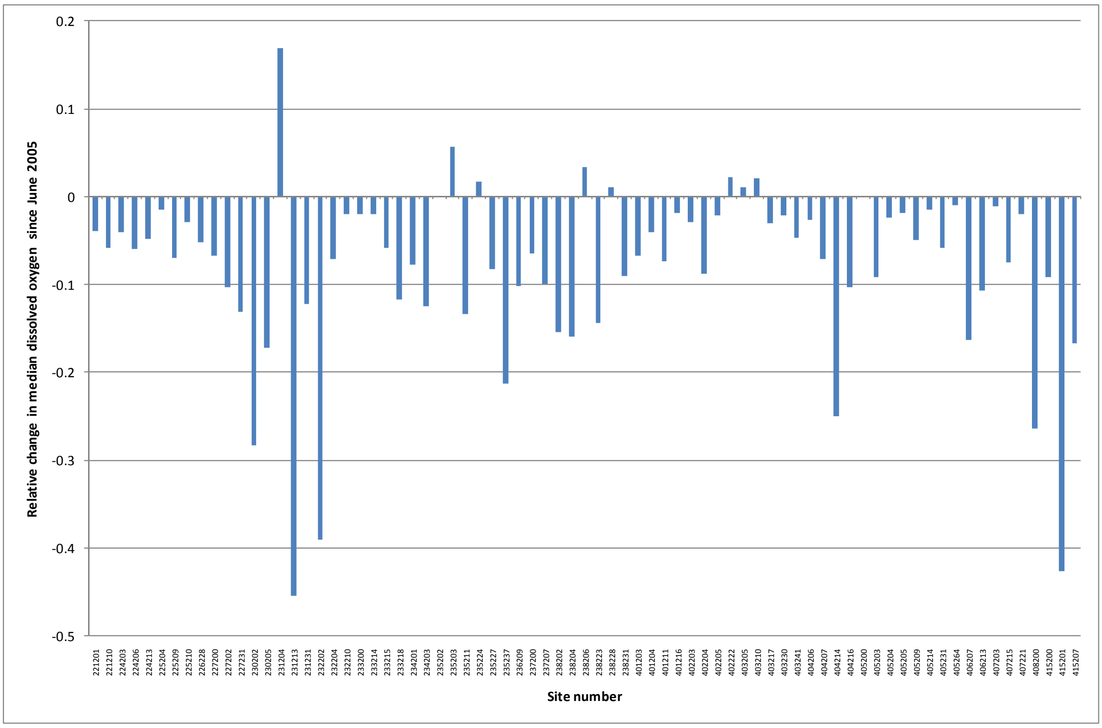
Dissolved oxygen levels were lower at most of the 75 assessed sites in the period July 2005 to December 2010 compared to the period January 1991 to June 2005, however, at most sites the difference was relatively small and unlikely to be significant (Figure 3-3). The greatest decreases in mean and median dissolved oxygen levels since June 2005 occurred at sites 230202, 231213, 232202, 415201 and 415207 (Figure 3-3). All of these sites are in the western part of the State (see Table 3-2 for site locations) and are in catchments that had severely reduced flow (and in some cases zero flow), during the drought.

Table 3-2: Sites where greatest trends in dissolved oxygen were observed

Site Number	Site Name	Strength of trend in time series plot
230202	Jacksons Creek @ Sunbury	Moderate decline
231213	Lerderderg River @ Sardine Creek O'Briens Crossing	Moderate decline
232202	Moorabool River @ Batesford	Strong decline
415201	Wimmera River @ Glenorchy Weir tail gauge	Moderate decline
415207	Wimmera River @ Eversley	Strong decline

Figure 3-3: Relative change in mean (top graph) and median (bottom graph) dissolved oxygen levels at 75 Regional Water Monitoring Partnership sites since June 2005. Bars show the difference in mean/median DO between the period July 2005 – December 2010 and the period January 1991 – June 2005 at each site, divided by the historical mean/median for that site.





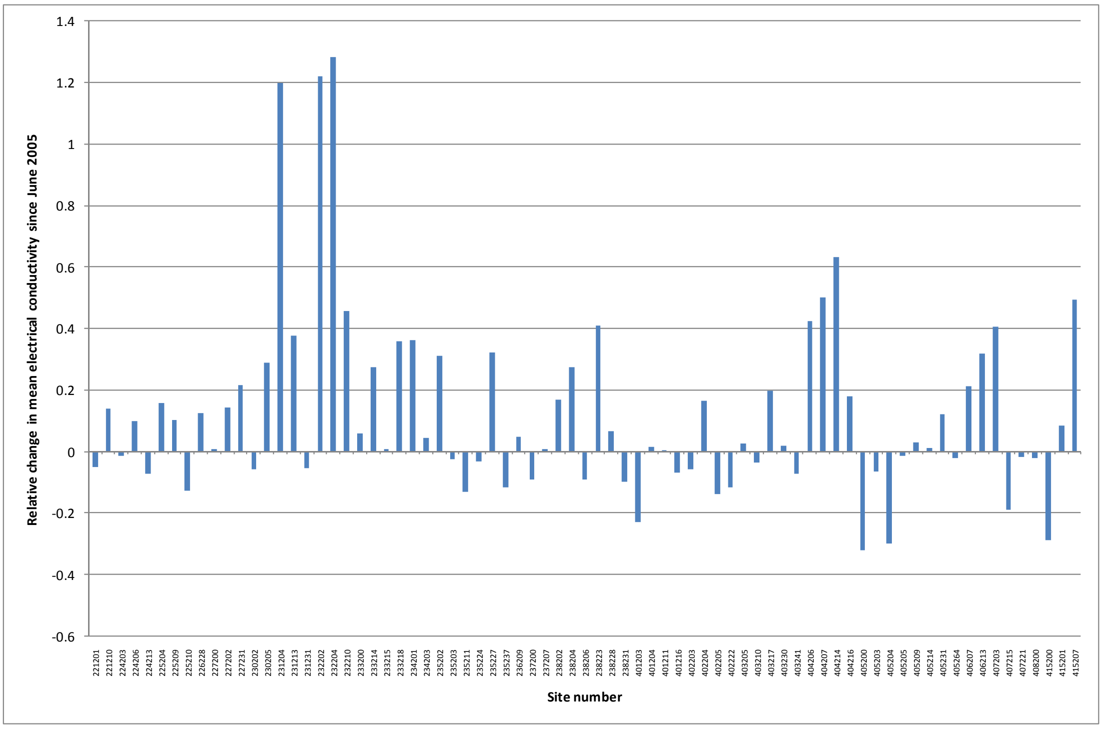
3.4. Electrical conductivity

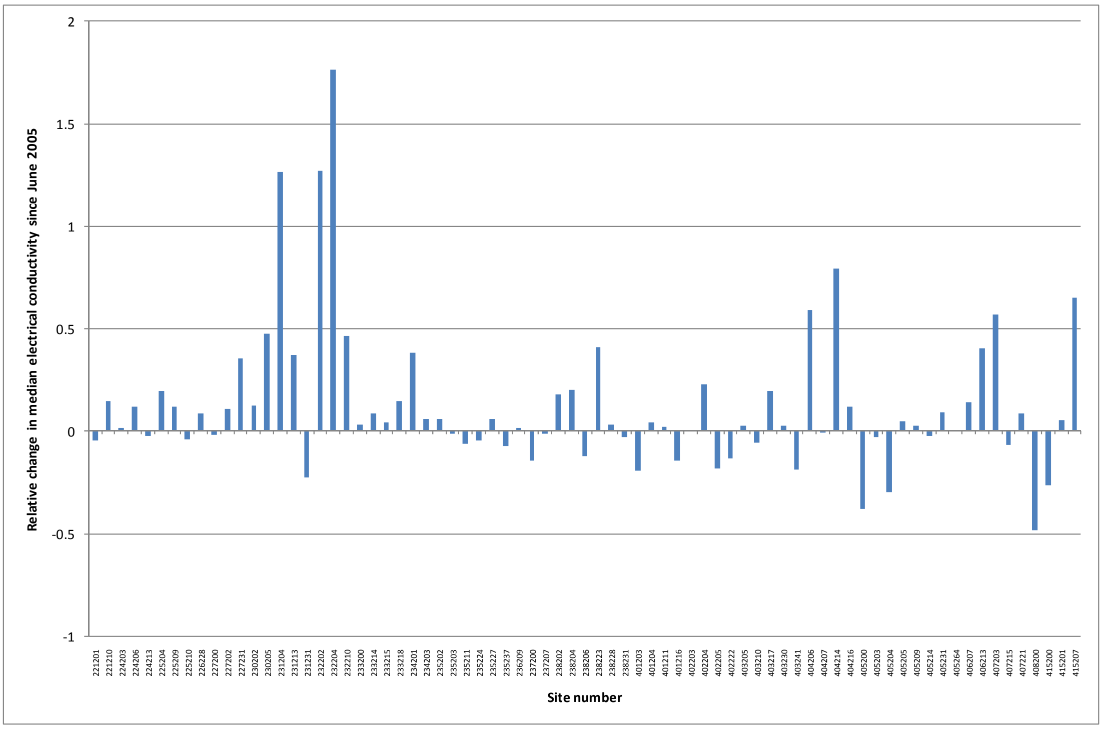
Electrical conductivity levels were higher at most of the 75 assessed sites in the period July 2005 to December 2010 compared to the period January 1991 to June 2005, however, at most sites the difference was relatively small and unlikely to be significant (Figure 3-4). The greatest increases in mean and median electrical conductivity levels since June 2005 occurred at sites 231204, 232202, 232204, 404206, 404214, and 415207 (Figure 3-4). All of these sites are in the northern and western parts of the state (see Table 3-3 for site locations) that are likely to have experienced greater intrusions of saline groundwater during the drought.

Table 3-3: Sites where greatest trends in electrical conductivity were observed

Site Number	Site Name	Strength of trend in time series plot
231204	Werribee River @ the Werribee Diversion Weir	Strong increase
232202	Moorabool River @ Batesford	Strong increase
232204	Moorabool River @ Morrisons	Strong increase
404206	Broken River @ Moorngag	Strong increase
404214	Broken Creek @ Katamatite	Strong increase
415207	Wimmera River @ Eversley	Moderate increase

Figure 3-4: Relative change in mean (top graph) and median (bottom graph) electrical conductivity levels at 75 Regional Water Monitoring Partnership sites since June 2005. Bars show the difference in mean/median electrical conductivity between the period July 2005 – December 2010 and the period January 1991 – June 2005 at each site, divided by the historical mean/median for that site.





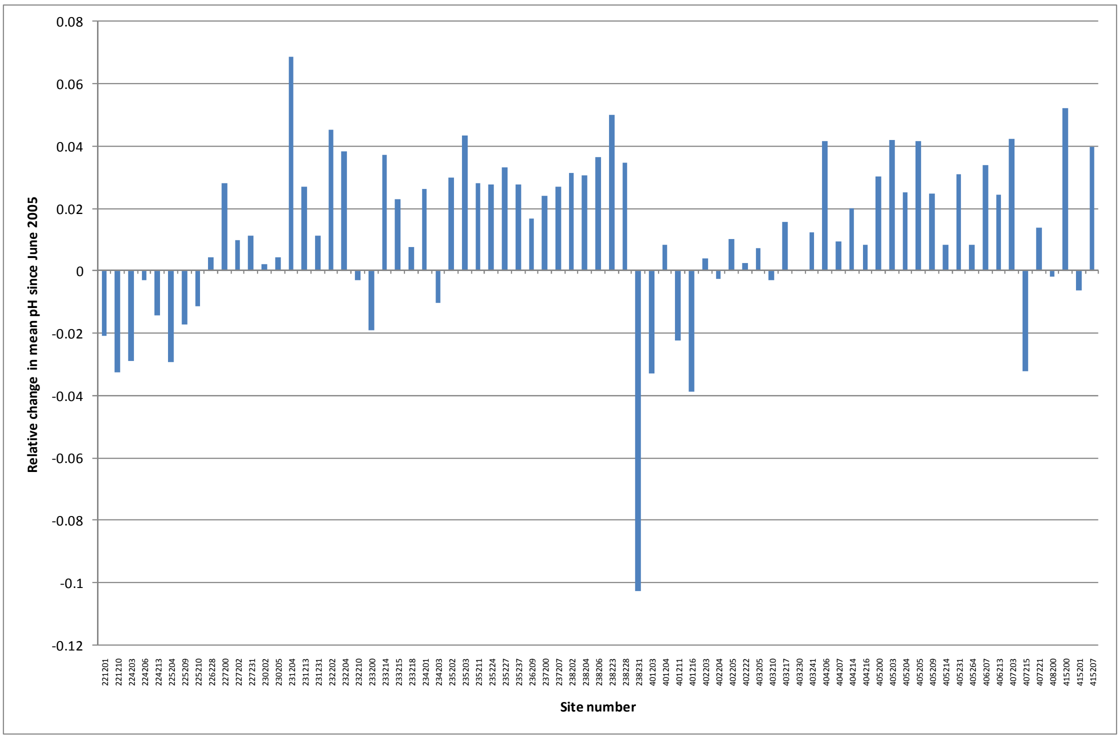
3.4.1. pH

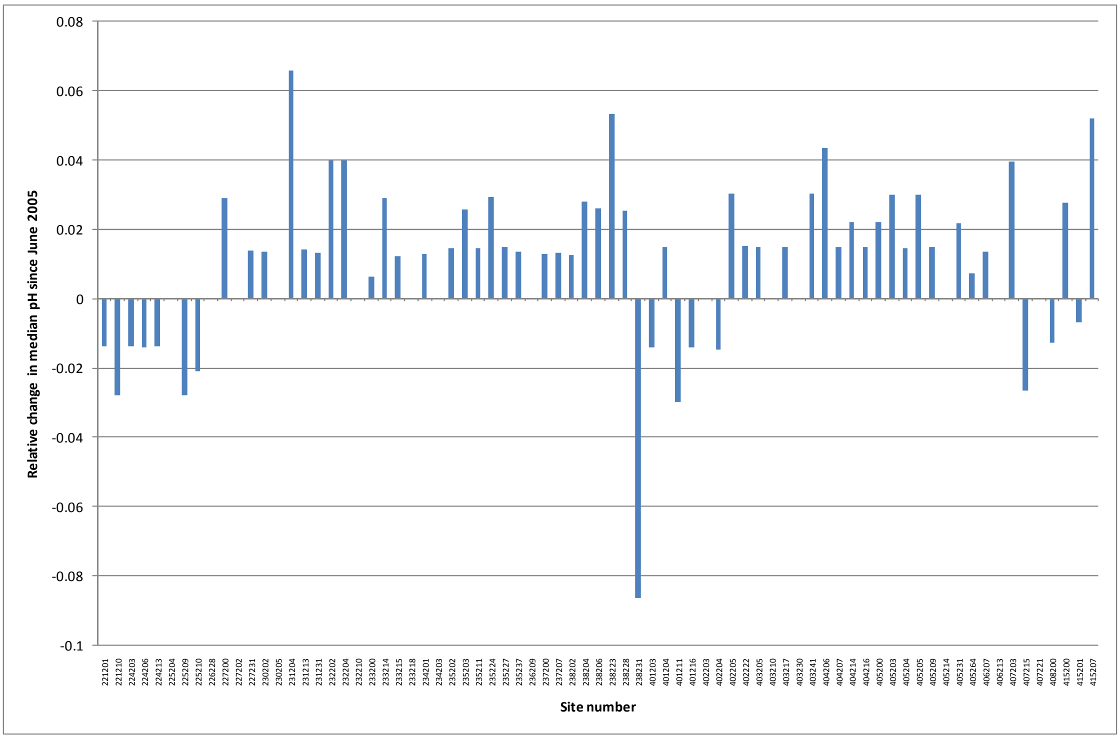
Mean and median pH levels at most of the 75 sites were slightly higher after June 2005 compared to the period January 1991 to June 2005, but these differences are very small and are not likely to be environmentally significant (Figure 3-5). Moderate declines in pH were observed at one site and moderate increases were observed at five sites (Table 3-4). REallThere were no distinct patterns within or between river catchments.

Table 3-4: Sites where greatest trends in pH were observed

Site Number	Site Name	Strength of trend in time series plot
231204	Werribee River @ Werribee Diversion Weir	Moderate increase
238223	Wando River @ Wando Vale	Moderate increase
238231	Glenelg River @ Big Cord	Moderate decrease
404206	Broken River @ Moorngag	Moderate increase
407203	Loddon River @ Laanecoorie	Moderate increase
415207	Wimmera River @ Eversley	Moderate increase

Figure 3-5: Relative change in mean (top graph) and median (bottom graph) pH at 75 Regional Water Monitoring Partnership sites since June 2005. Bars show the difference in mean/median pH between the period July 2005 – December 2010 and the period January 1991 – June 2005 at each site, divided by the historical mean/median for that site.





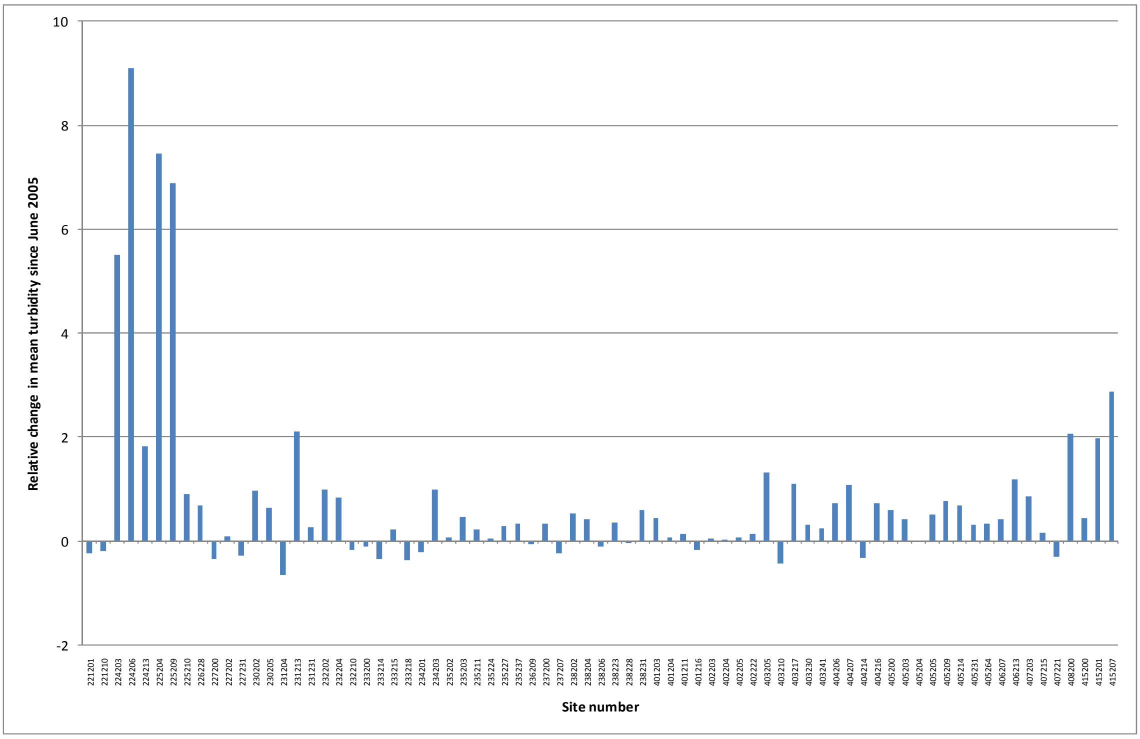
3.4.2. Turbidity

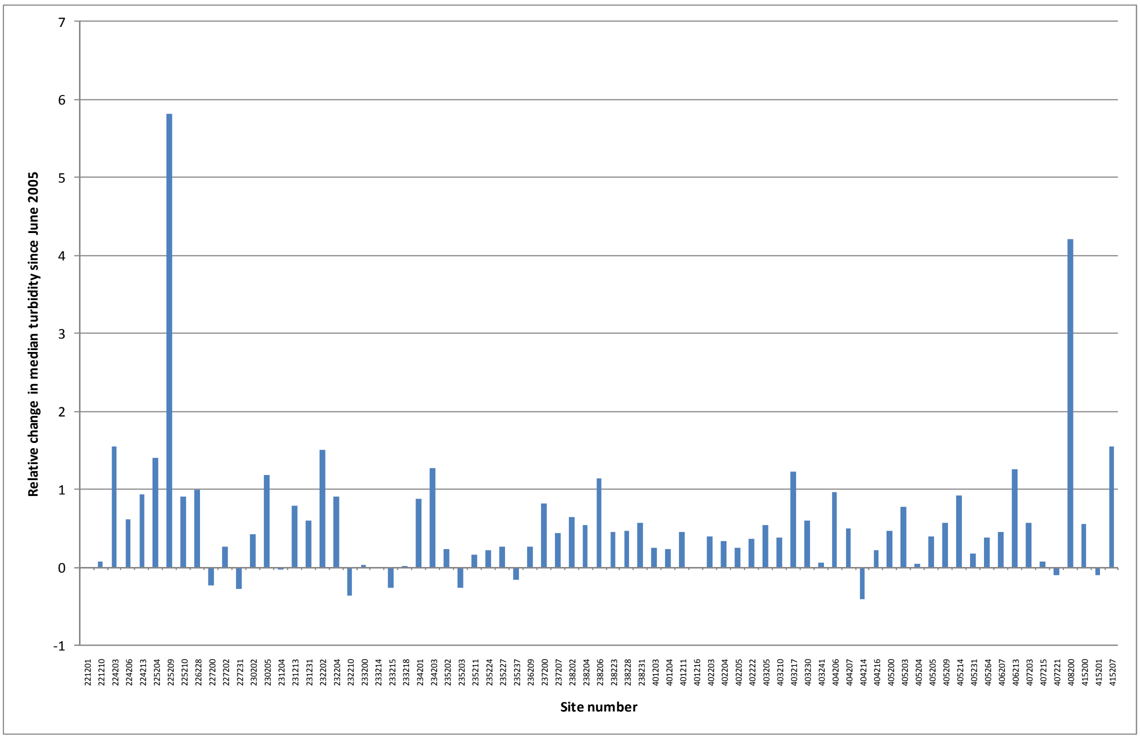
Mean and median turbidity levels were higher after June 2005 compared to the period January 1991 to June 2005 at most of the 75 assessed sites (Figure 3-6), but in most cases the increase is not likely to be statistically or environmentally significant. Only two sites had a very noticeable and consistent increase in turbidity after June 2005 and the greatest change was evident in the Macalister River @ Licola (Table 3-5). Three other sites had isolated records of very high turbidity, which probably related to specific flood events (Table 3-5). Mean turbidity levels at those three sites were much higher after June 2005, but median turbidity levels were only slightly higher (Figure 3-6).

Table 3-5: Sites where greatest trends in Turbidity were observed

Site Number	Site Name	Strength of trend in time series plot
224203	Mitchell River @ Glenaladale	Several higher than normal events
224206	Wonnongatta River @ Crooked River	Several higher than normal events
225204	Macalister River @ Glenmaggie (tail gauge)	Several very high readings
225209	Macalister River @ Licola	Consistently higher readings after June 2005
408200	Avoca River @ Coonooer	Consistently higher readings after June 2005

Figure 3-6: Relative change in mean (top graph) and median (bottom graph) turbidity at 75 Regional Water Monitoring Partnership sites since June 2005. Bars show the difference in mean/median turbidity between the period July 2005 – December 2010 and the period January 1991 – June 2005 at each site, divided by the historical mean/median for that site.





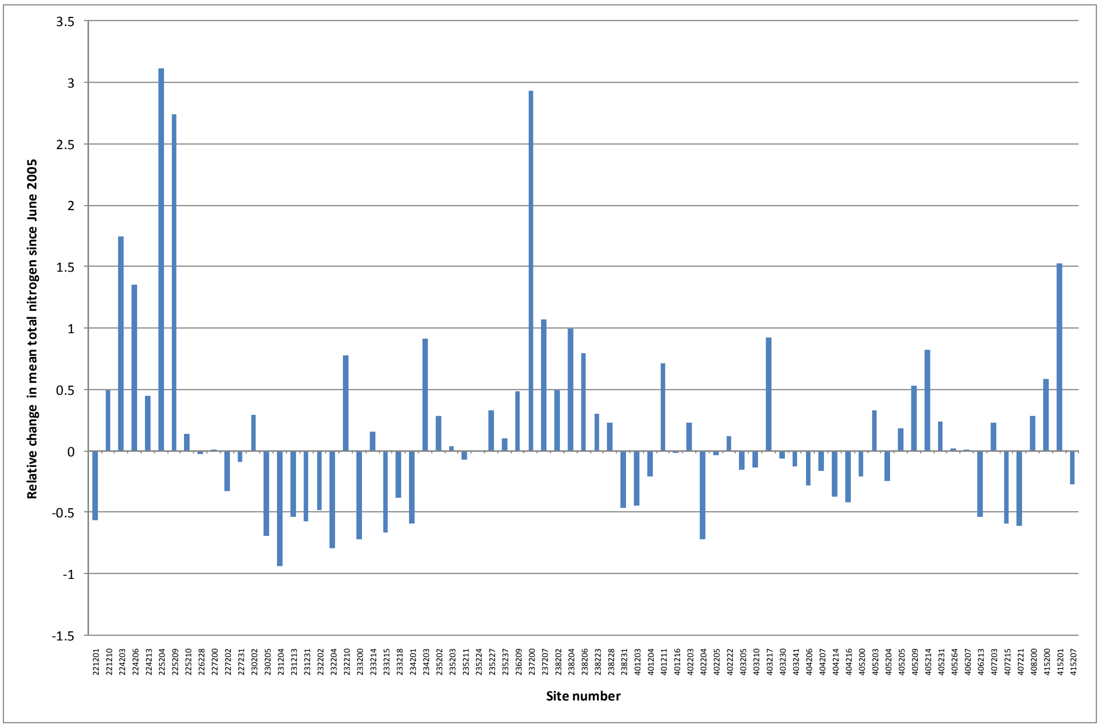
3.4.3. Total nitrogen

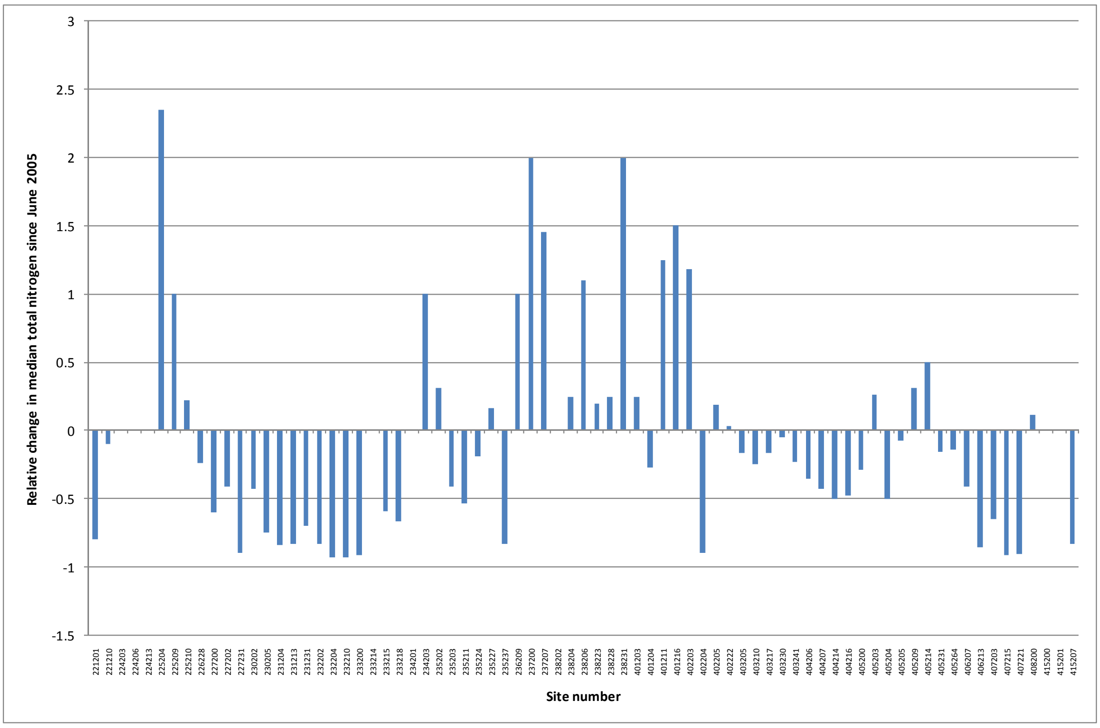
There was no consistent trend in total nitrogen concentrations across the state since June 2005, although there were some consistent patterns within individual catchments. Total nitrogen concentrations at sites in the Werribee (basin # 231) and Broken River (basin # 404) catchments generally decreased after June 2005, while concentrations in the Mitchell River (basin # 224), Thomson River (basin # 225), Portland (basin # 237) and Glenelg River (basin # 238) basins generally increased after June 2005 (Figure 3-7). The biggest increases in mean concentration and in median concentrations respectively were recorded in the Macalister River @ Glenmaggie tail gauge and in the Macalister River @ Licola, after large floods in 2007 (Table 3-6).

Table 3-6: Sites where greatest trends in total nitrogen (TN) concentration were observed

Site Number	Site Name	Strength of trend in time series plot
225204	Macalister River @ Glenmaggie (tail gauge)	Very high TN after 2007 then tailed off
225209	Macalister River @ Licola	High after 2007

Figure 3-7: Relative change in mean (top graph) and median (bottom graph) total nitrogen concentration at 75 Regional Water Monitoring Partnership sites since June 2005. Bars show the difference in mean/median total nitrogen concentration between the period July 2005 – December 2010 and the period January 1991 – June 2005 at each site, divided by the historical mean/median for that site.





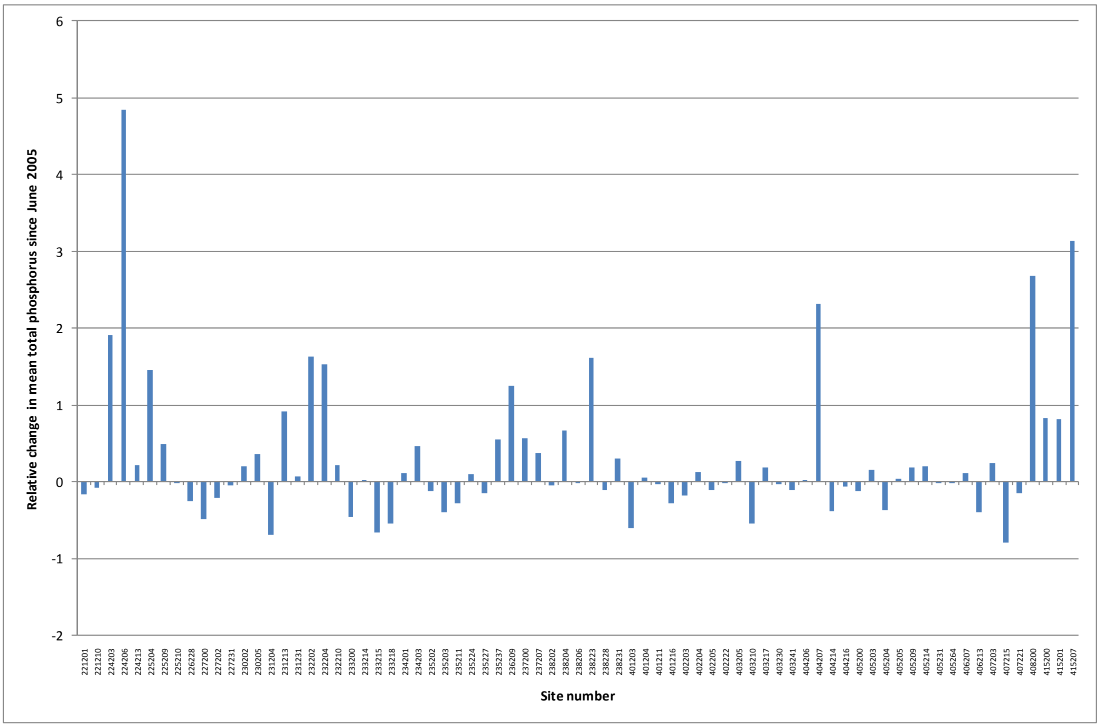
3.5. Total phosphorus

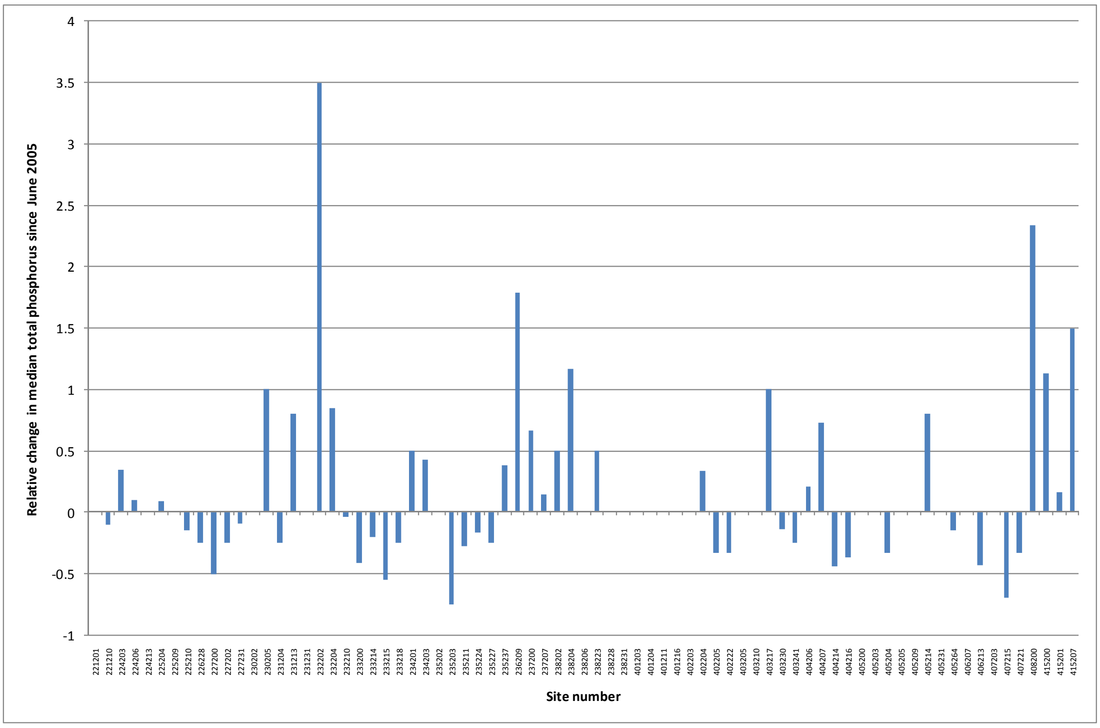
There was no consistent trend in total phosphorus concentrations across the state since June 2005, although there were some consistent patterns within individual catchments. Total phosphorus concentrations generally increased in the Corangamite (basin # 234), Portland (basin # 237) and Wimmera (basin # 415) river basins and decreased in the South Gippsland (basin # 227) and Barwon (basin # 233) river basins since June 2005 (Figure 3-8). The biggest increases in median total phosphorus concentrations were recorded in the Moorabool River @ Batesford, the Hopkins River @ Hopkins Falls, the Avoca River @ Coonooer and the Wimmera River @ Eversley (Table 3-7). Increases in total phosphorus at other sites since June 2005 have generally been associated with a small number of high records for several months after large flood events. The only site with a consistent decline in both mean and median total phosphorus levels since June 2005 was the Loddon River @ Newstead (Figure 3-8). That decline was mainly associated with very low flows during the drought.

Table 3-7: Sites where greatest trends in total phosphorus (TP) concentration were observed

Site Number	Site Name	Strength of trend in time series plot
224203	Mitchell River @ Glenaladale	Increase in TP for several months after floods
224206	Wonnongatta River @ Crooked River	Increase in TP associated with a single event
225204	Macalister River @ Glenmaggie (tail gauge)	Increase in TP for several months after floods
230205	Deep Creek @ Bulla (D/S of Emu Creek Junct.)	TP increased since end of the drought
232202	Moorabool River @ Batesford	Clear increase in mean and median TP
232204	Moorabool River @ Morrison	Numerous high TP events, but no change to median
236209	Hopkins River @ Hopkins Falls	Clear increase in mean and median TP
238204	Wannon River @ Dunkeld	TP less variable, fewer low readings and fewer very high readings
238223	Wando River @ Wando Vale	Several high values but no change in median
403217	Rose River @ Matong North	Slight increase in TP
404207	Holland River @ Kelfeera	Pattern driven by a single very high record during a flood
407215	Loddon River @ Newstead	Very low TP levels during the drought
408200	Avoca River @ Coonooer	Clear increase in mean and median TP
415200	Wimmera River @ Horsham	Return to pre-drought patterns
415207	Wimmera River @ Eversley	Clear increase in mean and median TP

Figure 3-8: Relative change in mean (top graph) and median (bottom graph) total phosphorus concentration at 75 Regional Water Monitoring Partnership sites since June 2005. Bars show the difference in mean/median total phosphorus concentration between the period July 2005 – December 2010 and the period January 1991 – June 2005 at each site, divided by the historical mean/median for that site.





4. Method for more detailed trend analyses at selected sites

4.1. Selected Sites for detailed Analyses

DSE invited each of the Catchment Management Authorities to nominate Regional Water Monitoring Partnership sites for more detailed trend analysis. The nominated sites had to already be on the list of 75 sites that were used in the broad state-wide analysis and also needed to be particularly relevant to one or more waterway management issues.

The Corangamite Catchment Management Authority, Goulburn-Broken Catchment Management Authority and Wimmera Catchment Management Authority each nominated several sites in order of importance for their own needs. The top two sites nominated by each of these three organisations, that were also on the list of 75 sites that had been included in the preliminary analysis, were selected for more detailed analysis. The final six sites were:

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

All six water quality parameters (i.e. dissolved oxygen, electrical conductivity, pH, turbidity, total nitrogen and total phosphorus) were analysed at each site. Analyses for dissolved oxygen were performed on the data which were measured as concentrations (mg/L), but these data were also converted to percent saturation, which is the unit for dissolved oxygen that is reported in the State Environment Protection Policy (Waters of Victoria) (SEPP, 2003). The concentration of dissolved oxygen is often used to determine when levels are critically low and likely to cause chronic or acute stress to certain biota (e.g. dissolved oxygen levels less than 5 mg/L are considered a risk to aquatic biota including native fish - Koehn and O'Connor, 1990). However, the amount of dissolved oxygen varies with water temperature, because cold water can hold more dissolved oxygen than warm water. The percent saturation measurement is standardised for water temperature and therefore removes some of the seasonal variation in the data.

4.2. Overall approach

The overall approach to the data analysis was as follows:

- Summarise the availability and standard of water quality data. This included a visual inspection of the data to exclude any clearly anomalous data points;
- 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];
- Fit a regression model over the reference period January 1991 to June 2005 to describe variation in each water quality variable;
- Apply the regression model to estimate water quality beyond the reference period (based on the historical data collected at the site), i.e. to estimate water quality after June 2005;
- 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;

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[1] Numerous other datasets including land use 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.

- Prepare a run chart showing the number of consecutive records above or below the predicted value in the current data;

- Provide some interpretation of the results including targeted follow up with relevant CMAs and water authorities regarding any patterns identified.

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

4.3. 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. However, the outliers were still plotted in the control charts to allow visual comparison against other data, unless it was infeasible to do so (e.g. for negative values where only a positive value is measurable). The date, value and magnitude of any outliers are described in the supporting text in the results section for each site.

4.4. 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. There was only one instance of a parameter having two samples taken on the same day (Wimmera River @ Horsham on 4/1/2005). When this occurred both readings were used in the analysis and were assigned the same mean daily flow and Date values. Quality codes accompanied the streamflow data, and only data with quality codes generally regarded as reasonable quality data were used in the analysis. 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.

4.5. 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 January 1991 to June 2005. 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 an in-house data analysis tool developed by SKM (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.

4.6. 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 DSE. Advice on how to use the spreadsheet was provided by Rob Goudy of the EPA.

For the control charts, the historical data period over which the models are fitted is from 1 January 1991 to 30 June 2005. New data were applied to the control charts from 1 July 2005 to the end of December 2010, which was the five year period of interest for these analyses. These periods are consistent with those used in previous studies.

The control chart parameters provided with the spreadsheet were not manipulated as part of the process. 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.

State Environment Protection Policy (Waters of Victoria) trigger values for all parameters were obtained from the State Environment Protection Policy guidelines (SEPP, 2003) and plotted on the control charts. As previously noted, these guidelines only specify a trigger value for the percent saturation of dissolved oxygen and so the control charts for dissolved oxygen concentration did not include a trigger value.

Run charts were prepared to display the number of consecutive data points above or below the modelled estimate. 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. 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 January 1991 and June 2005). Any runs in the new data period (i.e. after June 2005) that exceeded the run chart limits were considered unusual and potentially indicate a more sustained change in the data at that particular site.

4.7. 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. We present the models that best describe the historical variation in each water quality variable, the control charts, run charts and a discussion of results for each water quality variable in separate sub-chapters. In these interpretation sections we describe how well the regression models fit the historical data (1991-2005) and how well they predict conditions after June 2005. 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.

5. Results for 233200 Barwon River @ Pollocksford

5.1. Site Location

The Barwon River @ 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 5-1. The Corangamite 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 5-1: Locality map for Barwon River @ Pollocksford

5.2. Data availability and quality

Water quality was sampled at Pollocksford on 175 occasions between January 1991 and June 2005. All required water quality parameters were collected on most occasions (Table 5-1), and very few records needed to be excluded from the analysis. Only one data point (-9 for dissolved oxygen on 17/1/1996) was considered to be an outlier and was excluded.

Table 5-1: Missing data over period of regression model fit (Jan 1991 – Jun 2005)

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	5	3	3	5	5	3
No. of data points removed as outliers	1	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	0	0	0	0	0	0
Sample size for regression analysis	169	172	172	170	170	172

Water quality was sampled at this site on 73 occasions between July 2005 and December 2010. All water quality variables were measured on most occasions and there were very few occasions where data from one or more variables were either not collected or were missing (Table 5-2).

Table 5-2: Missing data over period of control chart application (Jul 2005 – 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	5	5	5	5	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	1	1
No. of data points not analysed due to missing flow data	1	1	1	1	1	1
No. of data points with zero flow data	0	0	0	0	0	0
Sample size for control chart application	67	67	67	67	70	70

5.3. Results

5.3.1. Dissolved oxygen

The regression model that best described variation in dissolved oxygen (mg/L) between 1991 and 2005 used date, water temperature and flow as explanatory variables (Table 5-3). It explained approximately 37% of the variation in the historic data (R^2 = 0.37). The best regression model for dissolved oxygen (% saturation) used date and flow as the explanatory variables, but it only explained about 10% of the variation in the historic data (Table 5-3). Date is a significant factor in both models and an inspection of the control charts, particularly for dissolved oxygen measured in percent saturation, suggests that average dissolved oxygen levels at this site generally declined between 1991 and 2005 (Figure 5-2 and Figure 5-4).

The median dissolved oxygen level (measured in mg/L and % saturation) has not noticeably increased in the Barwon River @ Pollocksford since 2005 (see Table 5-4), but there have been more records of very high levels of dissolved oxygen and even super saturation (Figure 5-4) and the average level of dissolved oxygen has increased. The control charts and run charts clearly highlight that the gradual decline in dissolved oxygen prior to 2005 has stopped, with most records after 2005 being higher than those predicted by the historical model (Figure 5-3 and Figure 5-5).

The State Environment Protection Policy trigger value for the Barwon River requires dissolved oxygen measurements to be between 85 and 110 % saturation with the objective being that 75% of the measurements over a 12 month period not exceed the trigger levels. Dissolved oxygen levels were broadly within the trigger values in between 1991 and 2001 and again between 2008 and 2010, but dissolved oxygen levels were below the lower trigger level on many occasions between 2001 and 2005 and were above the upper trigger level between 2006 and 2008 (see Figure 5-4). Moreover, the regression models were not very good at predicting when very high or very low dissolved oxygen levels were likely to occur (see Figure 5-2 and Figure 5-4). Very low levels of dissolved oxygen are likely to be more of a threat to aquatic biota than very high dissolved oxygen levels, but very high levels of dissolved oxygen may be an indicator of other problems.

Only two dissolved oxygen records (in January 2006 and February 1998) were low enough to be a real threat to aquatic biota (Figure 5-2). Super-saturated levels of dissolved oxygen were recorded in 2006, and to a lesser extent between 2007 and 2008 and again between 1994 and 1996. Many of these very high levels of dissolved oxygen are well outside what was experienced prior to 2005 (see Figure 5-4) and may indicate some level of stress in the system. The longest run of higher than expected levels of dissolved oxygen occurred in 2007, 2009 and 2010 (see Figure 5-3 and Figure 5-5), which were all years with very low rainfall and warm weather. Super-saturation is often due to 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. The control charts presented here have highlighted some recent changes in dissolved oxygen levels at this site. However, including measurements of chlorophyll-a in future models may improve their predictive ability.

Table 5-3: Best fit regression models to describe variation in dissolved oxygen in the Barwon River @ Pollocksford between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Dissolved Oxygen (DO) [mg/L]	DO = 26.9776 – (0.0002738*Date) – (0.2007*Temp) –(0.0462*Flow$^{0.4}$)	168	0.37	13%
Dissolved Oxygen (DO) (% saturation)	DO% = 238.929 – (0.002781*Date) – (0.4255*Flow$^{0.4}$)	168	0.10	14%

Table 5-4: Summary statistics for historical (1991-2005) and current (2005 – 2010) dissolved oxygen data recorded in the Barwon River @ Pollocksford

Parameter	Record	N	Mean	Median	Standard Deviation
Dissolved oxygen mg/L	Historical	168	9.45	9.7	1.57
	Current	61	9.48	9.5	2.02
Dissolved oxygen % Sat	Historical	168	94.04	94.76	13.71
	Current	61	96.02	93.03	21.01

Figure 5-2: Control chart for dissolved oxygen (in mg/L) in the Barwon River @ Pollocksford

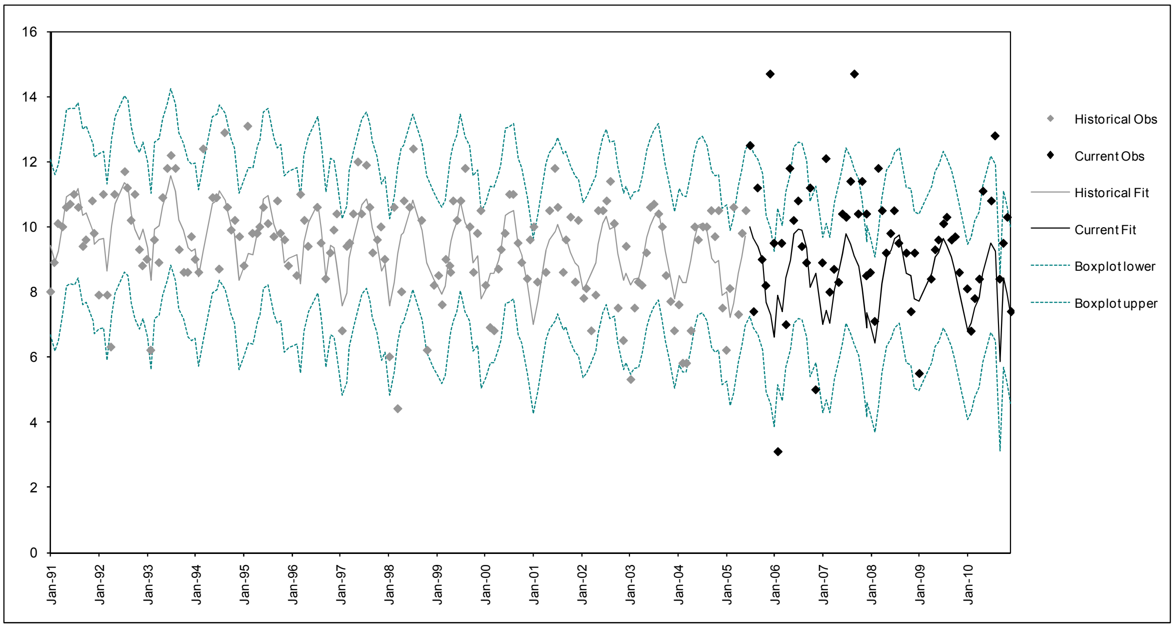


Figure 5-3: Run chart for dissolved oxygen (in mg/L) in the Barwon River @ Pollocksford

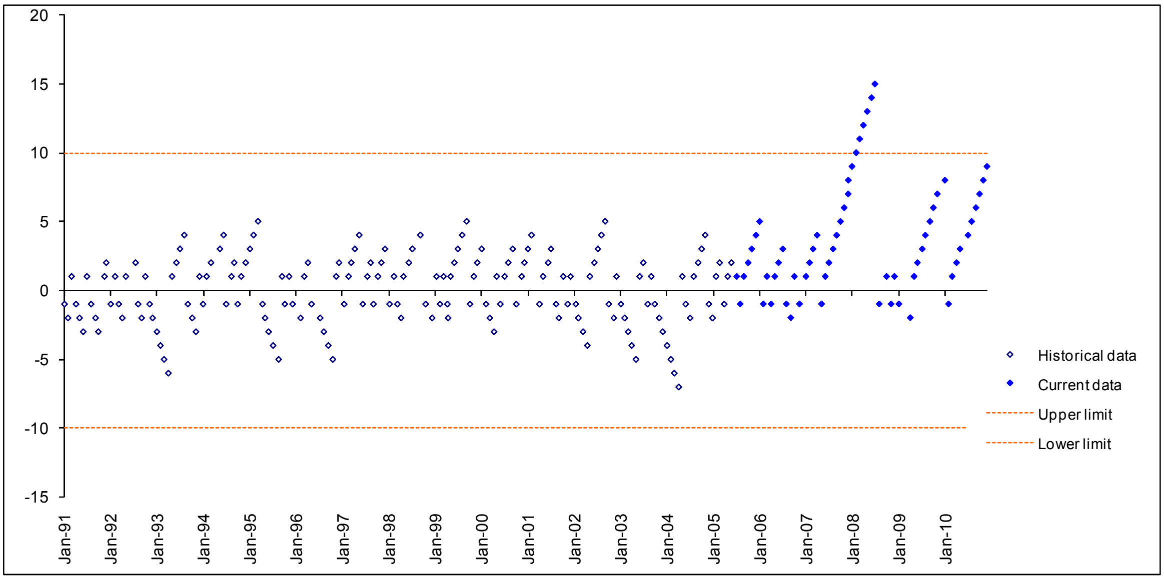


Figure 5-4: Control chart for dissolved oxygen (in % saturation) in the Barwon River @ Pollocksford

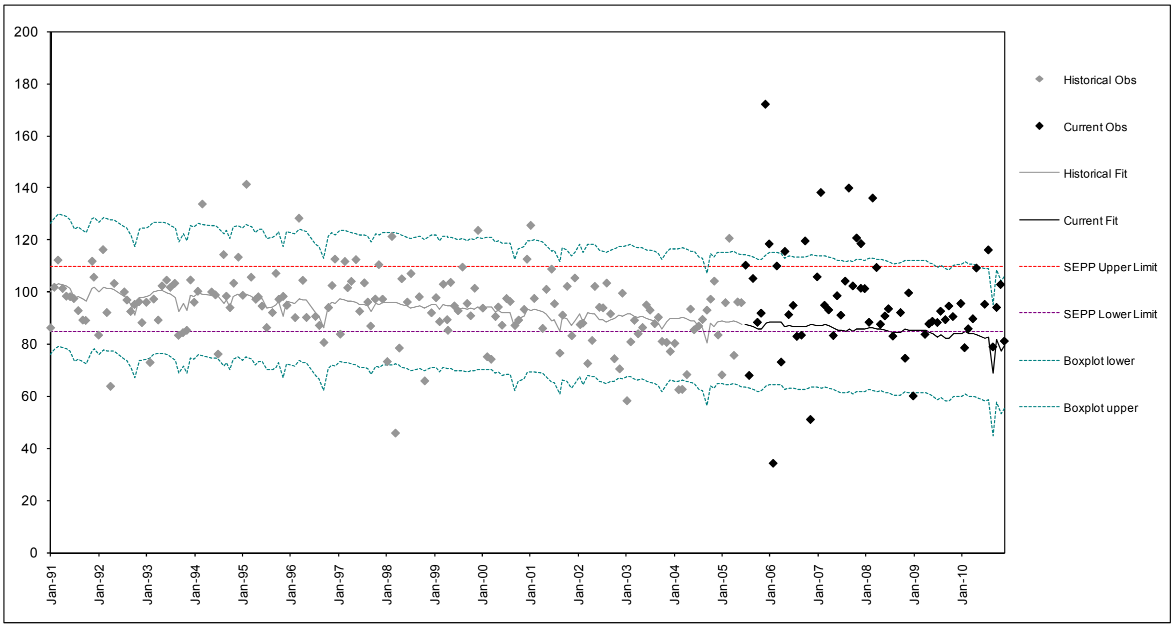
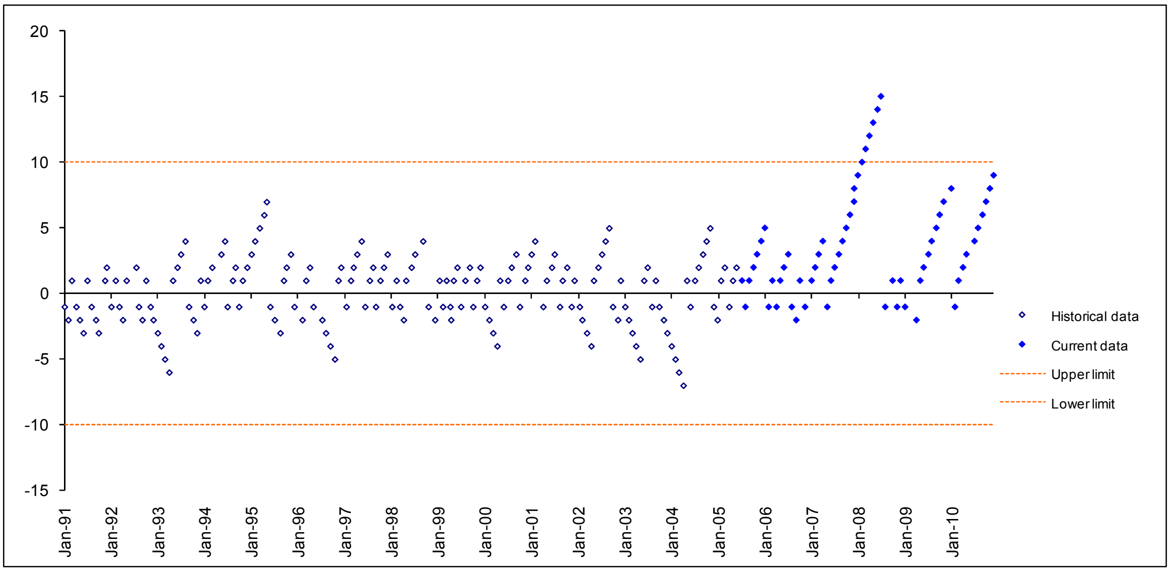


Figure 5-5: Run chart for dissolved oxygen (in % saturation) in the Barwon River @ Pollocksford



5.3.2. Turbidity

Turbidity levels in the Barwon River @ Pollocksford frequently exceeded the State Environment Protecton Policy (Waters of Victoria) trigger value of 10 NTU in the period between 1991 and June 2005 (Figure 5-6). High turbidity levels were rarely recorded between July 2005 and December 2010 and therefore the State Environment Protection Policy (Waters of Victoria) objective for 75% of monthly readings to be below 10 NTU in any given twelve month period was generally met after July 2005 (Figure 5-6).

Variation in turbidity levels at this site was relatively well explained ($R^2 = 0.58$) by date, flow and electrical conductivity - EC (Table 5-5). The model was a reasonably reliable predictor of turbidity after 2005 (in particular note the relatively accurate prediction of very high turbidity in May 2010 shown in Figure 5-6), but there were some instances of long runs where the recorded value was consistently higher than the predicted value (Figure 5-7). Given all of these patterns, turbidity levels were considered to be within control at this site.

Table 5-5: Best fit regression model to describe variation in turbidity in the Barwon River @ Pollocksford between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Turbidity	Turbidity = 165.346 – (0.00247*Date) + (0.0129*Flow) – (0.0164*EC)	172	0.58	109%

Table 5-6: Summary statistics for historical (1991-2005) and current (2005 – 2010) turbidity data recorded in the Barwon River @ Pollocksford

Parameter	Record	N	Mean	Median	Standard Deviation
Turbidity	Historical	172	13.53	3.1	22.26
	Current	61	11.94	3.2	37.17

Figure 5-6: Control chart for turbidity (in NTU) in the Barwon River @ Pollocksford

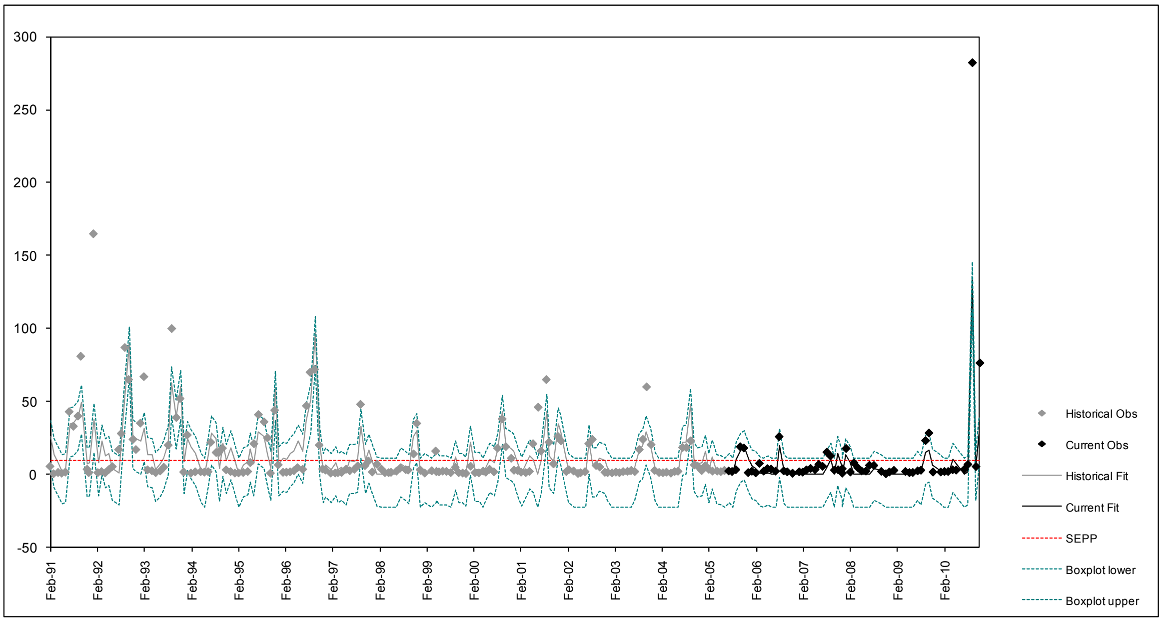
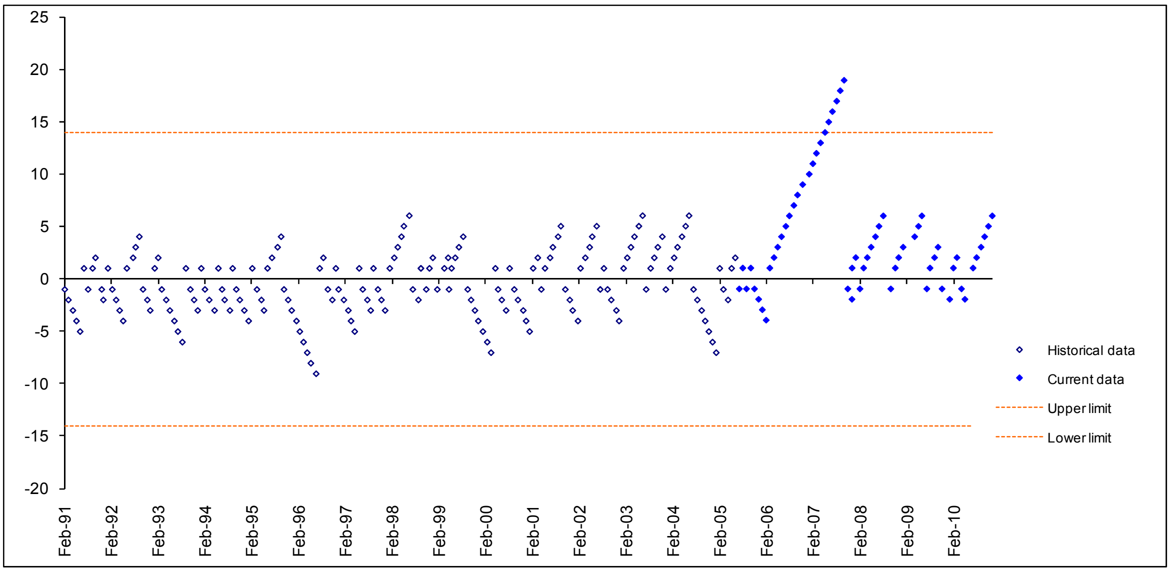


Figure 5-7: Run chart for turbidity (in NTU) in the Barwon River @ Pollocksford



5.3.3. Electrical conductivity

Electrical conductivity in the Barwon River @ Pollocksford is consistently higher than the State Environment Protection Policy (Waters of Victoria) trigger value of 1500 µS/cm (Figure 5-8), however there has been no change in the mean, median or standard deviation since 2005 (Table 5-8). The regression model that best explains historical variation in electrical conductivity at this site used season, water temperature and flow as predictor variables (Table 5-7). The model provided a reasonably good fit (R^2 = 0.43) for the period 1991 – 2005. The model also predicted electrical conductivity levels after 2005 reasonably well (Figure 5-8). Only one low value in June 2006 and one high value in late 2008 were out of control (Figure 5-8). This illustrates how control charts could alert to unusual values being measured and potentially trigger further investigations at the time of collection, rather than at a later point in time.

The long run of lower than expected electrical conductivity levels in late 2005 and throughout 2006 (Figure 5-9) is not likely to be a concern because low conductivity may be beneficial to environmental values in the system.

Table 5-7: Best fit regression model to describe variation in electrical conductivity in the Barwon River @ Pollocksford between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Conductivity (EC)	$EC^{0.4}$ = 25.97+ (0.664*Season) – (0.1932*Temp) – (0.387*$Flow^{0.4}$)	172	0.43	25%

Table 5-8: Summary statistics for historical (1991-2005) and current (2005 – 2010) electrical conductivity data (in µS/cm) recorded in the Barwon River @ Pollocksford

Parameter	Record	N	Mean	Median	Standard Deviation
Conductivity	Historical	172	1850.5	1928.5	589.1
	Current	61	1843.9	1859.8	606.3

Figure 5-8: Control chart for electrical conductivity (µS/cm) in the Barwon River @ Pollocksford

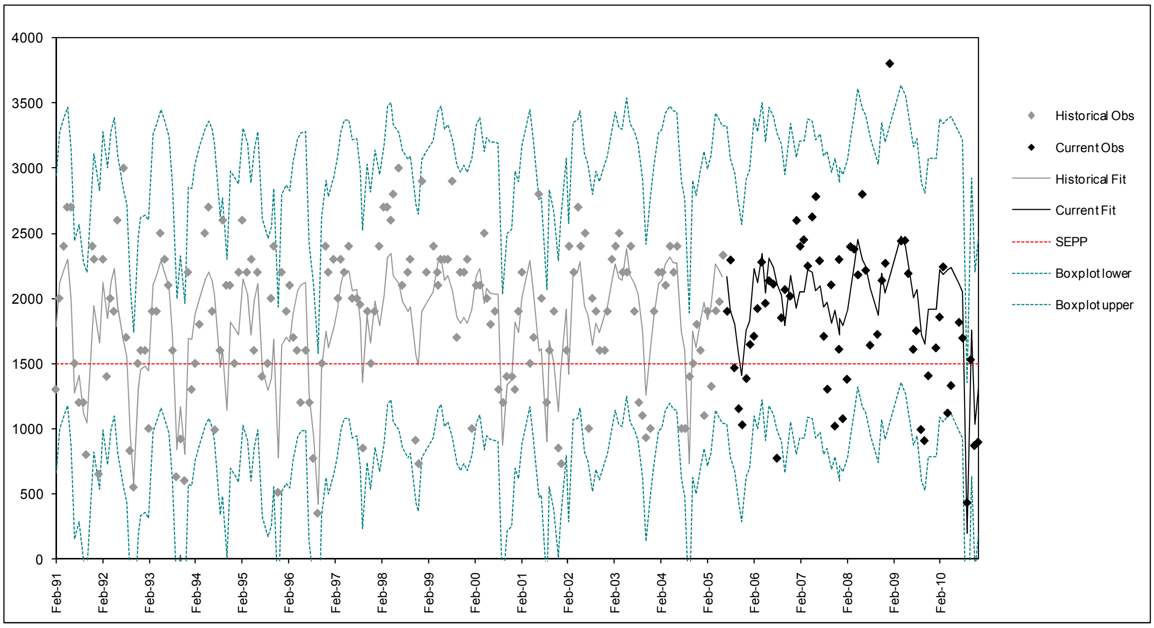
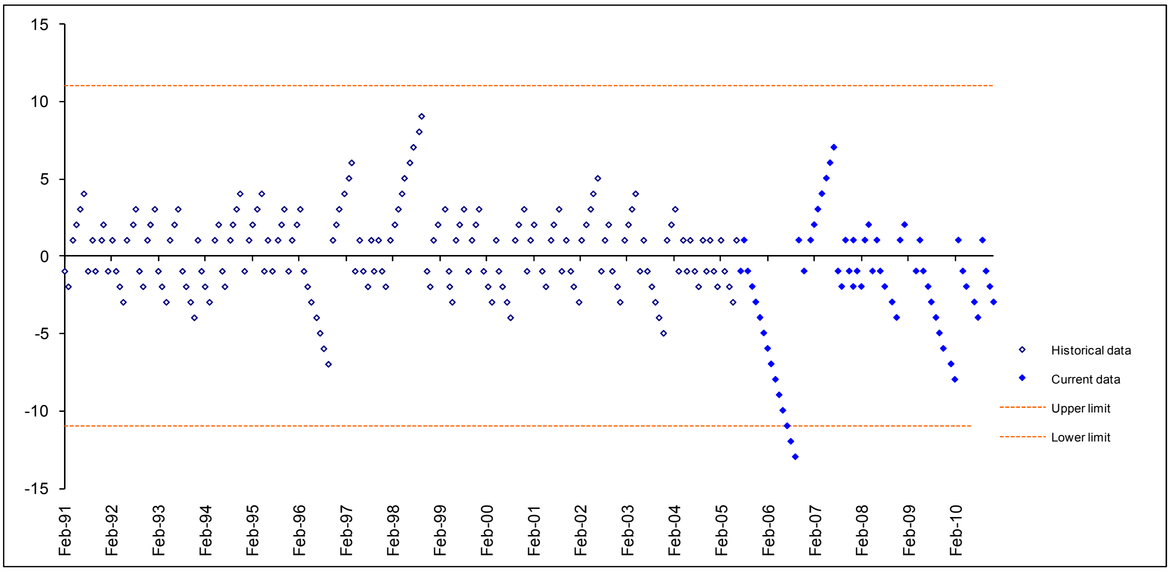


Figure 5-9: Run chart for electrical conductivity (µS/cm) in the Barwon River @ Pollocksford



5.3.4. pH

The pH regression model had poor goodness of fit statistics (R^2 = 0.15) with flow as the only explanatory variable (Table 5-9). However, the standard error estimate was only 6 %, which indicates that the variability around the mean is low. The median and mean pH levels in the Barwon River between 2005 and 2010 are virtually the same as recorded during the historical period (Table 5-10), but those summary statistics do not accurately reflect conditions during that period, because pH is measured on a logarithmic scale and therefore small numerical changes can represent large changes in condition. Moreover, the regression model does not predict quite obvious temporal patterns. pH levels between July 2005 and June 2007 were generally higher than average, while pH was generally lower than average between March 2008 and March 2010 (Figure 5-10 and Figure 5-11). The higher pH levels recorded from 2005 to 2008 correlate with very high levels of dissolved oxygen (possibly even super saturated levels of dissolved oxygen), indicating reduced dissolved CO_2 from photosynthetic production.

Overall, pH levels at this site are within the lower and upper State Environment Protection Policy (Waters of Victoria) trigger values of 6.5 (25th percentile) and 8.3 (75th percentile) respectively (Figure 5-10), and therefore pH is not currently considered to be a variable of concern at this site.

Given the poor fit of the regression models for describing pH in this analysis, the effort required for future assessments of pH in the Barwon River @ Pollocksford can be reduced to using a simple control chart based on the historical median and historical variation.

Table 5-9: Best fit regression model to describe variation in pH in the Barwon River @ Pollocksford between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
pH	$pH^{0.4} = 2.3151 – (0.00479*Flow^{0.4})$	170	0.15	6%

Table 5-10: Summary statistics for historical (1991-2005) and current (2005 – 2010) pH data recorded in the Barwon River @ Pollocksford

Parameter	Record	N	Mean	Median	Standard Deviation
pH	Historical	169	7.84	7.8	0.54
	Current	61	7.84	7.9	0.55

Figure 5-10: Control chart for pH in the Barwon River @ Pollocksford

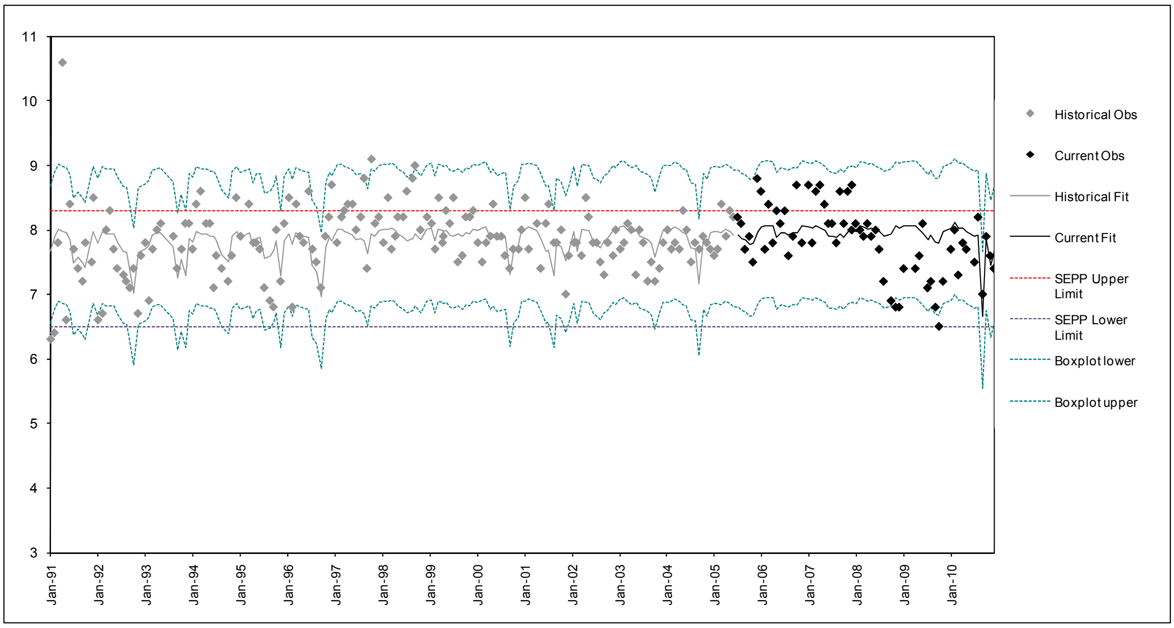
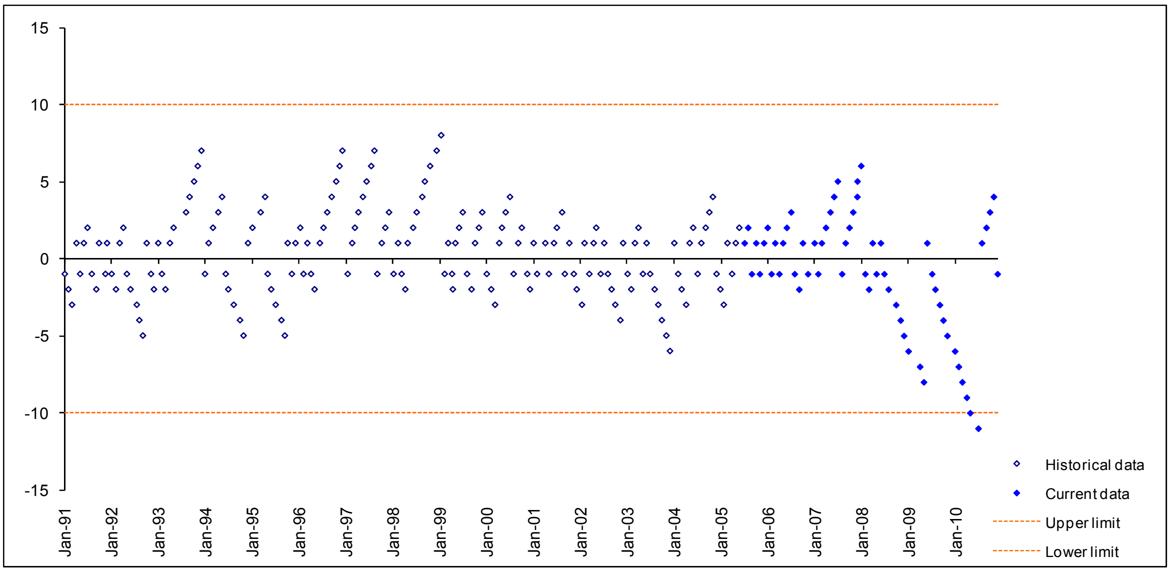


Figure 5-11: Run chart for pH in the Barwon River @ Pollocksford



5.3.5. Nutrient assessments

Our initial models for historical nutrient patterns in the Barwon River @ Pollocksford (see Table 5-11) were very unreliable because there were numerous records of very high levels for total nitrogen and total phosphorus that were up to ten times the mean of all historical records and an order of magnitude higher than the State Environment Protection Policy (Waters of Victoria) trigger values (Figure 5-12 and Figure 5-14). Those very high values had high statistical leverage in the regression models and swamped other patterns in the data. The complete absence of extremely high nutrient records after 2000, suggests a significant change in land or industrial management in the catchment. Several discussions with the Corangamite Catchment Management Authority and Central Highlands Water highlighted two significant changes within the catchment that could have affected nutrient levels:

1. In the late 1990s the Corangamite CMA worked with dairy farmers in the Colac region to improve nutrient management practices on their properties and at dairies.

2. In the late 1990s the South Ballarat Treatment Plant, which discharges treated wastewater into the Leigh River, was upgraded to incorporate a Biological Nutrient Removal (BNR) process. The South Ballarat Treatment Plant discharges approximately 18 ML/day of treated wastewater into the Leigh River, which is a tributary of the Barwon River that joins upstream of the Pollocksford monitoring site. Reasonable flows in the Leigh River would dilute the wastewater and it would have little effect on nutrient levels in the Barwon River. However, under very low flow conditions, discharge from the South Ballarat Treatment Plant would account for most of the flow in the lower reaches of the Leigh River and would contribute a significant portion of flow to the Barwon River @ Pollocksford. The highest total nitrogen and total phosphorus concentrations in the Barwon River @ Pollocksford were recorded during very low flow conditions and therefore it is likely that discharge from the treatment plant was having an effect. The BNR upgrade at the South Ballarat Treatment Plant reduced phosphorus levels in the discharged water by approximately 80% and converted most of the nitrogen to nitrate, which is more readily processed in the environment.

The upgrade to the South Ballarat Treatment Plant and improved nutrient management on dairy farms are likely to have greatly reduced nutrient levels in the Barwon River @ Pollocksford. As a result, data collected prior to the changes are not likely to be a reliable predictor of future nutrient concentrations. We therefore fitted new regression models to describe variation in total nitrogen and total phosphorus concentrations between January 2000 and June 2005 (see Sections 5.3.6 and 5.3.7) and used those models to predict nutrient concentrations from July 2005 to June 2010. The new models were based on fewer data, but still explained much more of the variation (R2 = 0.33 compared to R2 = 0.21 for total nitrogen, and R2 = 0.15 compared to R2 = 0.04 for total phosphorus) Moreover, the updated models incorporated flow, which was not a significant factor in the previous models, and provided a much better prediction of future nutrient concentrations.

We would not have been justified in excluding the component of the historical record that contained inconveniently high nutrient concentrations without understanding why those very high values occurred. However, by doing so we were able to greatly improve our assessment of current nutrient conditions. This example highlights the need to have a good understanding of the system being modelled or monitored so all results can be appropriately interpreted.

Table 5-11: Best fit regression models to describe variation in total nitrogen and total phosphorus in the Barwon River @ Pollocksford between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Total nitrogen (TN)	$TN^{0.4}$ = 6.0303 – (0.0000957*Date) – (0.0528*Temp)	171	0.21	154%
Total phosphorus (TP)	$TP^{0.4}$ = 1.6019 – (0.0000198*Date) + (0.0455*Season) – (0.00491*Temp)	173	0.04	83%

Figure 5-12: Control chart for total nitrogen (mg/L) in the Barwon River @ Pollocksford using data from 1991 – 2010

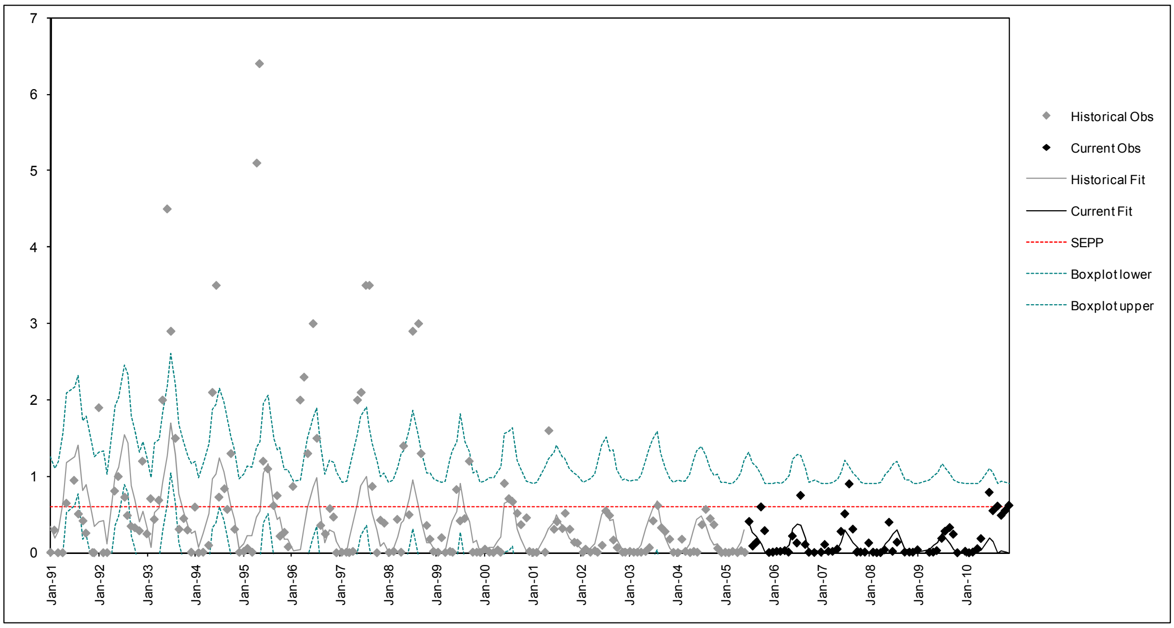


Figure 5-13: Run chart for total nitrogen in the Barwon River @ Pollocksford using data from 1991 – 2010

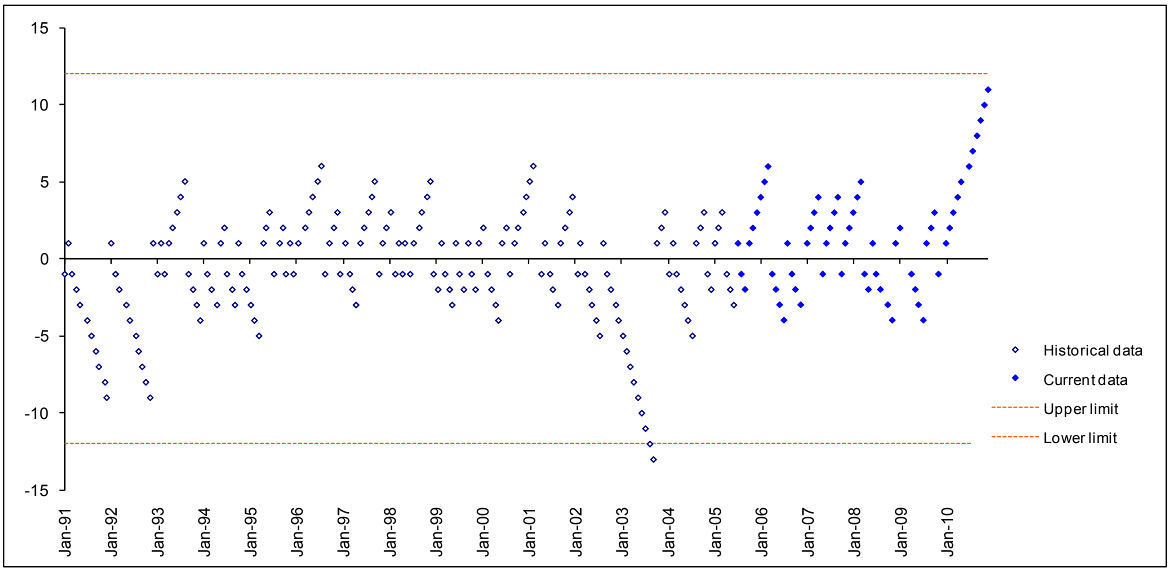


Figure 5-14: Control chart for total phosphorus (mg/L) in the Barwon River @ Pollocksford 1991-2010

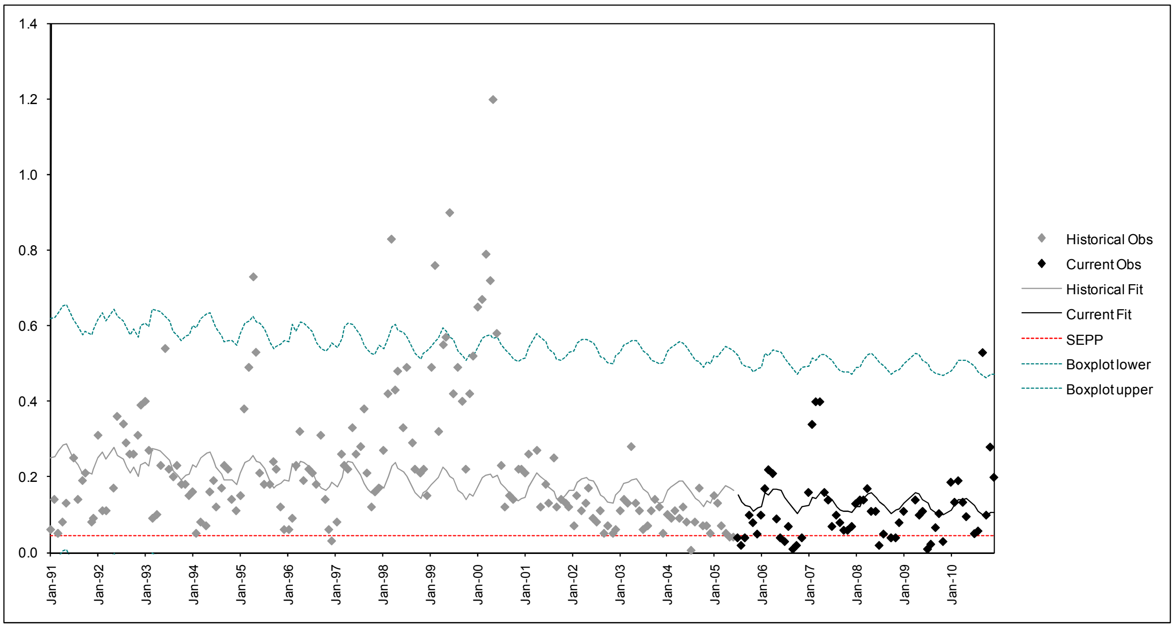
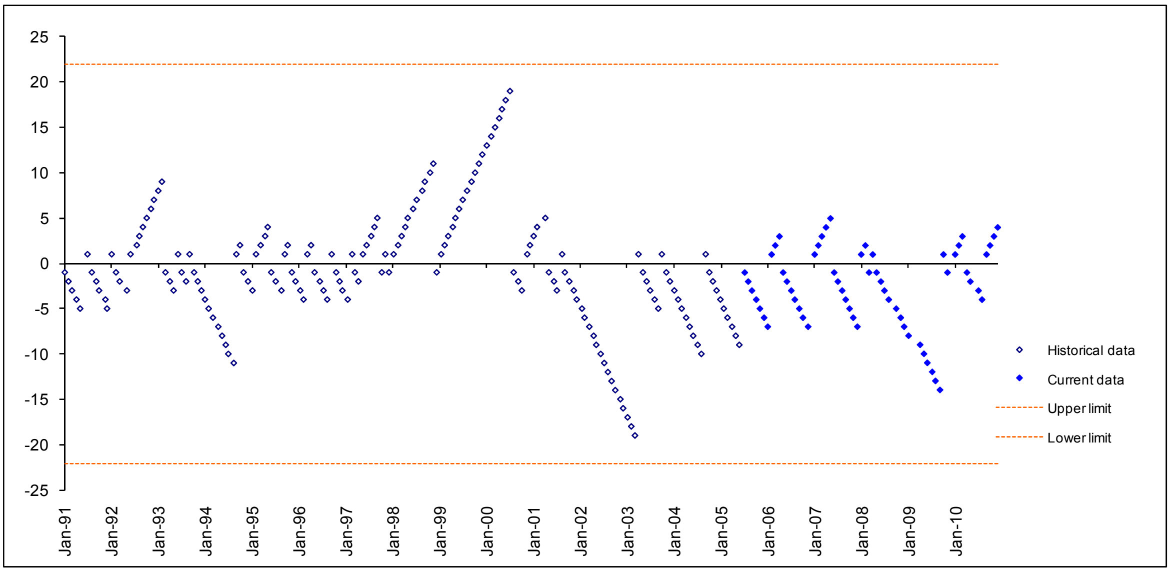


Figure 5-15: Run chart for total phosphorus (mg/L) in the Barwon River @ Pollocksford 1991-2010



5.3.6. Total nitrogen

Variation in total nitrogen between January 2000 and June 2005 was best explained by a combination of water temperature, date and flow (R^2 = 0.33) (Table 5-12). Flow appears to be a particularly important explanatory variable and as a result the predicted concentrations for total nitrogen after June 2005 were much lower and less variable than in the preceding five years (Figure 5-16). The average concentration for total nitrogen recorded in the Barwon River after 2005 was slightly lower than the average concentration recorded between January 2000 and June 2005, but there was little difference in the median concentration recorded during the historical and current monitoring periods (Table 5-13). More importantly, total nitrogen concentrations in the Barwon River @ Pollocksford after June 2005 were not as low as predicted by the historical model. The discrepancy can be seen in the control chart, where most observed values are shown above the predicted value (Figure 5-16); and is most evident in the run chart that shows long runs of consecutive values above the predicted value (Figure 5-17). Despite the large difference between modelled and recorded values, only five observations for total nitrogen fall above the upper limit of the model and therefore are likely to trigger further investigation (Figure 5-16). Moreover, the model is reasonably good at predicting the high levels of total nitrogen that occurred during high flow events in the second half of 2010 (Figure 5-16).

Total nitrogen concentrations recorded in the Barwon River @ Pollocksford since January 2000 generally are below the State Environment Protection Policy (Waters of Victoria) trigger value of ≤0.6 mg/L (Figure 5-16). The predictive model developed during this project explains a moderate amount of the variation in total nitrogen concentration between January 2000 and June 2005 and appears to predict the high nutrient levels associated with higher flow events in 2010. However, the model underestimated total nitrogen concentrations during the worst part of the drought. One of the main limitations of the model is the relatively short amount of time over which the model was developed. It is likely that a longer historical record will produce a more reliable model, but it is also important to ensure that the predictive model is based on a period of record that experienced similar conditions to those expected during the test period. In this case, it was necessary to omit all records collected before January 2000 to ensure that the model accurately reflected current nutrient management.

Table 5-12: Best fit regression model to describe variation in total nitrogen in the Barwon River @ Pollocksford between between 2000 and 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Total nitrogen (TN) Post 2000	$TN^{0.4}$ = 6.9042 - (0.0308*Temp) – (0.0001172*Date) + (0.0197*$Flow^{0.4}$)	65	0.33	128%

Table 5-13: Summary statistics for historical (2000-2005) and current (2005 – 2010) total nitrogen (mg/L) data recorded in the Barwon River @ Pollocksford

Parameter	Record	N	Mean	Median	Standard Deviation
Total nitrogen	Historical	65	0.203	0.05	0. 29
	Current	59	0.184	0.05	0.24

Figure 5-16: Control chart for total nitrogen (mg/L) in the Barwon River @ Pollocksford using data from 2000 – 2010

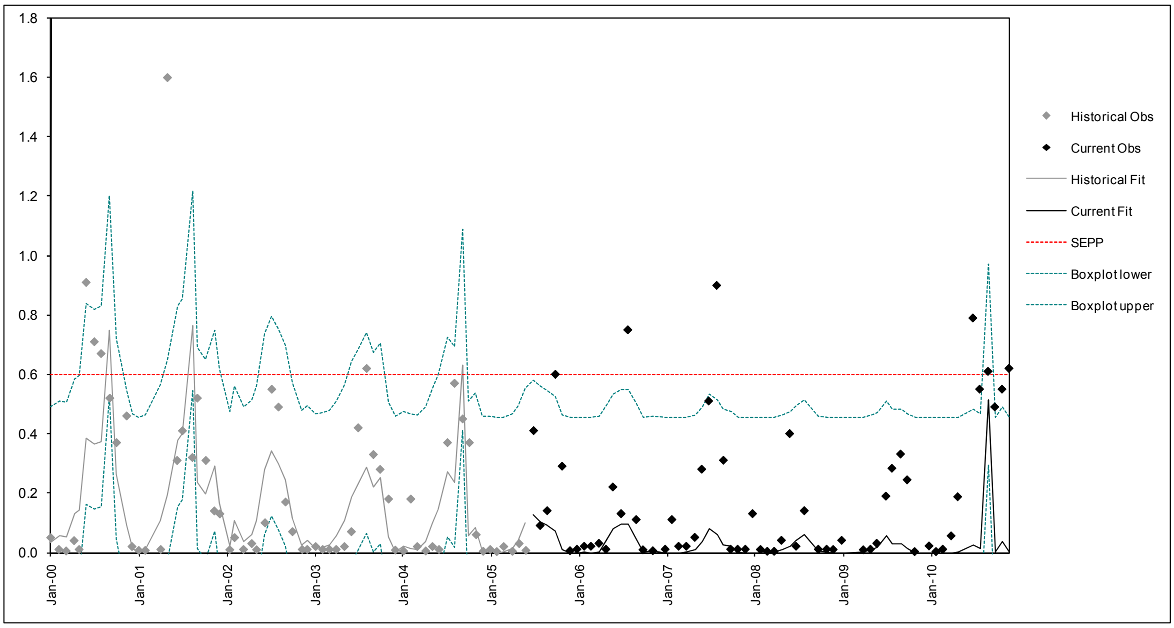
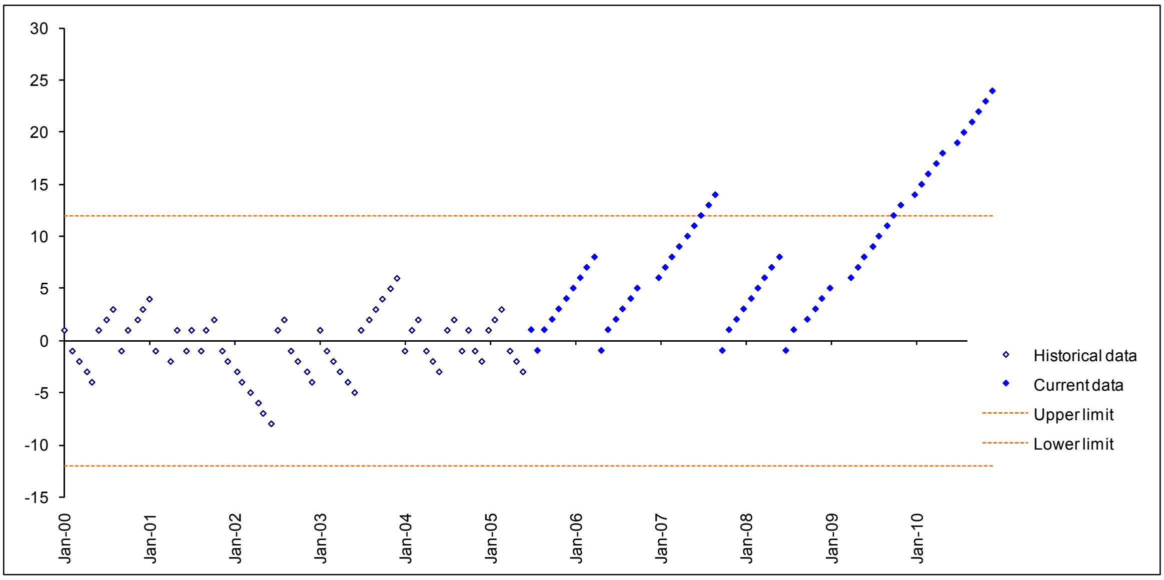


Figure 5-17: Run chart for total nitrogen in the Barwon River @ Pollocksford using data from 2000 – 2010



5.3.7. Total phosphorus

Regression models did not describe the variation in total phosphorus concentrations in the Barwon River @ Pollocksford (see Figure 5-18) for the same reasons described for total nitrogen. Therefore we only present results from 2000 onwards.

Total phosphorus concentrations in the Barwon River @ Pollocksford generally exceeded the State Environment Protection Policy (Waters of Victoria) trigger value of ≤0.045 mg/L for the whole period from January 2000 to June 2010 (Figure 5-18). Moreover none of the tested predictor variables explained the variation in total phosphorus very well. The best model for data collected between January 2000 and June 2005 used water temperature, flow, rainfall in the preceding 72 hours, time since last rainfall event greater than 20 mm and turbidity, but it only explained 21% of the total variation (R^2 = 0.21). Rainfall data from the Gnarwarre (Barwon River @ Pollocksford) rainfall gauge (Site # 087162) were used for the analysis. Total phosphorus records collected between July 2005 and June 2010 were on average higher and more variable than the total phosphorus levels recorded between January 2000 and June 2005 (Table 5-15). In particular, there were many more records greater than 0.15 mg/L after June 2005, including three records at the start of 2007 that were greater than 0.30 mg/L and would be considered out of control compared to historical patterns (Figure 5-18). The model did however predict the very high total phosphorus concentration recorded during a high flow event in spring 2010 (Figure 5-18). As described in the previous section for total nitrogen, the fit of the model for total phosphorus is compromised by the shorter record of suitable historical data. The data collected between 1991 and 1999 would not have improved the fit of the model in this case and also would not accurately reflect nutrient management actions that are currently in place.

Table 5-14: Best fit regression model to describe variation in total phosphorus in the Barwon River @ Pollocksford between 2000 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Total phosphorus (TP) Post 2000	$TP^{0.4}$ = 0.3209 + (0.0756*Season) + (0.007132*$Flow^{0.4}$) + (0.00001955*TimeSinceRain) + (0.002057*Turbidity)	51	0.36	45%

Table 5-15: Summary statistics for historical (2000-2005) and current (2005 – 2010) total phosphorus data recorded in the Barwon River @ Pollocksford

Parameter	Record	N	Mean	Median	Standard Deviation
Total Phosphorus	Historical	51	0.109	0.11	0.06
	Current	60	0.118	0.10	0.10

Figure 5-18: Control chart for total phosphorus (mg/L) in the Barwon River @ Pollocksford using data from 2000 – 2010

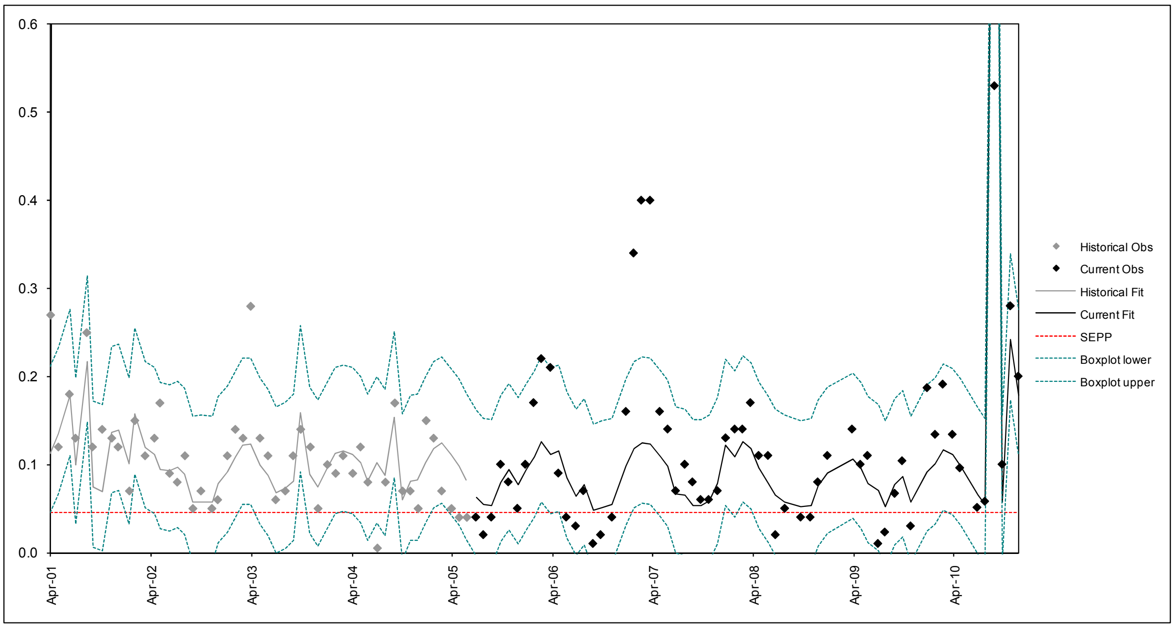
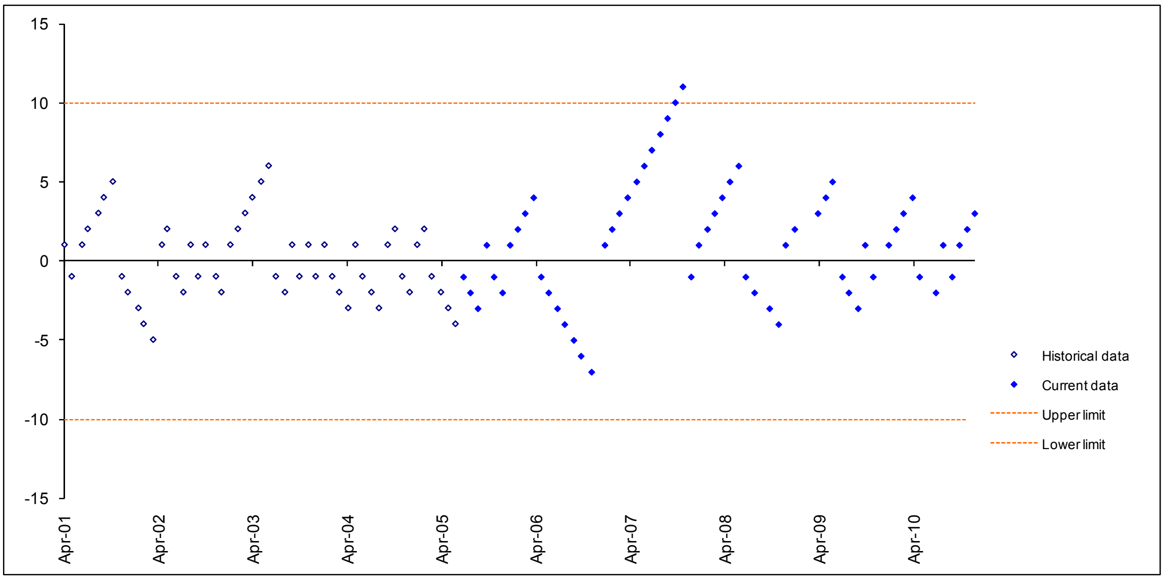


Figure 5-19: Run chart for total phosphorus (mg/L) in the Barwon River @ Pollocksford using data from 2000 – 2010



6. Results for 235227 Gellibrand River @ Bunkers Hill

6.1. Site Location

The Bunkers Hill (streamflow gauge number 235227) gauging station is located on the Gellibrand River between Love Creek and the Carlisle River (Figure 6-1). The local catchment includes areas of native forest, dairy farming, pine plantations and apple orchards, and groundwater extraction and on-stream diversions higher up in the catchment influence flow at this site. The Corangamite CMA nominated the site as being of interest, from a water quality perspective, in relation to the effect of works done near this site.

Figure 6-1: Locality map for Gellibrand River @ Bunkers Hill

6.2. Data availability and quality

Water quality was sampled at Bunkers Hill on 174 occasions between January 1991 and June 2005. There were very few missing data and no identified outliers or errors (Table 6-1). As a result, each model used at least 165 measurements.

Table 6-1: Missing data over period of regression model fit (Jan 1991 – Jun 2005)

Missing data elements	Dissolved oxygen	Turbidity	Electrical conductivity	pH	Total nitrogen	Total phosphorus
No. of missing water quality readings on days when at least on other parameter was recorded	3	1	1	9	5	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	0
No. of data points not analysed due to missing or zero flow data	0	0	0	0	0	0
Sample size for regression analysis	171	173	173	165	169	172

Water quality measurements were taken on 65 occasions at Bunkers Hill between July 2005 and December 2010. Nutrients were not recorded on one of these occasions. Two records for electrical conductivity in June and August 2008 were an order of magnitude higher than all other records (i.e. they were in excess of 2,000 µS/cm compared to a mean of approximately 220 µS/cm) and were omitted on the assumption that they were errors.

Table 6-2: Missing data over period of control chart application (Jul 2005 – 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	0	0	0	0	1	1
No. of data points removed as outliers	0	0	2	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 flow data	0	0	0	0	0	0
No. of data points with zero flow data	0	0	0	0	0	0
Sample size for control chart application	65	65	63	65	64	64

6.3. Results

6.3.1. Dissolved oxygen

Variation in dissolved oxygen (mg/L) levels in the Gellibrand River @ Bunkers Hill between 1991 and 2005 was well explained by a combination of season, water temperature and flow (Table 6-3). The regression model predicted dissolved oxygen levels between 2005 and 2010 reasonably well (Figure 6-2), and there were no extended runs above or below predicted values (Figure 6-3). Average dissolved oxygen levels were slightly lower after 2005 compared to the historical period (Table 6-4), but only two values (both recorded in 2009) were outside the model limits and would potentially be identified as points of concern (Figure 6-2).

The percent saturation of dissolved oxygen was best explained by the factors season and flow, but the fit (R^2 = 0.32) was not as good as the model for absolute dissolved oxygen (Table 6-3). The control chart for the percent saturation of dissolved oxygen shows a considerable number of points below the lower SEPP trigger value of 85% and highlights several instances of extremely low dissolved oxygen that would be considered out of control and a potential cause for concern (Figure 6-4). If the data were analysed at the time of collection then those results would most likely trigger immediate further investigation. It is worth noting, however, that there are no excessively long runs of very low dissolved oxygen that are outside the experience of the model for this site (Figure 6-5).

Table 6-3: Best fit regression model to describe variation in dissolved oxygen in the Barwon River @ Pollocksford between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R2)	Standard Error of Estimate (% of mean)
Dissolved oxygen (DO) [mg/L]	DO = 11.7627–(0.4521*Season)–(0.2387*Temp) + (0.0728*$Flow^{0.4}$)	171	0.65	9%
Dissolved oxygen (DO) [% saturation]	DO = 81.7768 – (5.0295*Season) + (0.6874*$Flow^{0.4}$)	171	0.32	10%

Table 6-4: Summary statistics for historical (1991-2005) and current (2005 – 2010) dissolved oxygen data recorded in the Gellibrand River @ Bunker Hill

Parameter	Record	N	Mean	Median	Standard Deviation
Dissolved oxygen mg/L	Historical	163	9.39	9.6	1.44
	Current	47	8.92	8.8	1.43
Dissolved oxygen % Sat	Historical	171	86.75	87.96	9.77
	Current	59	81.96	86.19	10.93

Figure 6-2: Control chart for dissolved oxygen (in mg/L) in the Gellibrand River @ Bunkers Hill

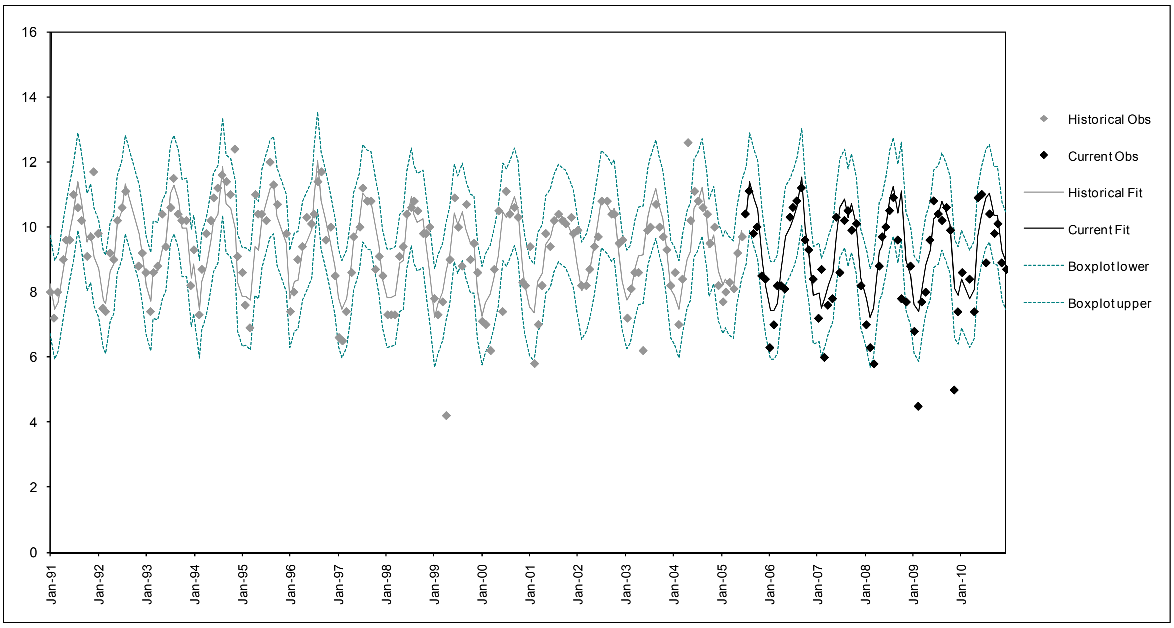


Figure 6-3: Run chart for dissolved oxygen (in mg/L) in the Gellibrand River @ Bunkers Hill

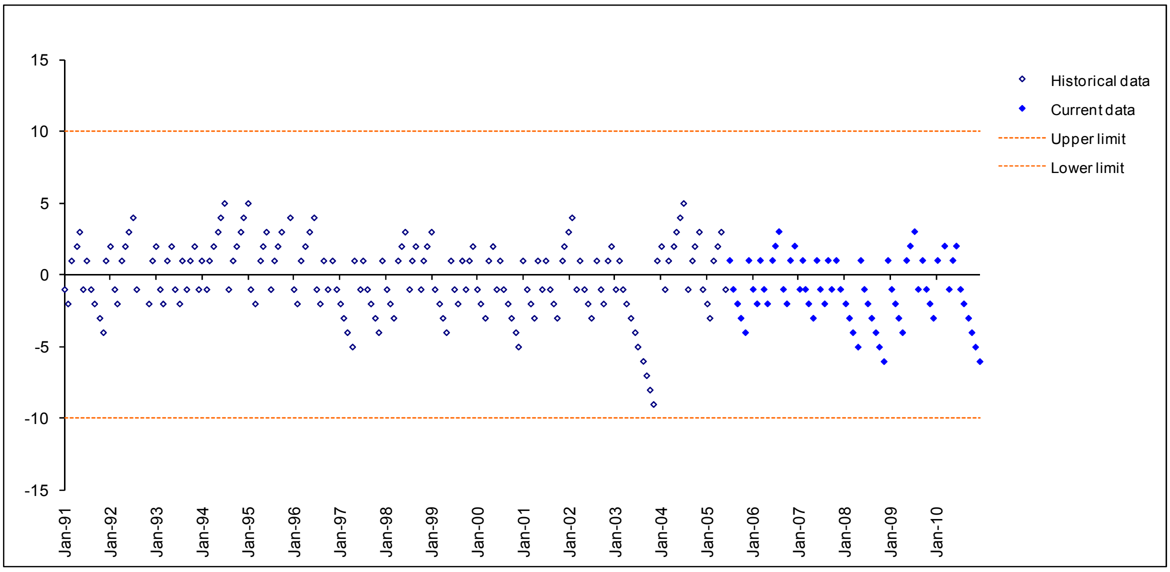


Figure 6-4: Control chart for dissolved oxygen (in % saturation) in the Gellibrand River @ Bunkers Hill

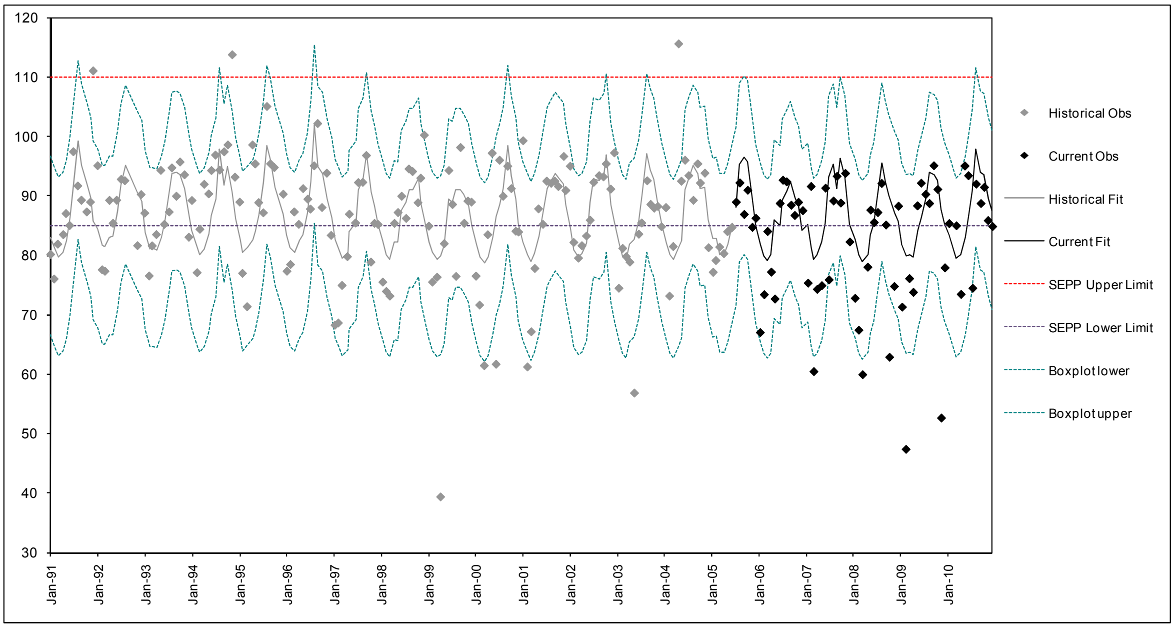
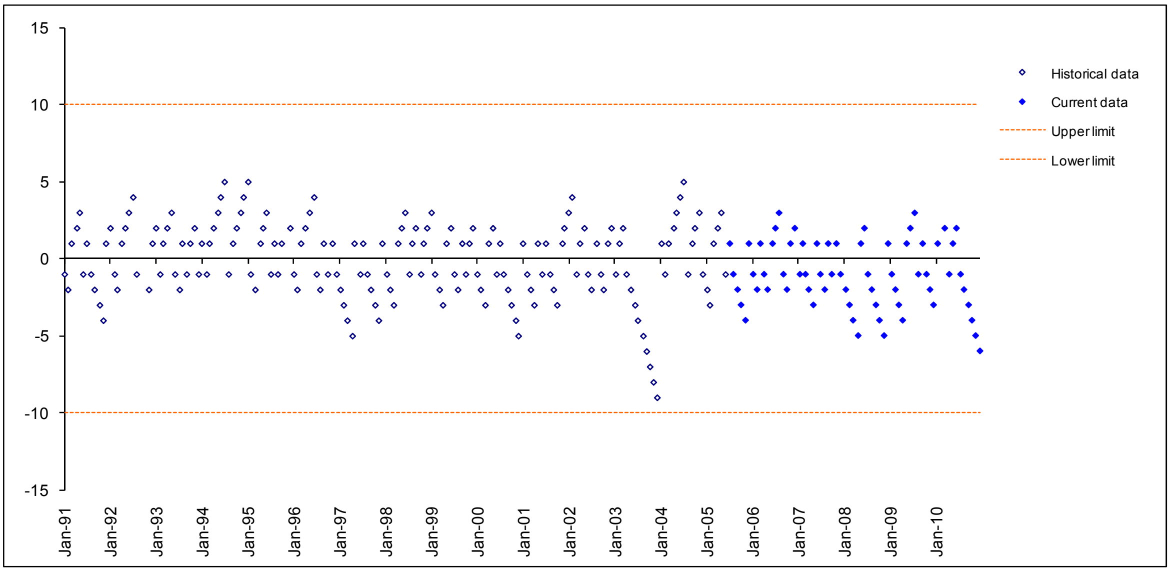


Figure 6-5: Run chart for dissolved oxygen (in % saturation) in the Gellibrand River @ Bunkers Hill



6.3.2. Turbidity

Variation in turbidity in the Gellibrand River @ Bunkers Hill between 1991 and 2005 was well explained by a combination of flow, water temperature and date (Table 6-5). Turbidity levels have generally increased since 2005 (Table 6-6) and there have been very long runs where the observed values were greater than the predicted values (Figure 6-7). Moreover there have been spikes in turbidity that are above the predicted fit and occasionally outside the upper limits of the model (Figure 6-6), which could be a trigger for further investigation, particularly since turbidity levels at this site also frequently exceed the State Environment Protection Policy (Waters of Victoria) trigger value of 5 NTU.

Table 6-5: Best fit regression model to describe variation in turbidity in the Barwon River @ Pollocksford between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R2)	Standard Error of Estimate (% of mean)
Turbidity	Turbidity0.4 = 3.7343 +(0.0277*Temp) – (0.0000601*Date) + (0.179*Flow0.4)	173	0.71	45%

Table 6-6: Summary statistics for historical (1991-2005) and current (2005 – 2010) turbidity data recorded in the Gellibrand River @ Bunker Hill

Parameter	Record	N	Mean	Median	Standard Deviation
Turbidity	Historical	162	9.96	6.55	8.25
	Current	44	14.44	7.85	14.08

Figure 6-6: Control chart for turbidity (in NTU) in the Gellibrand River @ Bunkers Hill 1991 – 2010

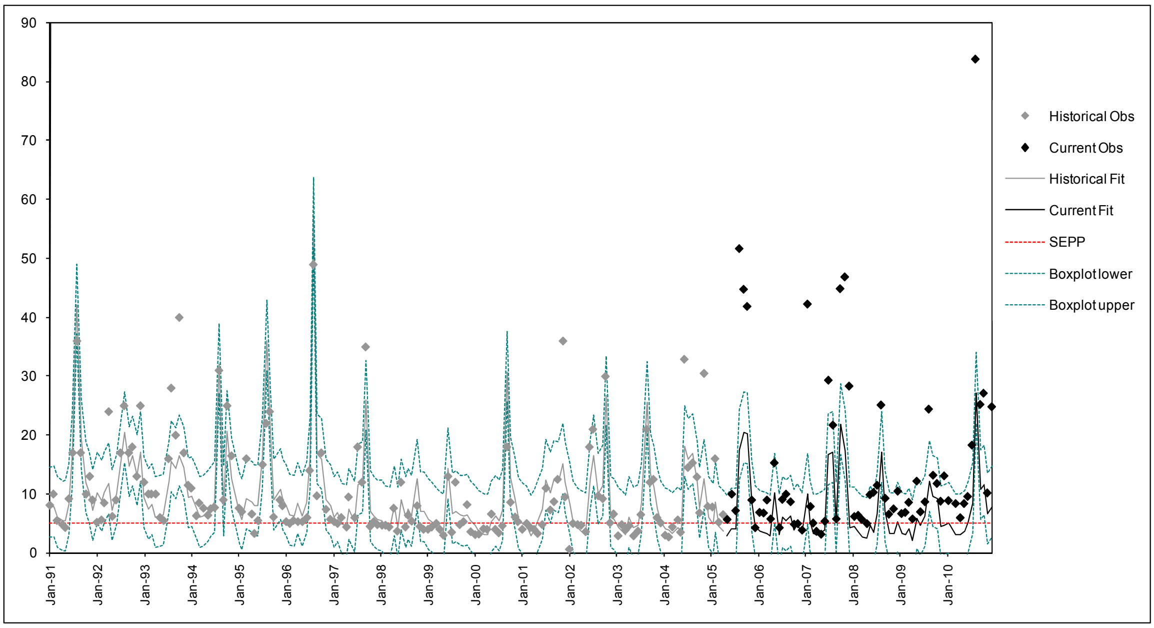
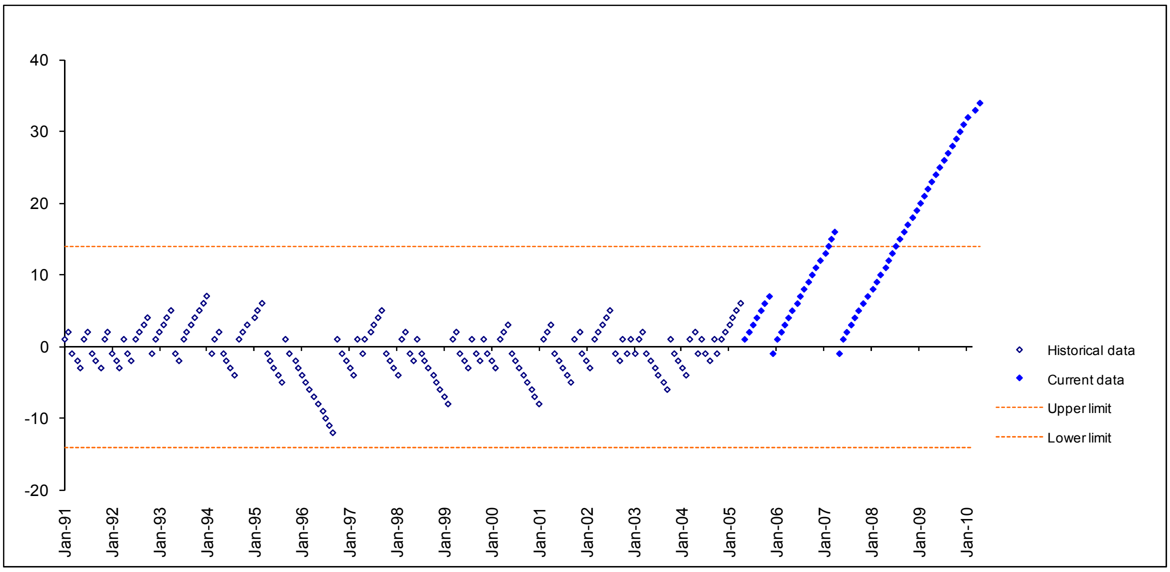


Figure 6-7: Run chart for turbidity (in NTU) in the Gellibrand River @ Bunkers Hill 1991 – 2010



6.3.3. Electrical conductivity

Variation in electrical conductivity in the Gellibrand River @ Bunkers Hill between 1991 and 2005 was reasonably well explained by a combination of season, water temperature, date and flow (Table 6-7). There has been little change in electrical conductivity at this site since 2005 (Table 6-8) and nearly all values are well predicted by the historical model (Figure 6-8). In 2005 and 2006 there was a long run of electrical conductivity records that were higher than the model predicted (Figure 6-9), but all values were well below the State Environment Protection Policy (Waters of Victoria) trigger value of ≤500 µS/cm and are therefore not likely to be of concern.

Table 6-7: Best fit regression model to describe variation in electrical conductivity in the Barwon River @ Pollocksford between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R2)	Standard Error of Estimate (% of mean)
Electrical conductivity (EC)	EC0.4 = 12.95+ (0.3825*Season) – (0.0595*Temp) – (0.0000535*Date) – (0.1202*Flow0.4)	173	0.5	16%

Table 6-8: Summary statistics for historical (1991-2005) and current (2005 – 2010) electrical conductivity data recorded in the Gellibrand River @ Bunker Hill

Parameter	Record	N	Mean	Median	Standard Deviation
Electrical conductivity	Historical	173	219.57	210	48.93
	Current	63	220.92	219	45.11

Figure 6-8: Control chart for electrical conductivity (in µS/cm) in the Gellibrand River @ Bunkers Hill 1991 – 2010

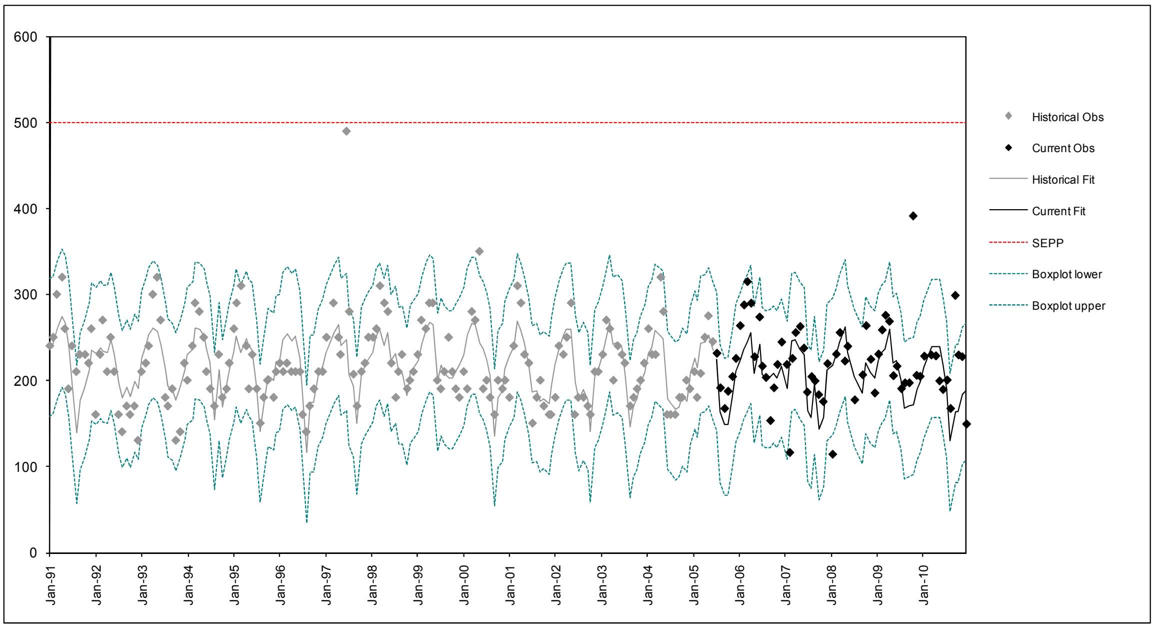
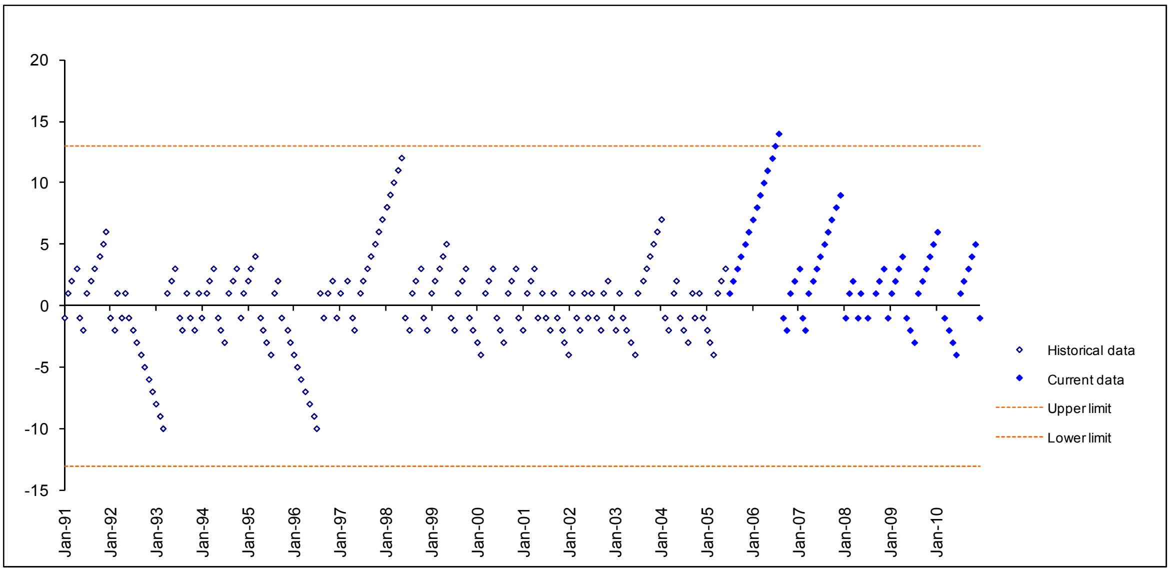


Figure 6-9: Run chart for electrical conductivity (in µS/cm) in the Gellibrand River @ Bunkers Hill 1991 – 2010.



6.3.4. pH

None of the predictor variables tested in the current project explained variation in pH at this site (best model fit had an R^2= 0.04 – see Table 6-9) and therefore the control chart presented in Figure 6-10 is no better than one based just on the historical median. Average and median pH levels at this site have increased since 2005 (Table 6-10). Most of those increases were between July 2005 and January 2008, and pH levels between 2008 and 2010 were relatively similar to those recorded prior to June 2005. pH levels above 7.5, and well above the range recorded between 1991 and 2005, have been recorded four times since 2006 (Figure 6-10). However, most records are generally within the State Environment Protection Policy (Waters of Victoria) trigger values of 6.4 (25th percentile lower limit) and 7.7 (75th percentile upper limit) (Figure 6-10 and Figure 6-11), and therefore pH is not likely to be a major concern.

Table 6-9: Best fit regression model to describe variation in pH in the Gellibrand River @ Bunkers Hill between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R2)	Standard Error of Estimate (% of mean)
pH	pH = 4.9949 +((0.0157*Temp) + (0.0000307Date)	165	0.04	5%

Table 6-10: Summary statistics for historical (1991-2005) and current (2005 – 2010) pH data recorded in the Gellibrand River @ Bunkers Hill

Parameter	Record	N	Mean	Median	Standard Deviation
pH	Historical	160	6.75	6.8	0.3435
	Current	57	6.98	6.9	0.3737

Figure 6-10: Control chart for pH in the Gellibrand River @ Bunkers Hill 1991 – 2010

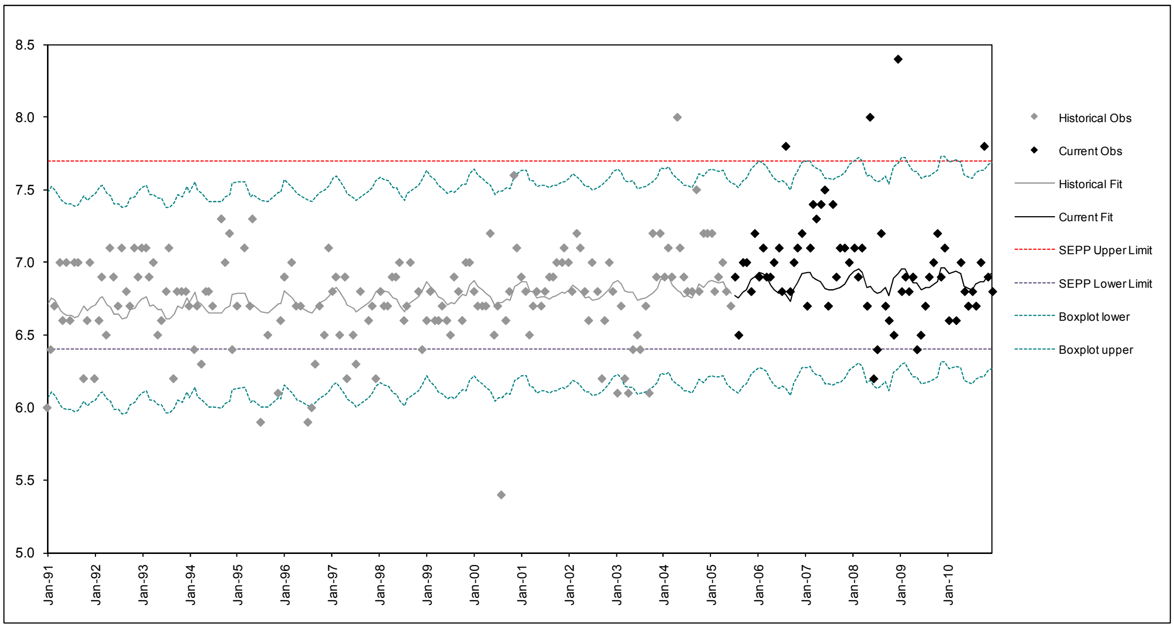
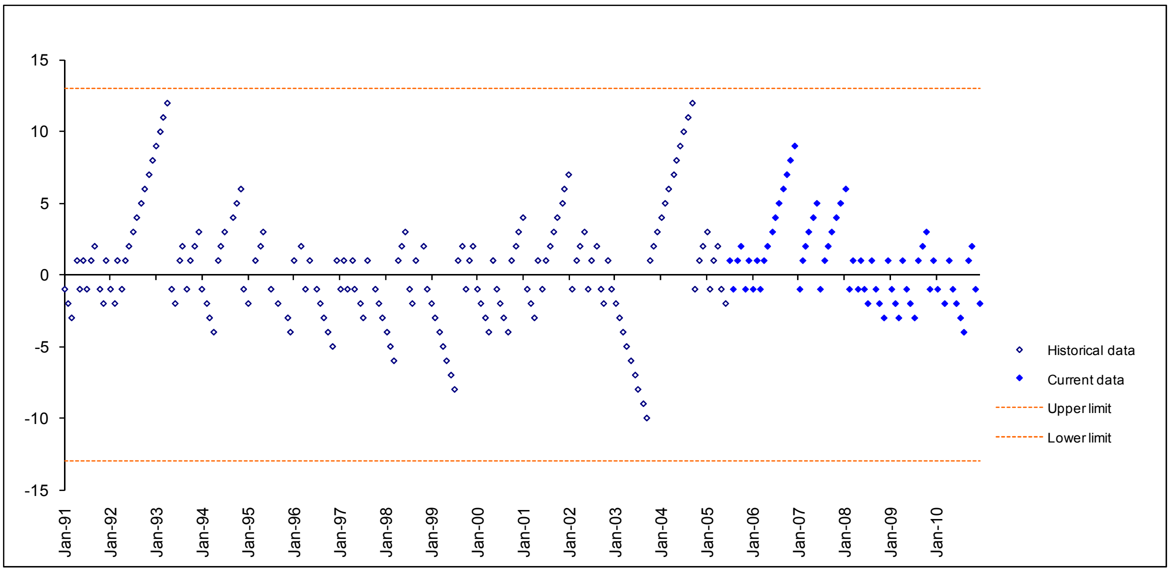


Figure 6-11: Run chart for pH in the Gellibrand River @ Bunkers Hill 1991 – 2010



6.3.5. Total nitrogen

Variation in total nitrogen in the Gellibrand River @ Bunkers Hill between 1991 and 2005 was reasonably well explained by a combination of season, flow and water temperature (Table 6-11). Total nitrogen levels since 2005 have been generally higher and more variable compared to the preceding 15 years (Table 6-12). Although there are no extended runs where the observed values exceed the predicted value (Figure 6-13), there were 10 occasions between 2006 and 2009 where total nitrogen levels were outside of the historical control and would warrant further investigation (Figure 6-12). Total nitrogen records frequently exceeded the State Environment Protection Policy (Waters of Victoria) trigger value of 0.350 mg/L, particularly after 2005 (Figure 6-12).

Table 6-11: Best fit regression model to describe variation in total nitrogen in the Barwon River @ Pollocksford between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R2)	Standard Error of Estimate (% of mean)
Total nitrogen (TN)	TN0.4 = 0.5514 – (0.0656*Season)– (0.0149*Temp) + (0.0236*Flow0.4)	169	0.5	56%

Table 6-12: Summary statistics for historical (1991-2005) and current (2005 – 2010) total nitrogen data recorded in the Gellibrand River @ Bunker Hill

Parameter	Record	N	Mean	Median	Standard Deviation
Total nitrogen	Historical	169	0.269	0.25	0.201
	Current	61	0.378	0.30	0.354

Figure 6-12: Control chart for total nitrogen (in mg/L) in the Gellibrand River @ Bunkers Hill 1991 – 2010

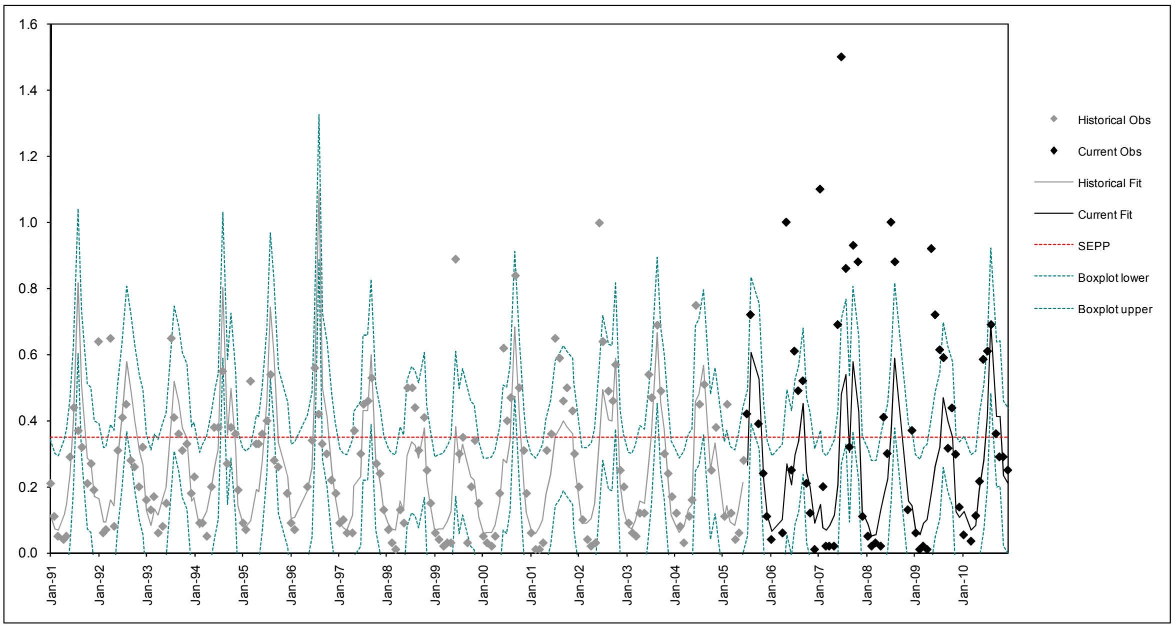
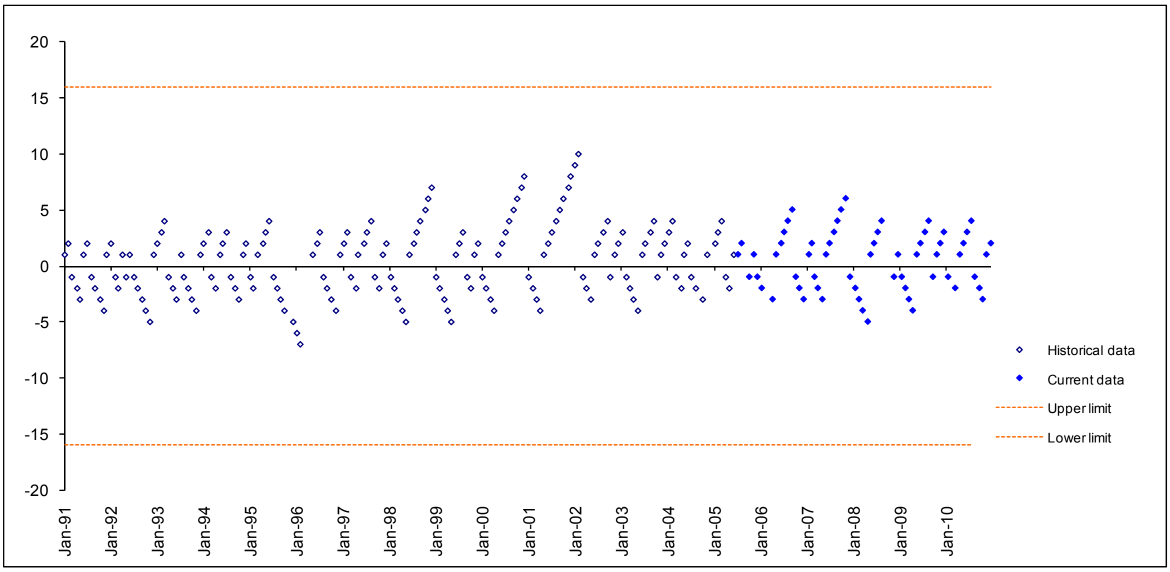


Figure 6-13: Run chart for total nitrogen (in mg/L) in the Gellibrand River @ Bunkers Hill 1991 – 2010



6.3.6. Total phosphorus

Variation in total phosphorus levels in the Gellibrand River @ Bunkers Hill between 1991 and 2005 was only moderately well explained by date, season, flow and water temperature (Table 6-13). The regression model was not very good at describing moderate or very high values in the period between January 1991 and June 2005 (Figure 6-14). Average and median total phosphorus levels at this site were lower after 2005, although variation remained similar (Table 6-14). The lower total phosphorus records after 2005 show up well in the run chart (Figure 6-15). However, all of the total phosphorus readings taken since 2005 were within control of the model and are consistent with historical records. Total phosphorus concentrations at this site vary between 0.02 mg/L and 0.05 mg/L, with occasional spikes during high flow conditions, and are generally above the State Environment Protection Policy (Waters of Victoria) trigger value of 0.025 mg/L.

Table 6-13: Best fit regression model to describe variation in total phosphorus in the Barwon River @ Pollocksford between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Total phosphorus (TP)	TP0.4 = –0.1551 – (0.021*Season) + (0.00549*Temp) + (0.00000513*Date) + (0.0127*Flow0.4)	172	0.31	53%

Table 6-14: Summary statistics for historical (1991-2005) and current (2005 – 2010) total phosphorus data recorded in the Gellibrand River @ Bunker Hill

Parameter	Record	N	Mean	Median	Standard Deviation
Total phosphorus	Historical	172	0.041	0.04	0.025
	Current	58	0.033	0.03	0.022

Figure 6-14: Control chart for total phosphorus (in mg/L) in the Gellibrand River @ Bunkers Hill 1991 – 2010

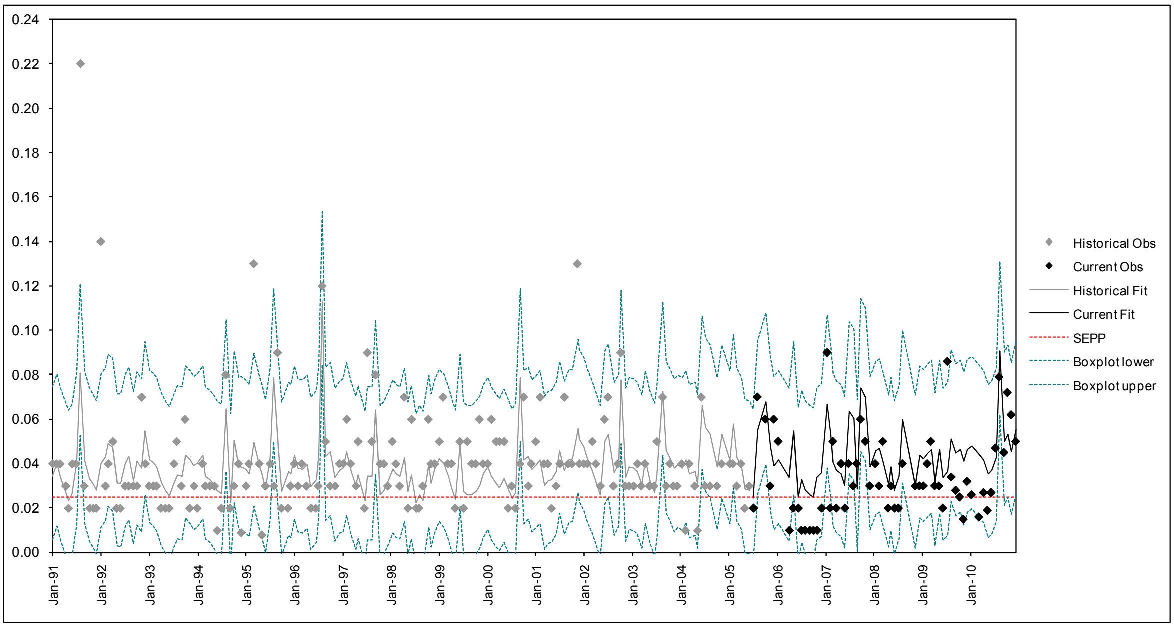
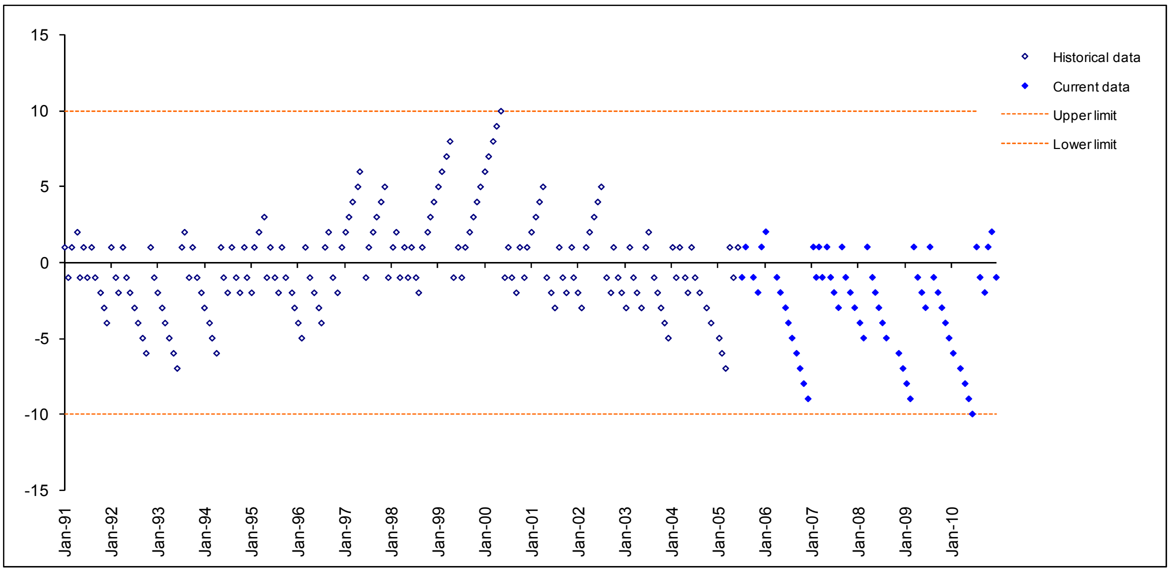


Figure 6-15: Run chart for total phosphorus (in mg/L) in the Gellibrand River @ Bunkers Hill 1991 – 2010

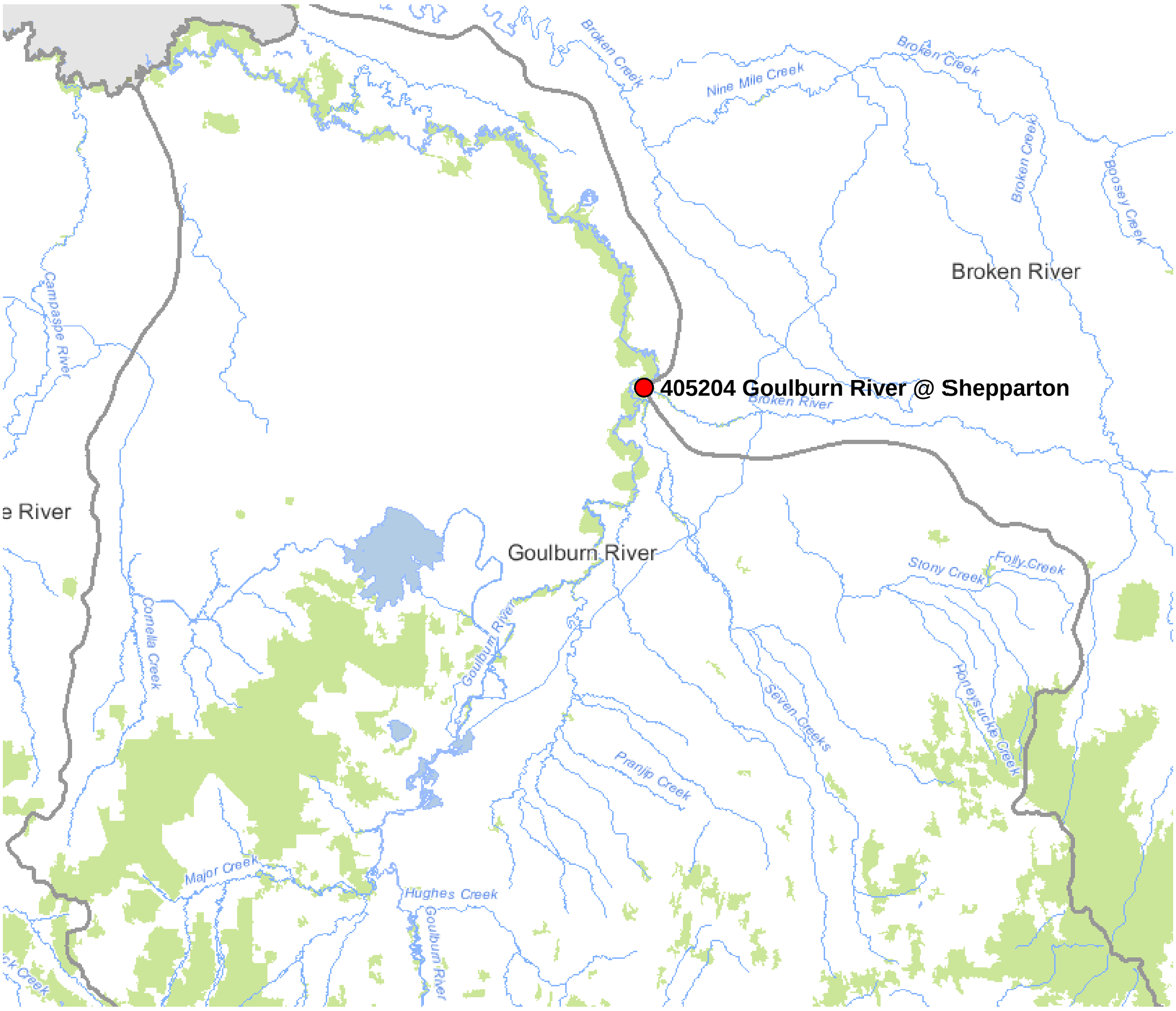


7. Results for 405204 Goulburn River @ Shepparton

7.1. Site Location

The Goulburn River @ Shepparton (streamflow gauge number 405204) is located immediately downstream of the Broken River. The location is shown in Figure 7-1. The Goulburn Broken CMA nominated the site as being of interest from a water quality perspective.

Figure 7-1: Locality map for Goulburn River @ Shepparton



7.2. Data availability and quality

Water quality at this site was sampled on 174 occasions between January 1991 and June 2005. The number of missing water quality data, missing temperature data or missing flow data is listed in Table 7-1, which indicates that 11 points were not included in the regression analysis. There are no outliers in the dataset.

Table 7-1: Missing data over period of regression model fit (Jan 1991 – Jun 2005)

Missing data elements	Dissolved oxygen	Turbidity	Electrical conductivity	pH	Total nitrogen	Total phosphorus
No. of missing water quality readings on days when at least on other parameter was recorded	0	1	0	2	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	0	0
No. of data points not analysed due to missing or incorrect flow data	11	11	11	11	11	11
Sample size for regression analysis	163	162	163	161	161	161

There were a total of 66 occasions on which water quality data had been sampled over the period of control chart application from July 2005 to December 2010. The number of missing data points due to missing water quality data, missing temperature data or missing flow data is listed in Table 7-2, which indicates that very few data points were missing for individual parameters, and again a small number of zero flow values are present.

Table 7-2: Missing data over period of control chart application (Jul 2005 – 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 on other parameter was recorded	1	1	1	1	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	1	1
No. of data points not analysed due to missing flow data	0	0	0	0	0	0
No. of data points with erroneous flow data	4	4	4	4	4	4
Sample size for control chart application	65	65	65	65	63	63

7.3. Results for each water quality variable

7.3.1. Dissolved oxygen

Variation in dissolved oxygen (mg/L) levels in the Goulburn River @ Shepparton between 1991 and 2005 was relatively well explained by a combination of water temperature and date (R^2 = 0.50; Table 7-3). Dissolved oxygen levels declined from 1991 to 2005, which is the reason why date was a significant predictor variable for the model (Figure 7-2). Since 2005, the observed dissolved oxygen levels have been consistently above those predicted by the model (Figure 7-3). This indicates that the declining trend in dissolved oxygen has been arrested somewhat. This may be from fresh inter-valley transfers from Lake Eildon into this reach since 2005 (Pat Feehan, *personal communication*, 1/5/12). Average dissolved oxygen levels were slightly lower after 2005 compared to the historical period (Table 7-4), but were all inside the model limits (Figure 7-2).

The percent saturation of dissolved oxygen was best explained by the factors temperature and date, but the fit (R^2 = 0.32) was not as good as the model for absolute dissolved oxygen (Table 7-3). The inclusion of temperature in the model means that temperature-dependent rates of primary production and community respiration are potentially driving dissolved oxygen dynamics. The control chart for percent saturation of dissolved oxygen shows many points below the lower SEPP trigger value of 85%, particularly after January 1995 (Figure 7-4). However, all values are within the model limits (Figure 7-4). As for absolute dissolved oxygen concentrations, percent saturation levels have been consistently above those predicted by the model since 2005 (Figure 7-5).

Table 7-3: Best fit regression models to describe variation in dissolved oxygen in the Goulburn River @ Shepparton between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Dissolved oxygen (DO) [mg/L]	DO= 20.2075 – (0.2314*Temp) – (0.000016*Date)	172	0.50	10%
Dissolved oxygen (DO) [% saturation]	DO= 177.3719 –(0.6482*Temp) – (0.001645*Date)	172	0.25	10%

Table 7-4: Summary statistics for historical (1991-2005) and current (2005 – 2010) dissolved oxygen data recorded in the Goulburn River @ Shepparton

Parameter	Record	N	Mean	Median	Standard Deviation
Dissolved oxygen mg/L	Historical	174	8.18	8.2	1.559
	Current	65	8.07	8	1.514
Dissolved oxygen % Sat	Historical	174	82.76	82.52	9.24
	Current	65	81.97	82.40	9.78

Figure 7-2: Control chart for dissolved oxygen (in mg/L) in the Goulburn River @ Shepparton 1991 – 2010

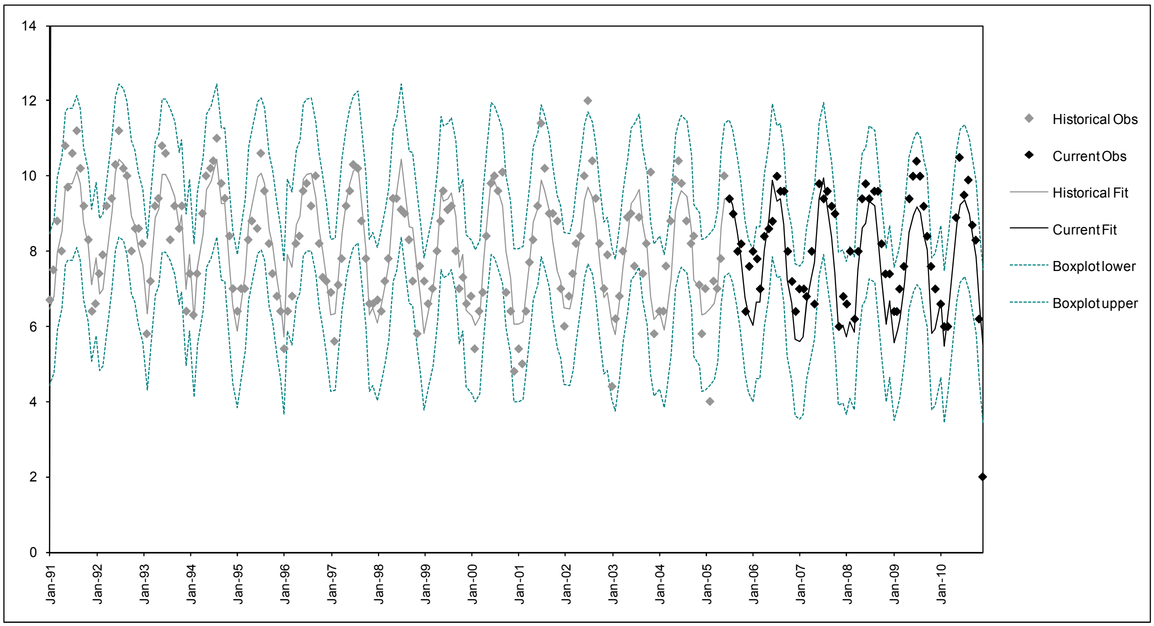


Figure 7-3: Run chart for dissolved oxygen (in mg/L) in the Goulburn River @ Shepparton 1991 – 2010

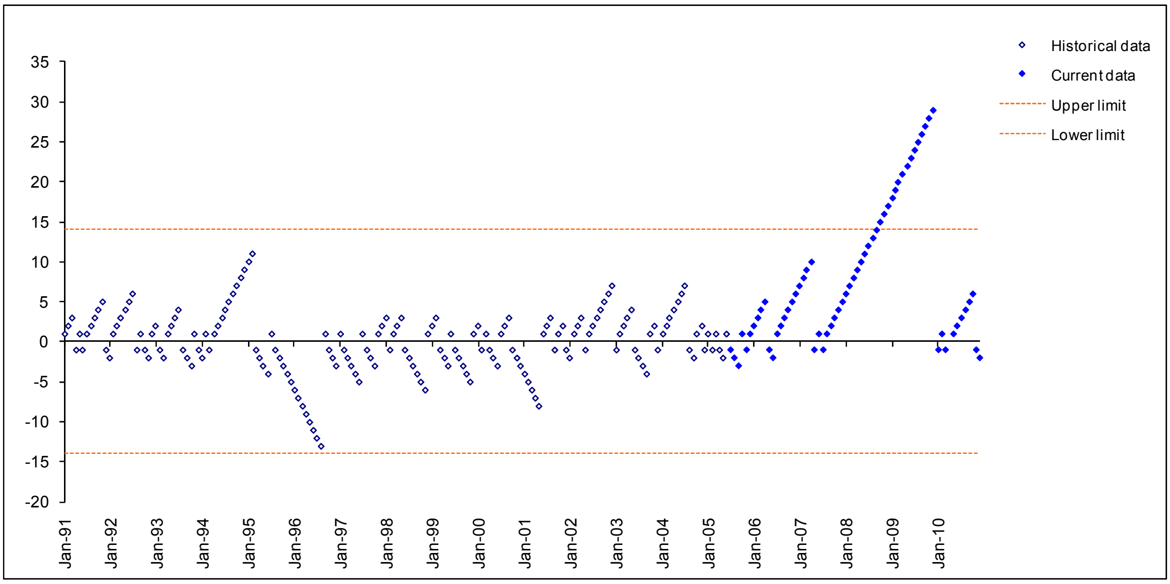


Figure 7-4: Control chart for dissolved oxygen (in % saturation) in the Goulburn River @ Shepparton 1991 – 2010

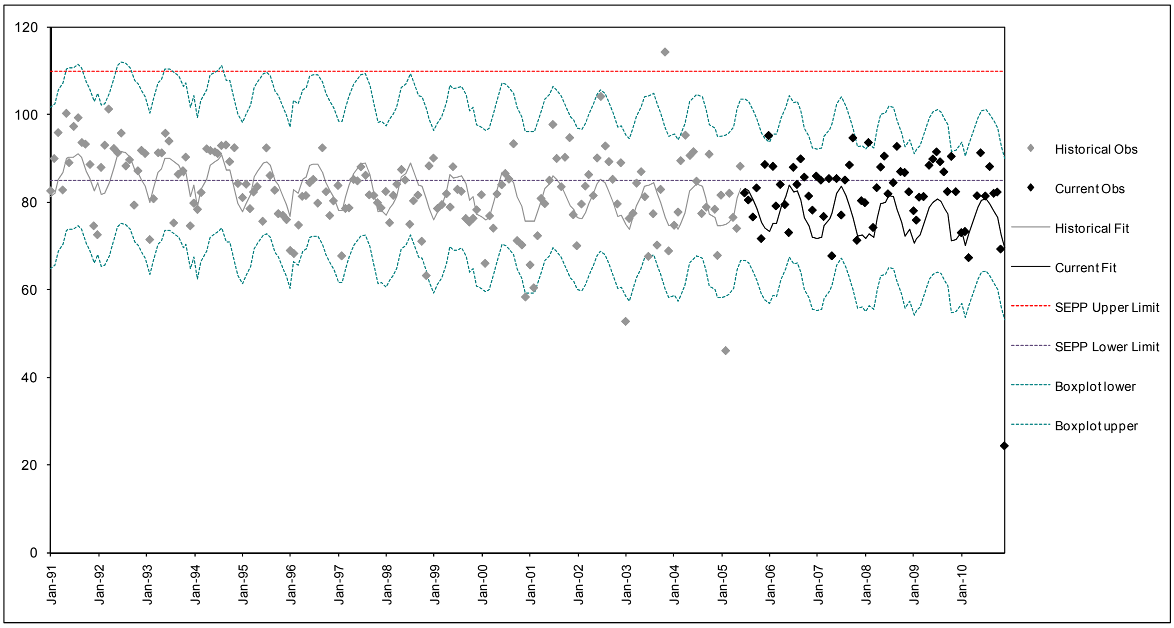
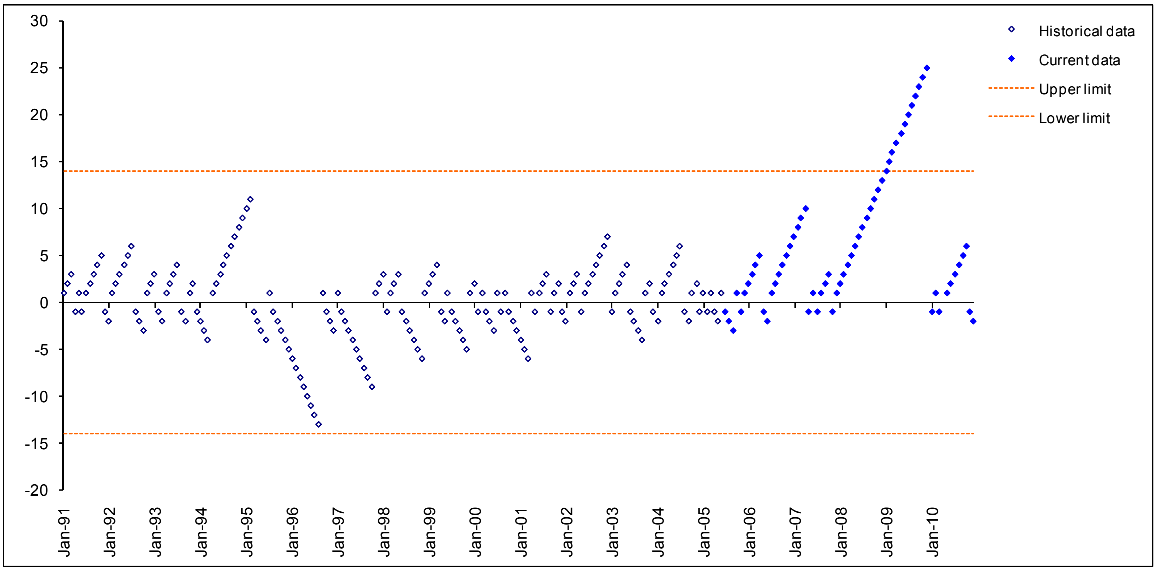


Figure 7-5: Run chart for dissolved oxygen (in % saturation) in the Goulburn River @ Shepparton 1991 – 2010



7.3.2. Turbidity

Variation in turbidity in the Goulburn River @ Shepparton between 1991 and 2005 was partly explained by a combination of flow, season and date (Table 7-5). Turbidity levels since 2005 have been similar to historical patterns (Table 7-6) and the observed values match the predicted values (Figure 7-7). The observed data are within the limits of the model, except on one occasion (Figure 7-6). That high observation could be a trigger for further investigation particularly since turbidity levels at this site frequently exceed the State Environment Protection Policy (Waters of Victoria) trigger value of 30 NTU.

Table 7-5: Best fit regression models to describe variation in turbidity in the Goulburn River @ Shepparton between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Turbidity	Turbidity0.4 = –1.0674 – (0.4*Season) + (0.0000898*Date) + (0.023*Flow0.4)	162	0.22	59%

Table 7-6: Summary statistics for historical (1991-2005) and current (2005 – 2010) turbidity data recorded in the in the Goulburn River @ Shepparton

Parameter	Record	N	Mean	Median	Standard Deviation
Turbidity	Historical	163	32.62	27	23.780
	Current	61	33.75	28.2	21.085

Figure 7-6: Control chart for turbidity (in NTU) in the Goulburn River @ Shepparton 1991 – 2010

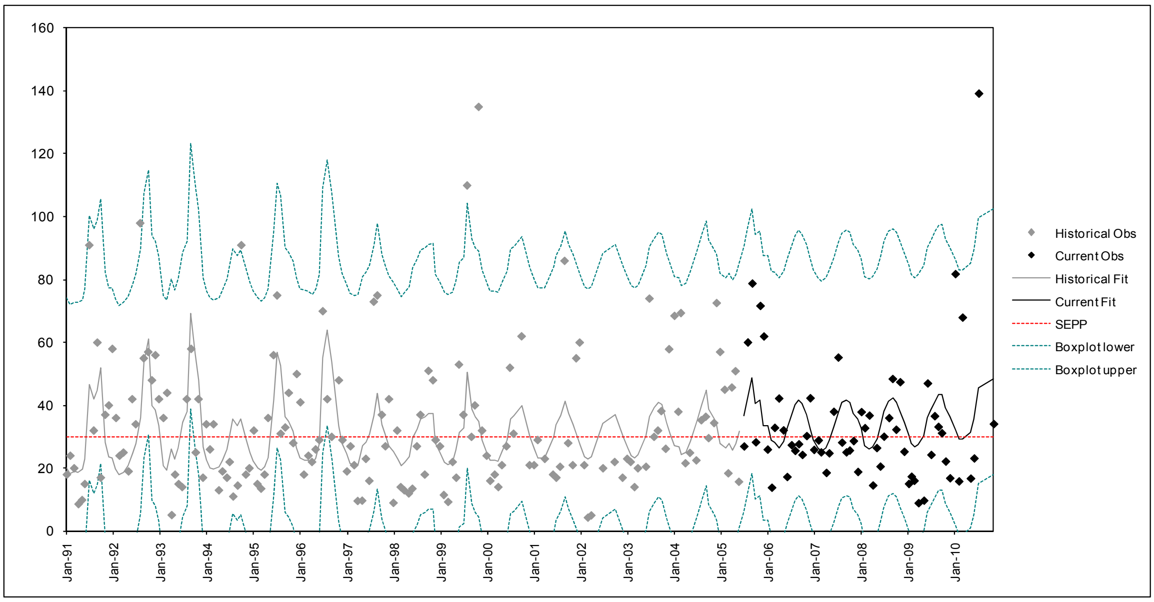
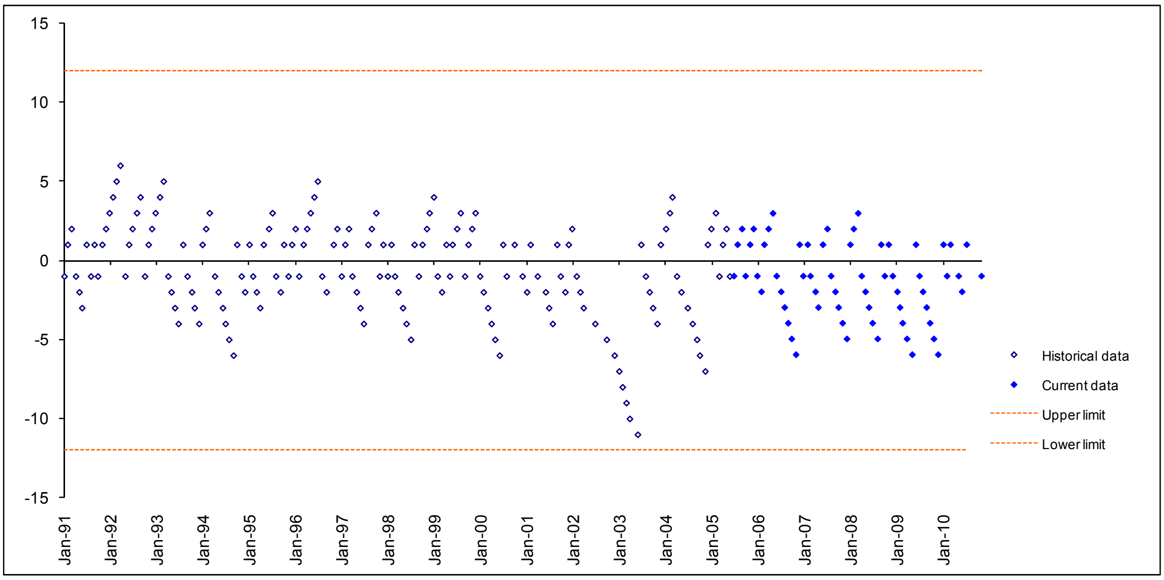


Figure 7-7: Run chart for turbidity (in NTU) in the Goulburn River @ Shepparton 1991 – 2010



7.3.3. Electrical conductivity

Variation in electrical conductivity in the Goulburn River @ Shepparton between 1991 and 2005 was moderately well explained by a combination of season, date and flow (Table 7-7). Average electrical conductivity levels were lower after 2005 compared to the historical period (Table 7-8). This is possibly attributed to a combination of lower saline groundwater tables due to the drought and fresh inter-valley transfers from Lake Eildon (Pat Feehan, *personal communication*, 1/5/12). The model predicted a decline in electrical conductivity levels for the last five years, but the observed data were further below the modelled fit (Figure 7-9). Electrical conductivity at this site is within the control limits on the control chart and is well below the State Environment Protection Policy (Waters of Victoria) trigger value of 500 µS/cm (Figure 7-8). It is therefore not considered a threat to aquatic ecosystems or other beneficial uses of the waterway.

Table 7-7: Best fit regression models to describe variation in electrical conductivity in the Goulburn River @ Shepparton between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Electrical conductivity (EC)	EC0.4 = 17.7729– (0.5009*Season) – (0.000175*Date) – (0.052*Flow0.4)	163	0.44	21%

Table 7-8: Summary statistics for historical (1991-2005) and current (2005 – 2010) electrical conductivity data recorded in the in the Goulburn River @ Shepparton

Parameter	Record	N	Mean	Median	Standard Deviation
Electrical conductivity (µS/cm)	Historical	163	179.83	180	48.33
	Current	61	129.07	130	31.68

Figure 7-8: Control chart for electrical conductivity (in µS/cm) in the Goulburn River @ Shepparton 1991 – 2010

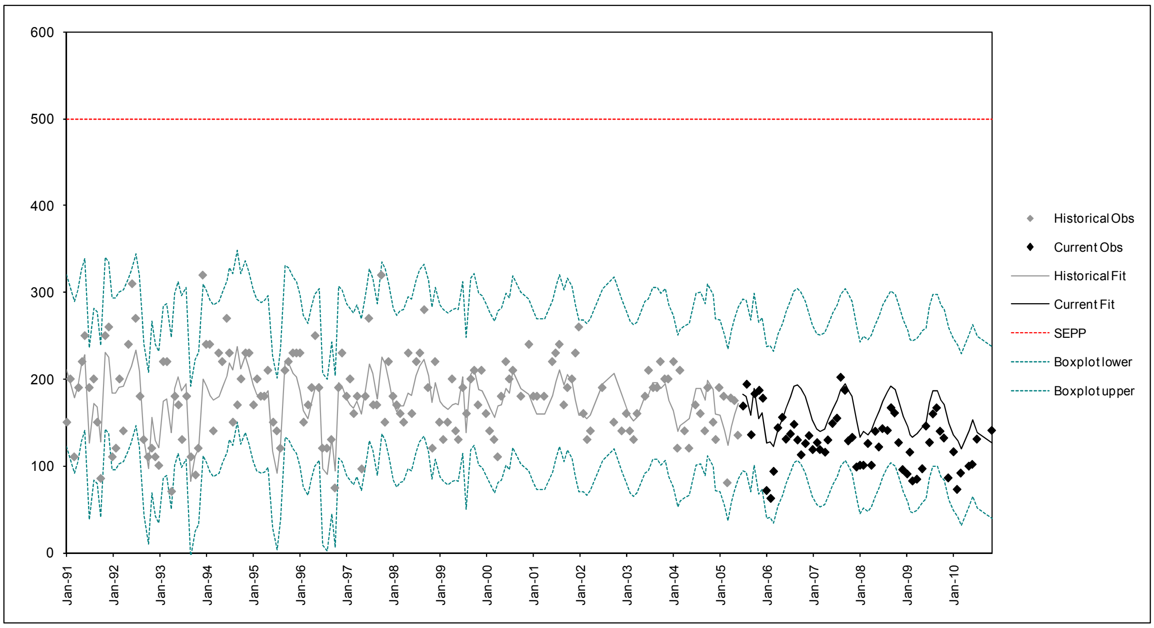
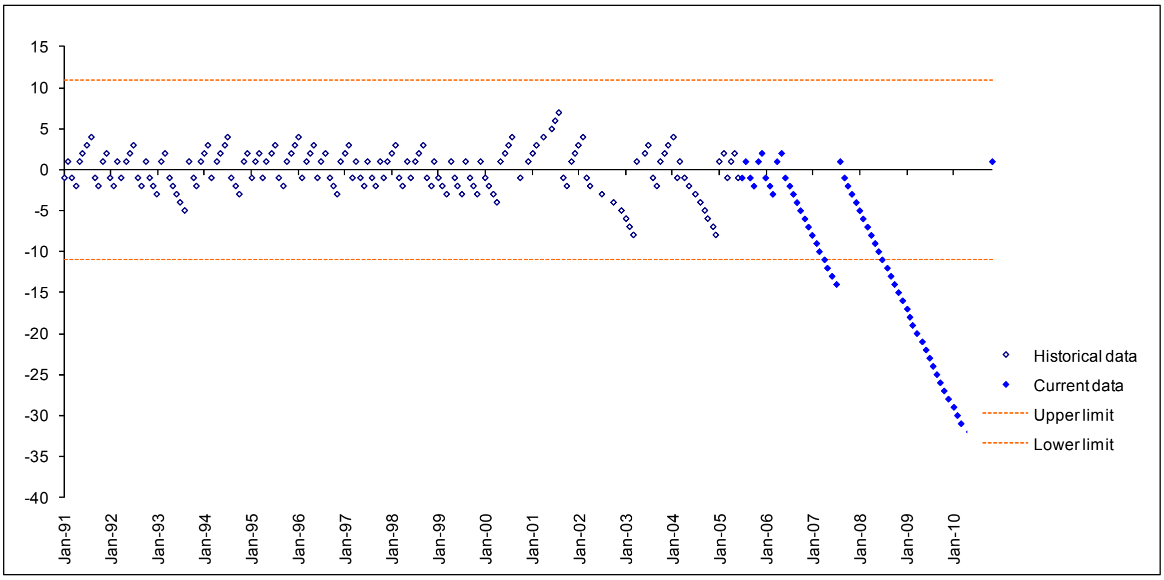


Figure 7-9: Run chart for electrical conductivity (in µS/cm) in the Goulburn River @ Shepparton 1991 – 2010



7.3.4. pH

None of the predictor variables tested in the current project explained variation in pH at this site (best model fit had an R^2= 0.09 – see Table 7-9) and therefore the control chart presented in Figure 7-10 is no better than one based just on the historical median. pH levels at this site increased between 1991 and 2005, and that trend continued after 2005 (Table 7-10; Figure 7-10; Figure 7-11). The reasons for the general increase in pH may be similar to those described for electrical conductivity (i.e. changes to groundwater levels and inter-valley transfer flows). pH levels at this site were within the model control limits and nearly all records since January 1999 lie within the lower and upper State Environment Protection Policy (Waters of Victoria) trigger values of 6.4 and 7.7 (Figure 7-10). For these reasons, we conclude that pH is not likely to be a major concern at this site. However, it will be worth monitoring the upward trend in pH to ensure that conditions do not become too alkaline.

Table 7-9: Best fit regression models to describe variation in pH in the Goulburn River @ Shepparton between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
pH	pH0.4= 1.8712 + (0.000005799*Date) - (0.0005198*Flow0.4)	161	0.09	5%

Table 7-10: Summary statistics for historical (1991-2005) and current (2005 – 2010) pH data recorded in the in the Goulburn River @ Shepparton

Parameter	Record	N	Mean	Median	Standard Deviation
pH	Historical	161	6.83	6.9	0.3312
	Current	61	7.03	7.0	0.2434

Figure 7-10: Control chart for pH (in pH units) in the Goulburn River @ Shepparton 1991 – 2010

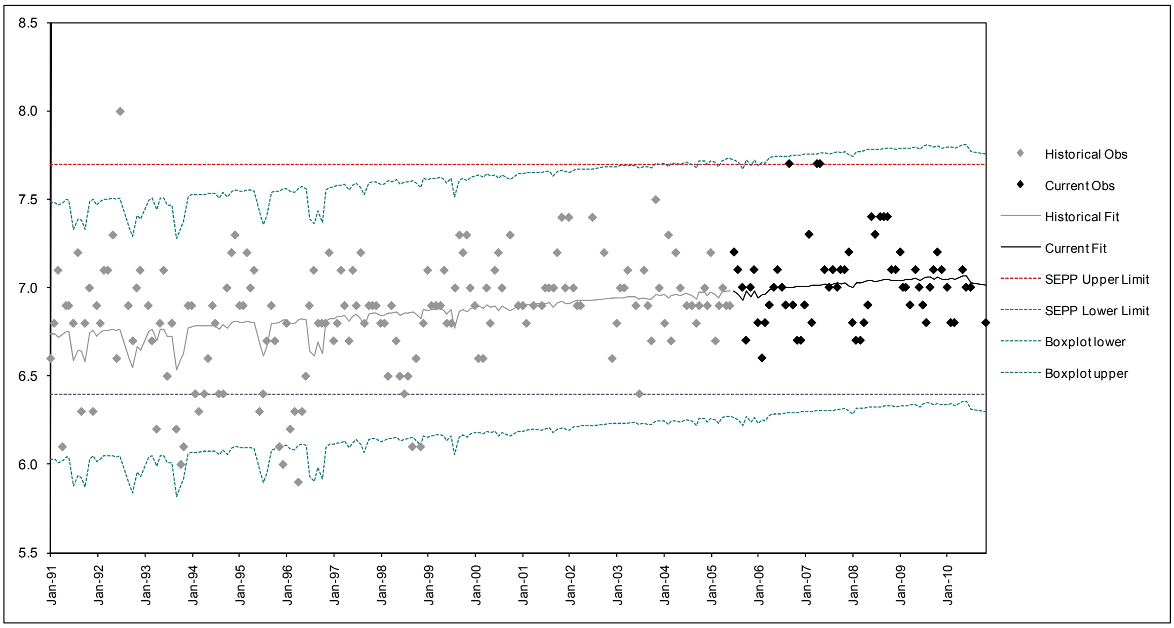
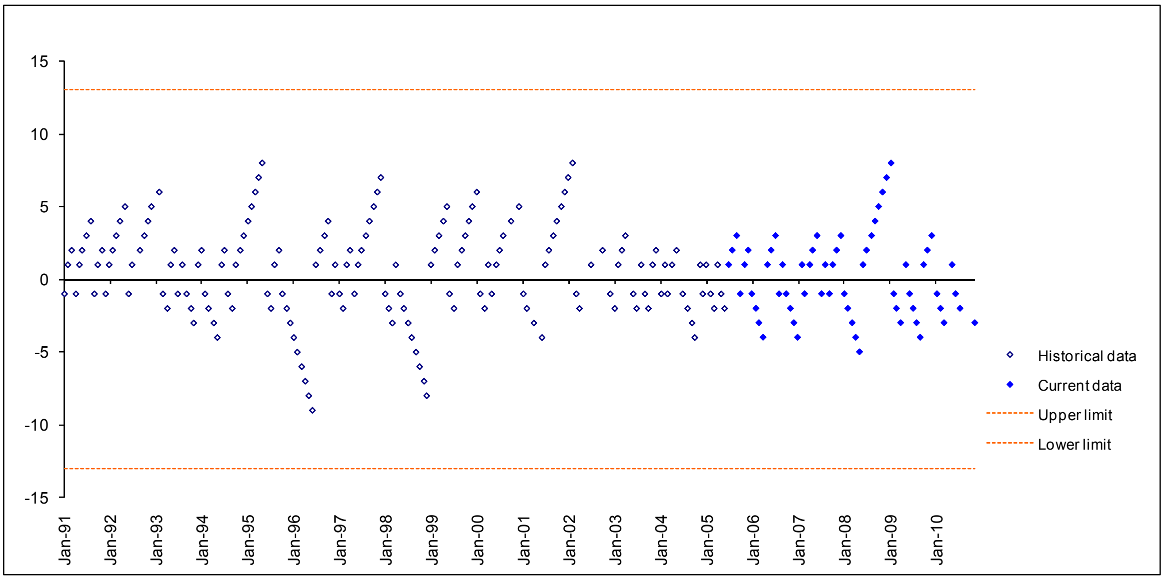


Figure 7-11: Run chart for pH (in pH units) in the Goulburn River @ Shepparton 1991 – 2010



7.3.5. Total nitrogen

Variation in total nitrogen in the Goulburn River @ Shepparton between 1996 and 2005 was reasonably well explained by a combination of season, water temperature, flow and time since rainfall (Table 7-11). The explanatory variable 'time since rainfall' (i.e. time since last rain event in which more than 20 mm of rain fell) indicates that run-off from urban stormwater and/or irrigation drains are drivers of total nitrogen levels at this site. Rainfall data were taken from the Shepparton Airport rainfall gauge operated by the Bureau of Meteorology (site 081125). Total nitrogen levels since 2005 have been generally lower compared to the preceding 15 years (Table 7-12). Although there are no extended runs where the observed values exceed the predicted value (Figure 7-13), there were two occasions between 2006 and 2009 where total nitrogen levels were outside of the historical control limits and would warrant further investigation (Figure 7-12). The total nitrogen levels are well below the State Environment Protection Policy (Waters of Victoria) trigger value of 0.900 mg/L.

Table 7-11: Best fit regression models to describe variation in total nitrogen in the Goulburn River @ Shepparton between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Total nitrogen (TN)	TN0.4 = 0.5998 – (0.1377*Season) – (0.014*Temp) + (0.004946*Flow0.4) – (0.0003567*TimeSinceRain)	92	0.57	74%

Table 7-12: Summary statistics for historical (1991-2005) and current (2005 – 2010) total nitrogen data recorded in the in the Goulburn River @ Shepparton

Parameter	Record	N	Mean	Median	Standard Deviation
Total nitrogen (mg/L)	Historical	91	0.146	0.10	0.1538
	Current	60	0.122	0.08	0.1439

Figure 7-12: Control chart for total nitrogen (in mg/L) in the Goulburn River @ Shepparton 1991 – 2010

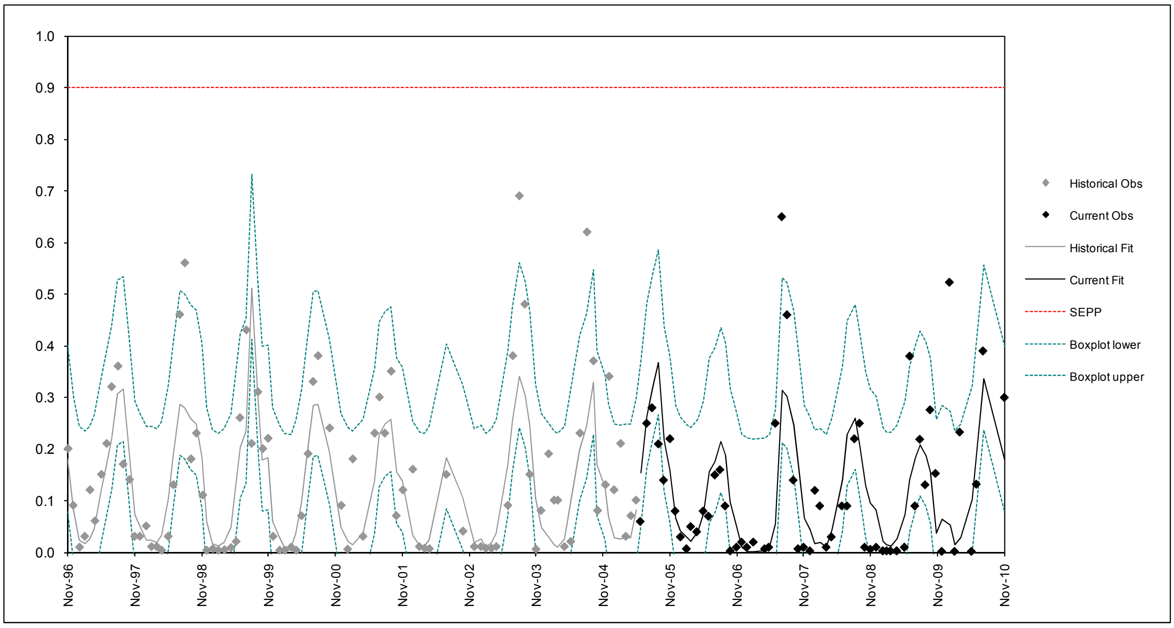
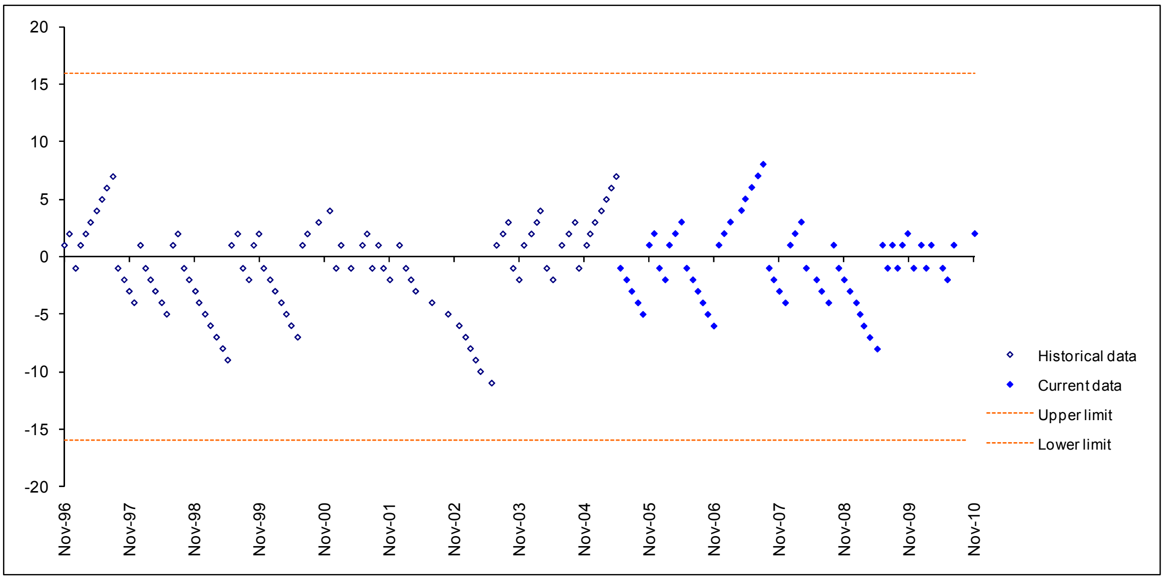


Figure 7-13: Run chart for total nitrogen (in mg/L) in the Goulburn River @ Shepparton 1991 – 2010



7.3.6. Total phosphorus

Variation in total phosphorus levels in the Goulburn River @ Shepparton between 1996 and 2005 was well explained by flow, turbidity and rainfall (Table 7-13). As with the total nitrogen analysis, rainfall data were taken from the Shepparton Airport rainfall gauge operated by the Bureau of Meteorology (site 081125). Average and median total phosphorus levels at this site were significantly lower after 2005 (Table 7-14). The lower total phosphorus records are highlighted in the run chart, which shows relatively long runs of consecutive values less than the predicted value (Figure 7-15). However, all of the total phosphorus readings taken since 2005 were just within the control limits of the model (Figure 7-15). The observed decline in total phosphorus since 2005 in the Goulburn River @ Shepparton is attributed to the drought and inter-valley transfers from Lake Eildon into this reach (Pat Feehan, *personal communication*, 1/5/12). Prior to 2005, total phosphorus levels at this site frequently exceeded the State Environment Protection Policy (Waters of Victoria) trigger value of 0.045mg/L, but most readings since 2006 have been below that trigger value (Figure 7-14). To assist future management actions at this site, the regression model could be updated to account for the recent decline in total phosphorus levels.

Table 7-13: Best fit regression models to describe variation in total phosphorus in the Goulburn River @ Shepparton between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Total phosphorus (TP)	TP0.4 = 0.1219 + (0.001254*Flow0.4) + (0.0528*Turbidity0.4) – (0.00003275*Rainfall)	89	0.60	37%

Table 7-14: Summary statistics for historical (1991-2005) and current (2005 – 2010) total phosphorus data recorded in the in the Goulburn River @ Shepparton

Perameter	Record	N	Mean	Median	Standard Deviation
Total phosphorus (mg/L)	Historical	89	0.077	0.07	0.0427
	Current	59	0.044	0.04	0.033

Figure 7-14: Control chart for total phosphorus (in mg/L) in the Goulburn River @ Shepparton 1991 – 2010

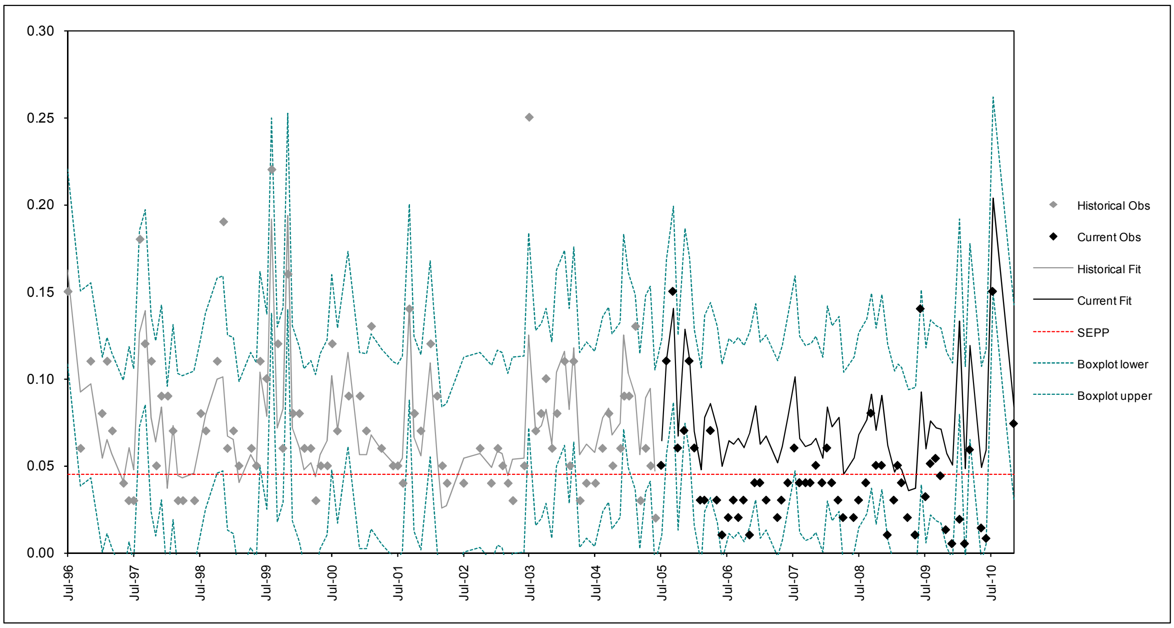
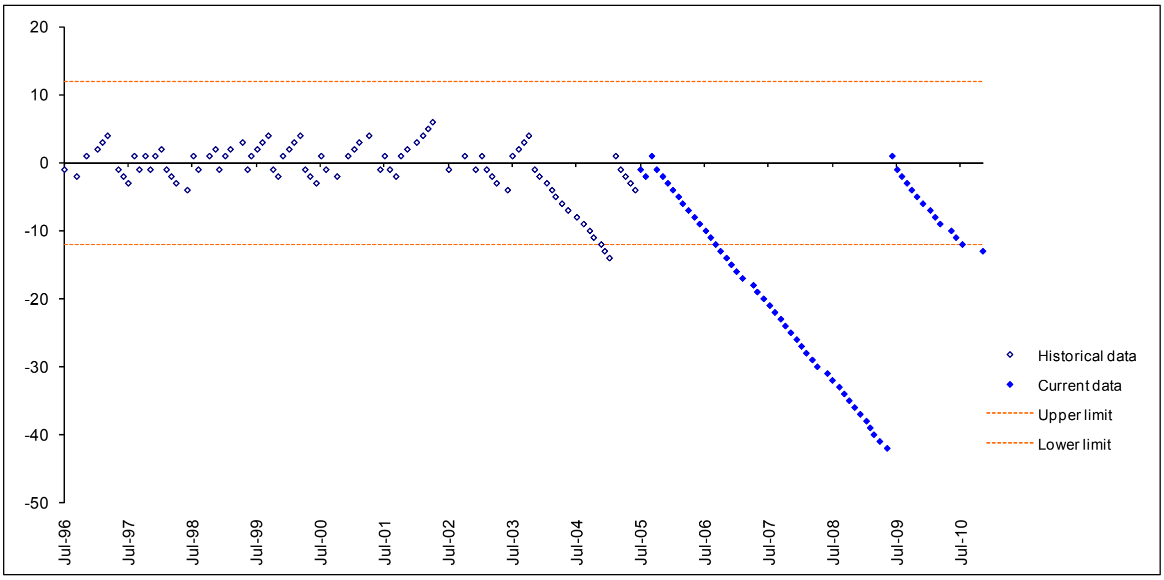


Figure 7-15: Run chart for total phosphorus (in mg/L) in the Goulburn River @ Shepparton 1991 – 2010



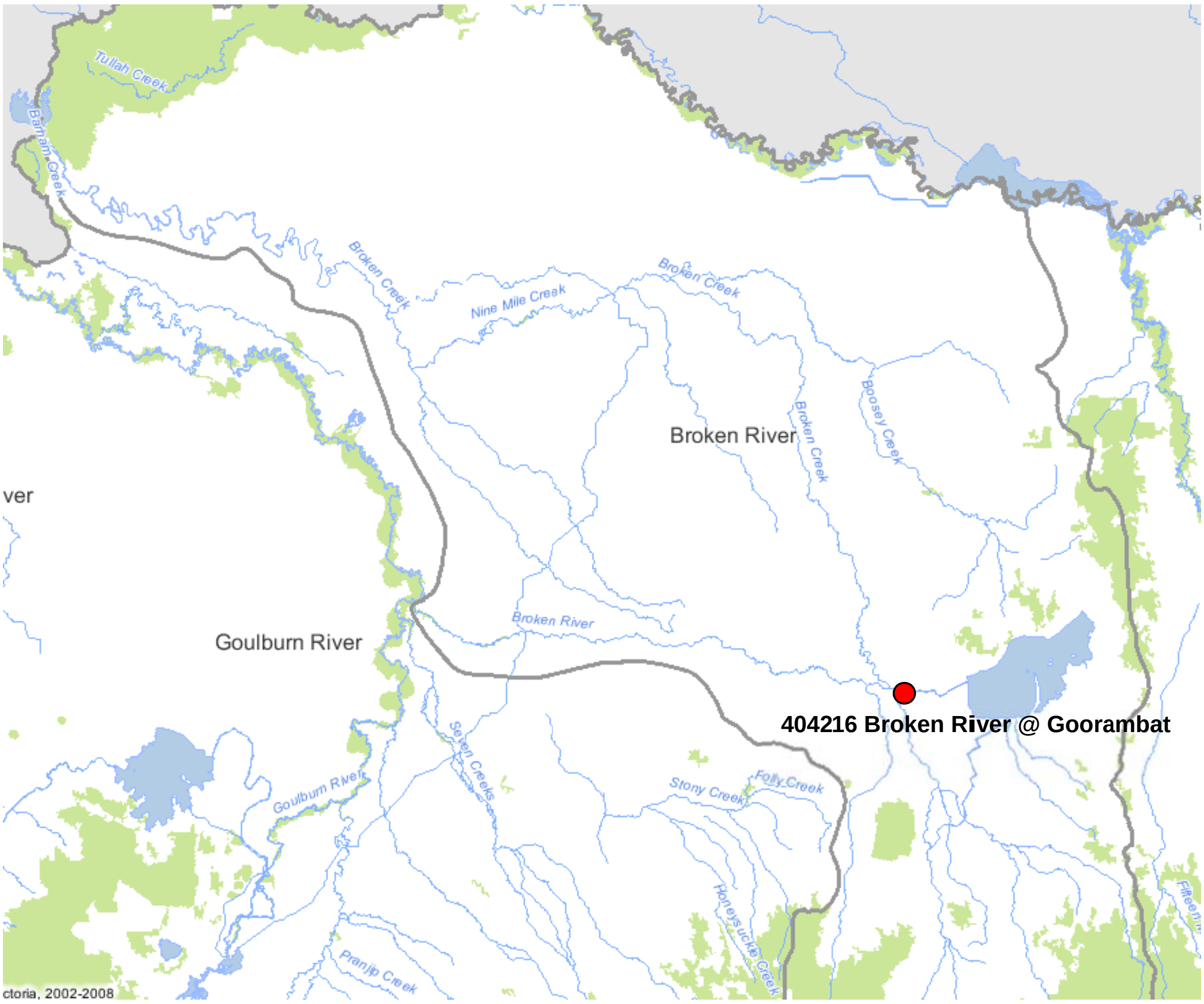
8. Results for 404216 Broken River @ Goorambat

8.1. 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 8-1). Flow and water quality at this site 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 @ 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 @ 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. We have addressed these issues 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.

Figure 8-1: Locality map for Broken River @ Goorambat



8.2. Data availability and quality

Water quality was monitored on 174 occasions between January 1991 and June 2005. All of the six target water quality variables were measured on most occasions (Table 8-1). Two potential outliers for electrical conductivity and one potential outlier for total phosphorus were identified. All three values were an order of magnitude higher than other records and did not coincide with other unusual water quality records. These potential outliers were excluded from the regression analyses that were used to describe variation in historical data, but were still plotted on the control charts.

Table 8-1: Missing data over period of regression model fit (Jan 1991 – Jun 2005)

Missing data elements	Dissolved oxygen	Turbidity	Electrical conductivity	pH	Total nitrogen	Total phosphorus
No. of missing water quality readings on days when at least on other parameter was recorded	2	1	0	4	0	0
No. of data points removed as outliers	0	0	2	0	0	1
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	0	0	0	0	0	0
Sample size for regression analysis	172	173	172	170	174	173

Water quality was monitored on 66 occasions between July 2005 and December 2010. The number of missing data points due to missing water quality data, missing temperature data or missing flow data is listed in (Table 8-2)

Table 8-2: Missing data over period of control chart application (Jul 2005 – 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	2	1	1	1	3	3
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	1	1
No. of data points not analysed due to missing flow data	0	0	0	0	0	0
No. of data points with missing or erroneous flow data	5	5	5	5	5	5
Sample size for control chart application	64	65	65	65	62	62

8.3. Results for each water quality variable

8.3.1. Dissolved oxygen

Variation in dissolved oxygen (mg/L) levels in the Broken River @ Goorambat between 1991 and 2005 was well explained by a combination of water temperature, date, flow in the Broken River and flow from Lake Mokoan (Table 8-3). The regression model predicted dissolved oxygen levels between 2005 and 2010 reasonably well, although there were two very high records and two very low records that may be considered out of control and may warrant further investigation (Figure 8-2). There were no extended runs above or below predicted values (Figure 8-3). There was a general decline in dissolved oxygen levels at this site between 1991 and 2005 and that trend continued as predicted after 2005 (Figure 8-2 and Table 8-3).

Variation in the percent saturation of dissolved oxygen between 1991 and 2005 was best explained by the same variables as dissolved oxygen measured in mg/L although the model fit was not as good (Table 8-3). The steady decline in dissolved oxygen at this site since 1997 is more obvious with the percent saturation data (see Figure 8-4). The control chart for percent saturation also highlights more records that would be considered out of control (Figure 8-4). The lowest records all occurred during the drought and are probably a function of critically low flows. Overall the regression model predicted changes in dissolved oxygen after 2005 reasonably well and there were no especially long runs above or below the predicted value (Figure 8-5).

Dissolved oxygen saturation levels at this site were consistently below the State Environment Protection Policy (Waters of Victoria) lower trigger levels of ≥85% (Figure 8-4) and the ongoing decline in dissolved oxygen is a potential concern. Close monitoring of dissolved oxygen levels at this site should continue.

Table 8-3: Best fit regression models to describe variation in dissolved oxygen in the Broken River @ Goorambat between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Dissolved oxygen (DO) [mg/L]	DO= 23.1716 – (0.2158*Temp) – (0.000243*Date) + (0.0544*FlowBroken0.4) + (0.0485*FlowMokoan0.4)	172	0.64	13%
Dissolved oxygen (DO) [% saturation]	DO= 212.1765 – (0.5726*Temp) – (0.002541*Date) + (0.4415*FlowBroken0.4) + (0.5786*FlowMokoan0.4)	172	0.31	12%

Table 8-4: Summary statistics for historical (1991-2005) and current (2005 – 2010) dissolved oxygen data recorded in the Broken River @ Goorambat

Parameter	Record	N	Mean	Median	Standard Deviation
Dissolved oxygen mg/L	Historical	172	7.89	7.9	1.636
	Current	59	6.85	7.0	2.077
Dissolved oxygen % Sat	Historical	172	79.36	80.05	11.61
	Current	59	67.97	70.48	16.00

Figure 8-2: Control chart for dissolved oxygen (in mg/L) in the Broken River @ Goorambat 1991 – 2010

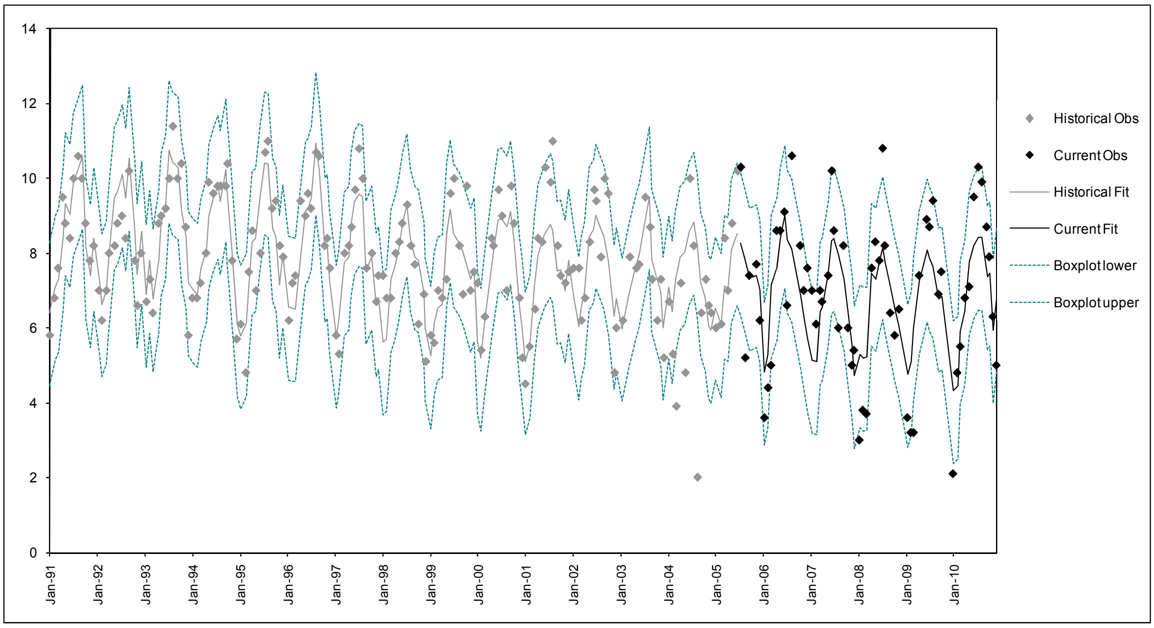


Figure 8-3: Run chart for dissolved oxygen (in mg/L) in the Broken River @ Goorambat 1991 – 2010

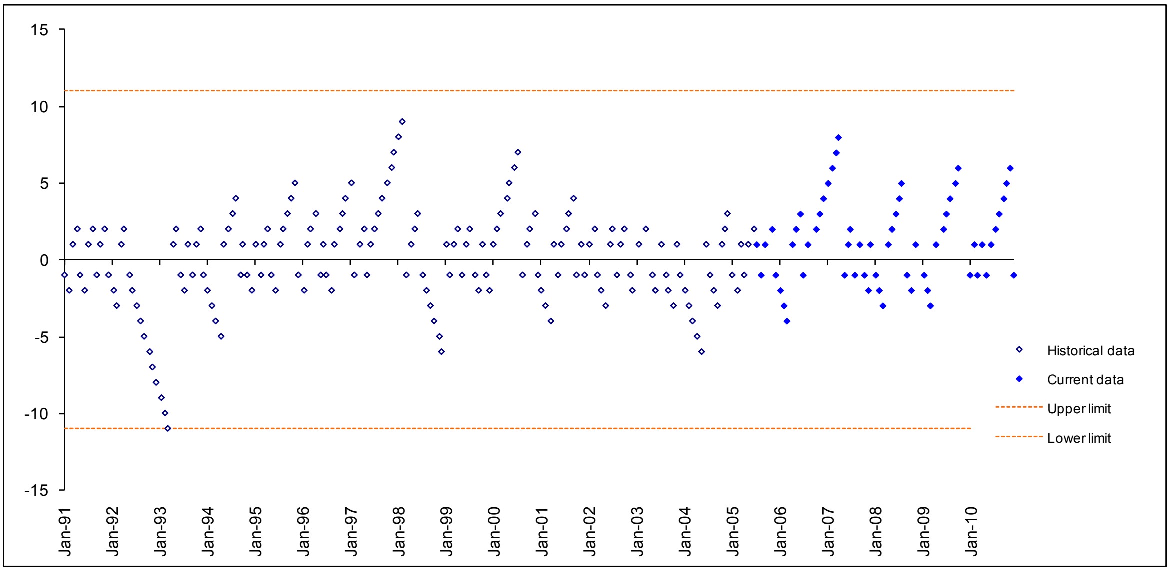


Figure 8-4: Control chart for dissolved oxygen (in % saturation) in the Broken River @ Goorambat 1991 – 2010

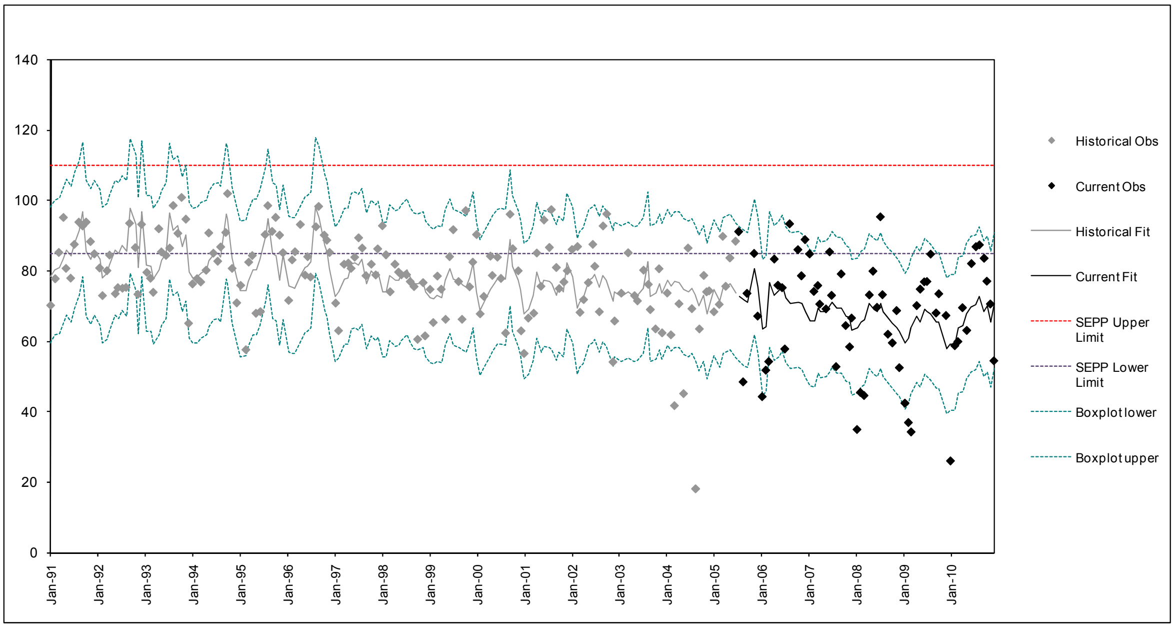
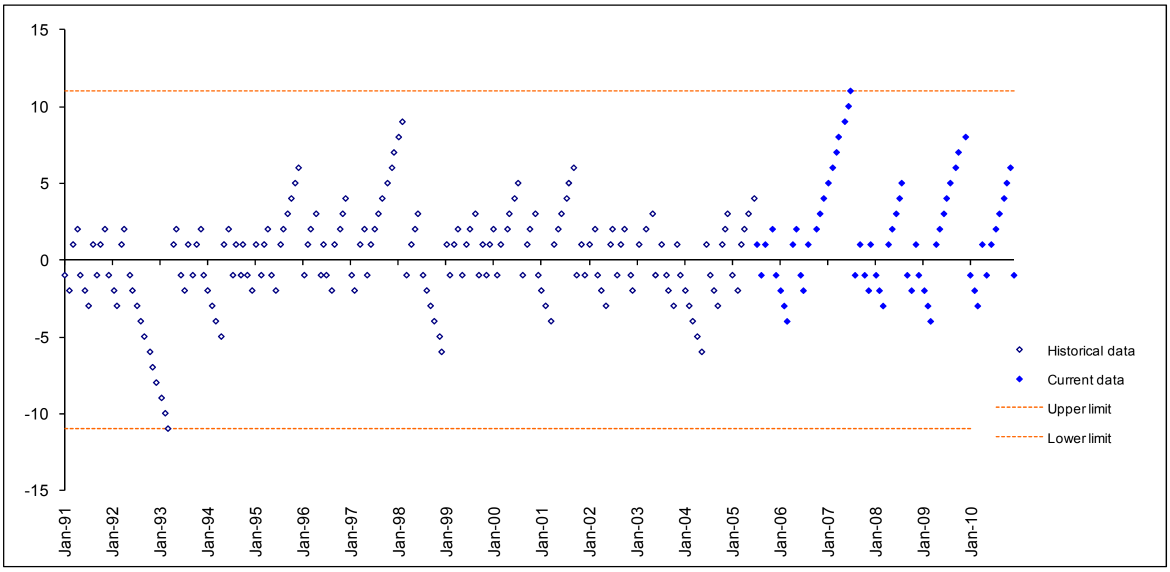


Figure 8-5: Run chart for dissolved oxygen (in % saturation) in the Broken River @ Goorambat 1991 – 2010



8.3.2. Turbidity

Variation in turbidity in the Broken River @ Goorambat between 1991 and 2005 was very well explained by flow in the Broken River, flow from Lake Mokoan and electrical conductivity (Table 8-5). Flow from Lake Mokoan was a particularly good predictor of high turbidity at this site. Turbidity in Lake Mokoan (and the Winton Wetlands) can be very high due to the shallow depths and strong wind driven wave action and therefore any flow from Lake Mokoan \ Winton Wetlands will have a noticeable effect on turbidity levels in the Broken River.

Turbidity results in the Broken River @ Goorambat were more variable after 2005 and the average and median levels both increased (Table 8-6). Moreover, there were at least 11 turbidity readings taken between 2006 and 2009 that were very high and were out of control compared to historical data (Figure 8-6). The very high turbidity levels may be due to ash and sediment that was washed into the Broken River after the December 2006 bushfires, which burned most of the Upper Goulburn and Broken Catchments (Pat Feehan, *personal communication*, 1/5/12). Silt and sediment from bushfires can wash into streams and then be remobilised during subsequent high flow events until it is flushed from the system (Smith *et al.*, 2011). Although the very high turbidity records were not well predicted by the model, they were episodic and there were no long runs of consecutive records that were above or below the predicted value (Figure 8-7).

Turbidity levels at this site frequently exceed the State Environment Protection Policy (Waters of Victoria) trigger level of ≤30 NTU (Figure 8-6) and may therefore represent a threat to ecosystem values and other beneficial uses of the waterway. Recent changes to the operation of Lake Mokoan, combined with the effects of drought and bushfires mean that turbidity levels at this site may continue to change over the next 5-10 years. As a result, there is likely to be tremendous value in plotting new data onto the control chart as they are collected, rather than waiting for five years to analyse trends. Turbidity monitoring at this site would be a good candidate for trialling an automated process to update control charts with new data as they are collected.

Table 8-5: Best fit regression models to describe variation in turbidity in the Broken River @ Goorambat between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Turbidity	$Turbidity = -15.8494 + (0.005257*FlowBroken) + (0.2954*EC) + (3.9635*FlowMokoan^{0.4})$	171	0.75	36%

Table 8-6: Summary statistics for historical (1991-2005) and current (2005 – 2010) turbidity data recorded in the in the Broken River @ Goorambat

Parameter	Record	N	Mean	Median	Standard Deviation
Turbidity (NTU)	Historical	173	50.11	37	34.87
	Current	65	82.89	45	90.61

Figure 8-6: Control chart for turbidity (in NTU) in the Broken River @ Goorambat 1991 – 2010

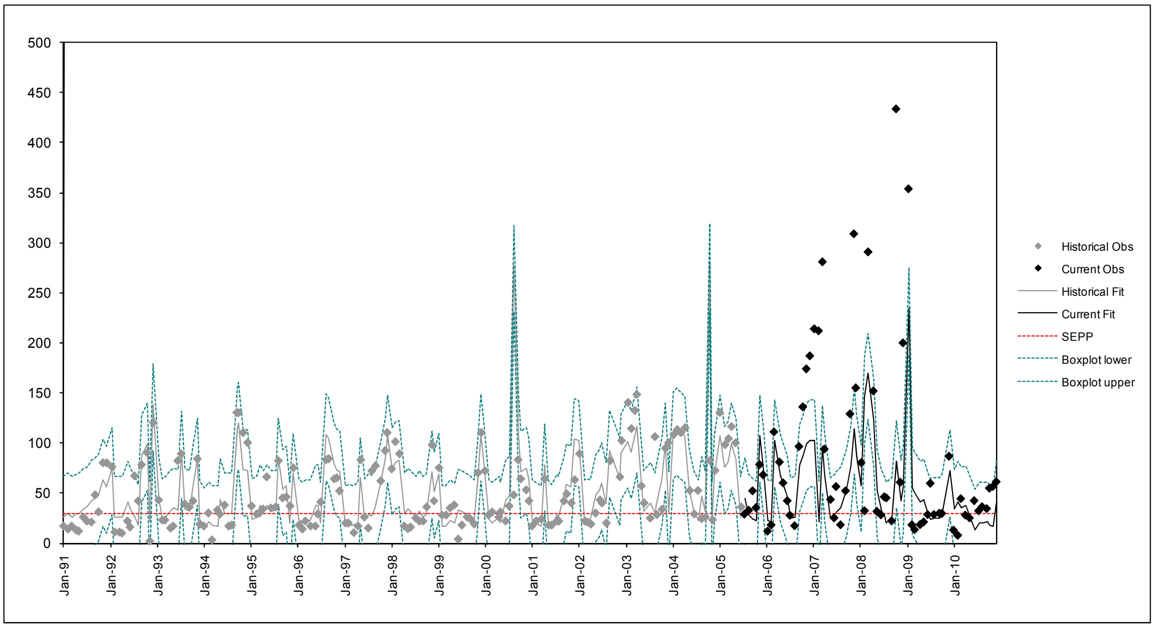
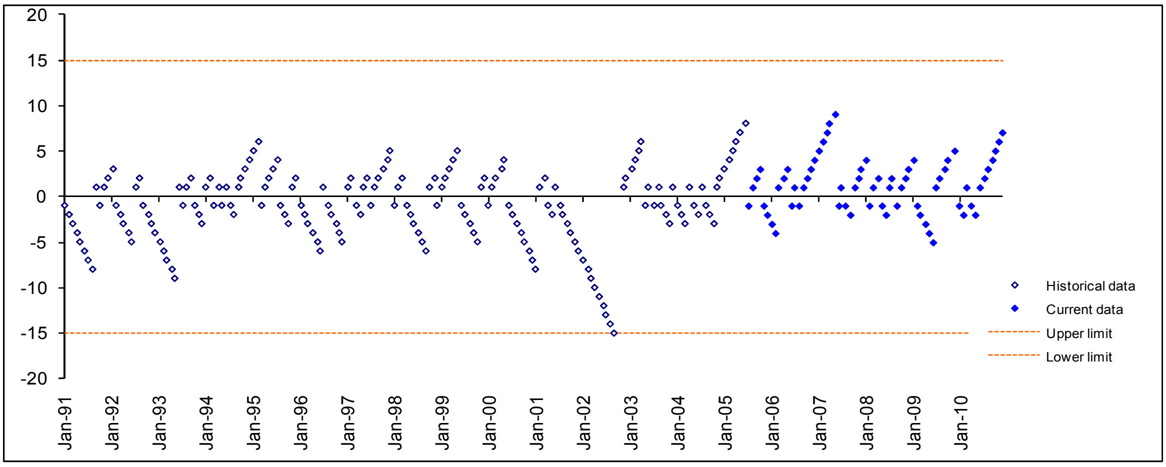


Figure 8-7: Run chart for turbidity (in NTU) in the Broken River @ Goorambat 1991 – 2010



8.3.3. Electrical conductivity

Variation in electrical conductivity in the Broken River @ Goorambat between 1991 and 2005 was reasonably well described by a combination of water temperature, flow in the Broken River and flow from Lake Mokoan (Table 8-7). Electrical conductivity at this site has increased since 2005 (Table 8-8). Particularly high levels were recorded between June 2007 and March 2008, which were out of control compared to historical patterns at this site (Figure 8-8). These spikes in electrical conductivity may be due to evapo-concentration or groundwater intrusion during the drought, which intensified in this period (Pat Feehan, *personal communication*, 1/5/12). Except for these spikes, electrical conductivity levels at this site were well below the State Environment Protection Policy (Waters of Victoria) trigger value of ≤500 µS/cm (Figure 8-8).

With the exception of the results in 2007 and 2008, the regression model that explained variation in the historical data, was reasonably good at predicting electrical conductivity at this site and there were no long runs where observed values were higher or lower than the predicted value (Figure 8-9). It is interesting to note that the model successfully predicted a decline in electrical conductivity at the end of 2009 and in 2010, after Lake Mokoan was decommissioned (Figure 8-8). Continuing to plot new values against the predicted levels will show whether the relationship between conductivity and the two flow parameters continues and whether the overall downward trend in conductivity, both in terms of the predicted values and the actual observations, continues.

Table 8-7: Best fit regression models to describe variation in electrical conductivity in the Broken River @ Goorambat between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Electrical conductivity (EC)	EC0.4 = 8.3748– (0.0257*Temp) – (0.0856*FlowBroken0.4)+ (0.1368*FlowMokoan0.4)	172	0.45	22%

Table 8-8: Summary statistics for historical (1991-2005) and current (2005 – 2010) electrical conductivity data recorded in the in the Broken River @ Goorambat

Parameter	Record	N	Mean	Median	Standard Deviation
Electrical conductivity (µS/cm)	Historical	173	178.23	160.00	96.90
	Current	61	203.63	170.96	121.52

Figure 8-7: Run chart for turbidity (in NTU) in the Broken River @ Goorambat 1991 – 2010

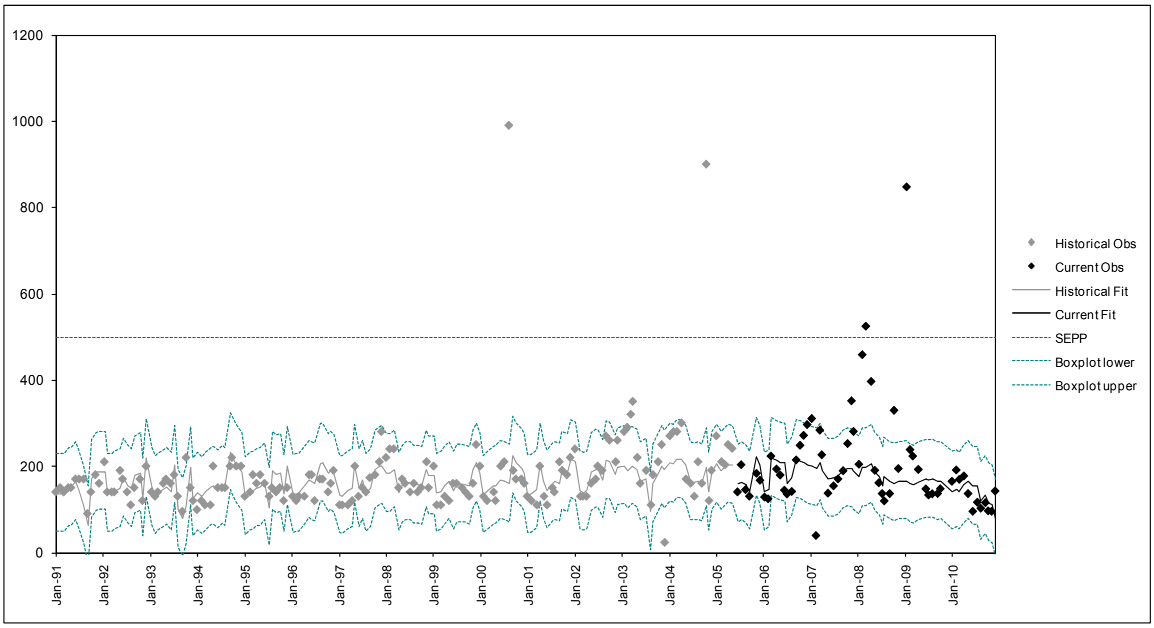
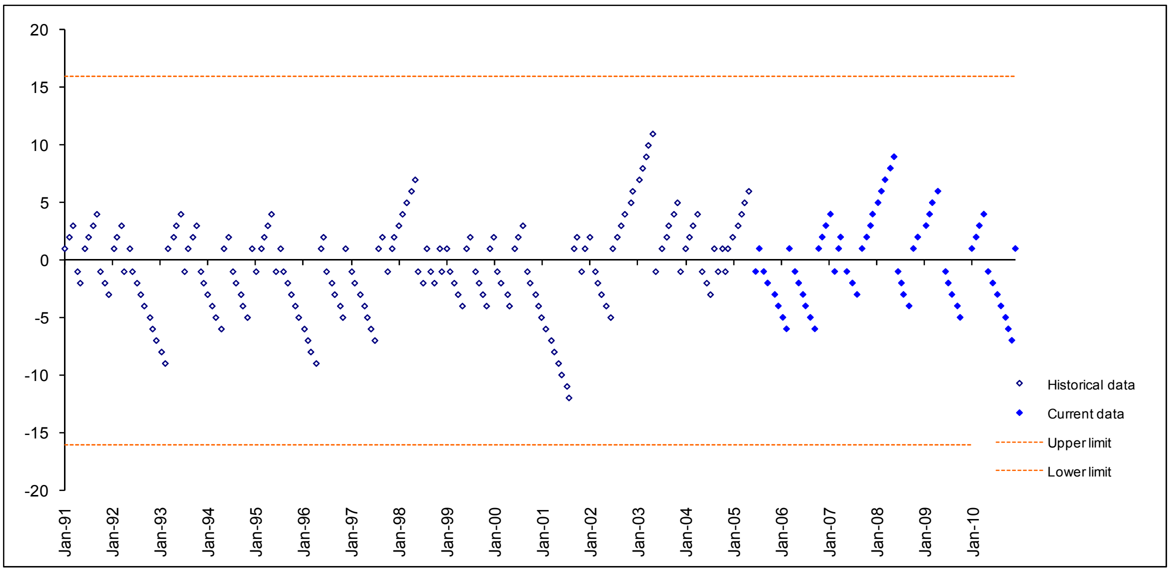


Figure 8-9: Run chart for electrical conductivity (in µS/cm) in the Broken River @ Goorambat 1991 – 2010



8.3.4. pH

None of the predictor variables tested in the current project explained variation in pH at this site (the best fitting model had an R^2 value of 0.12 – see Table 8-9) and therefore the control chart presented in Figure 8-10 is no better than one based just on the historical median. Average and median pH levels at this site have increased slightly since 2005 (Table 8-10), but most records since January 1998 lie between the lower and upper State Environment Protection Policy (Waters of Victoria) trigger values of 6.4 and 7.7 respectively (Figure 8-10).

Table 8-9: Best fit regression models to describe variation in pH in the Broken River @ Goorambat Turbidity between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
pH	$pH^{0.4}$= 1.8606 + (0.00000557*Date) + (0.000519*$FlowBroken^{0.4}$) + (0.002288*$FlowMokoan^{0.4}$)	170	0.12	5%

Table 8-10: Summary statistics for historical (1991-2005) and current (2005 – 2010) pH data recorded in the in the Broken River @ Goorambat

Parameter	Record	N	Mean	Median	Standard Deviation
pH	Historical	170	6.84	6.8	0.3611
	Current	61	6.95	6.9	0.3335

Figure 8-10: Control chart for pH (in pH units) in the Broken River @ Goorambat 1991 – 2010

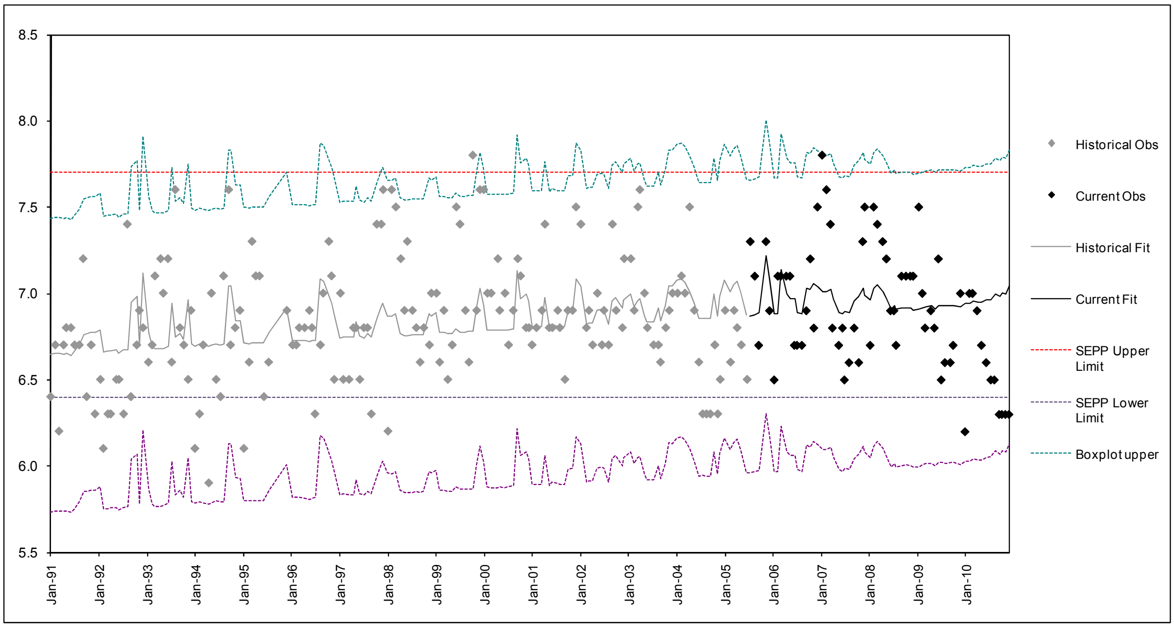
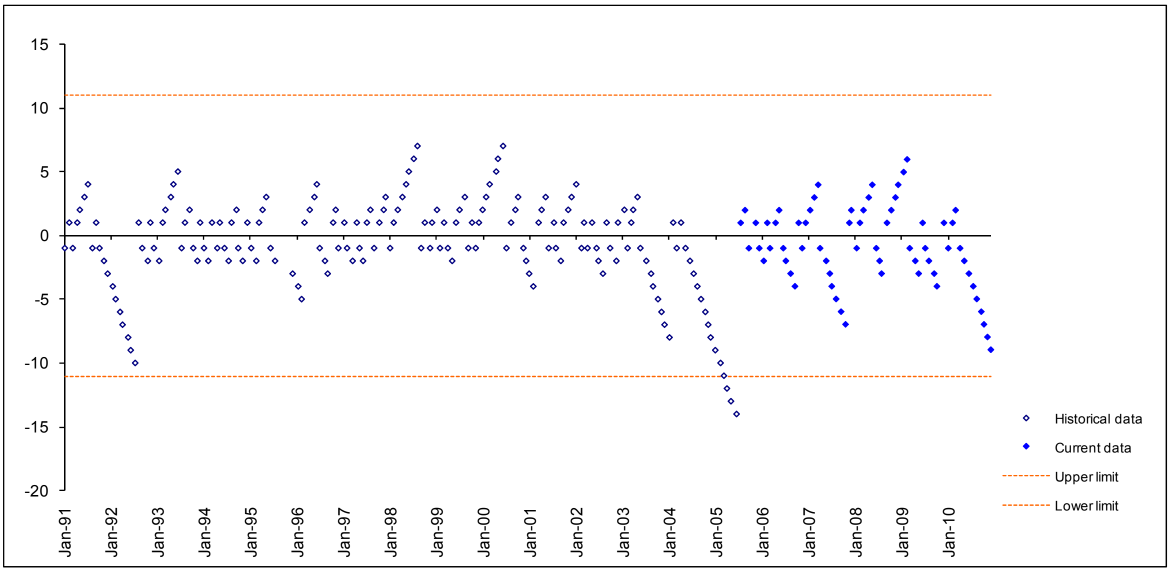


Figure 8-11: Run chart for pH (in pH units) in the Broken River @ Goorambat 1991 – 2010



8.3.5. Total nitrogen

Variation in total nitrogen in the Broken River @ Goorambat between 1991 and 2005 was partly explained by a combination of season, water temperature and flow in the Broken River (Table 8-11). Total nitrogen levels at this site have generally declined since June 2005 (Table 8-12) and have often been less than predicted (Figure 8-12 and Figure 8-13). Higher total nitrogen levels were recorded on two or three occasions in 2007, but those observations were not out of control compared to historical patterns (Figure 8-12). Moreover, total nitrogen levels at this site have mostly remained well below the State Environment Protection Policy (Waters of Victoria) trigger level of ≤0.900 mg/L since 1991 (Figure 8-12).

Table 8-11: Best fit regression models to describe variation in total nitrogen (in mg/L) in the Broken River @ Goorambat between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Total nitrogen (TN)	TN = 0.4477 – (0.0777*Season)– (0.0118*Temp) + (0.001884*FlowBroken$^{0.4}$)	174	0.21	80%

Table 8-12: Summary statistics for historical (1991-2005) and current (2005 – 2010) total nitrogen (in mg/L) data recorded in the in the Broken River @ Goorambat

Parameter	Record	N	Mean	Median	Standard Deviation
Total nitrogen (mg/L)	Historical	174	0.268	0.235	0.234
	Current	56	0.167	0.130	0.145

Figure 8-12: Control chart for total nitrogen (in mg/L) in the Broken River @ Goorambat 1991 – 2010

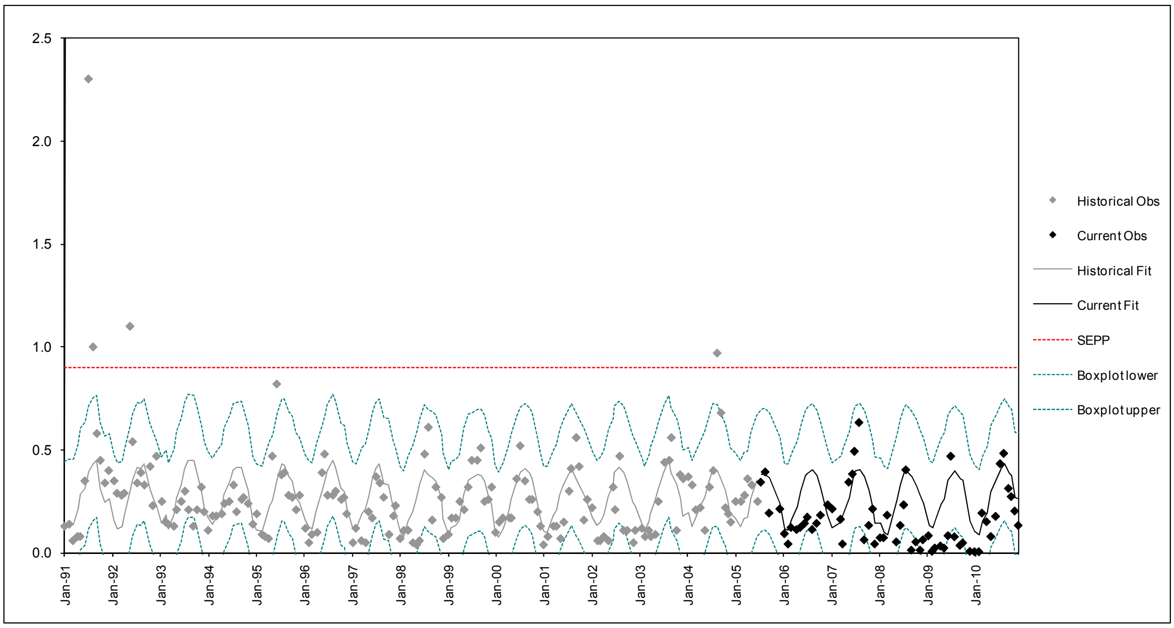
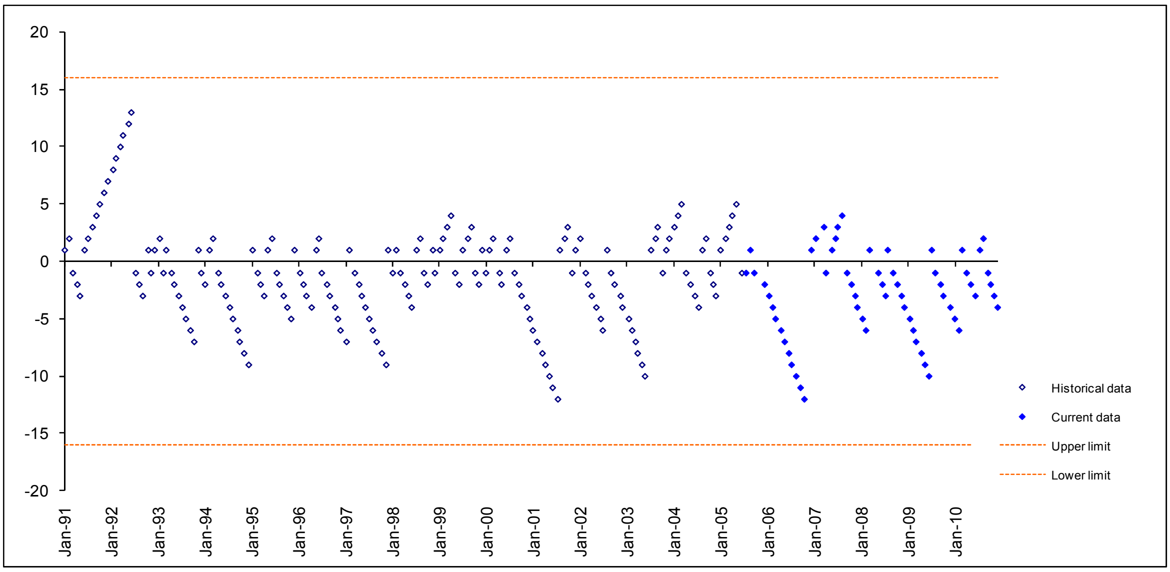


Figure 8-13: Run chart for total nitrogen (in mg/L) in the Broken River @ Goorambat 1991 – 2010



8.3.6. Total phosphorus

Variation in total phosphorus in the Broken River @ Goorambat between 1991 and 2005 was moderately well explained by season, date, flow in the Broken River and turbidity (Table 8-13). Turbidity can influence nutrient levels because nutrients can bind to soil particles and get washed into the river. However, turbidity in the Broken River is also correlated with flow from Lake Mokoan, which may explain why it was highlighted as an important predictor variable in this analysis. Average and median total phosphorus levels at this site were slightly lower after 2005 compared to the period 1991 to 2005 (Table 8-14). That decline in total phosphorus may be partly due to reduced flow from Lake Mokoan towards the end of the drought and after decommissioning. For the most part, total phosphorus observations after June 2005 were much lower than in previous years (Figure 8-14) and were nearly always lower than predicted (Figure 8-15).

The high total phosphorus levels recorded in 2007 and 2008 (Figure 8-14) were probably due to run-off from bushfire affected areas (Pat Feehan, *personal communication*, 1/5/12). However, it is interesting to note that the observed values on those occasions were much lower than predicted by the model (Figure 8-14). The large underestimate is mainly due to the influence of turbidity, which was very high on those occasions and was used as a predictor variable in the model. This pattern adds strength to the theory that high turbidity and nutrient levels after 2006 were due to sediment and ash from the bushfires in December 2006. Sediment that is washed into the rivers will be mobilised by subsequent events until it is flushed from the reach, which may take several years (Smith *et al.*, 2011). However, nutrients that are bound to these sediments will be processed more rapidly and so spikes in nutrient levels will generally not persist as long.

Prior to 2005, total phosphorus levels in the Broken River @ Goorambat nearly always exceeded the State Environment Protection Policy (Waters of Victoria) trigger level of ≤0.045mg/L (Figure 8-14). If not for the effect of the bushfires, total phosphorus levels at this site since June 2005 may have stayed below the State Environment Protection Policy (Waters of Victoria) trigger level for most of the time. This decline in total phosphorus concentration is likely to be due to reduced outflows from Lake Mokoan. It will be interesting to see if total phosphorus levels remain low and whether the model used in this analysis is a reliable predictor of total phosphorus given the changed operation of Lake Mokoan. Once more data have been collected it may be necessary to update the regression models to ensure they more accurately reflect the current operation of Lake Mokoan and the water supply system more generally.

Table 8-13: Best fit regression models to describe variation in Total Phosphorus (in mg/L) in the Broken River @ Goorambat between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Total phosphorus (TP)	$TP^{0.4}$ = -0.1061 – (0.063*Season) + (0.00001014*Date) – (0.005752*FlowBroken$^{0.4}$) + (0.0009455*Turbidity)	172	0.42	41%

Table 8-14: Summary statistics for historical (1991-2005) and current (2005 – 2010) Total Phosphorus (in mg/L) data recorded in the in the Broken River @ Goorambat

Parameter	Record	N	Mean	Median	Standard Deviation
Total phosphorus (mg/L)	Historical	172	0.120	0.105	0.089
	Current	60	0.119	0.097	0.098

Figure 8-14: Control chart for total phosphorus (in mg/L) in the Broken River @ Goorambat 1991 – 2010

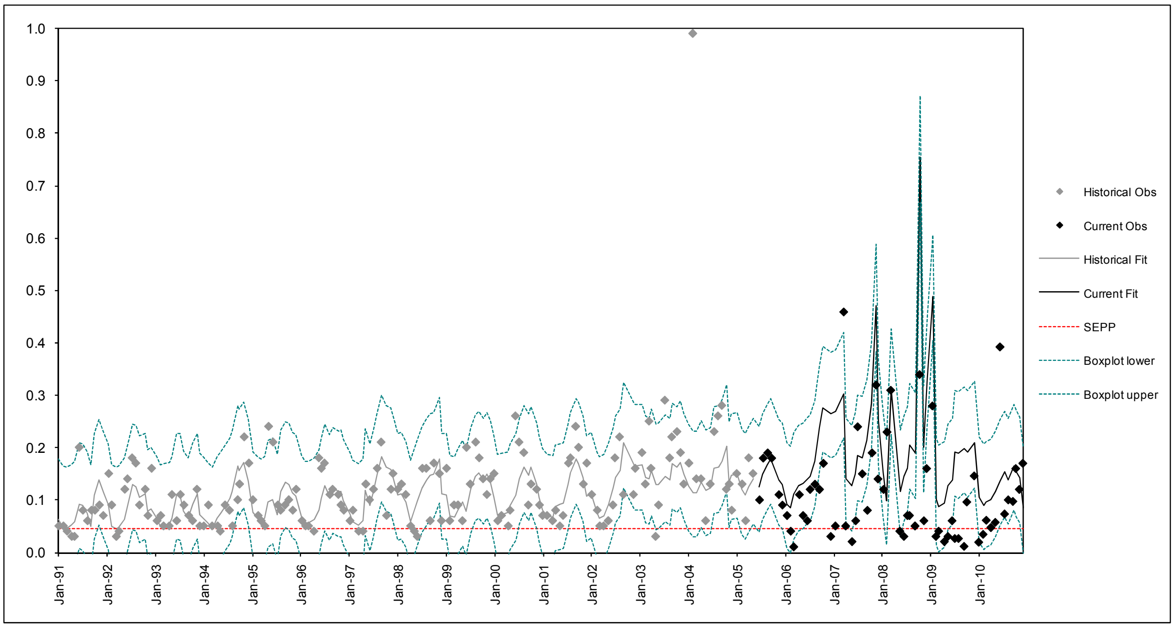
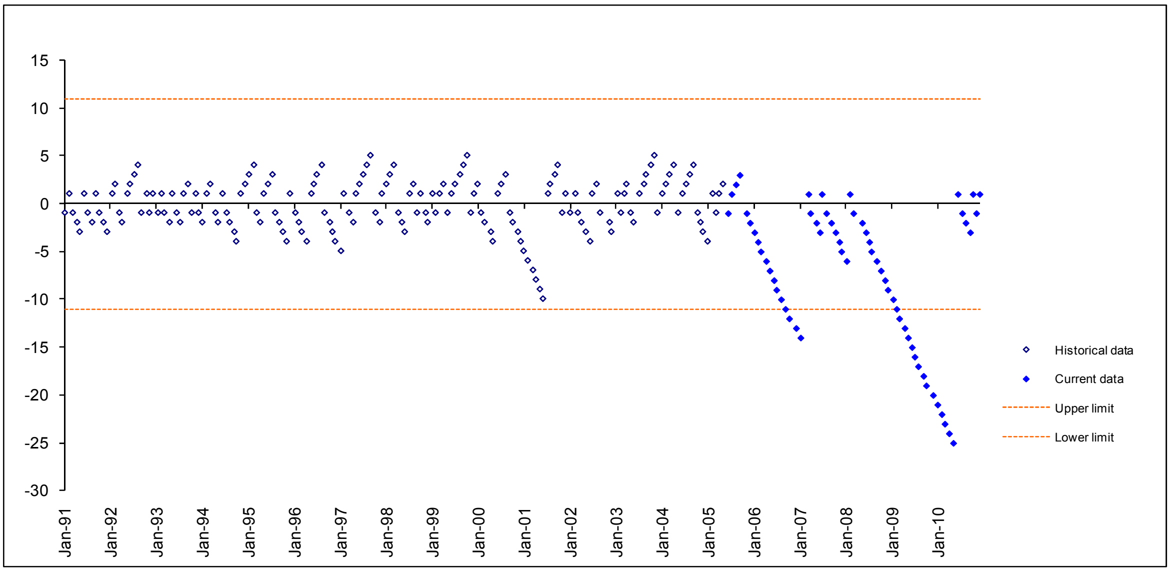


Figure 8-15: Run chart for total phosphorus (in mg/L) in the Broken River @ Goorambat 1991 – 2010

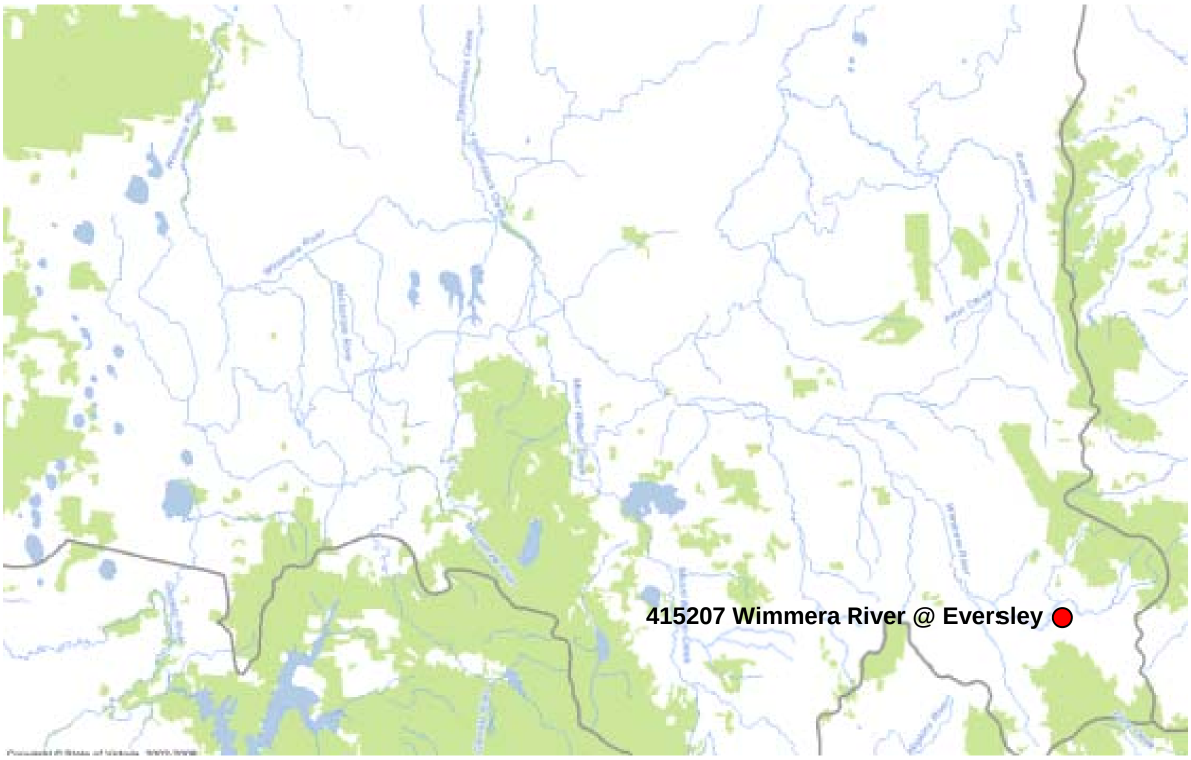


9. Results for 415207 Wimmera River @ Eversley

9.1. Site Location

The Wimmera River @ 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 9-1). The Wimmera CMA nominated the site as being of interest from a water quality perspective.

Figure 9-1: Locality map for Wimmera River @ Eversley



9.2. Data availability and quality

Water quality was monitored @ Eversley on 174 occasions between January 1991 and June 2005. There were very few missing water quality data, missing temperature data or missing flow data (Table 9-1). There were three days with 'zero-flow', which were excluded from the analysis.

Table 9-1: Missing data over period of regression model fit (Jan 1991 – Jun 2005)

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	0
No. of data points not analysed due to missing or zero flow data	3	3	3	3	3	3
Sample size for regression analysis	170	171	170	168	171	171

Water quality was monitored on 63 occasions between July 2005 and December 2010. There were no missing data, but nearly one third of the readings were taken during the drought when there was no flow (Table 9-2).

Table 9-2: Missing data over period of control chart application (Jul 2005 – 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	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	0	0	0
No. of data points not analysed due to missing flow data	0	0	0	0	0	0
No. of data points with zero flow data	19	19	19	19	19	19
Sample size for control chart application	63	63	63	63	63	63

9.3. Results for each water quality variable

9.3.1. Dissolved oxygen

Variation in dissolved oxygen (mg/L) levels in the Wimmera River @ Eversley between 1991 and 2005 was moderately well explained (R^2 = 0.49) by a combination of season, temperature, date and flow (Table 9-3). 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 tended to underestimate the highest values and overestimated the lowest values (Figure 9-2). The upper reaches of the Wimmera River have very low flow during summer 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). These factors may explain the high seasonal variation in dissolved oxygen at the site.

Average and median dissolved oxygen levels were lower after 2005 compared to the historical period (Table 9-4). Dissolved oxygen levels were inside the modelled control limits until the end of 2008, but were consistently below the predicted values after 2008 (Figure 9-2). The trend for observed values to be consistently lower than predicted after 2008 is clearly demonstrated in the run chart (Figure 9-3). The very low dissolved oxygen levels recorded in the Wimmera River @ Eversley since September 2009 may be due to the breakdown of organic debris that was washed into the river during floods (G. Fletcher, *personal communication,* 1/5/12).

The percent saturation of dissolved oxygen was best explained by season, water temperature, date and flow, but the fit (R^2 = 0.24) was not as good as the model for absolute dissolved oxygen (Table 9-3). The importance of water temperature as a predictor of dissolved oxygen means that temperature-dependent rates of primary production and community respiration are potentially driving dissolved oxygen dynamics. The control chart for the percent saturation of dissolved oxygen shows a considerable number of points below the lower SEPP trigger level of 85%, and outside the modelled control limits (Figure 9-4). Most of the dissolved oxygen records taken at this site since January 2008 were well below the lower State Environment Protection Policy (Waters of Victoria) trigger level and may represent a threat to the aquatic values and other beneficial uses of the waterway. The run chart clearly shows that the regression model did not predict the very low dissolved oxygen levels recorded after 2008 (Figure 9-5).

Table 9-3: Best fit regression models to describe variation in dissolved oxygen in the Wimmera River @ Eversley between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Dissolved oxygen (DO) [mg/L]	DO = 23.9259 – (1.1365*Season) – (0.1349*Temp) –(0.0002551*Date) – (0.002106*Flow)	170	0.49	15%
Dissolved oxygen (DO) [% saturation]	$DO^{0.4}$ = 9.6474 – (0.3149*Season) + (0.0126*Temp) –(0.00007622*Date) – (0.0005806*Flow)	170	0.24	16%

Table 9-4: Summary statistics for historical (1991-2005) and current (2005 – 2010) dissolved oxygen data recorded in the Wimmera River @ Eversley

Parameter	Record	N	Mean	Median	Standard Deviation
Dissolved oxygen mg/L	Historical	173	8.82	9	1.83
	Current	62	7.05	7.65	2.98
Dissolved oxygen % Sat	Historical	173	86.73	88.61	15.51
	Current	62	67.11	69.08	29.11

Figure 9-2: Control chart for dissolved oxygen (mg/L) in the Wimmera River @ Eversley 1991 – 2010

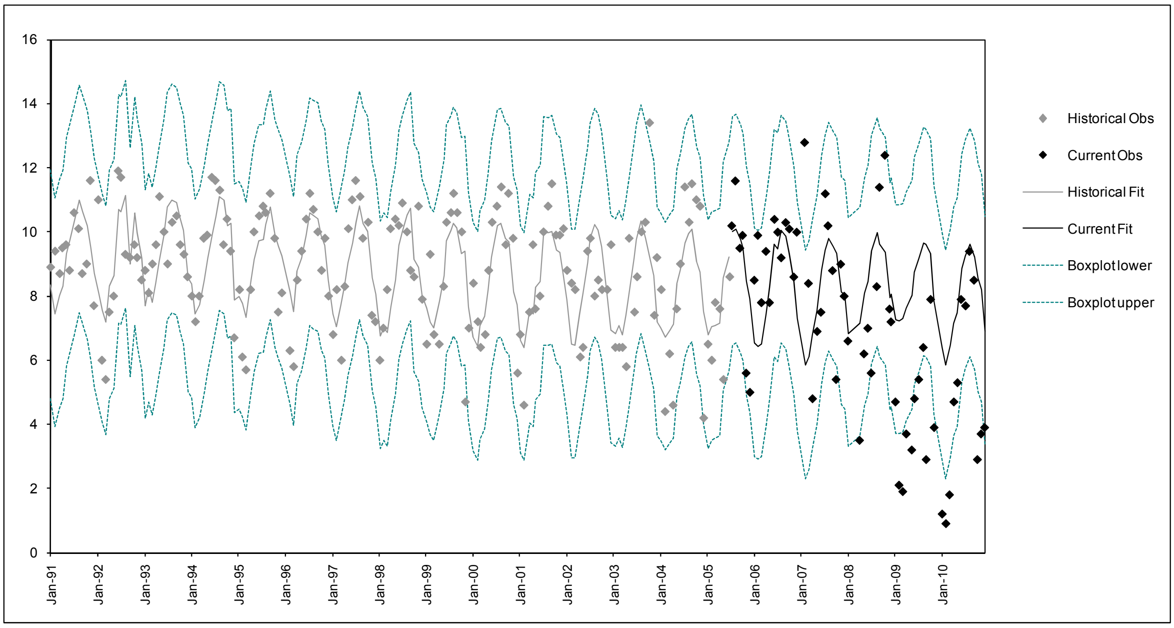


Figure 9-3: Run chart for dissolved oxygen (mg/L) in the Wimmera River @ Eversley 1991 – 2010

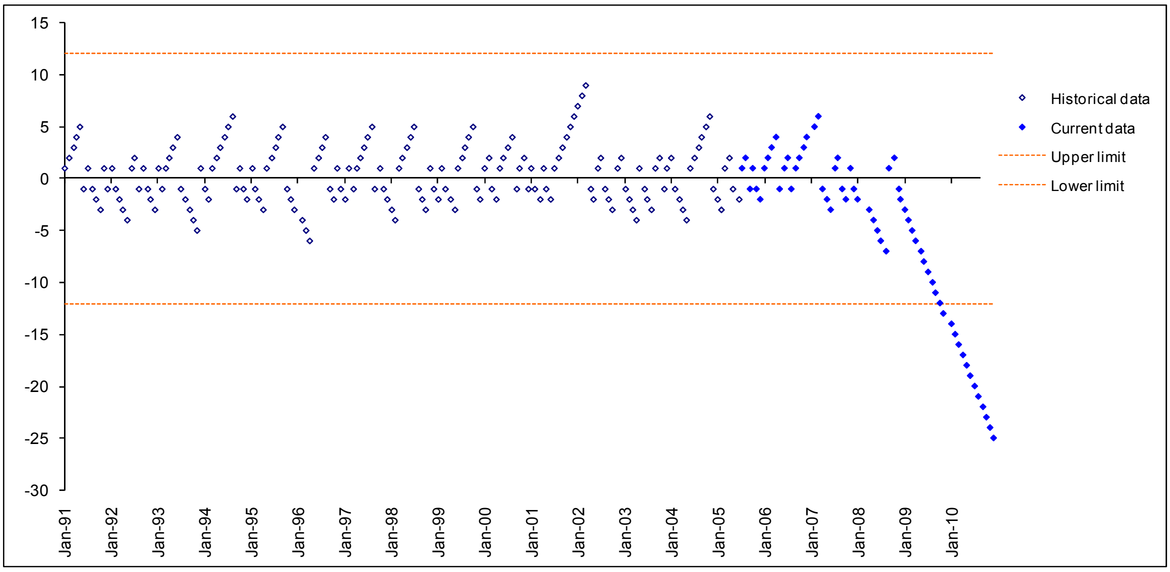


Figure 9-4: Control chart for percent saturation dissolved oxygen in the Wimmera River @ Eversley 1991 – 2010

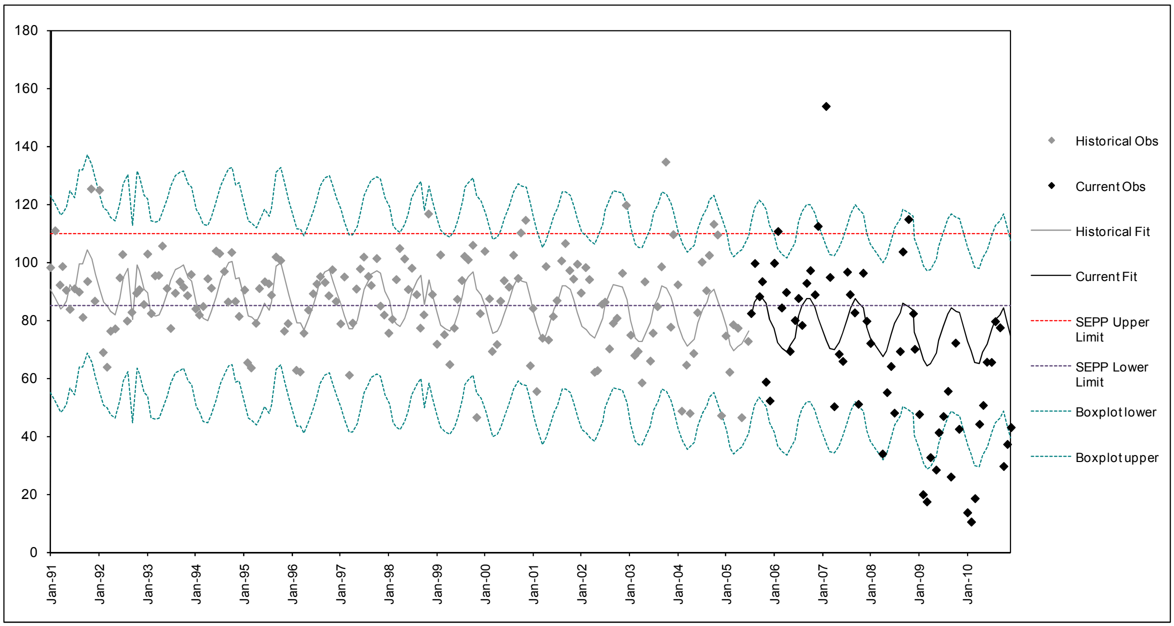
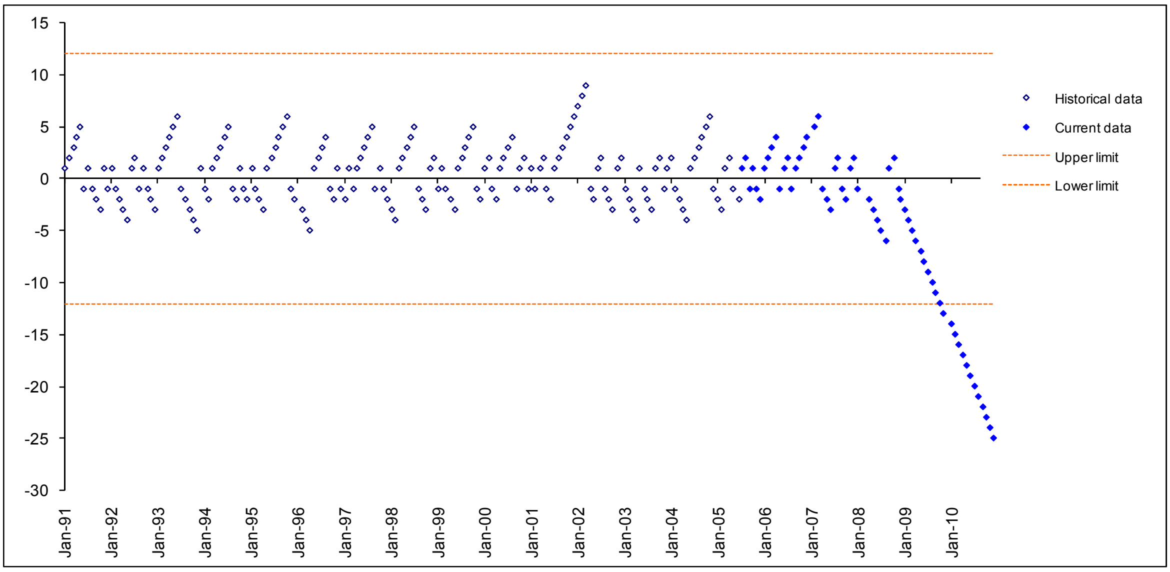


Figure 9-5: Run chart for percent saturation dissolved oxygen in the Wimmera River @ Eversley 1991 – 2010



9.3.2. Turbidity

Variation in turbidity in the Wimmera River @ Eversley between 1991 and 2005 was explained reasonably well (R^2= 0.41) by a combination of flow and rainfall (Table 9-5). Rainfall data were taken from the Eversley rainfall gauge (Site # 079014) operated by the Bureau of Meteorology. Since 2005, average and median turbidity levels have been significantly higher than the historical record (Table 9-6). The model did not predict this increase and consequently the observed values were higher than those predicted by the model and commonly outside the model limits (Figure 9-6; Figure 9-7). Since 2005, turbidity levels at this site have frequency exceeded the State Environment Protection Policy (Waters of Victoria) trigger level of ≤10 NTU and therefore observations outside of control may be a trigger for further investigation at the time of the observation. High turbidity levels from mid-2007 to September 2009 were not able to be explained by the model, but may be due to high planktonic algal growth in the sampling pool during the worst part of the drought (M. Toomey, *personal communication*, 1/5/12). The very high turbidity levels recorded after September 2009 can be explained by large floods, which entrained large amounts of organic debris into the river (G. Fletcher, *personal communication,* 1/5/12).

Table 9-5: Best fit regression models to describe variation in turbidity in the Wimmera River @ Eversley between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Turbidity	Turbidity = 1.5781 + (2.2216*Flow$^{0.4}$) + (0.1277*Rainfall)	171	0.41	87%

Table 9-6: Summary statistics for historical (1991-2005) and current (2005 – 2010) turbidity data recorded in the in the Wimmera River @ Eversley

Parameter	Record	N	Mean	Median	Standard Deviation
Turbidity (NTU)	Historical	171	8.26	5.8	9.14
	Current	65	26.3	11.4	51.6

Figure 9-6: Control chart for turbidity (in NTU) in the Wimmera River @ Eversley 1991 – 2010

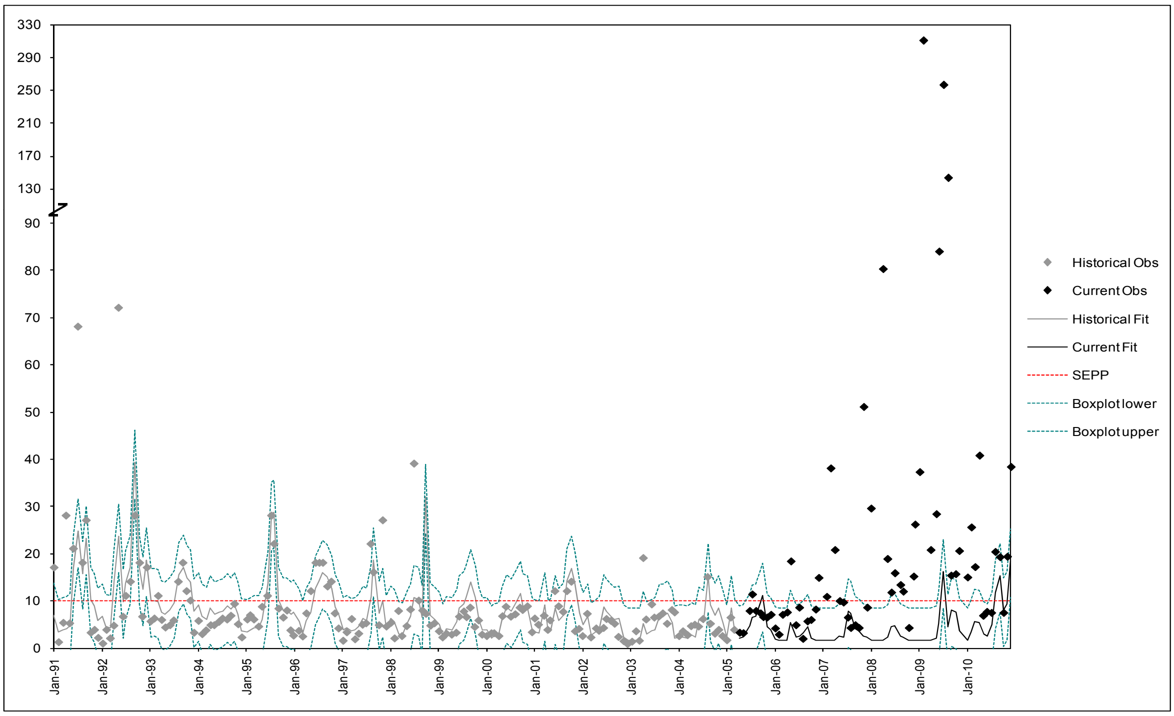
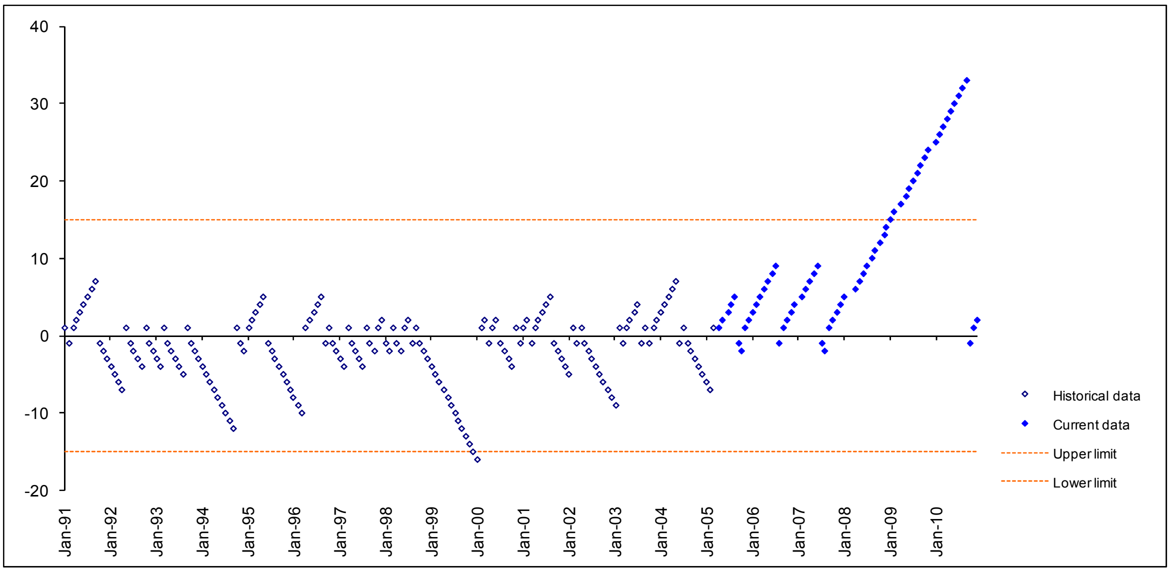


Figure 9-7: Run chart for turbidity (in NTU) in the Wimmera River @ Eversley 1991 – 2010



9.3.3. Electrical conductivity

Variation in electrical conductivity in the Wimmera River @ Eversley between 1991 and 2005 was well explained by a combination of season, date and flow (Table 9-7). Average electrical conductivity levels were much higher after 2005 compared to the historical period (Table 9-8). High electrical conductivity levels, outside of control, correlate with cease-to-flow events in the Wimmera River during the drought. The model reliably predicted electrical conductivity levels when the river was flowing (i.e. in winter 2007 and from winter 2009 onwards) (Figure 9-9). Electrical conductivity levels at this site nearly always exceed the State Environment Protection Policy (Waters of Victoria) trigger level of ≤500 µS/cm for the protection of aquatic ecosystems and other beneficial uses of the waterway (Figure 9-8). Therefore, any readings that are also outside of control of the model may be a trigger for further investigations.

Table 9-7: Best fit regression models to describe variation in conductivity in the Wimmera River @ Eversley between 1991 and June 2005.

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Electrical conductivity (EC)	$EC^{0.4}$ = 26.8993 –(2.6463 *Season) – (0.1628*Temp) – (1.2526*$Flow^{0.4}$)	170	0.69	31%

Table 9-8: Summary statistics for historical (1991-2005) and current (2005 – 2010) conductivity data recorded in the in the Wimmera River @ Eversley

Parameter	Record	N	Mean	Median	Standard Deviation
Electrical conductivity (µS/cm)	Historical	173	2292	2100	1246
	Current	62	3287	3344	1885

Figure 9-8: Control chart for electrical conductivity (in µS/cm) in the Wimmera River @ Eversley 1991 – 2010

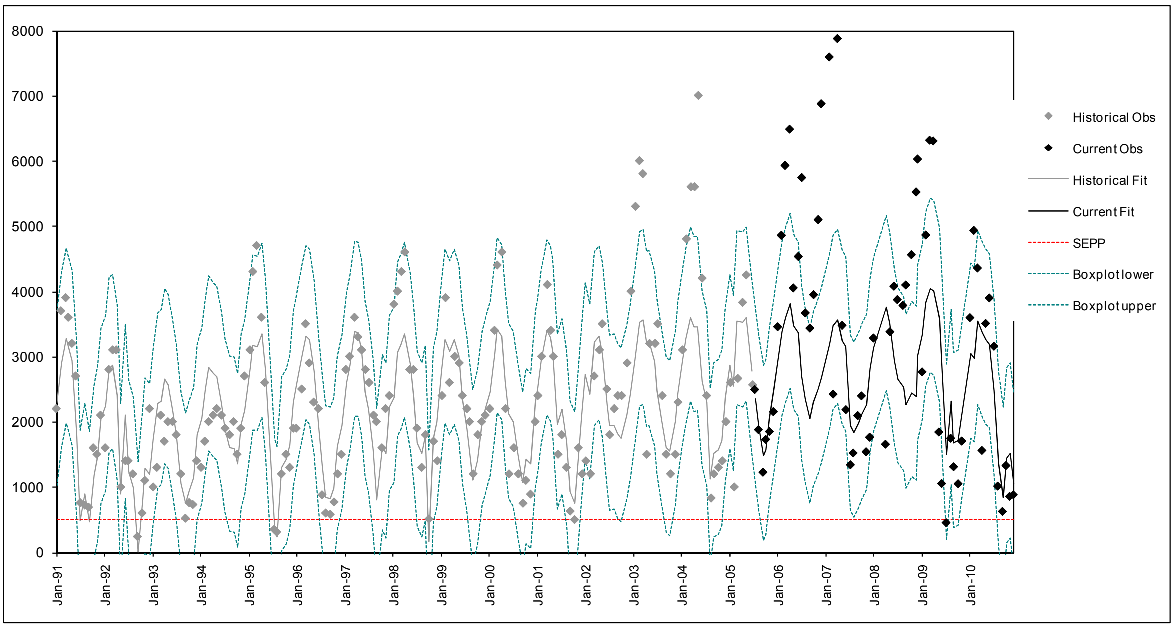
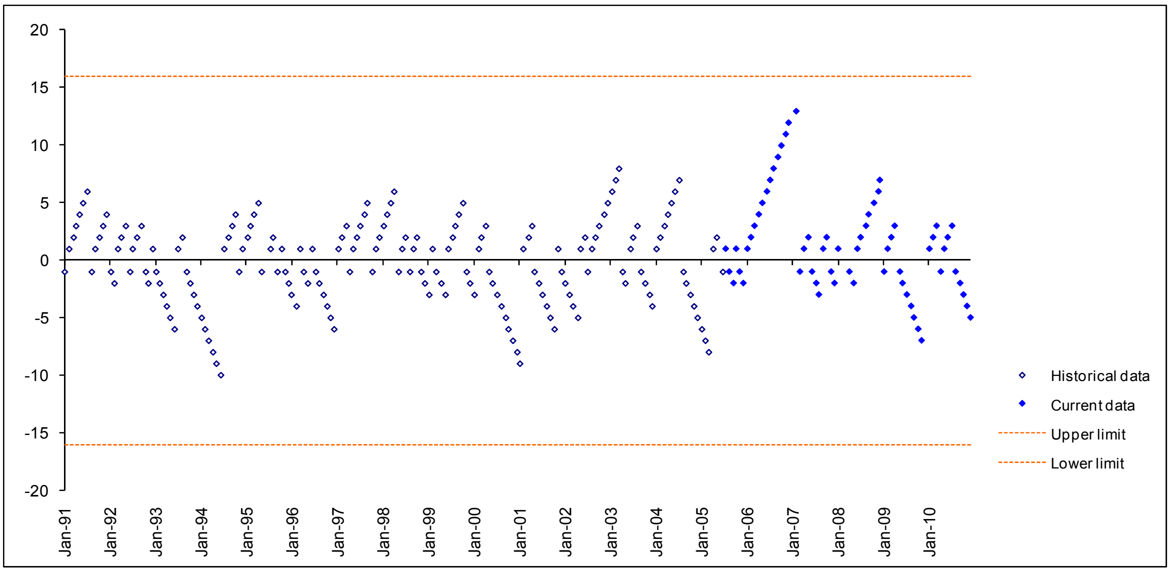


Figure 9-9: Run chart for electrical conductivity (in µS/cm) in the Wimmera River @ Eversley 1991 – 2010



9.3.4. pH

Variations in pH in the Wimmera River @ Eversley were partly explained (R^2= 0.27) by temperature, date and flow (Table 9-9). The regression model predicts an increasing trend in pH, and since 2005, average and median pH levels at this site have increased (Table 9-10). pH levels at this site have exceeded the upper State Environment Protection Policy (Waters of Victoria) trigger level of 8.3 on numerous occasions since 2005, and a few observations have been outside of the upper and lower model control limits (Figure 9-10; Figure 9-11). The higher pH levels recorded from 2005 to 2009 correlate with cease-to-flow conditions and probable high rates of photosynthesis from algal blooms and aquatic plants. The lower pH levels recorded since the September 2009 floods may be due to the decomposition of organic matter that was washed into the river by the floods. The decomposition process will release carbon dioxide, which in turn reduces pH levels in the water. Another explanation is that the floods and more consistent higher flows that have persisted since them, flushed accumulated algae from the monitoring site and has prevented excessive accumulation of planktonic algae and algal blooms.

Table 9-9: Best fit regression models to describe variation in pH in the Wimmera River @ Eversley between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
pH	pH = 5.5787+ (0.0101*Temp) – (0.00004183*Date) – (0.0616*Flow$^{0.4}$)	168	0.27	5%

Table 9-10: Summary statistics for historical (1991-2005) and current (2005 – 2010) pH data recorded in the in the Wimmera River @ Eversley

Parameter	Record	N	Mean	Median	Standard Deviation
pH	Historical	171	7.70	7.70	0.404
	Current	62	7.96	7.95	0.600

Figure 9-10: Control chart for pH in the Wimmera River @ Eversley 1991 – 2010

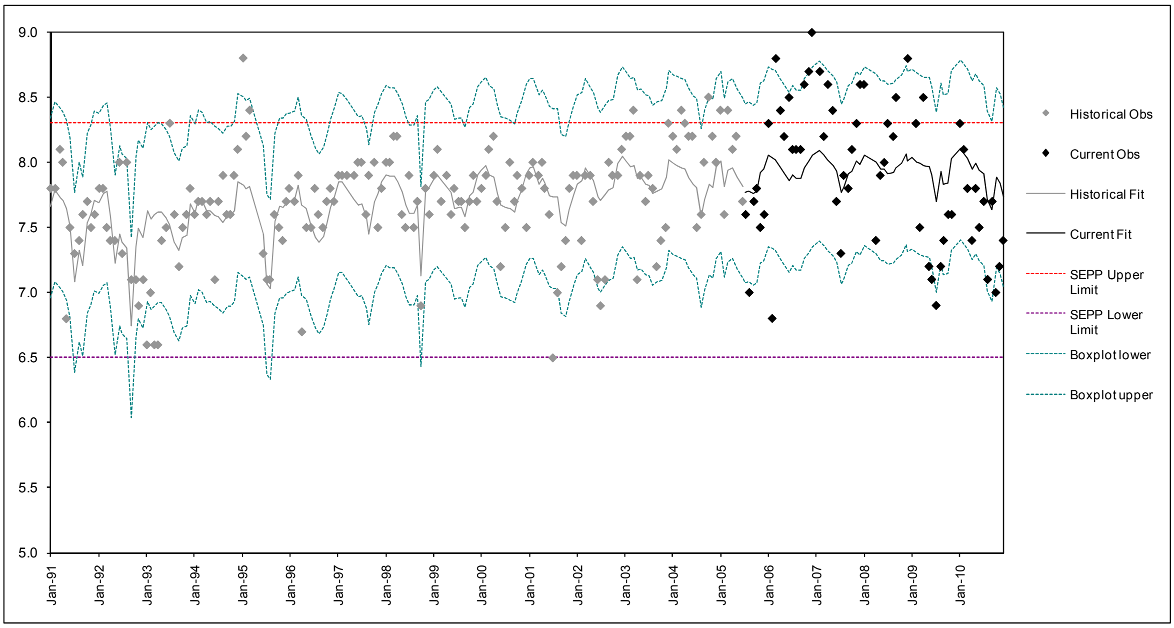
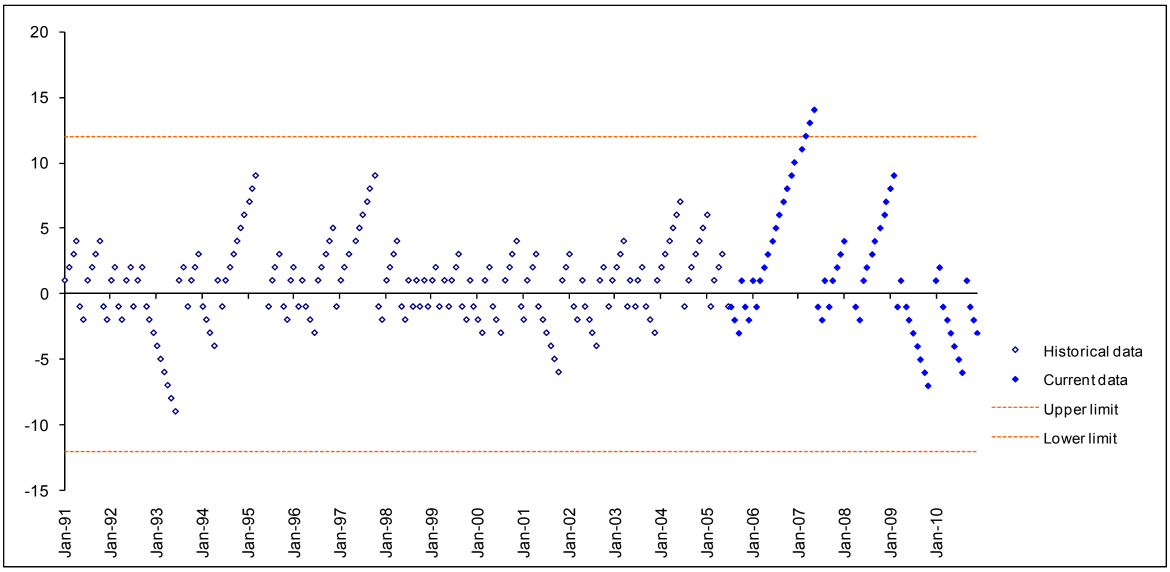


Figure 9-11: Run chart for pH in the Wimmera River @ Eversley 1991 – 2010



9.3.5. Total nitrogen

Variation in total nitrogen in the Wimmera River @ Eversley between 1991 and 2005 was moderately well explained by a combination of water temperature, date, flow and turbidity (Table 9-11). Average and median total nitrogen levels decreased since 2005, but were more variable compared to the preceding 15 years (Table 9-12). Although there were no extended runs where the observed values exceed the predicted value (Figure 9-13), there were five occasions between 2006 and 2010 where total nitrogen levels were outside of the historical control limits and may warrant further investigation (Figure 9-12). The greater scatter in the data since 2005 is potentially due to internal loading of nutrients after the September 2009 floods (M. Toomey, *personal communication*, 1/5/12). Total nitrogen concentrations at this site were generally well below the State Environment Protection Policy (Waters of Victoria) trigger levels of ≤0.600 mg/L

Table 9-11: Best fit regression models to describe variation in total nitrogen in the Wimmera River @ Eversley between 1991 and June 2005.

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Total nitrogen (TN)	$TN^{0.4}$ = 2.8151 – (0.0126*Temp) – (0.00004606*Date) +(0.0101*$Flow^{0.4}$) + (0.004759*Turbidity)	171	0.44	125%

Table 9-12: Summary statistics for historical (1991-2005) and current (2005 – 2010) total nitrogen data recorded in the in the Wimmera River @ Eversley

Parameter	Record	N	Mean	Median	Standard Deviation
Total nitrogen (mg/L)	Historical	174	0.117	0.065	0.187
	Current	62	0.078	0.010	0.230

Figure 9-12: Control chart for total nitrogen (in mg/L) in the Wimmera River @ Eversley 1991 – 2010

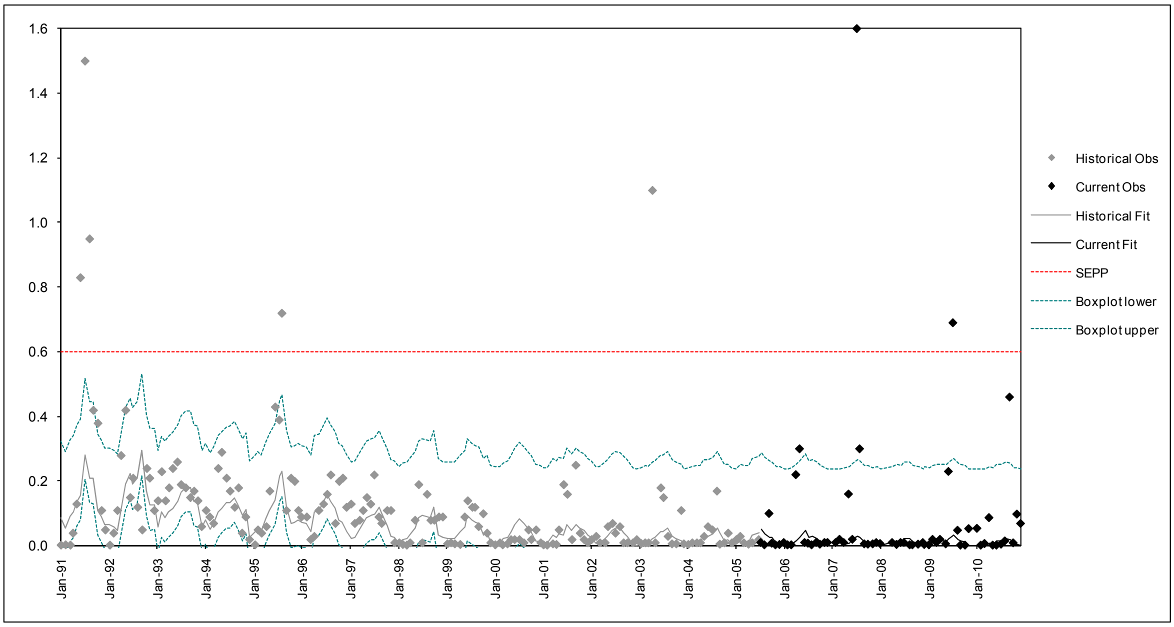
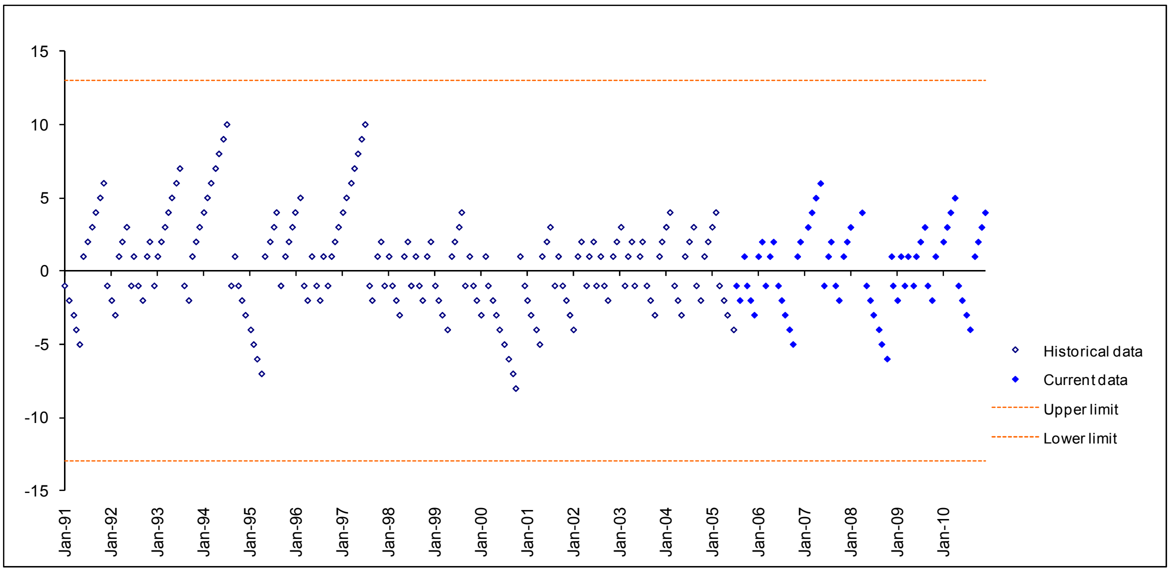


Figure 9-13: Run chart for total nitrogen (in mg/L) in the Wimmera River @ Eversley 1991 – 2010



9.3.6. Total phosphorus

Variation in total phosphorus concentration in the Wimmera River @ Eversley between 1991 and 2005 was moderately well explained by date, flow, turbidity and water temperature (R^2= 0.43) (Table 9-13). Average and median total phosphorus concentrations at this site were higher and more variable since 2005 compared to the historical record (Table 9-14). This contrasts with the decline in total nitrogen concentration observed over the same period, but correlates with an increase in turbidity (see Sections 9.3.5 and 9.3.2). The strong 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. The model fits the total phosphorus data reasonably well after 2005 (see Figure 9-14 and Figure 9-15) and accurately predicted the spike in total phosphorus associated with the September 2009 floods (Figure 9-14). However, there were still a few observations that were outside of the model controls that could trigger further investigation, especially since total phosphorus concentrations at this site frequently exceeded the State Environment Protection Policy (Waters of Victoria) trigger level of ≤0.025 mg/L (Figure 9-14).

Table 9-13: Best fit regression models to describe variation in total phosphorus in the Wimmera River @ Eversley between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Total phosphorus (TP)	$TP^{0.4}$ = –0.8004 + (0.003676*Temp) + (0.00001782*Date) + (0.007736*$Flow^{0.4}$) + (0.00373*Turbidity)	171	0.43	77%

Table 9-14: Summary statistics for historical (1991-2005) and current (2005 – 2010) total phosphorus data recorded in the in the Wimmera River @ Eversley

Parameter	Record	N	Mean	Median	Standard Deviation
Total phosphorus (mg/L)	Historical	174	0.025	0.020	0.024
	Current	62	0.096	0.043	0.133

Figure 9-14: Control chart for total phosphorus (in mg/L) in the Wimmera River @ Eversley 1991 – 2010

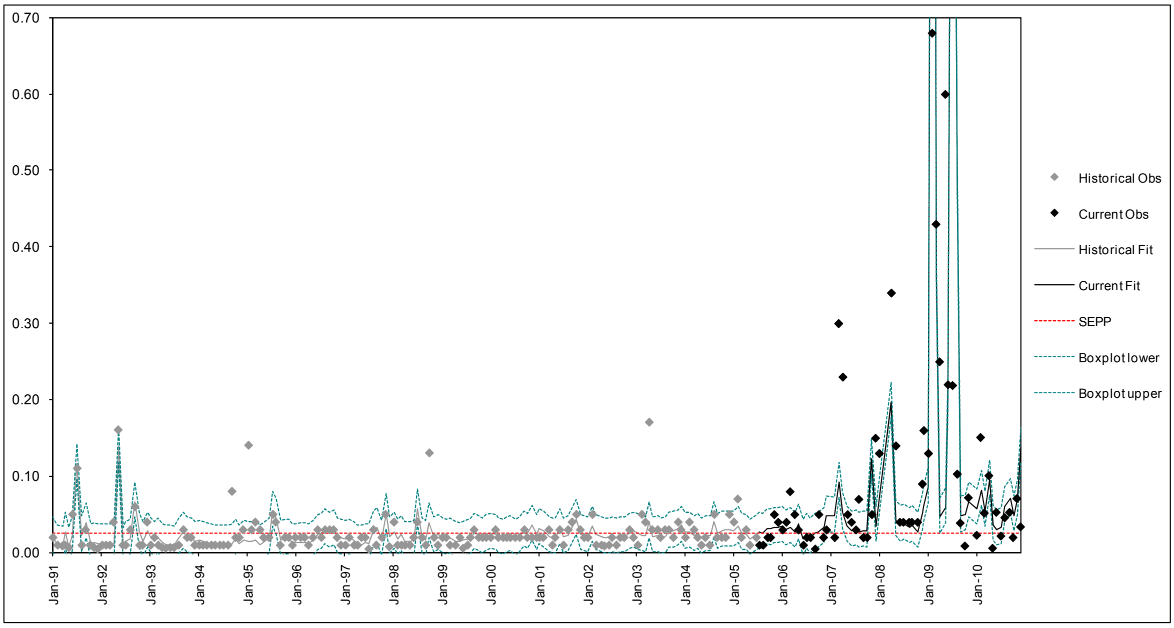
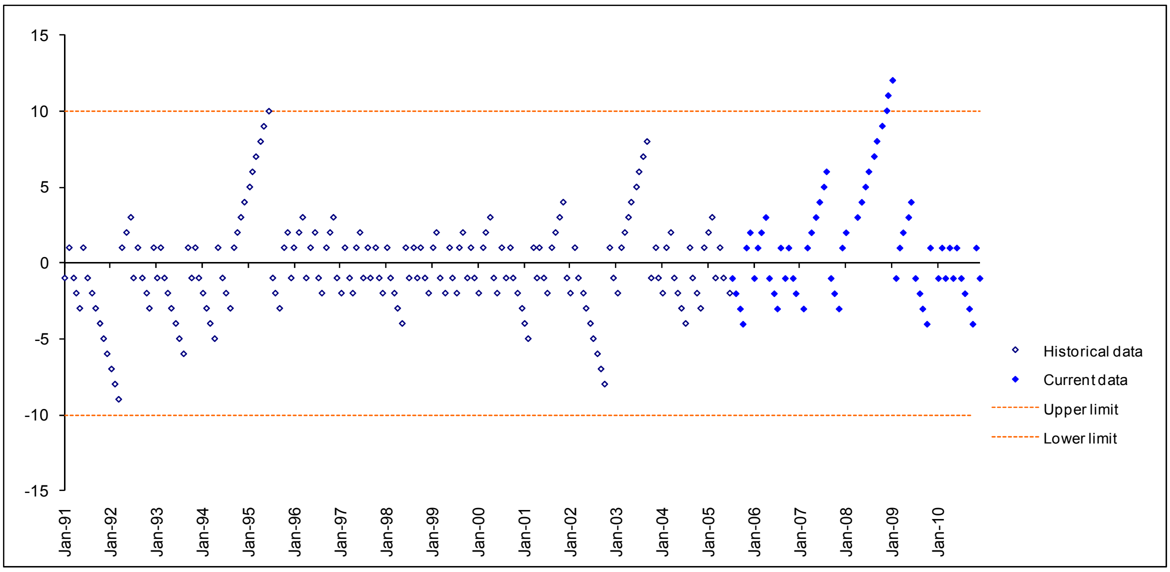


Figure 9-15: Run chart for total phosphorus (in mg/L) in the Wimmera River @ Eversley 1991 – 2010



10. Results for 415200 Wimmera River @ Horsham

10.1. Site Location

The Wimmera River monitoring site at Horsham (streamflow gauge number 415200) is located midway along the Wimmera River, just downstream of Horsham and immediately upstream of the junction with the MacKenzie River (Figure 10-1). The site receives streamflows from the Grampians and the Pyrenees. The Wimmera CMA nominated the site as being of interest from a water quality perspective.

Figure 10-1: Locality map for Wimmera River @ Horsham

10.2. Data availability and quality

Water quality was monitored in the Wimmera River @ Horsham on 177 occasions between January 1991 and June 2005. All water quality variables were measured on 167 occasions (Table 10-1). One turbidity record (310 NTU recorded on 1/11/1993) was an order of magnitude higher than other records and was excluded from the analysis because it was considered an outlier. There was no flow in the Wimmera River on six occasions during the historic period and those data were also excluded from the model fitting analysis to ensure they did not overly influence the results.

Table 10-1: Missing data over period of regression model fit (Jan 1991 – Jun 2005)

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	2	0	0	2	4	4
No. of data points removed as outliers	0	1	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	6	6	6	6	6	6
Sample size for regression analysis	169	170	171	169	167	167

Water quality was monitored in the Wimmera River @ Horsham on 66 occasions between July 2005 and December 2010. There were very few missing data during this period, but 42 of the records were taken during cease-to-flow conditions (Table 10-2). The cease-to-flow results represent two thirds of all records from the test period and were retained for use in the control and run charts. During the drought, non-zero flows were mainly recorded in late winter and spring. However, there was some flow on all monitoring occasions after the floods that occurred in 2009 and 2010.

Table 10-2: Missing data over period of control chart application (Jul 2005 – Dec 2010)

Missing data elements	Dissolved oxygen	Turbidity	Electrical conductivity	pH	Total nitrogen	Total phosphorus
No. of missing water quality readings one days when at least one other parameter was recorded	2	1	1	1	3	3
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 flow data	0	0	0	0	0	0
No. of data points with zero flow data	41	42	42	42	41	41
Sample size for control chart application	64	65	65	65	63	63

10.3. Results for each water quality variable

10.3.1. Dissolved oxygen

Variation in dissolved oxygen (mg/L) levels in the Wimmera River @ Horsham between 1991 and 2005 was moderately well explained (R^2 = 0.47) by a combination of season, temperature and flow (Table 10-3). Average and median dissolved oxygen levels were slightly lower and more variable after 2005 compared to the previous 15 years (Table 10-4). There was high seasonal variability both in the historical and current records above and below the fit of the model, but observed levels were within the upper and lower limits of the model (Figure 10-2). Dissolved oxygen levels were consistently below those predicted by the model after the September 2009 flood (Figure 10-3). These low levels are probably due to the breakdown of organic debris that was deposited in the river during the floods (G. Fletcher, *personal communication,* 1/5/12).

The percent saturation of dissolved oxygen was best explained by the factors season and flow, but the fit (R^2 = 0.19) was not as good as the model for absolute dissolved oxygen (Table 10-3). The control chart for the percent saturation of dissolved oxygen shows the majority of observed data below the lower SEPP trigger level of 85% (Figure 10-4). Percent saturation levels have been consistently below those predicted by the model since the September 2009 flood event (Figure 10-5). The hypoxic (<5mg/L) and anoxic (<2mg/L) dissolved oxygen conditions observed at this site can cause chronic or acute stress to aquatic organisms and potentially cause fish kills. Therefore, any instances of low dissolved oxygen are likely to trigger further investigation.

Table 10-3: Best fit regression models to describe variation in dissolved oxygen in the Wimmera River @ Horsham between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Dissolved oxygen (DO) [mg/L]	$DO^{0.4} = 2.4096 - (0.1037 * Season) - (0.0169 * Temp) + (0.00556 * Flow^{0.4})$	169	0.47	19%
Dissolved oxygen (DO) [% saturation]	$DO = 68.1655 - (7.5328 * Season) + (0.433 * Flow^{0.4})$	169	0.19	19%

Table 10-4: Summary statistics for historical (1991-2005) and current (2005 – 2010) dissolved oxygen data recorded in the Wimmera River @ Horsham

Parameter	Record	N	Mean	Median	Standard Deviation
Dissolved oxygen mg/L	Historical	175	7.00	7.00	1.742
	Current	63	6.42	6.60	2.142
Dissolved oxygen % Sat	Historical	175	69.64	70.73	14.66
	Current	63	66.00	68.77	23.18

Figure 10-2: Control chart for dissolved oxygen (in mg/L) in the Wimmera River @ Horsham 1991 – 2010

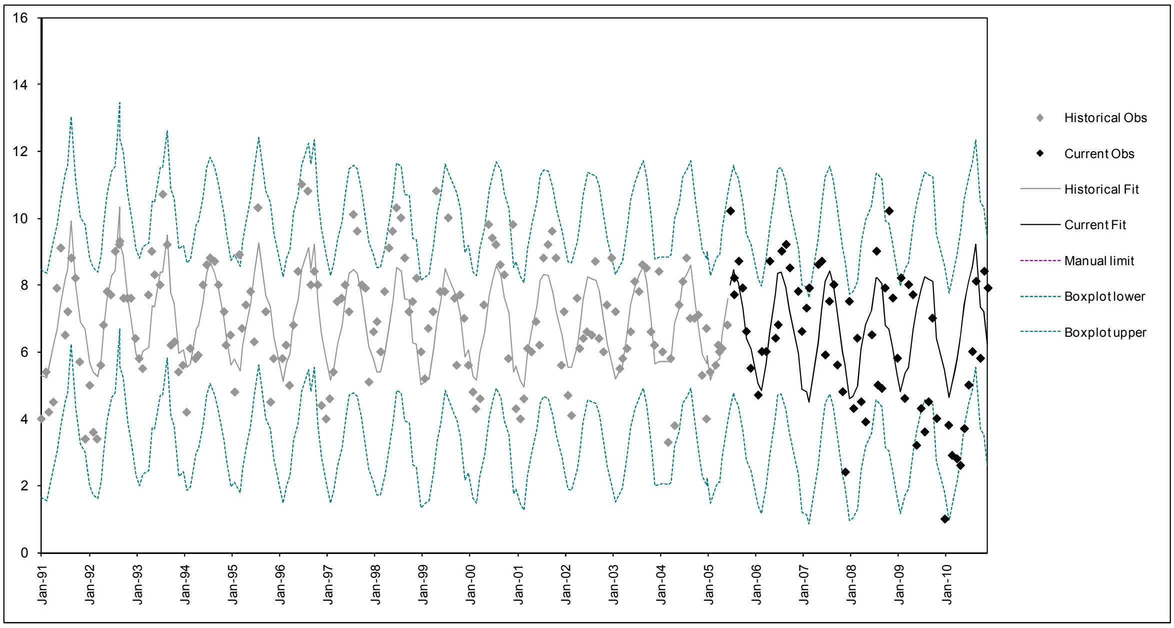


Figure 10-3: Run chart for dissolved oxygen (in mg/L) in the Wimmera River @ Horsham 1991 – 2010

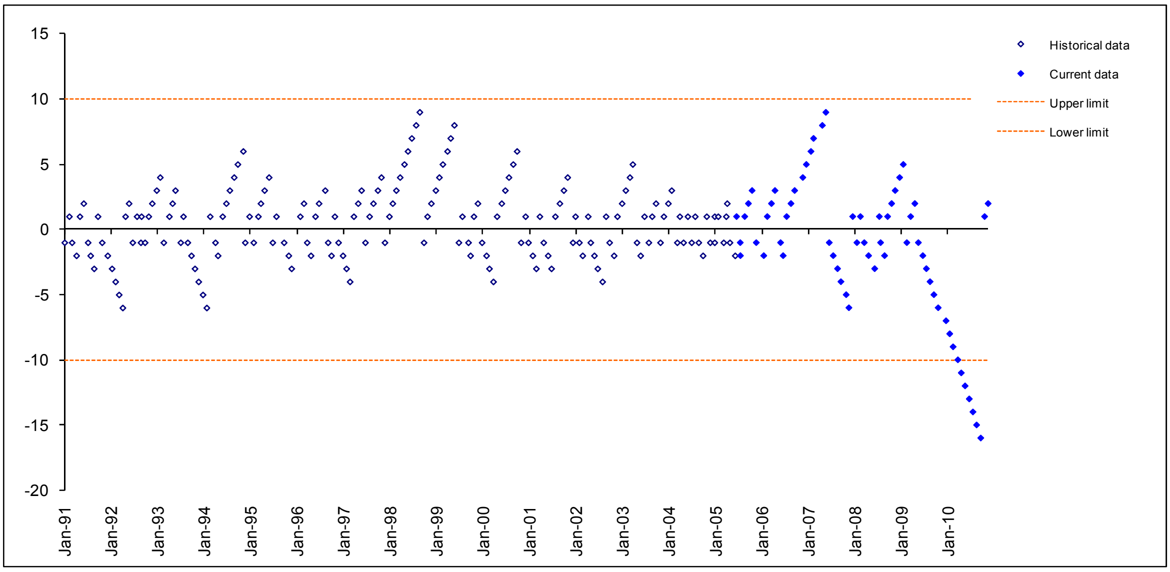


Figure 10-4: Control chart for percent saturation dissolved oxygen in the Wimmera River @ Horsham 1991 – 2010

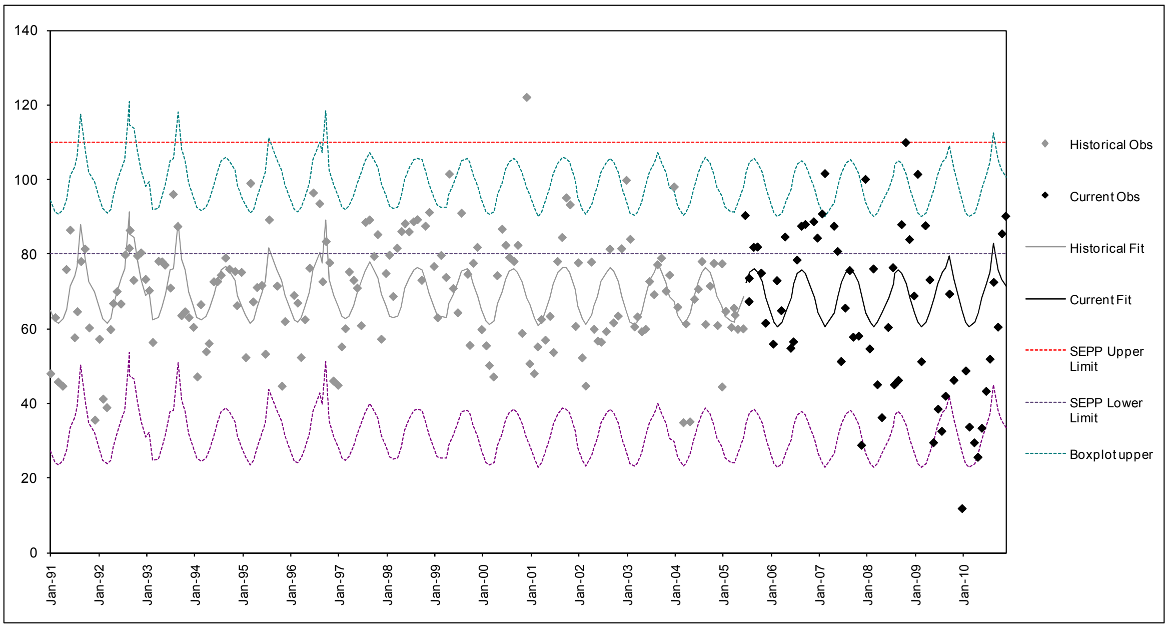
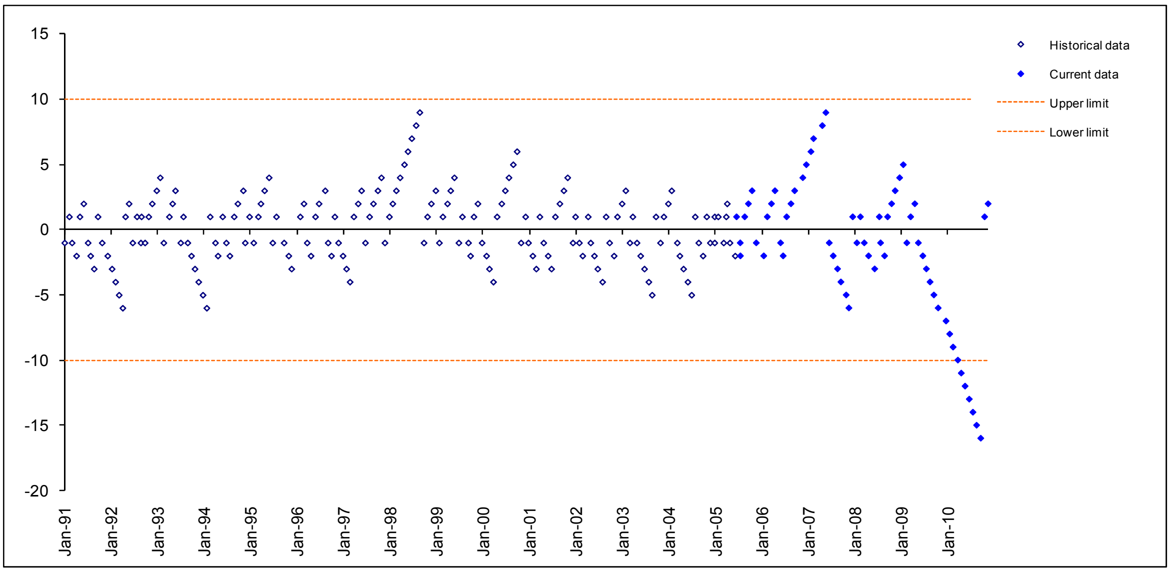


Figure 10-5: Run chart for percent saturation dissolved oxygen in the Wimmera River @ Horsham 1991 – 2010



10.3.2. Turbidity

Variation in turbidity in the Wimmera River @ Horsham between 1991 and 2005 was explained reasonably well (R^2= 0.51) by a combination of flow, electrical conductivity and time since the last rainfall event > 20 mm (Table 10-5). Rainfall data were taken from the Horsham rainfall gauge (site # 079082) operated by the Bureau of Meteorology. The importance of electrical conductivity as a predictor variable suggests that increasing salinities influences the flocculation of suspended particles. 'Time since rainfall' also indicates that the first flush of stormwater from Horsham may affect turbidity levels at this site. Since 2005, average and median turbidity levels have been slightly higher than the historical record (Table 10-6). However, the pattern is not uniform. Turbidity was generally lower than predicted between July 2005 and March 2008 and then was much higher than predicted including several spikes that were above the upper limits of the model and are considered out of control (Figure 10-6 and Figure 10-7). Some of these spikes coincide with high flow events through the upper catchment, but it is not clear what caused high turbidity levels throughout 2008. Turbidity levels at this site only drop below the State Environment Protection Policy (Waters of Victoria) trigger of ≤10 NTU during low flow periods (Figure 10-6).

Table 10-5: Best fit regression models to describe variation in turbidity in the Wimmera River @ Horsham between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Turbidity	$Turbidity^{0.4}$ = 7.7 + (0.0002057*Flow) – (0.2539*$EC^{0.4}$) - (0.001301*TimeSinceRain)	170	0.51	88%

Table 10-6: Summary statistics for historical (1991-2005) and current (2005 – 2010) turbidity data recorded in the in the Wimmera River @ Horsham

Parameter	Record	N	Mean	Median	Standard Deviation
Turbidity (NTU)	Historical	177	23.19	12.00	34.04
	Current	65	29.37	17.00	33.73

Figure 10-6: Control chart for turbidity (in NTU) in the Wimmera River @ Horsham 1991 – 2010

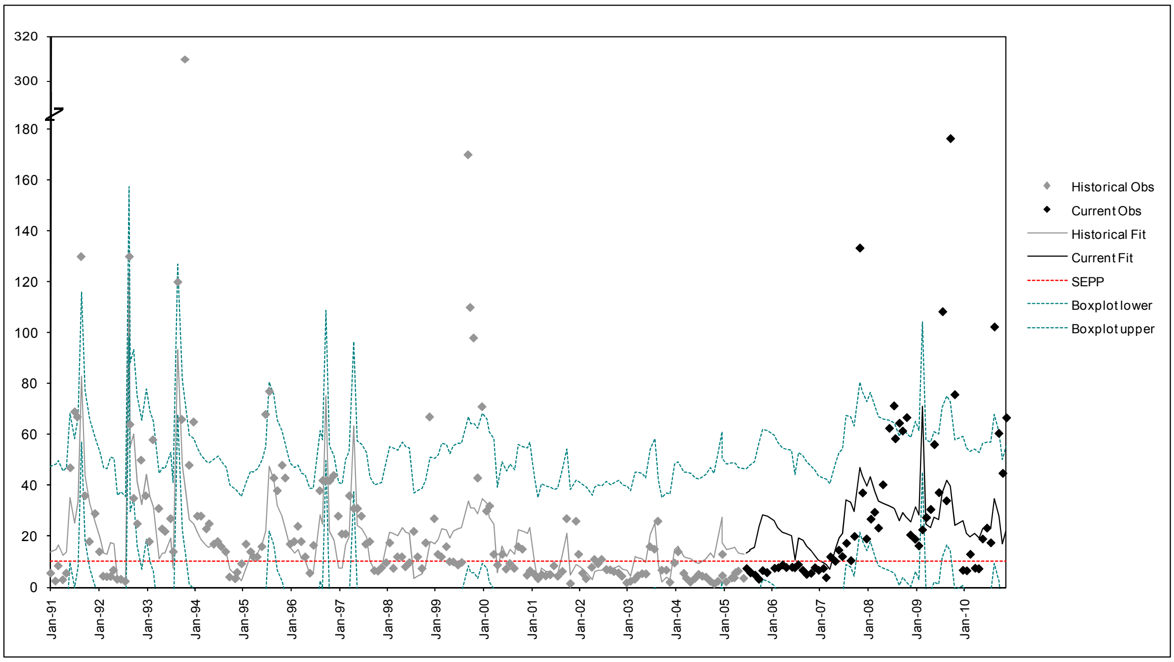
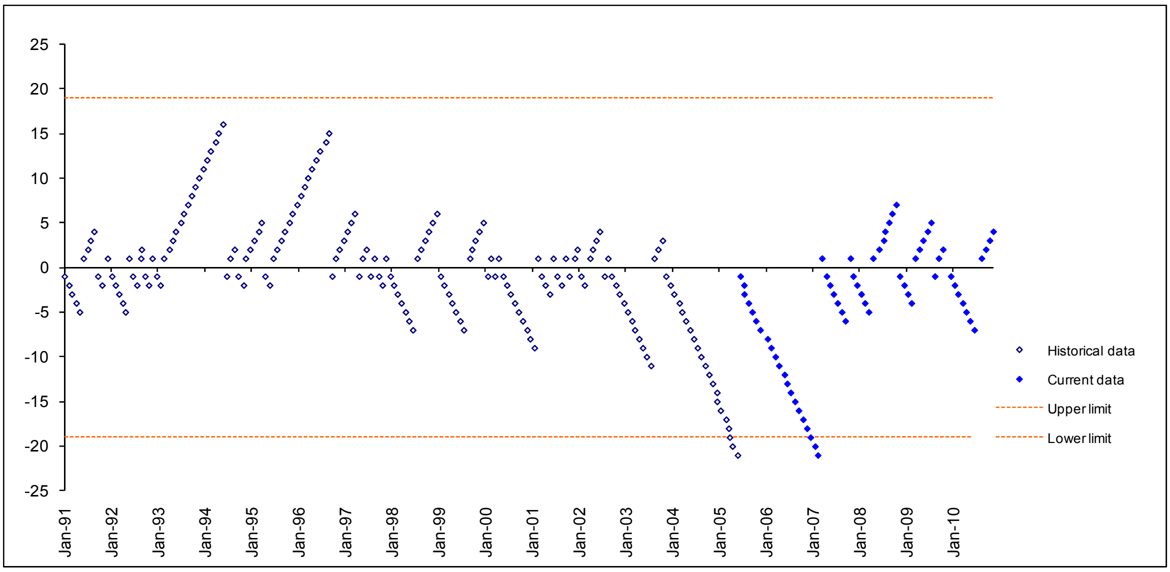


Figure 10-7: Run chart for turbidity (in NTU) in the Wimmera River @ Horsham 1991 – 2010



10.3.3. Electrical conductivity

Variation in electrical conductivity in the Wimmera River @ Horsham between 1991 and 2005 was poorly explained (R^2= 0.18) by the predictor variables considered in our analysis (Table 10-7). The control chart presented in Figure 10-8 is no better than one based on the historical median. Average electrical conductivity levels were significantly lower after 2005 compared to the historical period (Table 10-8). Since 2005, the observed data have been consistently below the model fit (Figure 10-9). The lower electrical conductivity levels after June 2005 may be attributed to the high proportion of water sourced from Horsham town stormwater runoff during the drought (M. Toomey, *personal communication*, 1/5/12). Prior to 2005, there were more saline flows from the upper catchment (G. Fletcher, *personal communication*, 1/5/12). Most electrical conductivity readings taken at this site since 2005 have been below the State Environment Protection Policy (Waters of Victoria) trigger level of ≤1500 µS/cm (Figure 10-8).

Table 10-7: Best fit regression models to describe variation in conductivity in the Wimmera River @ Horsham between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
Electrical conductivity (EC)	EC0.4 = 18.5157 – (0.2785*Flow0.4)	171	0.18	39%

Table 10-8: Summary statistics for historical (1991-2005) and current (2005 – 2010) conductivity data recorded in the in the Wimmera River @ Horsham

Parameter	Record	N	Mean	Median	Standard Deviation
Electrical conductivity (µS/cm)	Historical	177	1333	1300	542
	Current	65	962	976	292

Figure 10-8: Control chart for electrical conductivity (in µS/cm) in the Wimmera River @ Horsham 1991 – 2010

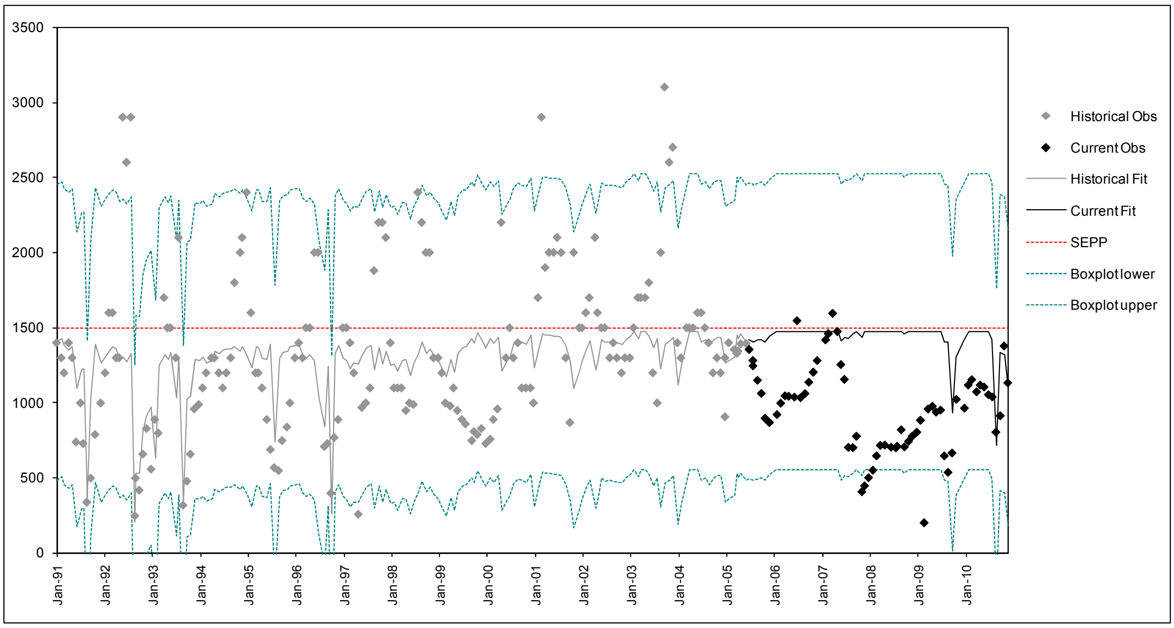
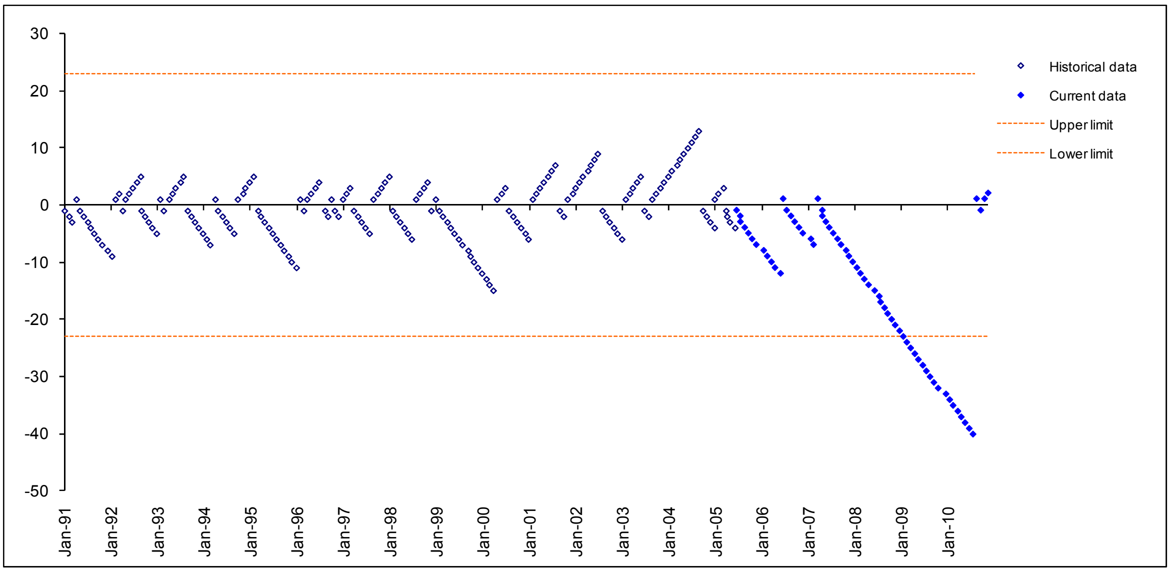


Figure 10-9: Run chart for electrical conductivity (in µS/cm) in the Wimmera River @ Horsham 1991 – 2010



10.3.4. pH

Variations in pH in the Wimmera River @ Horsham between 1991 and 2005 was very poorly explained (R^2= 0.02) by the predictor variables tested in this analysis (Table 10-9). The control chart presented in Figure 10-10 is therefore no better than one based just on the historical median. Average and median pH levels at this site have increased slightly and become more variable compared to the historical record (Table 10-10). However, nearly half of the pH readings taken between 2007 and 2009 were much higher than any pH levels recorded during the historic period and many exceeded the upper State Environment Protection Policy (Waters of Victoria) trigger level of 8.3 (Figure 10-10). These very high pH records may be due to high rates of photosynthesis from increased algal growth that is likely to have occurred under very low flow and cease-to-flow conditions. Lower readings since the September 2009 floods may be due to improved flushing of the site and/or the decomposition of organic matter that was washed into the Wimmera River during the flood.

Table 10-9: Best fit regression models to describe variation in pH in the Wimmera River @ Horsham between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R^2)	Standard Error of Estimate (% of mean)
pH	pH0.4= 2.209 – (0.001037*Flow0.4)	169	0.02	5%

Table 10-10: Summary statistics for historical (1991-2005) and current (2005 – 2010) pH data recorded in the in the Wimmera River @ Horsham

Parameter	Record	N	Mean	Median	Standard Deviation
pH	Historical	175	7.21	7.20	0.38
	Current	65	7.50	7.40	0.51

Figure 10-10: Control chart for pH in the Wimmera River @ Horsham 1991 – 2010

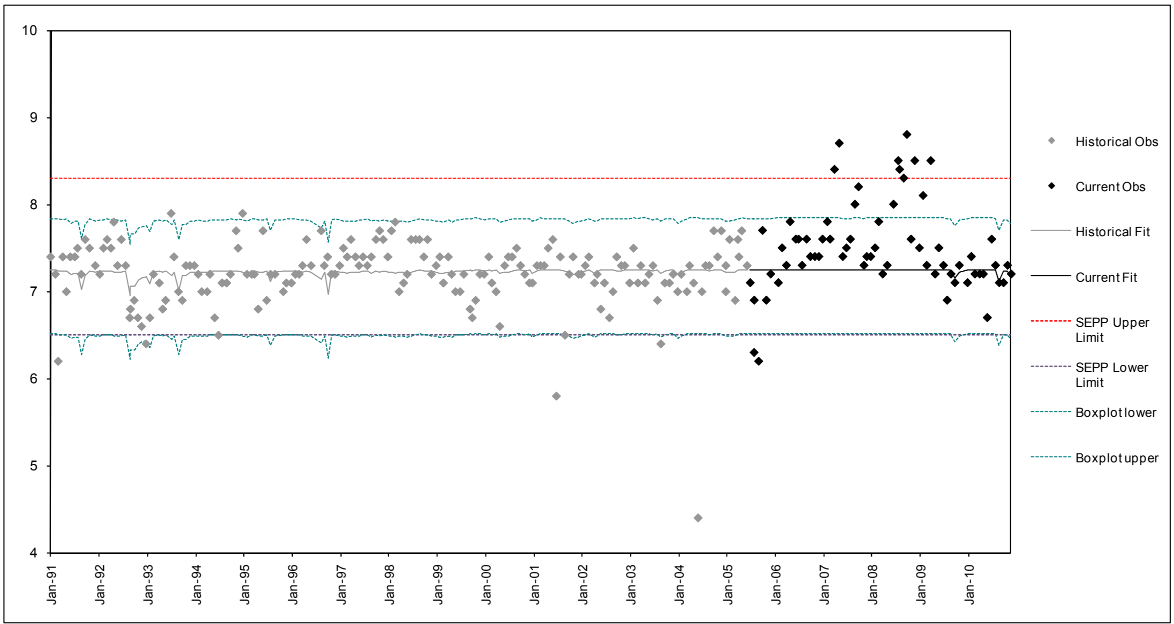
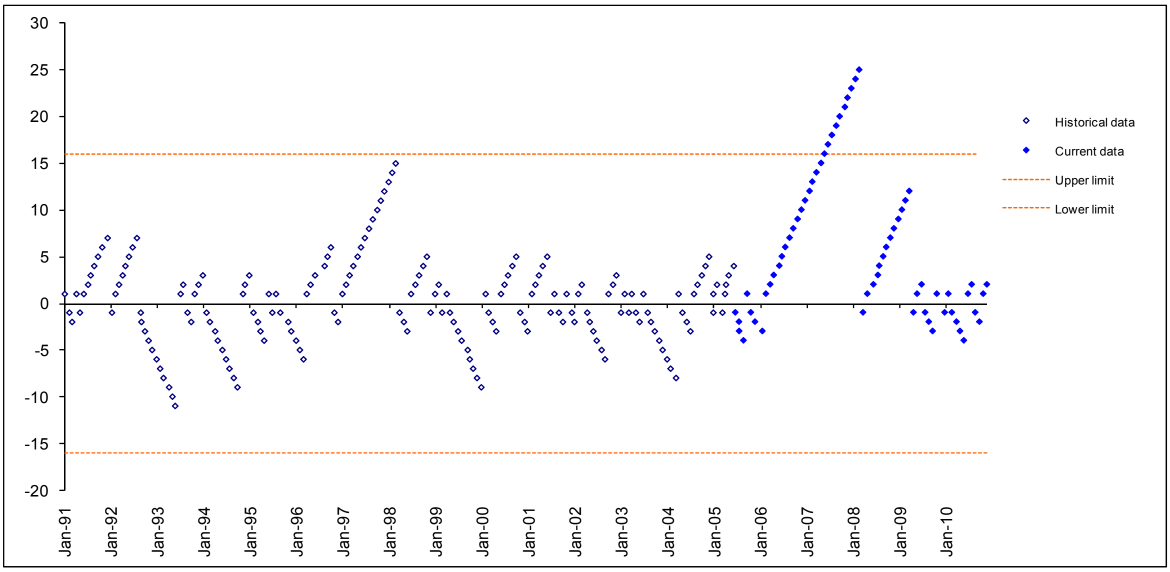


Figure 10-11: Run chart for pH in the Wimmera River @ Horsham 1991 – 2010



10.3.5. Total nitrogen

Variation in total nitrogen in the Wimmera River @ Horsham between 1991 and 2005 was poorly explained by the predictor variables tested in our analysis. The best model was based on a combination of temperature, flow and turbidity (Table 10-11). Total nitrogen levels since June 2005 have been more variable compared to the preceding 15 years (Table 10-12). Although there were no extended runs where the observed values exceed the predicted value (Figure 10-13), there were fifteen occasions between 2006 and 2010 where total nitrogen levels were outside of the historical control (Figure 10-12). These high values may be due to the disproportionately high contribution of stormwater run-off from Horsham to the river flow at this site during the drought (M. Toomey, personal communication, 1/5/12). However, total nitrogen concentrations recorded at this site since January 1991 have all been well below the State Environment Protection Policy (Waters of Victoria) trigger level of ≤0.900 mg/L (Figure 10-12).

Table 10-11: Best fit regression models to describe variation in total nitrogen (in mg/L) in the Wimmera River @ Horsham between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R2)	Standard Error of Estimate (% of mean)
Total nitrogen (TN)	TN0.4 = 0.2288 – (0.008671*Temp) – (0.0008644*Flow0.4) + (0.0502*Turbidity0.4)	167	0.23	166%

Table 10-12: Summary statistics for historical (1991-2005) and current (2005 – 2010) total nitrogen (in mg/L) data recorded in the in the Wimmera River @ Horsham

Parameter	Record	N	Mean	Median	Standard Deviation
Total nitrogen (mg/L)	Historical	173	0.048	0.020	0.0874
	Current	62	0.073	0.020	0.1029

Figure 10-12: Control chart for total nitrogen (in mg/L) in the Wimmera River @ Horsham 1991 – 2010

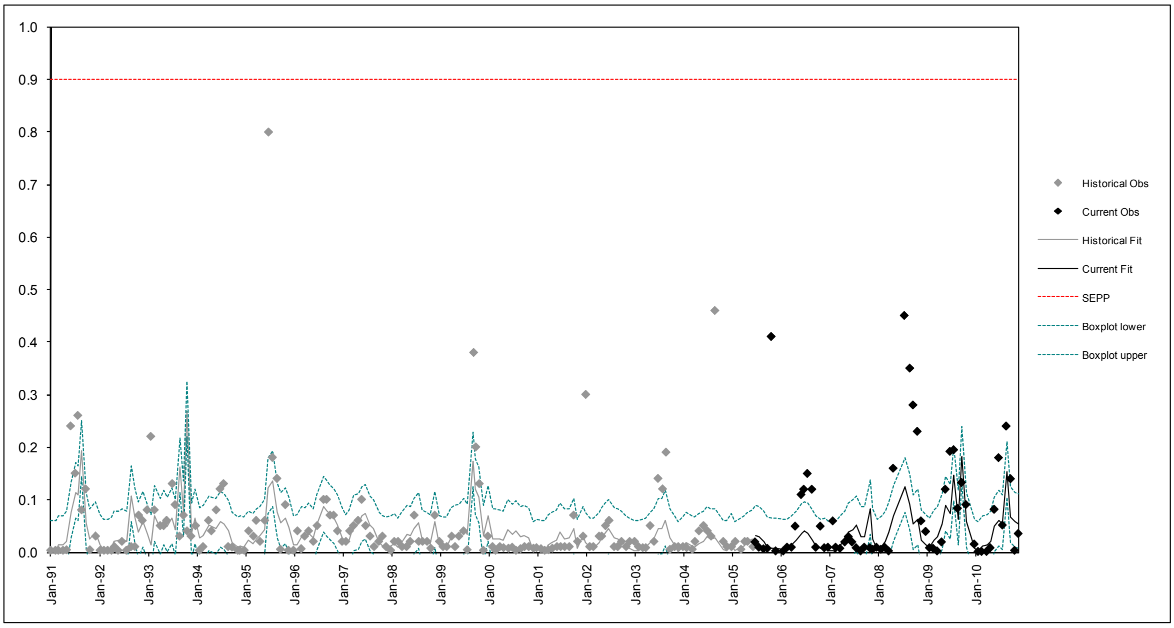
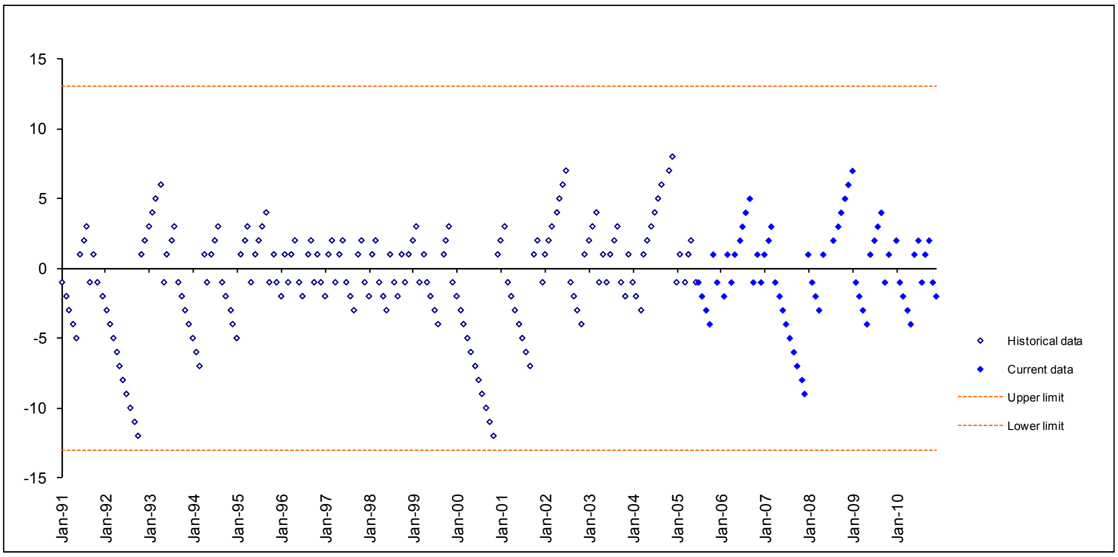


Figure 10-13: Run chart for total nitrogen (in mg/L) in the Wimmera River @ Horsham 1991 – 2010



10.3.6. Total phosphorus

Variation in total phosphorus concentration in the Wimmera River @ Horsham between 1991 and 2005 was well explained by flow and turbidity (R^2= 0.59) (Table 10-13). However, the average and median total phosphorus levels post-2005 at this site were higher and more variable compared to the historical record (Table 10-14). The observed levels, particularly during 2008/09 did not match those predicted by the model (Figure 10-14). There are also at least eleven data points that are above the control limits of the model that may trigger further investigations, particularly since most records after September 2007 exceeded the State Environment Protection Policy (Waters of Victoria) trigger level of ≤0.040 mg/L (Figure 10-14). The increase in total phosphorus at this site correlates well with an increase in turbidity and total nitrogen and decrease in electrical conductivity that were attributed to the high proportion of water sourced from Horsham town stormwater runoff during the recent drought conditions (M. Toomey, *personal communication*, 1/5/12).

Table 10-13: Best fit regression models to describe variation in total phosphorus (in mg/L) in the Wimmera River @ Horsham between 1991 and June 2005

Parameter	Model	Sample Size	Coefficient of determination (R2)	Standard Error of Estimate (% of mean)
Total phosphorus (TP)	TP0.4 = 0.1317 + (0.001808*Flow0.4) + (0.042*Turbidity0.4)	167	0.59	50%

Table 10-14: Summary statistics for historical (1991-2005) and current (2005 – 2010) total phosphorus (in mg/L) data recorded in the in the Wimmera River @ Horsham

Parameter	Record	N	Mean	Median	Standard Deviation
Total phosphorus (mg/L)	Historical	173	0.042	0.030	0.0319
	Current	62	0.070	0.060	0.0507

Figure 10-14: Control chart for total phosphorus (in mg/L) in the Wimmera River @ Horsham 1991 – 2010

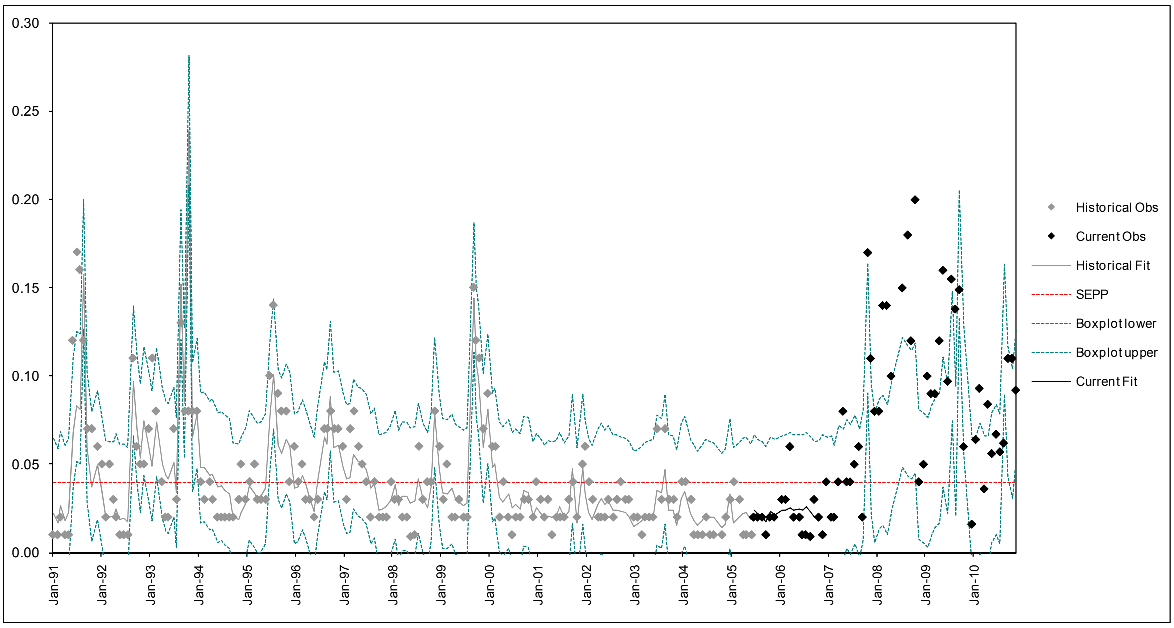
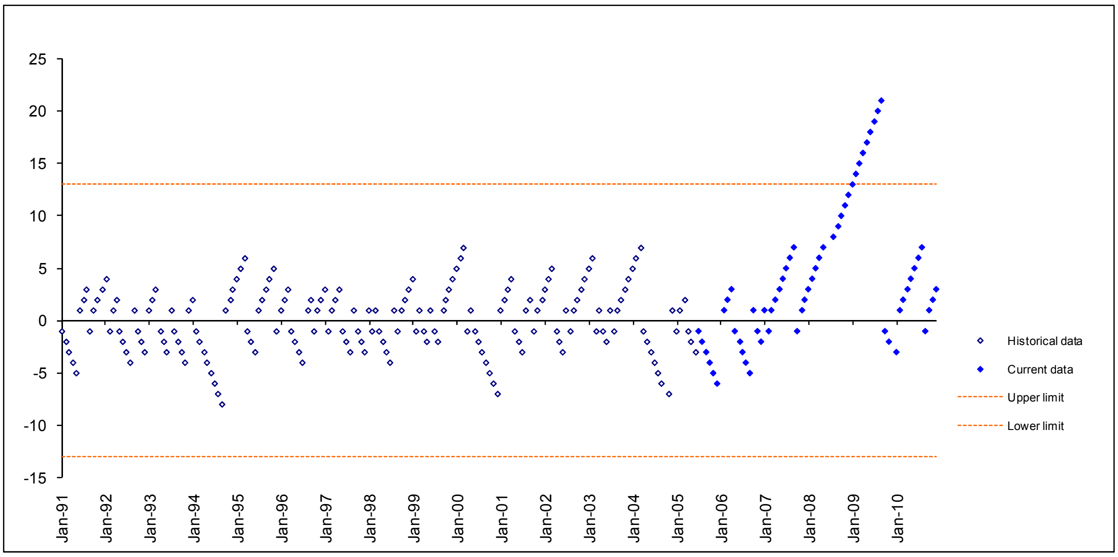


Figure 10-15: Run chart for total phosphorus (in mg/L) in the Wimmera River @ Horsham 1991 – 2010



11. Conclusions and Recommendations

The water quality trends and relative effectiveness of control charts and run charts to highlight changes in water quality at all six sites are summarised in Table 11-2. A comparison of results across all sites highlights the following points with regard to the use of control charts for water quality analyses and the ability of this method to alert to possible trends.

11.1. Model fits vary between variables and between sites

Our analyses only used predictor variables that were likely to have a direct influence on the water quality variable of interest. For example, flow, rainfall and water temperature were tried in all models because all six of the water quality variables of interest are known to be affected by these parameters under certain circumstances. Electrical conductivity was used as a predictor in the turbidity models, because suspended particles are more likely to settle out of suspension at high salinity, which would in turn reduce turbidity readings. However, other water quality variables were not used as predictor variables even if they were likely to have a strong correlation with the water quality variable of interest. For example, total nitrogen was not used to explain variation in total phosphorus because even though they are likely to co-vary, they do not directly influence each other. Excluding co-correlated variables that do not have any causal link with the water quality variable of interest may reduce the statistical fit of some models, but is likely to improve any interpretation of temporal changes in water quality.

Other predictor variables such as changes to land use and bushfire history were considered during the method development stage of the project, but were discounted because they were not routinely measured at an appropriate temporal scale and therefore could not be readily fitted to the regression models. Sourcing and manipulating intermittent datasets and matching them to water quality data collected at different frequencies or over different time periods can involve a lot of effort, and that effort is not warranted if the data cannot be reliably used in the final analysis.

We tested many combinations of predictor variables to find the regression model that explained most of the variation in historical data (i.e. for the period 1991-2005) for each water quality variable at each site. Model fits varied widely between variables and between sites. Historical variation in turbidity was generally well explained by predictor variables at most sites and the model for turbidity in the Broken River at Goorambat explained the most variation ($R^2 = 0.75$) out of all the models tested in this study. Variation in pH was not well explained by models at any sites and the model for pH in the Wimmera River at Horsham had the poorest fit ($R^2 = 0.02$) of all tested models.

The poor model fits for pH are partly due to the range of predictor variables available, because there are not clear links between many of them and pH. Moreover, because pH is measured on a logarithmic scale, variation is not well described by simple regression models, even if the predictor variables are transformed. None of the models for pH used in this study were noticeably better than a constant only model and given the effort required to fit models to historical data, we recommend that future water quality trend analyses use the historical median to produce control charts and run charts for pH.

From a management perspective it is important that the predictor variables used in the models make intrinsic sense and where possible have a direct causal link to the water quality variable of interest. As previously mentioned, the predictor variables tested in this project were limited to those variables that were measured concurrently at each site. The overall strength of control charts is to some extent determined by how well the models are able to predict conditions and the size of the errors associated with those estimates. Models that can predict water quality conditions with a high degree of confidence (i.e. small confidence limits) will be much better at highlighting when water quality is deviating too far from levels that are expected at a site given the prevailing conditions. Early detection of emerging issues may be important as it will allow waterway managers to assess risks and if necessary intervene before too much environmental damage is done. With this in mind, it may be worth investigating the factors that affect water quality at certain sites of interest and then implement a monitoring program to measure more relevant predictor variables. For example, more widespread monitoring of chlorophyll-a levels may help determine when or explain why supersaturated levels of dissolved oxygen are likely to occur and reduce the uncertainty associated with those predictions.

11.2. Different predictor variables were important at each site

Flow was a significant predictor for all water quality variables at most sites. However, the combination of predictor variables differed between sites. Some of these differences are quite informative. For example, cumulative rainfall in the preceding 72 hours and time since the last rainfall event greater than 20 mm explained a significant amount of historical variation in nutrient concentrations in the Barwon River @ Pollocksford and in the Goulburn River @ Shepparton. Both of these sites are in catchments with intensive agriculture and drains that will efficiently carry run-off from agricultural land during rain events. In contrast, local rainfall had little effect on nutrient levels in the Gellibrand River @ Bunkers Hill, which is in a mainly forested catchment. It is interesting to note that local rainfall was not a significant predictor of nutrient levels in the Broken River @ Goorambat, which has similar levels of irrigated agriculture to the Goulburn River @ Shepparton. The difference between the Goulburn and Broken River sites may be due to the number and location of irrigation drains that discharge into the river near the respective water quality monitoring sites. It may also be because historically water quality in the Broken River @ Goorambat has been heavily influenced by regulated flow from Lake Mokoan, which may have masked any effects of local run-off.

Recent rainfall amounts and the time since the last major rain event also explained a large amount of the variation in turbidity levels in the Wimmera River @ Eversley and the Wimmera River @ Horsham. Erosion is a significant problem in parts of the upper Wimmera River and heavy rainfall is likely to wash fine clay particles into the river at Eversley. Turbidity in the Wimmera River @ Horsham is negatively correlated with time since the last significant rain event and it is possible that the catchment needs to be saturated before there is significant run-off into the river.

The main message from these results is that water quality is strongly influenced by local conditions and separate models need to be developed to determine the suite of variables that are likely to best predict water quality at each site. Moreover, care must be taken when trying to extrapolate water quality trends from a single site or from a small number of sites to a larger scale or when trying to describe regional trends.

11.3. It is important to understand the history of catchment management at each site

Changes in land or river management can have a very noticeable effect on some water quality parameters and if they are not accounted for can have a very disruptive effect on the models that are used to describe variation in historical data and on the application of the control charts. Two examples have been identified in the current study.

First, changes to the operation of the South Ballarat Treatment Plant and the introduction of nutrient management plans on dairy farms near Colac in the late 1990's virtually eliminated incidents of extremely high nitrogen and phosphorus concentrations in the Barwon River @ Pollocksford. Regression models based on data collected between 1991 and 2005 did not adequately describe variation in total nitrogen or total phosphorus and did not reliably predict nutrient concentrations after 2005. Restricting the period of historical data to only include data collected after 1999 meant that the conditions under which the regression model was developed were directly comparable to the conditions experienced during the test period and therefore the control charts that were developed from those models were relevant and informative.

Second, water quality in the Broken River @ Goorambat was influenced by flow and conditions in the Broken River and by water that was released out of Lake Mokoan. Lake Mokoan was created by damming Winton and Green Swamps to supply the Murray and Goulburn Irrigation Areas. However, it is a very shallow lake that has a history of poor water quality and algal blooms. Outflows from Lake Mokoan entered the Broken River a short distance upstream of the Goorambat monitoring site and have a large influence on water quality at Goorambat. In 2009, Lake Mokoan was decommissioned and efforts were put in place to rehabilitate the Winton Wetlands. Water from the Winton Wetlands can still flow to the Broken River during wet weather events, but those flows will be much less frequent than they were when Lake Mokoan was being actively managed as part of the irrigation supply system. Our regression analyses identified flow from Lake Mokoan as a significant predictor of water quality (particularly turbidity, dissolved oxygen and electrical conductivity) in the Broken River @ Goorambat. If there were no longer any chance of flow from Lake Mokoan entering the Broken River there would be little value in using it as a predictor variable in the models. In fact, if flow from the Winton Wetlands could not affect water quality in the Broken River @ Goorambat, there would be little value in using any data collected before 2009 to predict water quality at our study site after 2009 because the historical conditions would not reflect current operating conditions.

Because flow can still enter the Broken River from the Winton Wetlands it is very useful to use a measure of that flow as an input to the models for that site as long as flow in the Broken River is also included. By including both flow variables, we are able to take account of the influence of inputs from Lake Mokoan or Winton Wetlands when they occur. At other times, the model assumes flow from Lake Mokoan is zero and estimates water quality from the other measured variables in the model. Any changes in the quality of water in Winton Wetlands over time as a result of its change in operation may however require a change to the regression models used in this analysis.

Both of the examples described above highlight the need to understand the history of land and catchment management at each site and ensure that the models fitted to historical data reasonably reflect current conditions. These crucial pieces of information may not be readily detected through purely statistical analyses of the data. In some cases removing data that do not represent current conditions may reduce the goodness-of-fit of the model. However, such decisions must be made if the control charts and run charts are going to be useful tools for assessing when water quality changes are out of control and warrant further investigation.

11.4. Control charts and run charts are useful for highlighting changes in water quality that differ from historical patterns

Normal methods of analysing temporal trends in water quality would focus on the average or median conditions and associated variation over a pre-determined historical period and compare those statistics against that recorded during a more recent period. Such approaches work well when background conditions during the historic period are similar to those experienced during the test period. However, they may erroneously identify a changed pattern as something that is out of keeping with expected results. By establishing a relationship between water quality and a suite of appropriate predictor variables, we can more reliably determine whether the observed water quality conditions are consistent with historical patterns at that site. They can also highlight when conditions change relative to historical patterns even when the actual values are below thresholds set by State Environment Protection Policy (Waters of Victoria) or ANZECC and may therefore otherwise be ignored. Looking at the problem another way, such analyses may identify instances where antecedent conditions prevent State Environment Protection Policy (Waters of Victoria) objectives from being met, and where no reasonable amount of management intervention will result in meeting those objectives. Several examples described below demonstrate how control charts highlight these differences.

The mean and median dissolved oxygen levels in the Goulburn River @ Shepparton between 2005 and 2010 were slightly lower than dissolved oxygen levels over the preceding 15 years. However, the control chart and run chart showed that dissolved oxygen levels since 2005 were actually higher than expected. The predictive model had correctly described a steady decline in dissolved oxygen levels at the site between 1991 and 2005. That decline was arrested after 2005, and although the pattern can be seen by simply plotting the data against the 20 year timeline, the arrested decline is much more obvious through the use of the control and run charts.

Other strong examples include the variation in total phosphorus in the Broken River @ Goorambat and in the Wimmera River @ Eversley. Models for both of these sites explained approximately 45% of the historical variation in total phosphorus levels and included turbidity as an explanatory variable. Between 2007 and 2009 total phosphorus levels in the Broken River @ Goorambat rose to more than three times the median value. These observations were much higher than previous records and would normally be considered out of control. However, the recorded values occurred during high flow events after the 2006 bushfires and the recorded levels of total phosphorus were actually much less than predicted by the model given the flow magnitude and associated turbidity levels. During and after the 2009 floods total phosphorus levels in the Wimmera River @ Eversley rose to more than 60 times the historical mean and median. However, as with the Broken River example, these extremely high levels were actually less than predicted by the models. While the very high nutrient levels in both examples is potentially a cause for concern, the finding that they are in keeping with expected results gives some confidence that they will return to more normal levels when the effect of the fires and floods has passed. Existing monthly monitoring is likely to be adequate to track these responses, and if conditions start to diverge from the expected pattern then more detailed investigations (e.g. installing continuous monitoring equipment and monitoring other variables) would be justified to identify the reason for the change.

The models and associated control charts and run charts do not always predict water quality changes even when severe changes are expected. For example, most of the models failed to reliably predict water quality conditions in the Wimmera River @ Eversley and Horsham during the drought. The Wimmera River was one of the most drought affected rivers in Victoria. It ceased-to-flow for extended periods after 2005 and water quality samples during that time were taken from isolated pools that did not receive any inflows for months at a time (M. Toomey, *personal communication,* 1/5/12) . High temperatures, changes to groundwater levels, and algal growth were all well beyond anything that had been experienced in the preceding 15 years and as a result many records were highlighted as being out of control. The severe conditions experienced in the Wimmera River during the drought were a concern and although not much could be done to address the issue at the time, being able to highlight the fact that conditions were outside of historical experience could be potentially useful for explaining related environmental changes such as fish deaths caused by low dissolved oxygen conditions. Data collected during the drought may also be used to predict what will happen during future droughts, and may provide a baseline that can be used to assess the effectiveness of any future mitigation actions.

11.5. How control charts can support assessment for the State Environment Protection Policy (Waters of Victoria)

Compliance with State Environment Protection Policy (Waters of Victoria) is currently assessed by comparing percentiles calculated from at least 11 monthly samples taken over a continuous 12 month period against specified trigger values for each water quality variable. The trigger values vary between different regions to reflect expected background conditions. If the collected data comply with the specified objective then environmental managers would normally conclude that conditions are acceptable. If the collected data do not comply with the specified objective then further investigations are conducted to determine why the compliance failed and to implement appropriate mitigation actions where necessary.

The current approach is practical and can be readily and consistently applied across the state. However, it does not necessarily take account of site specific issues unless the stated objective is not met and can therefore be a relatively blunt tool. Control charts have the potential to improve the application of State Environment Protection Policy (Waters of Victoria) and particular make it more sensitive to individual circumstances at particular sites.

Control charts can be used in conjunction with State Environment Protection Policy (Waters of Victoria) to determine whether water quality conditions at a particular site are other than expected and whether those differences are likely to represent a risk to aquatic ecosystems and other beneficial uses. Table 11-1 describes four different scenarios where water quality either complies or does not comply with State Environment Protection Policy (Waters of Victoria) objectives and is in or out of control based on prevailing conditions. By using control charts, environmental managers are less likely to invest valuable resources trying to mitigate conditions when the State Environment Protection Policy (Waters of Victoria) objective is not met, if the observed conditions are expected and can be readily explained. Control charts will also help environmental managers to identify potential problems before the State Environment Protection Policy (Waters of Victoria) trigger levels are exceeded, which may enable them to implement effective mitigation strategies early, at less cost and before any environmental damage is done. Control charts that use models that can predict water quality conditions with high precision (i.e. those that have relatively narrow confidence limits) will be most useful for all of these assessments.

The use of control charts may also influence how water quality condition is reported across the state. Under the current system, water quality condition is often reported in terms of the proportion of sites within a particular region or across the whole state that comply with the State Environment Protection Policy (Waters of Victoria) objectives. Such reporting does not consider what factors are contributing to the lack of compliance at particular sites and more importantly does not consider whether anything can be done to change the level of compliance. By using control charts to assess the condition at a particular site in relation to its historical condition and to other factors at the time of assessment, relevant agencies may be able to report condition in a more meaningful context and be better placed to prioritise and implement appropriate management strategies.

Table 11-1: Example scenarios that show how control charts may be used to support State Environment Protection Policy (Waters of Victoria) assessments and responses

Scenario	Water quality variable complies with SEPP (WoV)	Water quality is within predicted range based on prevailing conditions	Interpretation and response
1	Does not comply	Outside of predicted range	Water quality is poor and mitigation actions should be implemented
2	Does not comply	Within predicted range	Either water quality at the site naturally exceeds the State Environment Protection Policy (Waters of Victoria) and therefore is not of concern or the current conditions can be readily explained by other known factors. Environmental manager may choose to address those contributing factors or continue to monitor without acting because the expectation is that conditions will improve of their own accord.
3	Does comply	Within predicted range	Water quality is good and no mitigation is required
4	Does comply	Outside of predicted range	Water quality is poorer than expected and therefore is of concern. More intensive monitoring or mitigation measures can be implemented before conditions get too bad.

11.6. Using control charts and run charts in the future

If reliable models can be developed to explain variation in water quality at a particular site then control charts and run charts will be very powerful tools for assessing water quality results as they are recorded. CMAs and other interested stakeholders can immediately compare a single water quality result against the prediction based on prevailing conditions at the time and decide whether the result is in keeping with historical patterns. Any recorded value that is very different to the predicted value, allowing for reasonable confidence limits, can be immediately identified and may trigger further investigation into potential causes.

The ability to rigorously evaluate individual water quality results as they are collected may help CMAs and other relevant agencies detect environmental stressors when they first occur, which means they may be able to implement appropriate mitigation actions before too much damage is done. Armed with these tools, CMA staff are able to more actively review water quality data as they are collected and use those data in their operational management decisions as well as in longer term strategic planning. Implementing mitigation measures as soon as potential problems arise and monitoring the effect of those actions is likely to accelerate and improve our understanding of specific relationships between water quality, ambient conditions and operational activities. Such information can be readily shared between different agencies and used in operational and strategic planning.

Surface water monitoring, including both flow and water quality parameters, represents a substantial investment by the Victorian Government and its agencies. The previous two water quality trend reports highlighted long-term patterns across the state. The next step will be to use the collected data to relate changes in a particular variable to other changes in the catchment. Such applications will enable agencies to better assess the effectiveness of management actions and to decide what particular management actions are needed and when they should be implemented. Moreover, it will highlight when conditions at a particular site are getting better or worse, which will allow the State Environment Protection Policy (Waters of Victoria) to be used more effectively.

Control charts and run charts are tools that have the potential to significantly increase the use of water quality data throughout Victoria and to increase engagement by CMA staff with the water monitoring program. Most importantly, these two tools will allow CMA staff to better manage their catchments and increase the utility of the state-wide surface water data set collected under Victoria's Regional Water Monitoring Partnerships.

11.7. When should the models in the control charts be updated

Control charts are only as useful as the models that are used to predict future observations. As has already been described, if there are major changes in environmental management practices or water supply systems within a catchment then the models will need to be updated to reflect the current situation. In most cases it will not be possible to update models as soon as management or operations within a catchment change because five or more years worth of data are likely to be needed to determine how water quality responds to the new conditions.

The Victorian *Water Act 1989* requires a review of the surface water monitoring program every 15 years. Unless there are major changes within a catchment, the regression models used to describe variation in water quality parameters at individual sites should remain valid for at least 15 years and therefore for most sites a review of the models once every 15 years should be adequate. A consistent run of water quality values above or below the expected value, or the regular occurrence of out of control readings, would be indicators that a model should be revised prior to the end of the 15 year period. The model updates should re-analyse the relationship between the original predictor variables and the response variable and also include any new variables that are expected to affect the target water quality variable and that are measured at the appropriate temporal scale. The 15 year reviews may also consider the suite of sites where detailed assessments are conducted. Sites that no longer need detailed analyses may either be omitted, or maintained without necessarily updating the existing model. Sites that have recently become a priority for water quality analysis may be added. New models will need to be developed for any new sites.

Table 11-2: summary table showing the best fitting regression model for each water quality variable at each site and an overview of trends since 2005

Site	Variable	Predictor variables	Regression model fit to historical data	Detectable trend since 2005	No. of current observations out of control	Comment
Barwon River @ Pollocksford	Dissolved oxygen (mg/L)	Date, Water temperature, Flow	$R^2 = 0.37$	Higher than predicted	6 values above upper limit	More frequent very high DO events since 2005, possibly due to increased algal growth and photosynthesis during the drought.
	Dissolved oxygen (% sat)	Date, Flow	$R^2 = 0.10$	Higher than predicted	9 values above upper limit; 3 values below lower limit	
	Turbidity (NTU)	Date, Flow, EC	$R^2 = 0.58$	Slightly higher than predicted	2 values above upper limit	Electrical conductivity was included in the model because of the potential causal link between it and turbidity and because initial analyses demonstrated that it improved the predictive capability of the model.
	Electrical conductivity (µS/cm)	Season, Water temperature, Flow	$R^2 = 0.43$	Slightly lower than predicted	1 value above upper limit	Little change compared to historical patterns
	pH	Flow	$R^2 = 0.15$	Higher than predicted 2005-2007; Lower than predicted 2008-2010.	0 values out of control	Tested variables did not predict pH very well and therefore it is probably not worth putting extra effort into constructing a site-specific model for pH.
	Total nitrogen (mg/L)	Water temperature, Date, Flow	$R^2 = 0.33$	Higher than predicted	4 values above upper limit	Nutrient concentration declined markedly after 2000 due to catchment management works, but some very high records after 2005 . TN higher than predicted after 2005, mainly because low flows during drought reduced magnitude of predicted value.
	Total phosphorus (mg/L)	Water temperature, Flow, Rainfall, Time since last rain, Turbidity	$R^2 = 0.21$	Slightly higher than predicted	3 values above upper limit	Nutrient concentration declined markedly after 2000 due to catchment management works. Model successfully predicted spike in TP during flood in 2010.

Site	Variable	Predictor variables	Regression model fit to historical data	Detectable trend since 2005	No. of current observations out of control	Comment
Gellibrand River @ Bunkers Hill	Dissolved oxygen (mg/L)	Season, Water temperature, Flow	R^2 = 0.65	No change	2 values below lower limit	Dissolved oxygen dropped below expected level on several occasions during the drought, but levels are not likely to be a problem for biota
	Dissolved oxygen (% sat)	Season, Flow	R^2 = 0.32	Slightly lower than predicted	5 values below lower limit	
	Turbidity (NTU)	Flow, Water temperature, Date	R^2 = 0.71	Higher than predicted	>10 values above upper limit	Turbidity increased since 2005 and more frequent high turbidity records that exceeded the SEPP trigger values
	Electrical conductivity (µS/cm)	Season, Water temperature, Date, Flow	R^2 = 0.50	Higher than predicted between 2005-2007; as predicted after 2007.	2 values above upper limit	Little change from historical patterns
	pH	Water temperature, Date	R^2 = 0.04	No change	4 values above upper limit	Tested variables did not predict pH very well and therefore it is probably not worth putting extra effort into constructing a site-specific model for pH.
	Total nitrogen (mg/L)	Season, Water temperature, Flow	R^2 = 0.50	Average levels were higher than expected	10 values above upper limit	TN was highest during the worst part of the drought.
	Total phosphorus (mg/L)	Season, Water temperature, Date, Flow	R^2 = 0.31	Lower than predicted	0 values out of control	TP levels frequently higher than SEPP trigger value, but was lower than expected based on historical patterns

Site	Variable	Predictor variables	Regression model fit to historical data	Detectable trend since 2005	No. of current observations out of control	Comment
Goulburn River @ Shepparton	Dissolved oxygen (mg/L)	Water temperature, Date	$R^2 = 0.5$	Higher than predicted	0 values out of control	The increase in dissolved oxygen at this site after 2005 arrested a decline over the previous 5-10 years. Change possibly due to freshwater releases from Lake Eildon to meet downstream demand.
	Dissolved oxygen (% sat)	Water temperature, Date	$R^2 = 0.25$	Higher than predicted	0 values out of control	
	Turbidity (NTU)	Season, Date, Flow	$R^2 = 0.22$	Slightly lower than predicted	1 value above upper limit	Similar to historical patterns
	Electrical conductivity (µS/cm)	Season, Date, Flow	$R^2 = 0.44$	Lower than predicted	0 values out of control	EC is well below SEPP trigger values and is not an issue at this site
	pH	Date, Flow	$R^2 = 0.09$	As predicted	0 values out of control	Tested variables did not predict pH very well and therefore it is probably not worth putting extra effort into constructing a site-specific model for pH. There has been a steady increase in pH at this site since 1991, but values are within the SEPP trigger levels.
	Total nitrogen (mg/L)	Season, Water temperature, Flow, Time since last rain	$R^2 = 0.57$	As predicted	2 values above upper limit	Similar to historical patterns and well below the SEPP trigger level
	Total phosphorus (mg/L)	Flow, Turbidity, Rainfall	$R^2 = 0.60$	Lower than predicted	0 values out of control	Big decline in TP at this site possibly due to run-off from irrigation areas and increased freshwater transfers from Lake Eildon to meet downstream demand in other catchments

Site	Variable	Predictor variables	Regression model fit to historical data	Detectable trend since 2005	No. of current observations out of control	Comment
Broken River @ Goorambat	Dissolved oxygen (mg/L)	Water temperature, Date, Flow in the Broken, Flow from Mokoan	R^2 = 0.64	As predicted	2 values above upper limit; 2 values below lower limit	Continued decline as predicted, but % saturation results are consistently below SEPP trigger level and are a potential cause for concern.
	Dissolved oxygen (% sat)	Water temperature, Date, Flow in the Broken, Flow from Mokoan	R^2 = 0.31	As predicted	1 value above upper limit; 7 values below lower limit	
	Turbidity (NTU)	Flow in the Broken, EC, Flow from Mokoan	R^2 = 0.75	Higher than predicted	>10 values above upper limit	Spikes in turbidity are possibly due to run-off and ash from the 2006 bushfires. Changes to operation of Lake Mokoan has also affected turbidity patterns, and ongoing investigation is warranted. This site is a good candidate for testing automated updates to control charts.
	Electrical conductivity (µS/cm)	Water temperature, Flow in the Broken, Flow from Mokoan	R^2 = 0.45	As predicted	6 values above upper limit	Spike in EC during the worst part of the drought, but there has been a decline since Lake Mokoan was decommissioned.
	pH	Date, Flow in the Broken, Flow from Mokoan	R^2 = 0.12	As predicted	0 values out of control	Tested variables did not predict pH very well and therefore it is probably not worth putting extra effort into constructing a site-specific model for pH. There has been a steady increase in pH at this site since 1991, but values are within the SEPP trigger levels.
	Total nitrogen (mg/L)	Season, Water temperature, Flow in the Broken	R^2 = 0.21	Lower than predicted	0 values out of control	TN was lower than expected probably due to reduced flows from Lake Mokoan. The slight peak in 2007 may be due to sediment input after the bushfires.
	Total phosphorus (mg/L)	Season, Date, Flow in the Broken, Turbidity	R^2 = 0.42	Lower than predicted	2 values above upper limit	General trend for lower TP, but several high spikes in 2007 and 2008 were linked to high turbidity events and may be due to run-off from areas burnt in the 2006 bushfires. Lower TP after that possibly due to decommissioning of Lake Mokoan.

Site	Variable	Predictor variables	Regression model fit to historical data	Detectable trend since 2005	No. of current observations out of control	Comment
Wimmera River @ Eversley	Dissolved oxygen (mg/L)	Season, Water temperature, Date, Flow	R^2 = 0.49	Lower than predicted	>10 values below lower limit	Lowest levels associated with very low flow during the worst part of the drought and after the 2009 floods, possibly due to decomposition of organic material washed in during the floods.
	Dissolved oxygen (% sat)	Season, Water temperature, Date, Flow	R^2 = 0.24	Lower than predicted	9 values below lower limit	
	Turbidity (NTU)	Flow, Rainfall	R^2 = 0.41	Higher than predicted	>10 above upper limit	Very high spikes recorded since 2007 possibly due to high levels of plankton growth during the drought and then associated with floods after September 2009.
	Electrical conductivity (µS/cm)	Season, Water temperature, Flow	R^2 = 0.69	Higher than predicted	>10 above upper limit	Highest EC levels recorded during cease-to-flow periods. The model doesn't predict these high EC records well because cease-to-flow events were not common during the historic period.
	pH	Water temperature, Date, Flow	R^2 = 0.27	Higher than predicted 2006-08; Lower than predicted 2009-10	4 values above upper limit; 3 values below lower limit	High pH during the drought exceeded the SEPP trigger levels and may be due to photosynthesis from planktonic algae. Lower pH during and after floods may be due to breakdown of organic material washed into the river during events.
	Total nitrogen (mg/L)	Water temperature, Date, Flow, Turbidity	R^2 = 0.44	As predicted	4 values above upper limit	TN was much lower after 2000 compared to previous 10 years. The model predicted TN after 2005 reasonably well.
	Total phosphorus (mg/L)	Water temperature, Date, Flow, Turbidity	R^2 = 0.43	Higher than predicted	6 values above upper limit	Very high spikes in TP due to floods were reasonably well predicted by the model, but high TP values during the drought were not well predicted or explained.

Site	Variable	Predictor variables	Regression model fit to historical data	Detectable trend since 2005	No. of current observations out of control	Comment
Wimmera River @ Horsham	Dissolved oxygen (mg/L)	Season, Water temperature, Flow	R^2 = 0.47	Lower than predicted	0 values out of control	Very low DO in last 2 years of drought due to very low flow conditions. Low levels after Sep 2009 floods possibly due to breakdown of organic material washed in during the floods. These low levels were not well predicted by the models.
	Dissolved oxygen (% sat)	Season, Flow	R^2 = 0.19	Lower than predicted	4 values above upper limit, 1 value below lower limit	
	Turbidity (NTU)	Flow, EC, Time since last rain	R^2 = 0.51	Lower than predicted	5 values above the upper limit	Model overestimated turbidity during very low and no flow conditions. Increase in turbidity at the end of the drought may be due to planktonic growth and after the 2009 floods.
	Electrical conductivity (µS/cm)	Flow	R^2 = 0.18	Lower than predicted	4 values below the lower limit	EC lower than expected after 2005 possibly because there is less flow from upstream reaches that have high salinity, lower groundwater levels and the relatively high contribution of stormwater run-off from Horsham.
	pH	Flow	R^2 = 0.02	Higher than predicted	>10 values above the upper limit	Tested variables did not predict pH very well and therefore it is probably not worth putting extra effort into constructing a site-specific model for pH. High pH levels during cease-to-flow events may be due to high photosynthesis from algae.
	Total nitrogen (mg/L)	Water temperature, Flow, Turbidity	R^2 = 0.23	Higher than predicted	>10 values above the upper limit	Model did not predict the magnitude of high TN events very well
	Total phosphorus (mg/L)	Flow, Turbidity	R^2 = 0.59	Higher than predicted	>10 values above the upper limit	Very high TP since 2007 may be partly due to large contribution of urban stormwater to flow in the Wimmera River during the drought.

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