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Victorian Water Quality Monitoring Network Trend Analysis

Mallee Catchment Management Authority Area

Produced for the Department of Natural Resources and Environment by Sinclair Knight Merz

Victoria ON THE MOVE

Victorian Water Quality Monitoring Network Trend Analysis

Mallee Catchment Management Authority Area

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Wimmera Catchment Management Authority Area

Prepared by W.E. Smith and R.J. Nathan
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Executive Summary

The Victorian Water Quality Monitoring Network (VWQMN) consists of around 280 stations located throughout Victoria. A range of water quality indicators are measured at these sites and data has been measured for up to 25 years at approximately monthly intervals. While this data set represents a substantial body of information, to date there has been no systematic and consistent analysis of the data that provides an assessment of the temporal and spatial variation of the indicators. Such analysis can provide valuable information regarding the impacts of past management practices on catchment processes, the impact of land management practices and interventions, and the likely direction of future water quality changes.

The scope of this report is to present the nature and significance of time trends in water quality data recorded at VWQMN sites within the region controlled by the Mallee Catchment Management Authority. Only stations with records greater than ten years were used, and the indicators considered were pH, turbidity, electrical conductivity (EC), total phosphorus and total nitrogen.

This study has been undertaken as part of a state-wide review of water quality trends, and companion reports have been prepared that present the trend results for other Victorian Catchment Management Authorities. In addition, a report covering the whole State has been produced that summarises the results obtained for the individual regions. This series of reports thus provides catchment managers with a valuable source document that contains information in a form that has not been previously available.

The GAM (Generalised Additive Model) approach was used to identify the magnitude and statistical significance of the time trends. The GAM approach has a number of significant advantages over traditional trend detection techniques as it easily accommodates problems associated with periods of missing data, serial correlation, seasonality, climatic influences, and non-constant variance. Overall, the GAM approach is ideally suited to the analysis of "real world" data, and its ability to satisfy the required statistical assumptions means that any inferences drawn regarding statistical significance are robust and accurate.

The preferred GAM model adopted for the study incorporates spline functions to account for the influence of both time and streamflow, and additional functions were included to remove the effects of seasonality, serial dependence, and non-normality. In some cases there was insufficient data to fit the preferred model, and thus it was necessary to use functions based on polynomial rather than spline terms.

Regional evaluation of trend patterns in the Mallee CMA were not possible due to the small amount of data available. Most trends were either decreasing or of zero magnitude.

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1. Introduction

The Victorian Water Quality Monitoring Network (VWQMN) consists of around 280 stations throughout Victoria. A range of water quality indicators are measured at these sites, and data has been measured for up to 25 years at approximately monthly intervals. While this data set represents a substantial body of information, to date there has been no systematic and consistent analysis of the data that provides an assessment of the temporal and spatial variation of the indicators. Such analysis can provide valuable information regarding the impacts of past management practices on catchment processes, the impact of land management practices and interventions, and the likely direction of future water quality changes.

The overall aim of this study was to investigate the nature and significance of time trends in water quality data recorded at VWQMN sites throughout Victoria. The indicators considered were pH, turbidity, electrical conductivity (EC), total phosphorus and total nitrogen, and in order to ensure that the trend results were meaningful, only those stations with at least 10 years of record were included in the analysis.

Rather than provide detailed trend results for all water quality sites across Victoria in a single report, it was decided to prepare separate documents for each region controlled by the Catchment Management Authorities (CMAs). Thus, reports have been prepared for all CMA regions within Victoria, namely:

- Corangamite
- East Gippsland
- Glenelg
- Goulburn
- Mallee
- North Central
- North East
- Port Phillip
- West Gippsland
- Wimmera

In addition, a report covering the whole State has also been produced that summarises the results obtained for the individual regions. It is hoped that this series of reports will provides catchment managers with a valuable source document that contains information in a form that has not been previously available.

This report presents a summary of the data availability (Section 2), the general approach used for the study (Section 3), and a description of the results obtained (Section 4).

2. Data Availability

2.1 General

Five pollutants were investigated for trend: pH, turbidity (Tb), electrical conductivity (EC), total phosphorus (TP) and total nitrogen (TN). Data was available at approximately 280 sites across Victoria, although not all pollutants have been sampled at every site. Significantly more data was available for pH, turbidity and electrical conductivity than for total phosphorus or total nitrogen.

Figure 2.1 shows the location of monitoring sites across the Mallee CMA and the range of pollutants that are sampled at each. All sites are referenced by a Site Identification Number (SINo) that uniquely identifies the information within the VWQMN data base. Superimposed over the site locations is the CMA boundary. A summary table of data availability within the Mallee Catchment Management Authority is presented in Table 2.1 and more detailed information on the data available for the catchment is presented in Appendix A.

2.2 Length and Consistency of the Data Record

The length of the data record varies with each site and the maximum length of available record is around 20 years. To ensure that any inferences regarding trend are robust and meaningful, a minimum record length of 10 years was adopted for all analyses. The VWQMN was established around 20 years ago, and thus all results presented in this report reflect trends that have occurred over (approximately) the last 10 to 20 years.

Observations are generally available at a monthly time step. As described in Section 3.2, the method used to remove the influence of serial dependence between observations requires the adoption of a fixed time step, and therefore a regular step of one month was adopted for all analyses. The preparation of data into a regular monthly time series presented two problems as follows:

- Samples were not taken in some months, and these months were therefore regarded as containing missing data. It should be noted that total nitrogen and total phosphorus had substantial amounts of 'missing' data as the early part of each data set had generally been sampled at three monthly intervals.
- Some sites had been sampled more than once in a month, and thus it was necessary to aggregate the observations to represent a single value. This aggregation was achieved using a simple arithmetic mean of the values within the interval. It should be noted that there were very few intervals with more than one sample and thus the aggregation represents very little compression (or loss) of data.

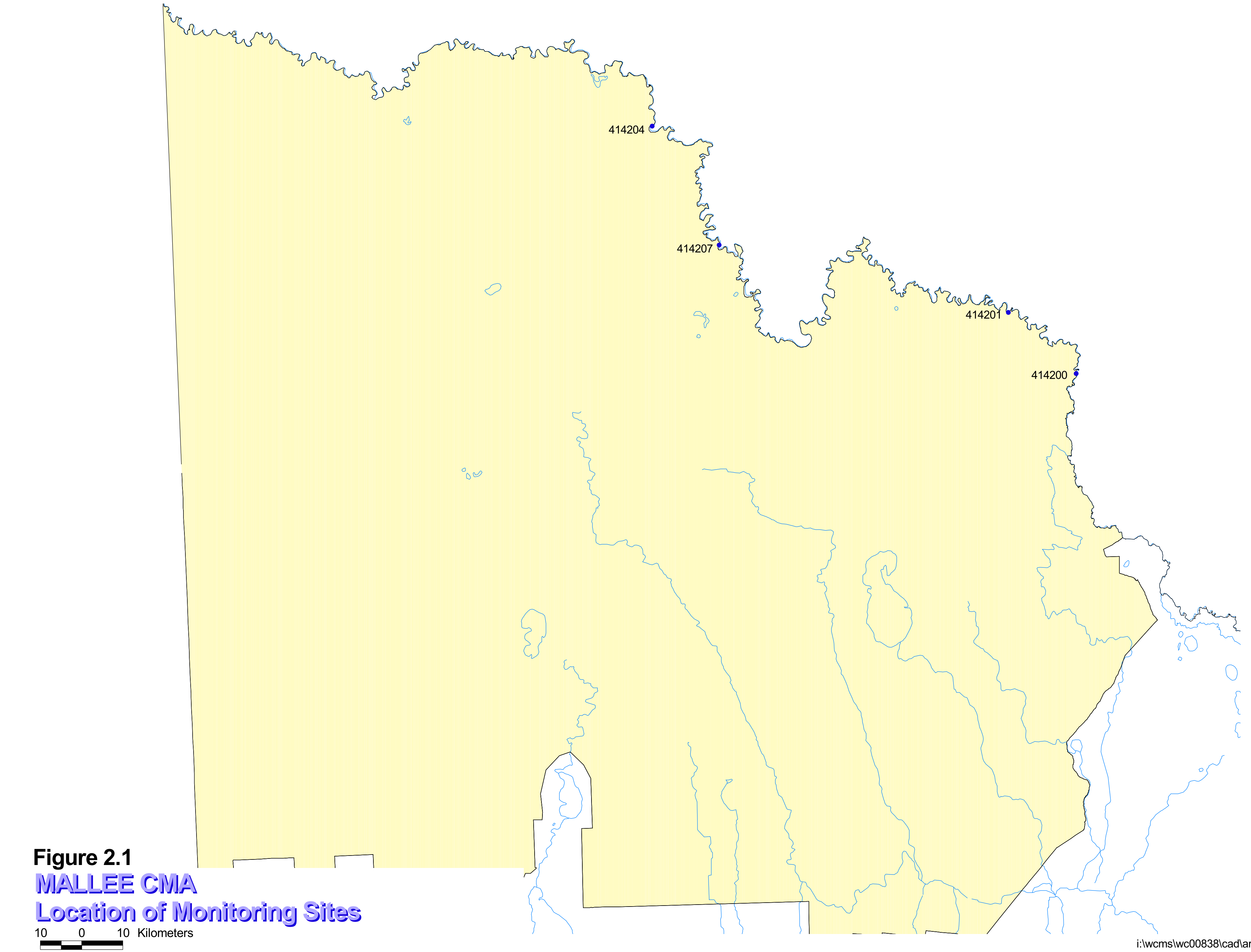


Figure 2.1

MALLEE CMA

Location of Monitoring Sites

i:\wcms\wc00838\cad\arcview\Malle.apr; Monitoring

Table 2.1: Summary of data analysed for the Mallee CMA

Station Number	Station Name	pH	Tb	EC	TN	Tp
409213	Murray River @ Piangil	✓	✓	✓		
414201	Murray River @ Boundary Bend	✓	✓	✓		
414204	Murray River @ Red Cliffs	✓	✓	✓		
414207	Murray River @ Colignan	✓	✓	✓		

2.3 Data Below the Detection Limit

Some data was reported as being less than a certain value (ie < 0.005mg/l) indicating that the measured concentration was less than the detection limit of the measuring technique. This was particularly a problem for the nutrient indicators, ie total phosphorus and oxidised nitrogen.

There are several possible approaches to dealing with this type of data. For example, the data could be treated as missing or else set to half the magnitude of the reporting limit.

There is no generally accepted approach to dealing with data below the reporting limit. While certain non-parametric approaches to trend analysis are not affected by such observations, it is usually necessary to treat the data in some manner to ensure that systematic error is not introduced into the analyses. For this study, all data recorded as being below the detection limit were simply set equal to the detection limit. Across the whole State, data treated in this manner represented less than 2% of the total sample, and therefore the manner of treatment is not expected to influence the results.

3. Model Selection and Formulation

3.1 General Requirements for Trend Analysis

There are many techniques available for the analysis of trends in data, each of which relies on different statistical assumptions. Differentiation between the techniques is based largely on the power of each technique to correctly detect trends given the properties of the particular data set under consideration. For example, substantial periods of missing data, as are commonly found in hydrologic time series, can drastically reduce the ability of a particular technique to detect the trend.

In practice, the investigation of trends is problematic as hydrologic data are generally:

- highly skewed (ie not normally distributed);
- serially dependent (particularly when using data collected at monthly or more frequent intervals);
- markedly seasonal;
- subject to periods of missing observations; and,
- are affected by exogenous influences (ie factors other than time that influence the response variable of interest).

Unfortunately, unless the correct preventative steps are taken, the above characteristics generally violate some (or all) of the underlying assumptions of all established trend detection techniques. Consequently, inferences regarding the statistical significance of suspected trends are often incorrect.

Recently Morton (1996) demonstrated the advantages of a parametric method, the Generalised Additive Model (GAM), to estimate time trends in hydrologic time series data. Morton showed how the technique can easily be used to satisfy all required assumptions. In particular, he highlights that the GAM approach is generally more flexible, and allows non-linear time trends and exogenous influences to be easily accommodated. Morton also makes the important point that existing non-parametric techniques do not cope very well with serially correlated data, a problem that is easily rectified with the GAM approach by the inclusion of an autoregressive term. An informal description of the GAM approach, and examples that illustrate application of the technique to a range of problems commonly encountered in hydrologic trend detection, is presented by Nathan et al. (1999).

In common with many trend tests, the main assumptions that need to be satisfied with the GAM technique are that the residuals must: (i) be normally distributed, (ii) have constant variance, and (iii) be serially independent. As discussed in Section 3.2, the latter assumption can usually be satisfied by jointly fitting a time series model. Errors associated with the remaining assumptions can usually be minimised by applying appropriate transformations to the data.

3.2 Overview of the GAM Approach

A GAM model can be formulated as follows:

$$y = \beta_0 + \beta_1 f(x_1) + \beta_2 f(x_2) + \ldots \beta_n f(x_n) + f(\varepsilon) \qquad (1)$$

where *y* is the water quality time series suspected of containing a trend, x_1, x_2, x_3 ... . x_n are explanatory variables, β_0 is a constant, and ε is an error term. In essence, the form of the model is similar to that used in multiple regression, though in the context of water quality trend detection, the explanatory variables may represent functional relationships between *y* and some other hydrologic time series, or else they may represent some other time-based function altogether. Importantly, all functional relationships incorporated into the model are fitted jointly.

When used for trend detection, one of the explanatory variables that needs to be included is an appropriate function of time. In its simplest formulation, the time variable adopted could simply consist of the (decimalised) date of the observation. If it is found that the time trend is non-linear over the period of record, then a spline or polynomial function can be fitted to the time component.

Other explanatory variables can be added successively as required. For example, if a water quality variable (such as turbidity) is dependent on flow magnitude, then it will be necessary to include a functional relationship between flow and turbidity. Other explanatory variables often required include terms for explaining diurnal or seasonal variation, or terms for removing serial dependence between observations.

After identifying necessary explanatory variables and the appropriate functional forms, a GAM is fitted to the water quality time series of interest. The time trend curve is characterised by the variation in *y* with time according to the explanatory variable(s) representative of average conditions. If a linear function of time is used then it will only be possible to characterise trend by a straight line. However, if a non-linear function is used then the time trend can be characterised as a smooth function varying over the period of record. The statistical significance of the time component is measured by the significance of the relevant coefficient in the model. The distribution of the fitted coefficients are based on the distribution of the random error term e .

3.3 Form of Adopted GAM Model

In this study, the choice of explanatory variables was made on the basis of preliminary analysis of the data sets and previous experience. Streamflow, measured at the time of sampling of the pollutant was included as the magnitude of flow has a major influence on the pollutant concentration. A seasonal component was also added to account for variability in the pollutant concentrations with time of year. Lastly, a time component was included to enable the assessment of the significance of trends with time. Logarithmic transformations were used to normalise selected variables in order to help normalise the residuals.

The appropriateness of several model forms were investigated for this study and two were adopted for use. The preferred model is based on the use of spline functions to account for the influence of time and flow, and the other model is based on polynomial functions. The general form of the two models used to assess trend in this study are:

$$y = \beta_0 + \beta_1 S\{Q;2\} + \beta_2 S\{t;2\} + \beta_3 \sin(2\pi i/12) + \beta_3 \cos(2\pi i/12) + AR1(\varepsilon) \quad (2)$$

$$y = \beta_0 + \beta_1 \log(Q) + \beta_2 (\log(Q))^2 + \beta_3 \sin(2\pi i/12) + \beta_3 \cos(2\pi i/12) + \beta_1 t + \beta_2 (t^2) + AR1(\varepsilon) \quad (3)$$

where:

	y	-	water quality indicator of interest
	β_n	-	model coefficients
	Q	-	streamflow (ML/day)
	t	-	time (month)
	i	-	month of year
	AR1(ε)	-	lag-one autoregressive model fitted to the error term

The water quality indicators (y) selected for analysis and the transformations required to ensure that the residuals are normally distributed with constant variance are:

pH	-	stream pH
log(Tb)	-	logarithmic transform of turbidity
log(EC)	-	logarithmic transform of electrical conductivity
log(TN)	-	logarithmic transform of total Nitrogen
log(TP)	-	logarithmic transform of total Phosphorus

The lag-one autoregressive model was fitted to the residuals to satisfy the assumption of serial independence; incorporation of this term thus ensures that the residuals of the current time step are not correlated with the residuals from the previous time step.

The spline form of the GAM model (Equation 2) is preferred as it is not affected by 'end effects' (ie the shape of the trend is not unduly influenced by a small number of data points at either end of the time series), and it does not make any assumptions about the underlying distribution of the data set. The primary disadvantages of the spline model are: (i) it is not possible to extrapolate the trends objectively into the future, (ii) they require more data to fit than the polynomial models, and (iii) the AR1 model cannot be fitted jointly (using the currently available software) with the other terms.

The advantage of the polynomial function relates primarily to the ability to be able to extrapolate the trends. The primary disadvantage is that the polynomial functions are subject to end-effects, ie a small number of observations at either end of the time series may unduly influence the shape of the inferred trend. A further disadvantage of using the polynomial function is that a particular shape of the data is assumed. For example, if a second order polynomial function is used (as adopted in Equation 3), the data set being modelled is assumed to have a parabolic shape.

3.4 Model Application

As indicated earlier, the spline model (Equation 2) was generally found to be more robust, and consequently this model was used in preference to the polynomial form (Equation 3). However, is some cases it was found that there was insufficient information to fit the spline form of the model with the autoregressive term fitted to the residuals, and an alternative model had to be used.

The following process was adopted when applying the GAM models to the data set:

1. Firstly, the spline model (as specified in Equation 2) was fitted to the data. Diagnostic plots were assessed to ensure that model assumptions were reasonably satisfied (see Section 3.5), and if acceptable the model results were adopted; as discussed below, outliers were excluded from the model fit.
2. If there was insufficient data to evaluate the spline model coefficients, then the spline model was re-fitted without the autoregressive term fitted to the residuals (ie without the AR1(ε) term in Equation 2).
3. If the residuals were not found to exhibit appreciable serial correlation, then the results from Step 2 were adopted.
4. If the residuals were found to exhibit appreciable serial correlation, then the polynomial form of the model was adopted (Equation 3).
5. If there was insufficient data to evaluate the polynomial model coefficients, then the model was re-fitted without the autoregressive term fitted to the residuals (ie without the AR1(ε) term in Equation 3).
6. If the residuals were not found to exhibit appreciable serial correlation, then the results from Step 5 were adopted.
7. If the residuals displayed significant dependence and neither forms of the model could be fitted, no assessment of trend was made, and the results were recorded as "not available".

The spline model with AR1 term was successfully fitted in the majority of cases (81%). Of the remaining stations, spline models with no AR1 term were fitted for 11% of cases and polynomial models with AR1 term were fitted for approximately 3% of cases leaving only 6% of cases for which no model could be successfully fitted.

Initial modelling of the data indicated that in some cases the model fit was unduly influenced by a small number of cases. In order to remove this bias, the outliers were excluded using an objective criterion based on Cook's statistic. Cook's statistic evaluates the sensitivity of the model to outliers by considering the influence of each data point on the coefficients of the fit of the data. A value of Cooks statistic greater than 2 was used as the basis for identification of outliers (Hill et al. 1992).

3.5 Model assessment

Having fitted the GAM models to the data, it was necessary to check that the model satisfied the required assumptions. The large number of models to be fitted (around 1000 for the whole State) precluded the detailed trialling of different model forms and variable transformations, though software was developed to allow the rapid visual assessment of the residuals to ensure that model assumptions (Section 3.1) were not appreciably violated.

An example of a GAM model fit to water quality data is provided in Figure 3.1, and examples of the diagnostic plots used to assess model validity are shown in Figures 3.2. The plots are based on electrical conductivity data from site number 235227, and an interpretation of the information is provided below.

Figure 3.1 shows the measured data, the fitted model and the time trend. This plot illustrates how well the data has been fitted and if there are any errors in either the model or the data. As can be seen from Figure 3.1, the fit for this site is reasonable, with a large amount of variability in the data being explained by the adopted model.

A plot of residuals versus time is a useful visual tool for evaluating the fit of the model over time and detecting the presence of underlying trends that may require the use of other explanatory variables. Figure 3.2(a) illustrates a residuals versus time plot, where it is seen that the residuals show constant variance. With very few exceptions, the residuals were found to be independent of time.

The constant variance assumption can be tested by examination of a plot of residuals against fitted values, an example of which is given in Figure 3.2(b). This figure illustrates that, as the data is evenly scattered around the 'Fitted EC' axis, the residuals exhibit constant variance. For pH, the condition of constant variance was generally met. However, for turbidity, electrical conductivity, total nitrogen and total phosphorus, the residuals often showed non-constant variance. To rectify this problem, a log transformation of each of these variables was tried resulting in significant improvement.

The assumption of no serial correlation was evaluated by plotting a correlogram, as illustrated in Figure 3.2(c). Lag values of greater than an absolute value of 0.2 (ie less than -0.2, or greater than +0.2) indicate that the residuals exhibit significant serial correlation. Evaluation of the correlogram for this site indicates that the fitting of a lag(1) AR model ensured that serial correlation was not a problem. However, as discussed in Section 3.4, some sites did not have sufficient data to allow the inclusion of an autoregressive term in the spline model, and the correlogram was used as the basis for deciding which model form to adopt.

The assumption of normally distributed residuals was evaluated by using a normal probability plot, as shown in Figure 3.2(d). The proximity of the data to the 1:1 line indicates how well the residuals follow a normal distribution. The residuals were generally found to be normally distributed.

Figure 3.1: Fit and trend for electrical conductivity for station 235227

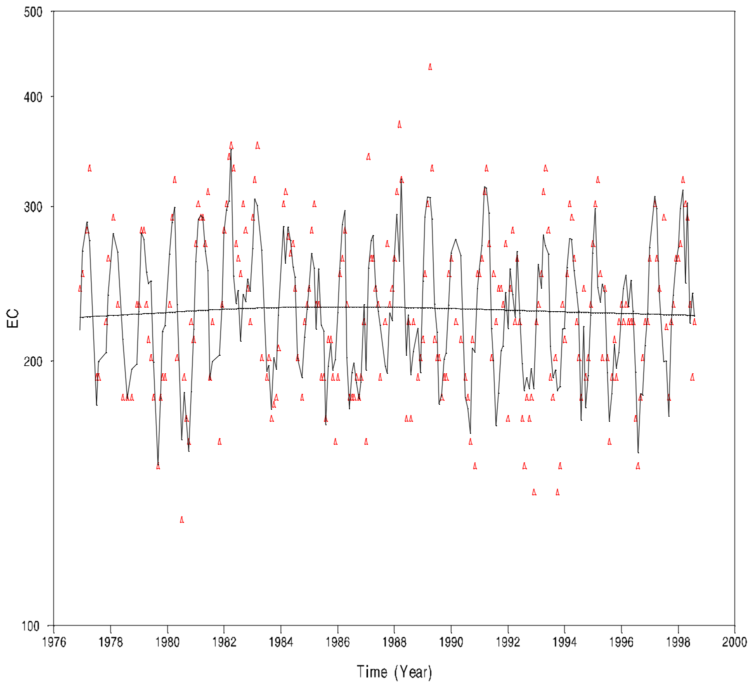
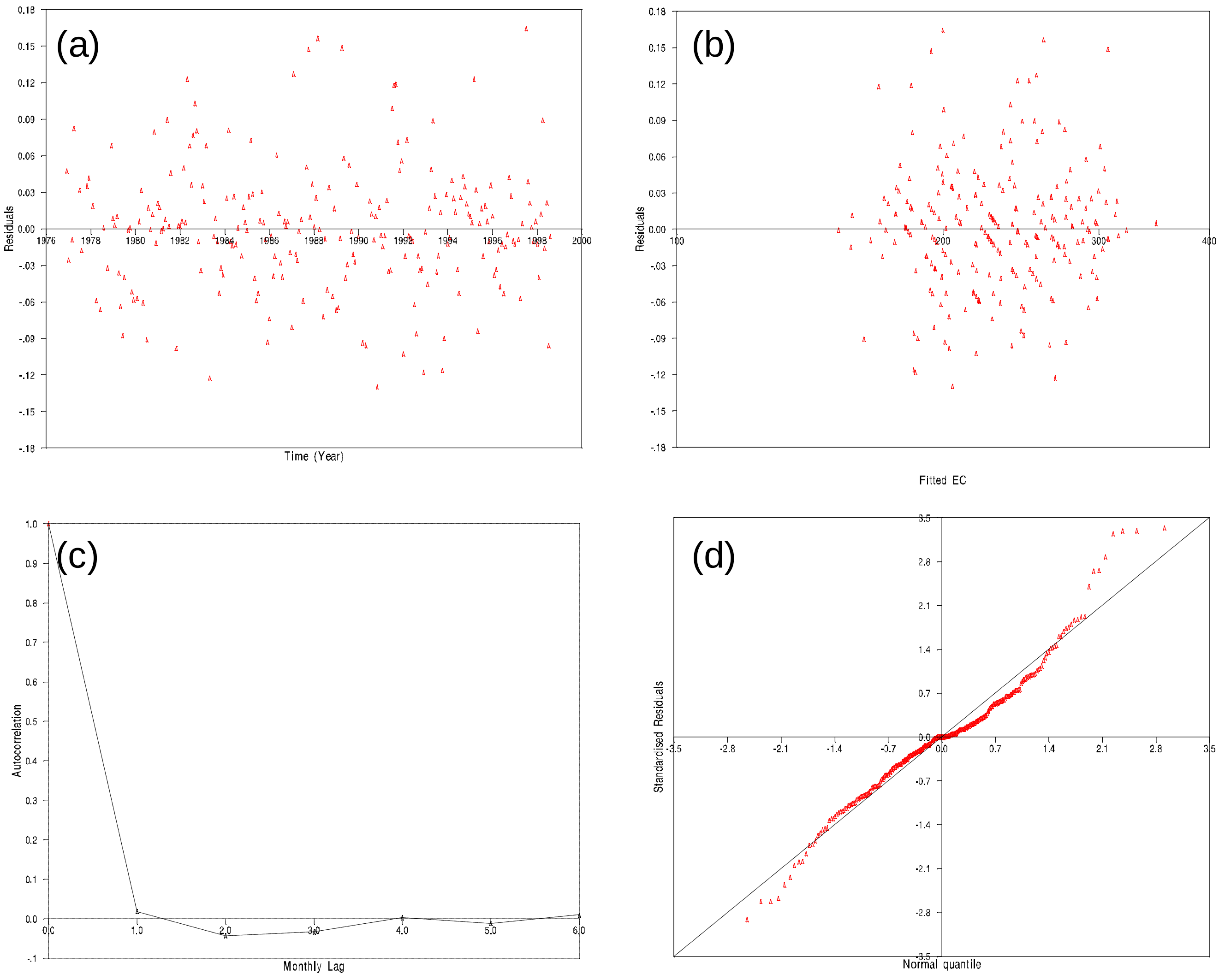


Figure 3.2: Diagnostic plots to evaluate the model assumptions



3.6 Characterisation of Trend

Both forms of the adopted GAM model (Equations 2 and 3) allow the evaluation of non-linear trends. Such models clearly illustrate the variation in trend over time, and in particular the spline form of the model allows a visual assessment of trend similar to that achieved using LOWESS plots (Cleveland, 1979). While plots of non-linear time trends allow inferences to be made regarding the nature (and hence possible causes) of trends over the historic period, they are not suited to providing a simple estimate of average annual trends.

Consider the example given in Figure 3.3 for which there is a clear, non-linear trend present in the data (as illustrated by the solid curvilinear line). The variation through time indicates a cyclic trend, in which an initial period of increasing trend is followed by decreasing values, and another subsequent period of increases. Such information, when combined with local knowledge of land-use changes or operational conditions, can provide a valuable basis on which to assess the causes of trends.

Figure 3.3 does not make it clear, however, whether there has been an overall increase or decrease in the linear component of the observed trend. In order to characterise this overall trend, a linear regression line has been fitted through the non-linear trend results, as illustrated by the broken line in Figure 3.3. This estimate of the linear component of the trend has been used to represent the overall trend at each site, and is used to construct "arrow" plots that reveal the degree of uniformity in trend results throughout a region (see Section 3.6.2).

3.6.1 Statistical Significance of Trends

In addition to the magnitude of the trend, the statistical significance of the trend also needs to be estimated. The significance indicates whether the trend can be validly discerned from within the noise of the data. Consider, for example, Figure 3.4. The plot shows the trend line though the data for site number 231231 and the gradient of the line (or magnitude of the trend) has been calculated as 16 µs/cm per annum. The significance of the trend has been calculated as 'nil', indicating that although the trend line exhibits a gradient, that gradient is not statistically significant.

Significance is determined from a t-test on the linear component of the time trend in the GAM model. A t-test is an expression of the probability that the nature of the trend has been accurately discerned from the data. The significance has therefore been reported at the 5% level (indicating a high probability of significance), 10% level (indicating a medium level of significance) and Nil (indicating that the trend is not significant).

Figure 3.3: Illustration of the non-linear and linear components of trend (for electrical conductivity for station 229214 in the Port Phillip CMA).

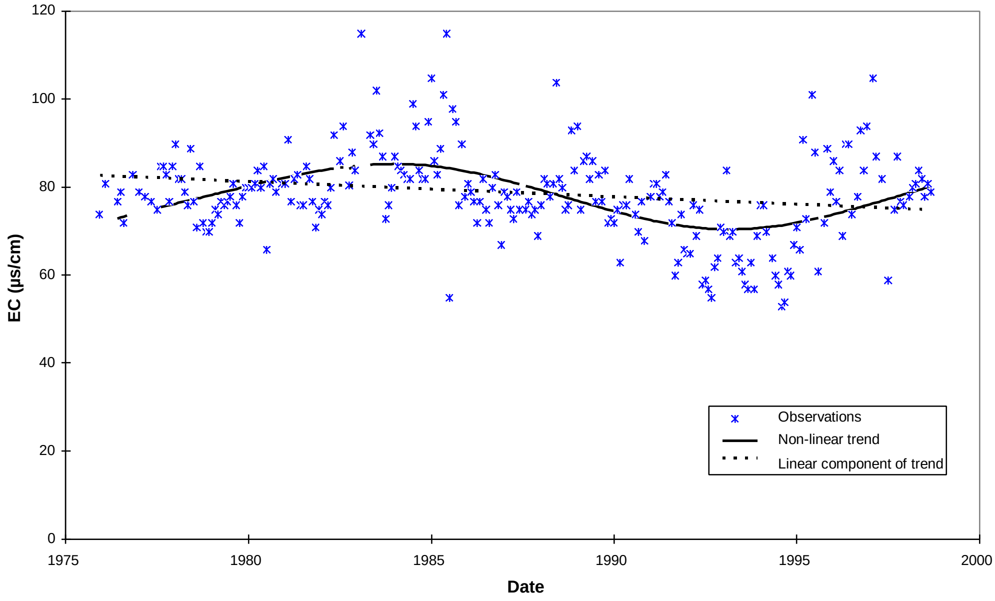
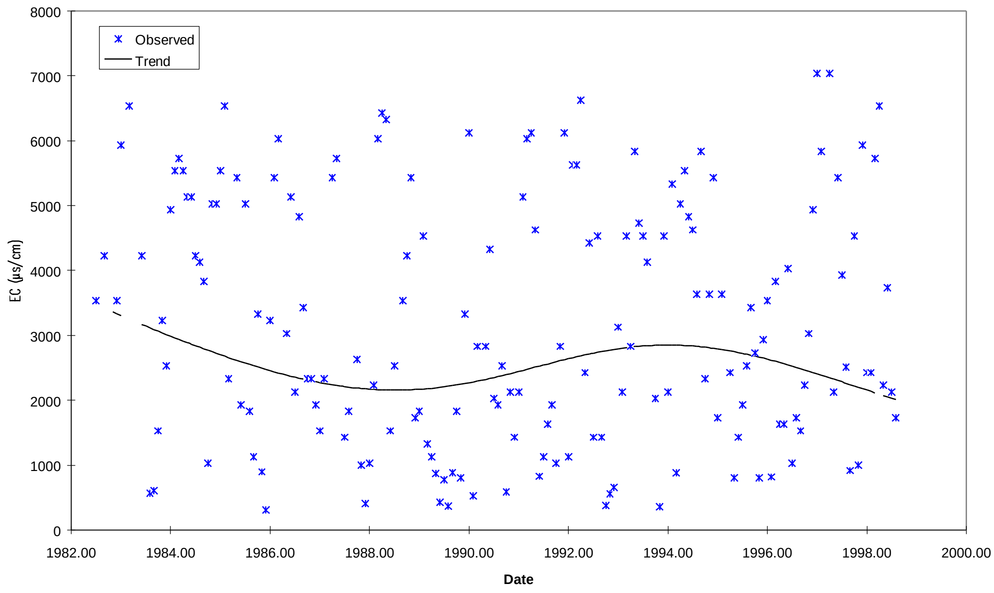


Figure 3.4: Illustration of a trend with nil significance (for electrical conductivity at station 231231 in the Port Phillip CMA).



3.6.2 Evaluation of Regional Trends

In addition to the reporting of trends at each site, maps indicating regional trends have also been produced. The maps use arrows to indicate the nature of the trend with the magnitude, direction and significance of the trend being illustrated by the direction, size, and shading of the arrows. The consistency of any regional trends are reflected in the consistency of the size and direction of the arrows.

Consider Figure 3.5. A red arrow pointing vertically upwards indicates an upwards trend and a blue arrow pointing vertically downwards indicates a downwards trend. The size of the arrows indicates the relative magnitude of the overall linear trend. A green circle indicates that the magnitude of the trend is approximately zero. Note that żero 'has been set differently for each pollutant based on reasonable detection limits for that pollutant and are listed as follows:

- pH : -0.025<limit<0.025 (/yr)
- turbidity : -0.25<limit<0.025 (NTU/yr)
- ec : -5.0<limit<5.0 (µs/cm/yr)
- total phosphorus: -0.5<limit<0.5g/l (µg/l/yr)
- total nitrogen: -0.003<limit<0.003 (mg/l/yr)

In addition to lower limits, upper limits have also been set (to prevent one arrow from completely dominating the map). These upper limits have been set as follows:

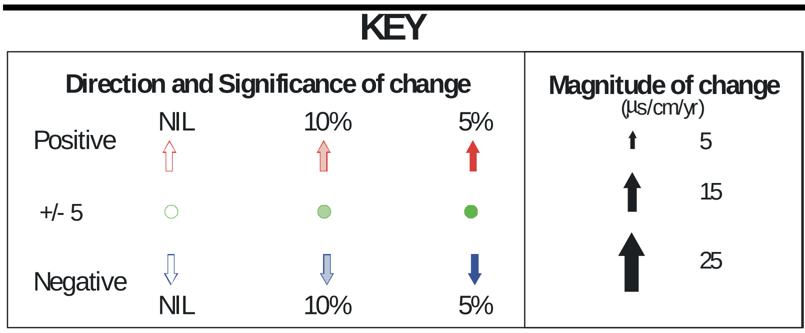
- pH: 0.1 (/yr)
- turbidity: 1 (NTU/yr)
- ec: 25 (µs/cm/yr)
- total phosphorus: 10.0 (µg/l/yr)
- total nitrogen: 0.05 (mg/l/yr)

Note that the magnitude of trends that exceed the above limits have been marked near the station number on the arrow map.

If an arrow or circle is infilled with solid colour then the trend is significant at the 5% level; if infilled with a shaded colour then the trend is significant at the 10% level, and if there is no infilling then the trend is not significant.

It should be noted that stations for which the estimated trend was not reliable do not have an arrow on the map, they simply have the station number. Station numbers have also been marked for total phosphorus and total nitrogen where there was insufficient data for analysis.

Figure 3.3: Key for arrow plots



4. Results

The results of the trend analysis have been presented in three different formats. Table 4.1 summarises the magnitude of change and the significance of the trend for each station. Appendix B contains plots of the fitted trend line for each station and pollutant modelled in the Mallee CMA. Finally, the arrow plots are presented in Figures 4.1 to 4.3 for each CMA. It should be noted that there was no nutrient data (total nitrogen or total phosphorus) for the Mallee.

There are too few stations with measured data to make substantial conclusions about the nature of trends in the region. For pH (Figure 4.1), three of the four trends have zero magnitude, and two of these were found to be not statistically significant. For turbidity (Figure 4.2), three of the four trends are decreasing, two of which are of relatively large magnitude and are highly significant. Electrical conductivity (Figure 4.3) is the only indicator with an increasing trend at Station 414202 (Murray River at Red Cliffs). The remaining trends for electrical conductivity are of zero magnitude.

Table 4.1: Trend Summary for the Mallee CMA

Station	PH		Turbidity		Electrical Conductivity		Total Nitrogen		Total Phosphorus	
	Linear Trend Per Year	Sig.	Linear Trend Per Year (NTU)	Sig.	Linear Trend Per Year (µs/cm)	Sig.	Linear Trend Per Year (mg/l)	Sig	Linear Trend Per Year (µg/l)	Sig.
409213	0.000	Nil	0.00	Nil	6.3	5%	-	-	-	-
414201	0.000	Nil	0.00	Nil	0.0	Nil	-	-	-	-
414204	0.000	Nil	-0.29	Nil	6.9	5%	-	-	-	-
414207	0.000	Nil	-0.70	5%	0.0	10%	-	-	-	-

Note: - no data available

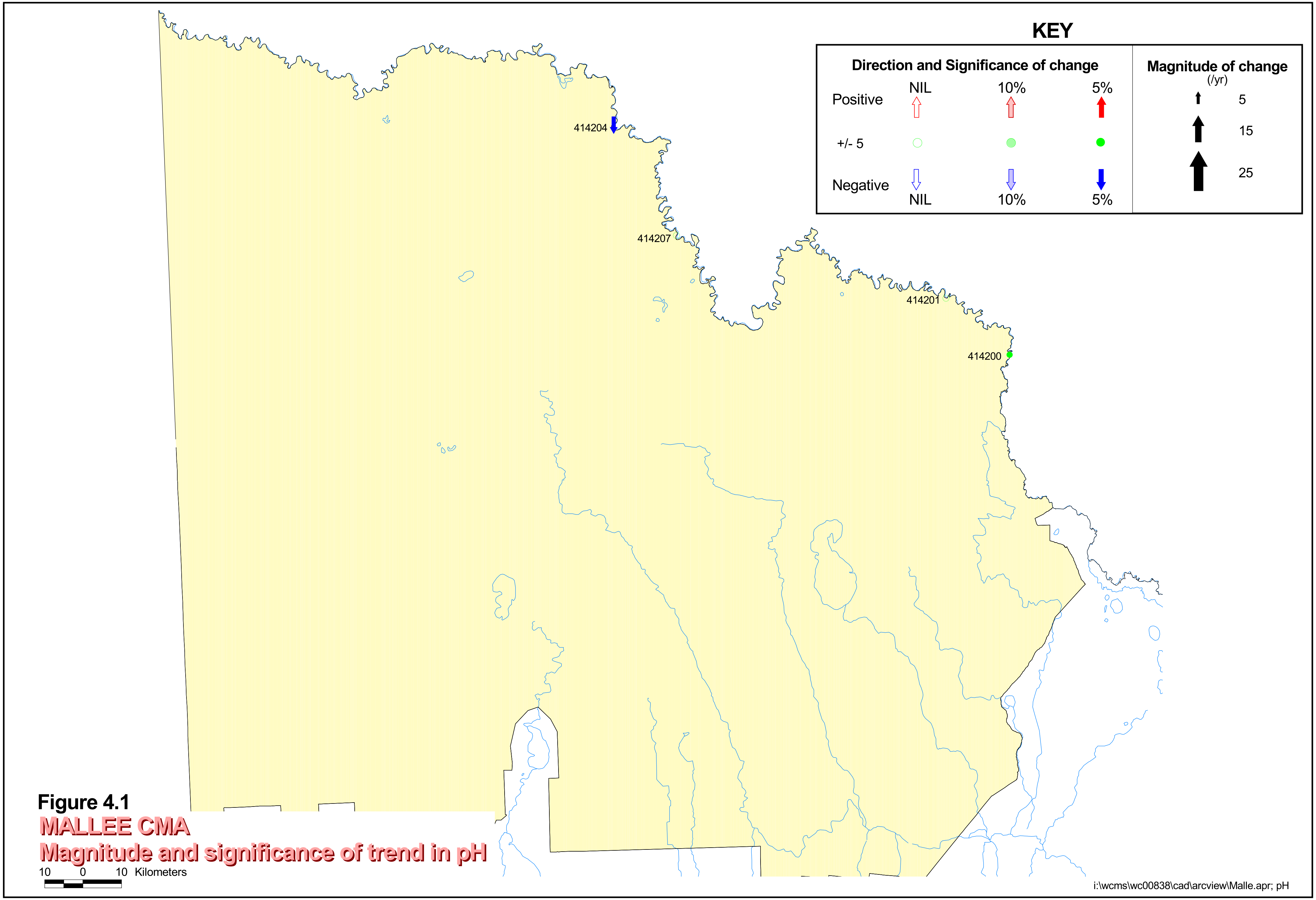


Figure 4.1

MALLEE CMA

Magnitude and significance of trend in pH

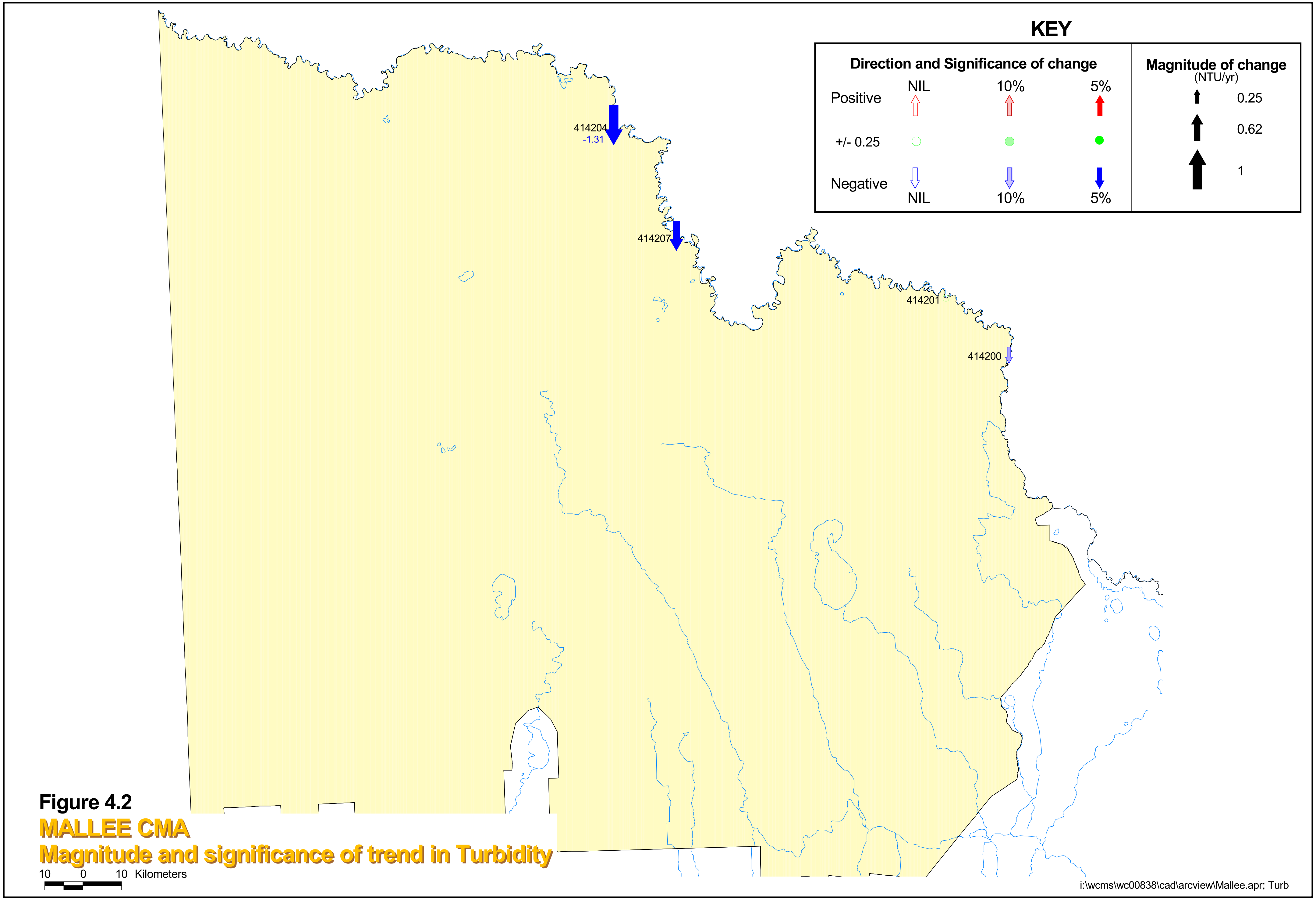


Figure 4.2
MALLEE CMA
Magnitude and significance of trend in Turbidity

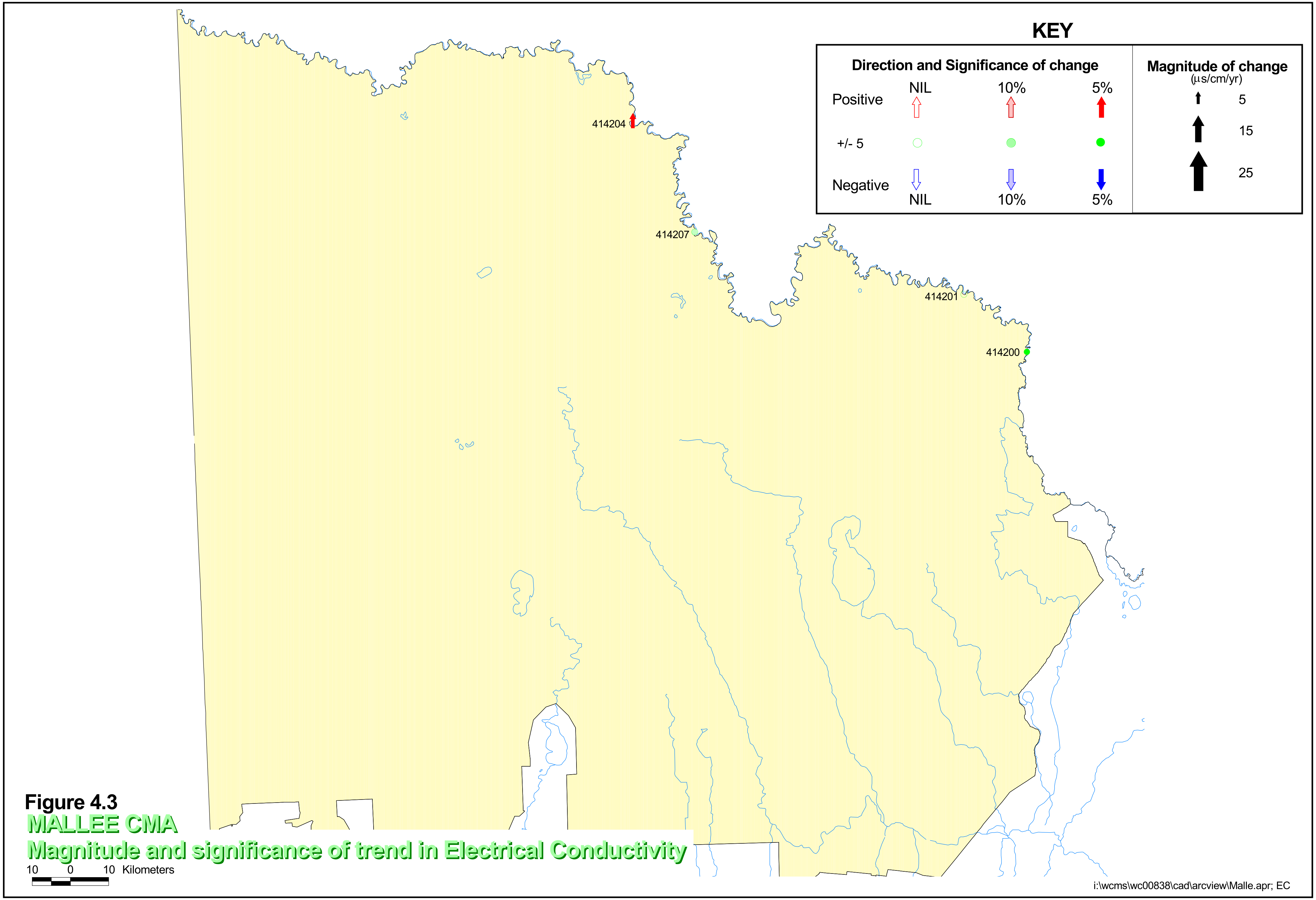


Figure 4.3
MALLEE CMA
Magnitude and significance of trend in Electrical Conductivity

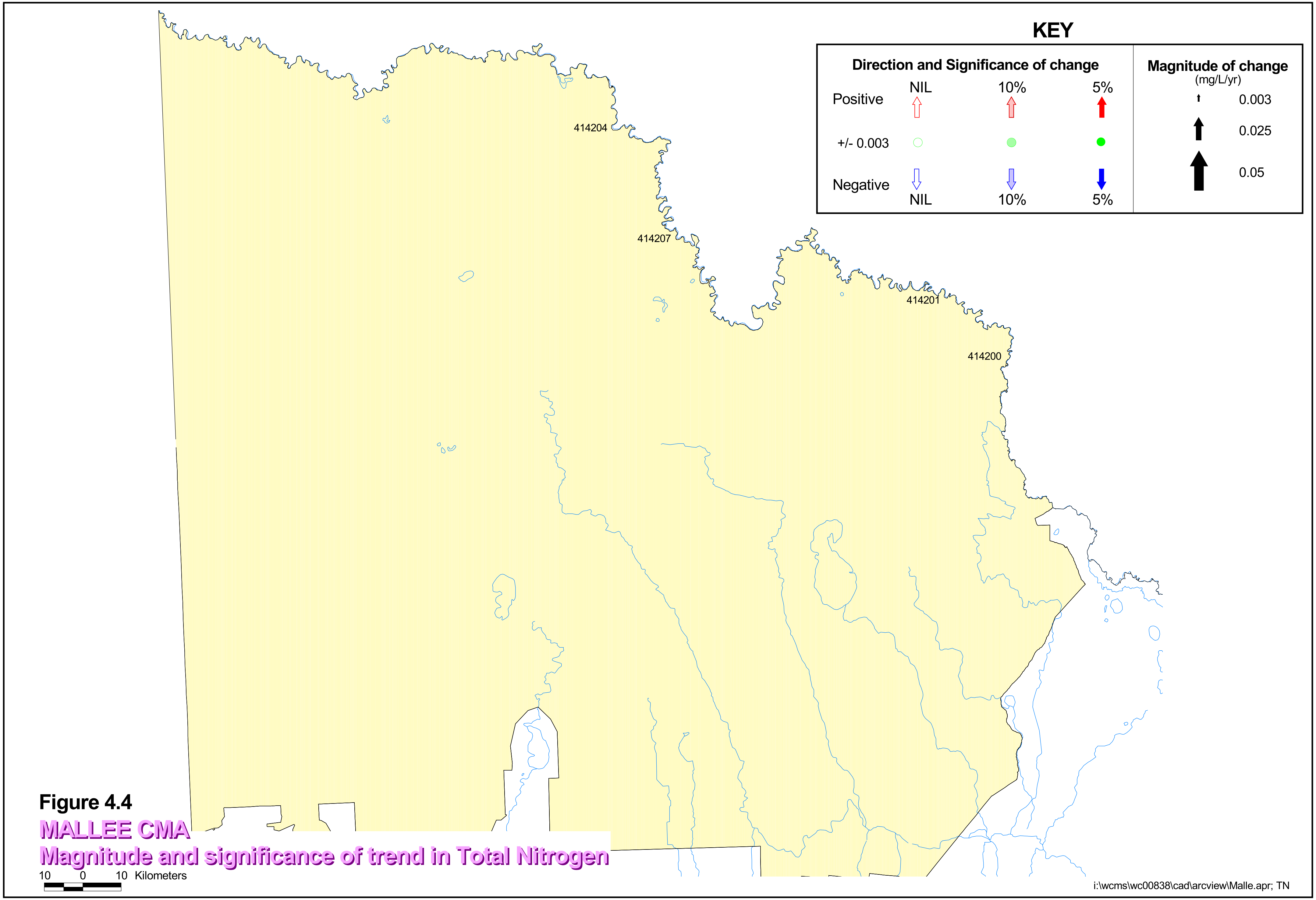


Figure 4.4

MALLEE CMA

Magnitude and significance of trend in Total Nitrogen

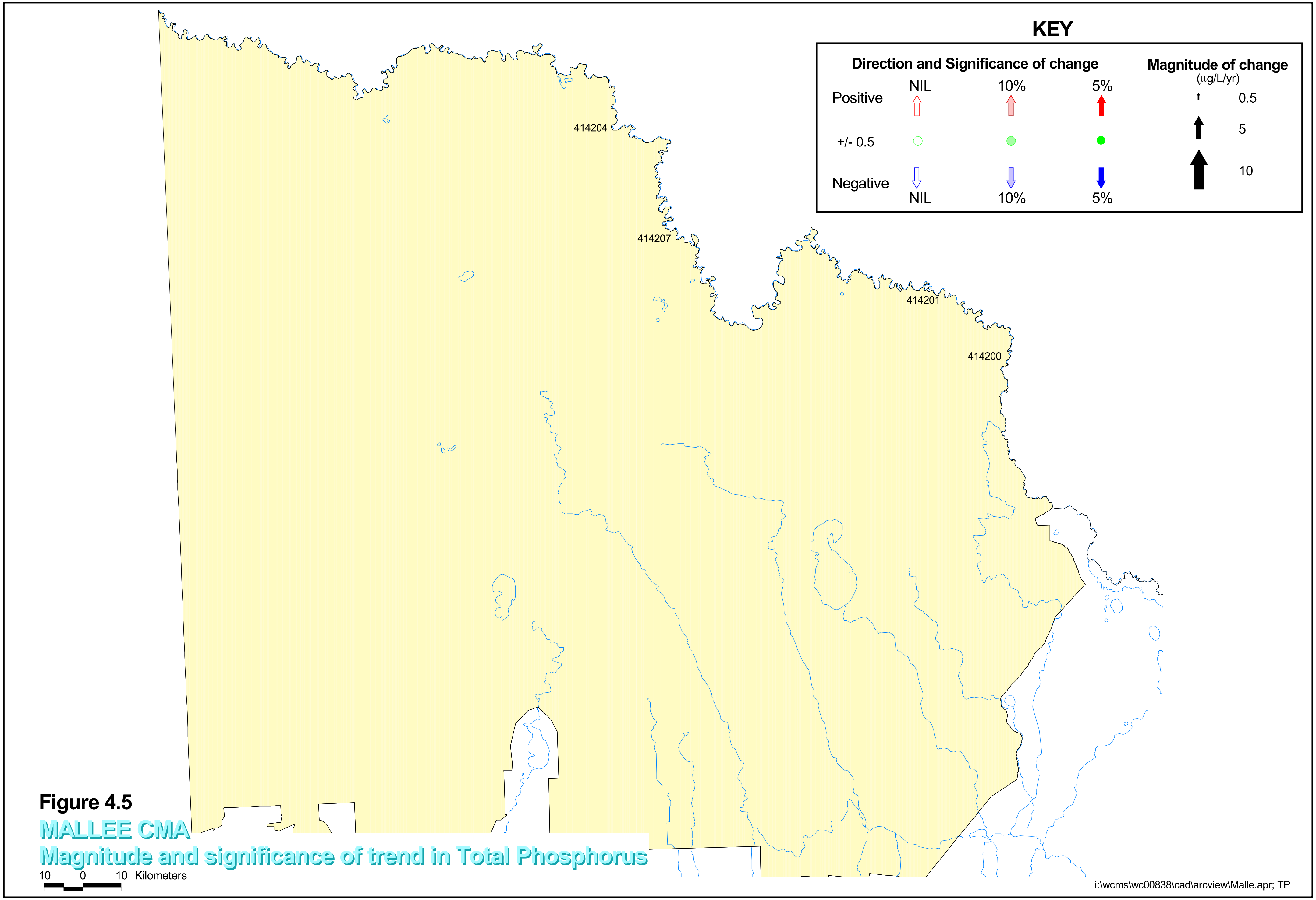


Figure 4.5

MALLEE CMA

Magnitude and significance of trend in Total Phosphorus

5. Conclusions

Water quality data from the VWRMN (Victorian Water Resources Monitoring Network) for the Mallee Region have been analysed to determine trends. A total of 4 stations were investigated for trends in pH, turbidity and electrical conductivity. No nutrient data was available for the region.

The GAM (Generalised Additive Models) method was used to determine the trends. GAM is particularly suited to investigating trends in water quality data as it accounts for the effects of exogenous influences (such as streamflow) and it elegantly deals with the common problems of missing data and serial correlation.

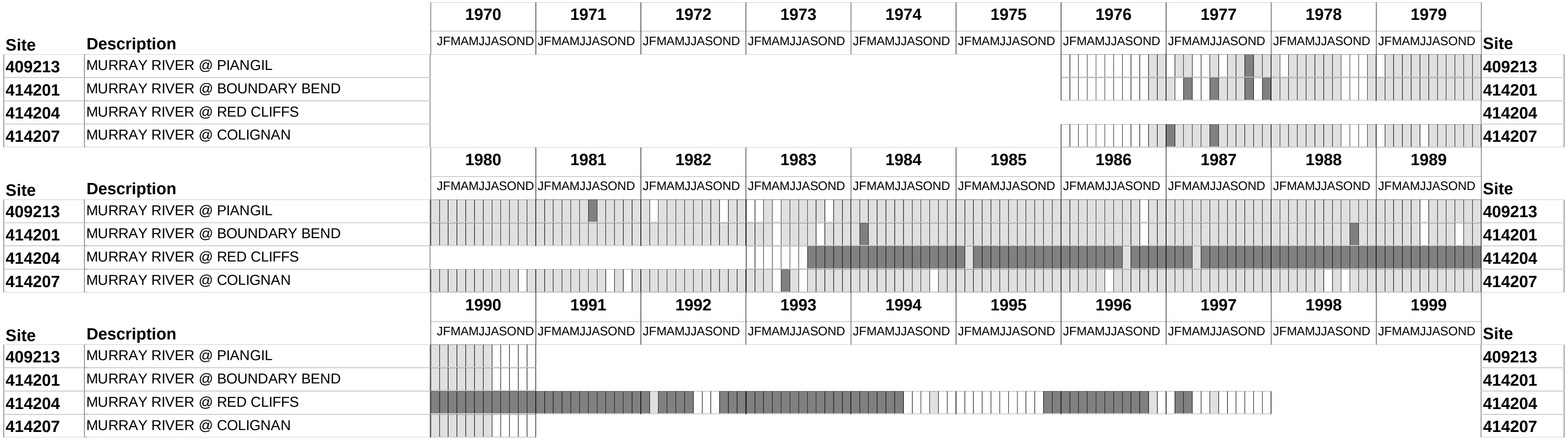
Only a small number of stations in the Mallee region had data available for trend analysis. There was no nutrient data available. The majority of trends were of decreasing or zero magnitude with only one trend (for electrical conductivity) that was increasing.

Finally, it should be noted that there are companion reports to this document, detailing similar analyses for each of the other nine Catchment Management Authorities. Additionally, there is a Statewide Summary, presenting an overview of the trend analysis for the State.

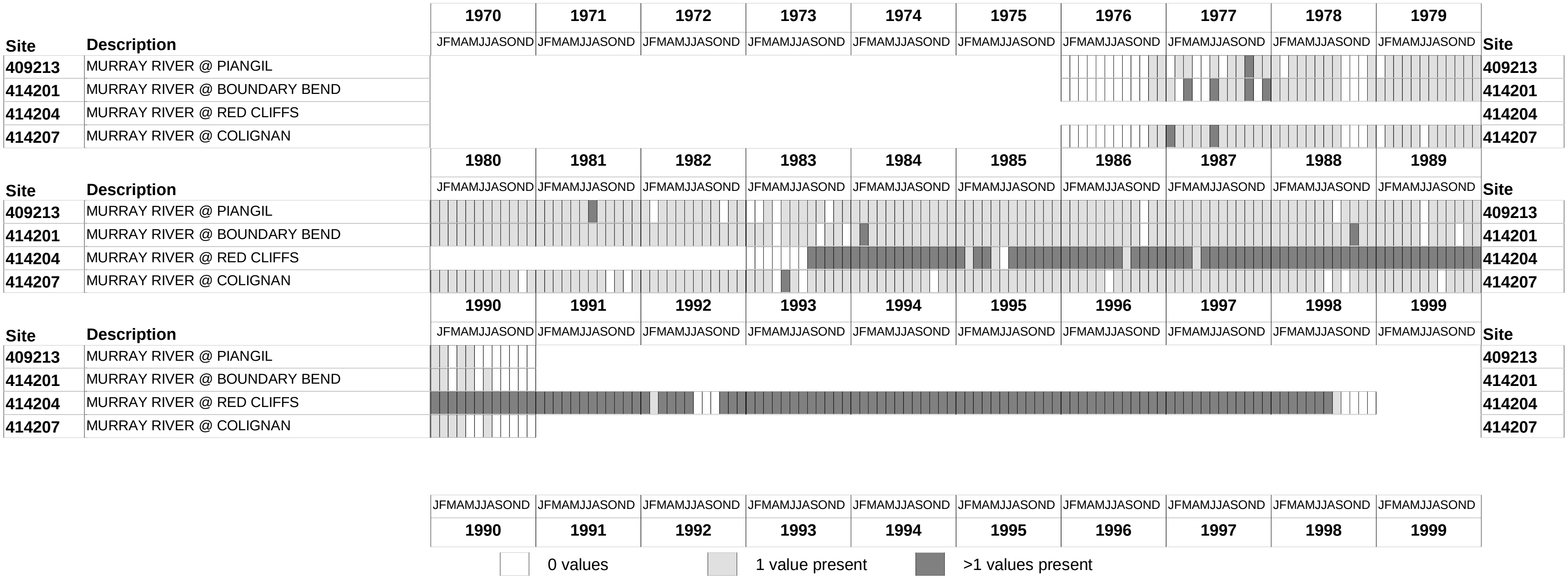
Appendix A - Data Availability in the Mallee CMA

CMA: Mallee

Monthly Summary of Discharge Data Availability



Monthly Summary of pH Data Availability



CMA: Mallee

Monthly Summary of Turbidity Data Availability

Site	Description	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	Site
		JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	
409213	MURRAY RIVER @ PIANGIL											409213
414201	MURRAY RIVER @ BOUNDARY BEND											414201
414204	MURRAY RIVER @ RED CLIFFS											414204
414207	MURRAY RIVER @ COLIGNAN											414207

Site	Description	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Site
		JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	
409213	MURRAY RIVER @ PIANGIL											409213
414201	MURRAY RIVER @ BOUNDARY BEND											414201
414204	MURRAY RIVER @ RED CLIFFS											414204
414207	MURRAY RIVER @ COLIGNAN											414207

Site	Description	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Site
		JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	
409213	MURRAY RIVER @ PIANGIL											409213
414201	MURRAY RIVER @ BOUNDARY BEND											414201
414204	MURRAY RIVER @ RED CLIFFS											414204
414207	MURRAY RIVER @ COLIGNAN											414207

Monthly Summary of Electrical Conductivity Data Availability

Site	Description	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	Site
		JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	
409213	MURRAY RIVER @ PIANGIL											409213
414201	MURRAY RIVER @ BOUNDARY BEND											414201
414204	MURRAY RIVER @ RED CLIFFS											414204
414207	MURRAY RIVER @ COLIGNAN											414207

Site	Description	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Site
		JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	
409213	MURRAY RIVER @ PIANGIL											409213
414201	MURRAY RIVER @ BOUNDARY BEND											414201
414204	MURRAY RIVER @ RED CLIFFS											414204
414207	MURRAY RIVER @ COLIGNAN											414207

Site	Description	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Site
		JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	
409213	MURRAY RIVER @ PIANGIL											409213
414201	MURRAY RIVER @ BOUNDARY BEND											414201
414204	MURRAY RIVER @ RED CLIFFS											414204
414207	MURRAY RIVER @ COLIGNAN											414207

JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND
1990	1991	1992	1993	1994	1995	1996	1997	1998	1999

0 values   1 value present   >1 values present

CMA: **Mallee**

Monthly Summary of Total Kjeldahl Nitrogen Data Availability

Site	Description	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	Site
		JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	
409213	MURRAY RIVER @ PIANGIL											**409213**
414201	MURRAY RIVER @ BOUNDARY BEND											**414201**
414204	MURRAY RIVER @ RED CLIFFS											**414204**
414207	MURRAY RIVER @ COLIGNAN											**414207**

Site	Description	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Site
		JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	
409213	MURRAY RIVER @ PIANGIL											**409213**
414201	MURRAY RIVER @ BOUNDARY BEND											**414201**
414204	MURRAY RIVER @ RED CLIFFS											**414204**
414207	MURRAY RIVER @ COLIGNAN											**414207**

Site	Description	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Site
		JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	
409213	MURRAY RIVER @ PIANGIL											**409213**
414201	MURRAY RIVER @ BOUNDARY BEND											**414201**
414204	MURRAY RIVER @ RED CLIFFS											**414204**
414207	MURRAY RIVER @ COLIGNAN											**414207**

Monthly Summary of Nitrate/Nitrite Data Availability

Site	Description	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	Site
		JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	
409213	MURRAY RIVER @ PIANGIL											**409213**
414201	MURRAY RIVER @ BOUNDARY BEND											**414201**
414204	MURRAY RIVER @ RED CLIFFS											**414204**
414207	MURRAY RIVER @ COLIGNAN											**414207**

Site	Description	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Site
		JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	
409213	MURRAY RIVER @ PIANGIL											**409213**
414201	MURRAY RIVER @ BOUNDARY BEND											**414201**
414204	MURRAY RIVER @ RED CLIFFS											**414204**
414207	MURRAY RIVER @ COLIGNAN											**414207**

Site	Description	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Site
		JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	
409213	MURRAY RIVER @ PIANGIL											**409213**
414201	MURRAY RIVER @ BOUNDARY BEND											**414201**
414204	MURRAY RIVER @ RED CLIFFS											**414204**
414207	MURRAY RIVER @ COLIGNAN											**414207**

JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND
1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**

0 values | 1 value present | >1 values present

CMA: Mallee

Monthly Summary of Total Phosphorus Data Availability

Site	Description	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	Site
		JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	
409213	MURRAY RIVER @ PIANGIL											409213
414201	MURRAY RIVER @ BOUNDARY BEND											414201
414204	MURRAY RIVER @ RED CLIFFS											414204
414207	MURRAY RIVER @ COLIGNAN											414207

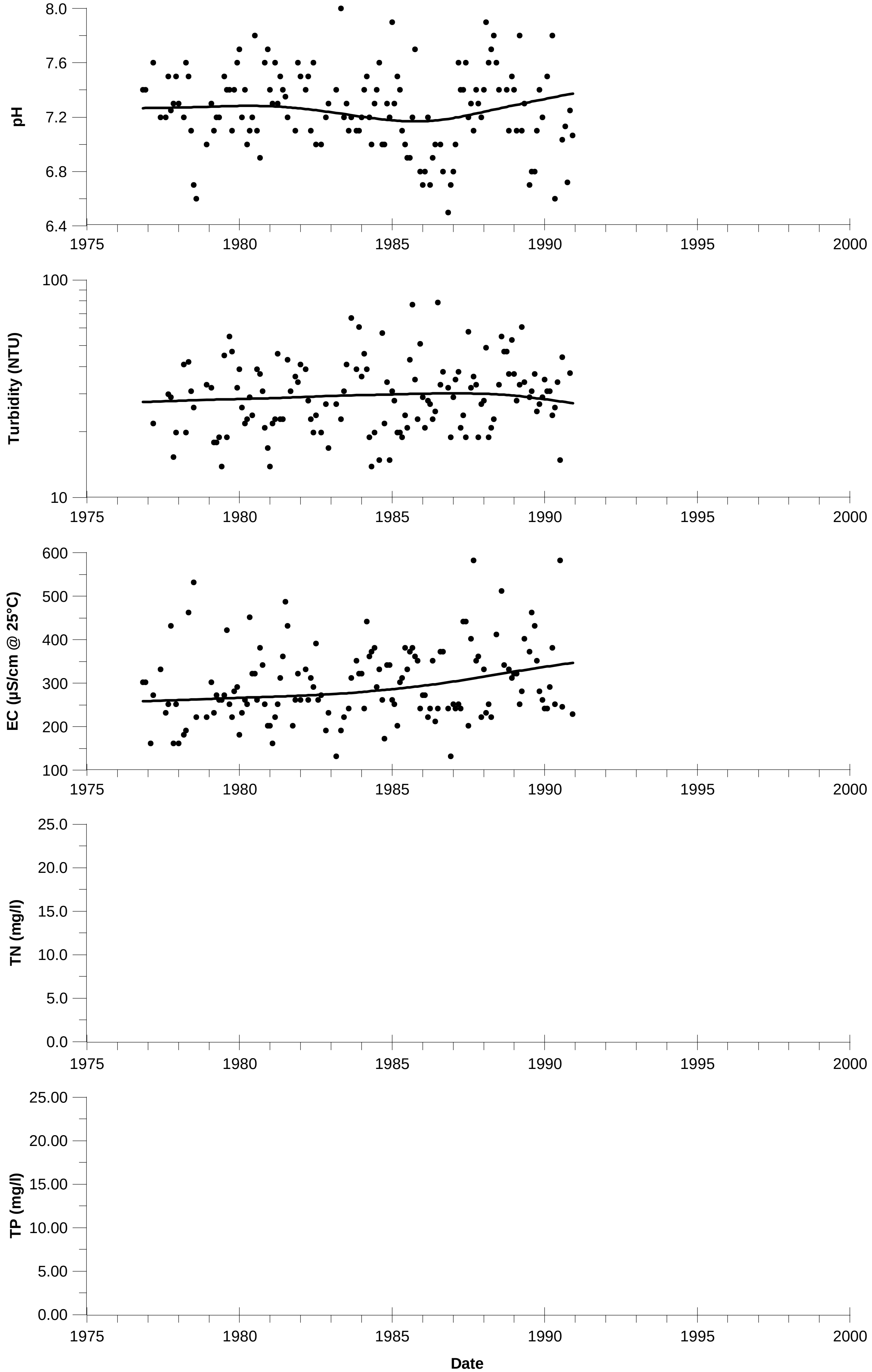
Site	Description	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	Site
		JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	
409213	MURRAY RIVER @ PIANGIL											409213
414201	MURRAY RIVER @ BOUNDARY BEND											414201
414204	MURRAY RIVER @ RED CLIFFS											414204
414207	MURRAY RIVER @ COLIGNAN											414207

Site	Description	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	Site
		JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	
409213	MURRAY RIVER @ PIANGIL											409213
414201	MURRAY RIVER @ BOUNDARY BEND											414201
414204	MURRAY RIVER @ RED CLIFFS											414204
414207	MURRAY RIVER @ COLIGNAN											414207

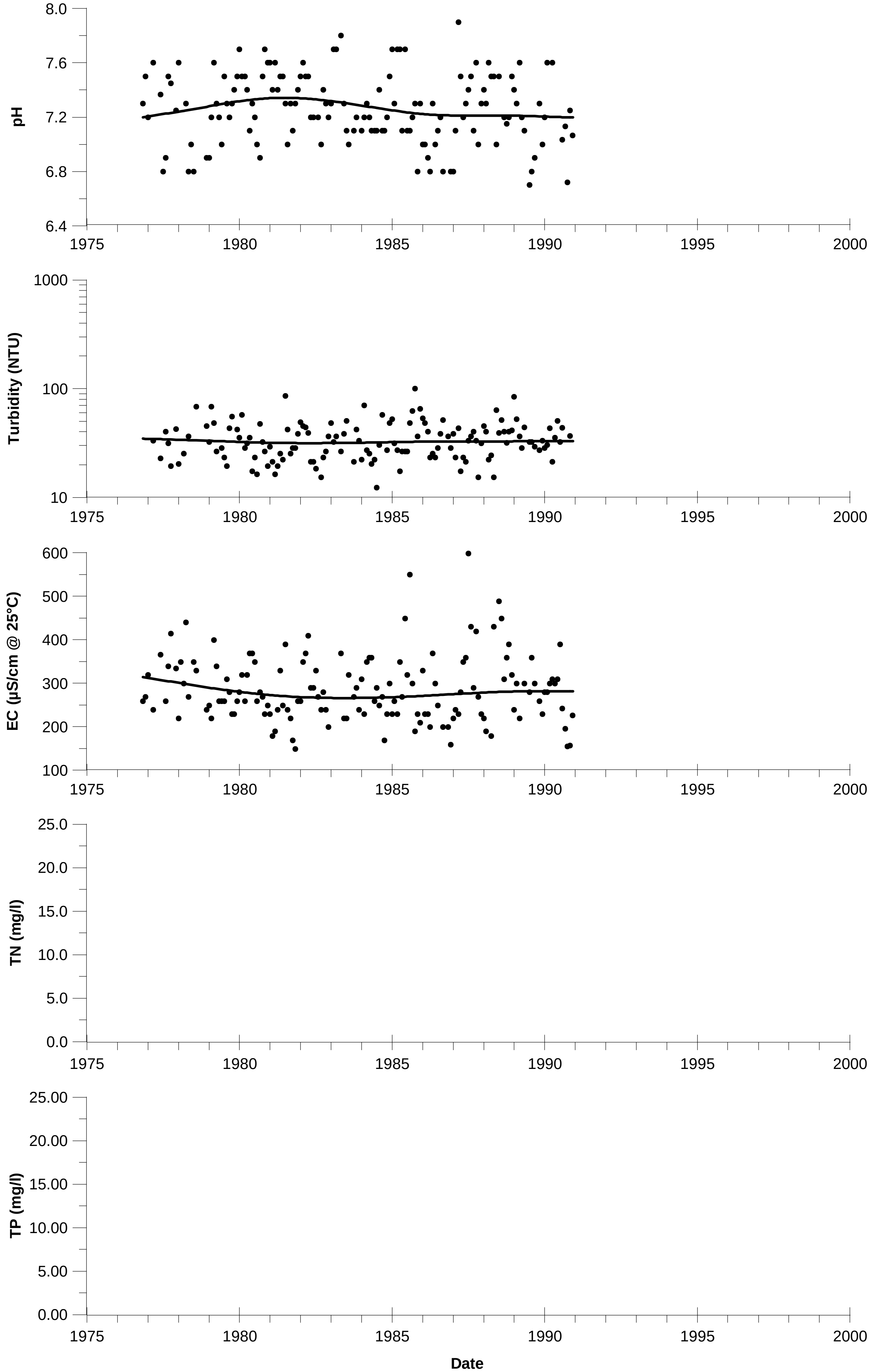
JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND	JFMAMJJASOND
1990	1991	1992	1993	1994	1995	1996	1997	1998	1999

0 values   1 value present   >1 values present

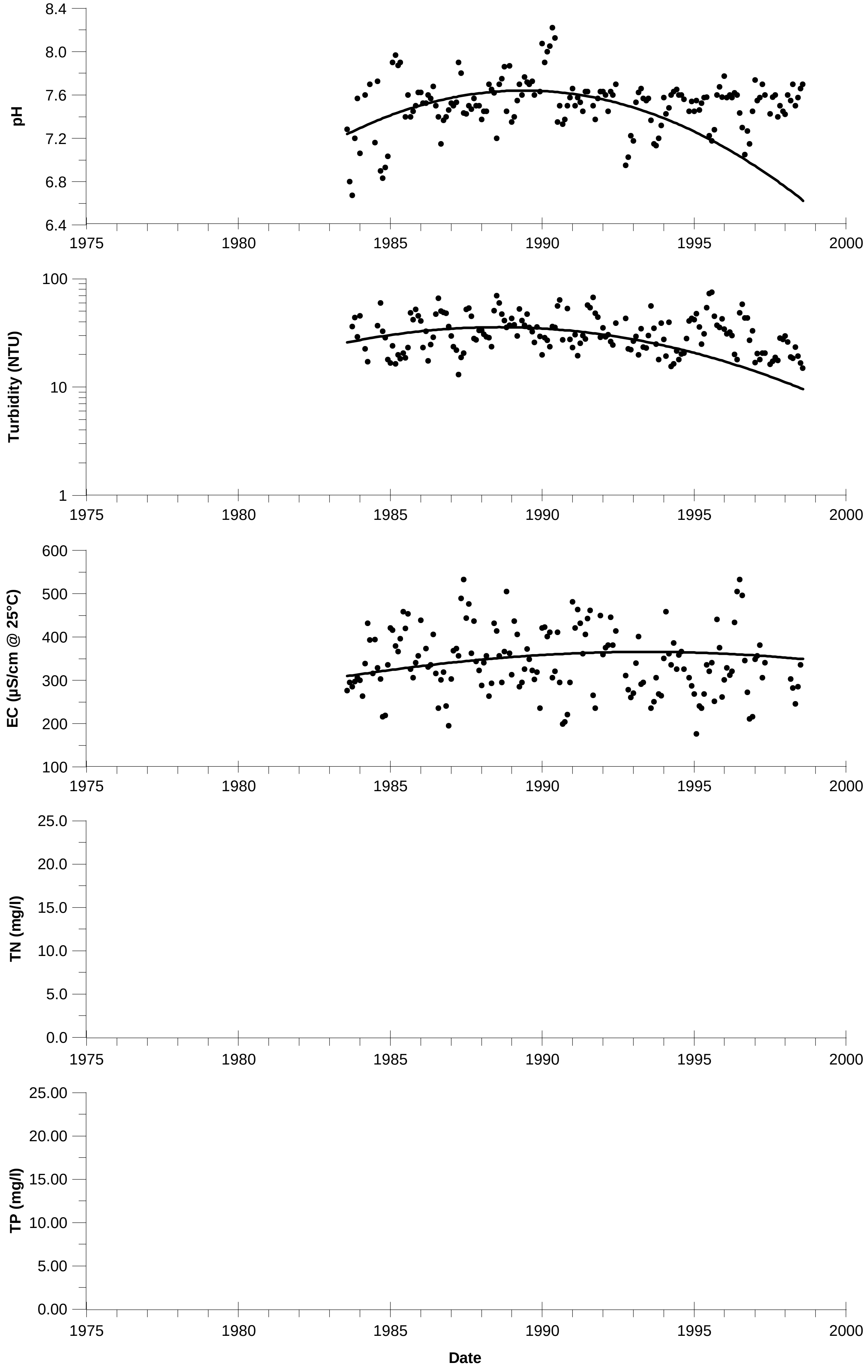
Appendix B - Trend plots for stations in the Mallee CMA



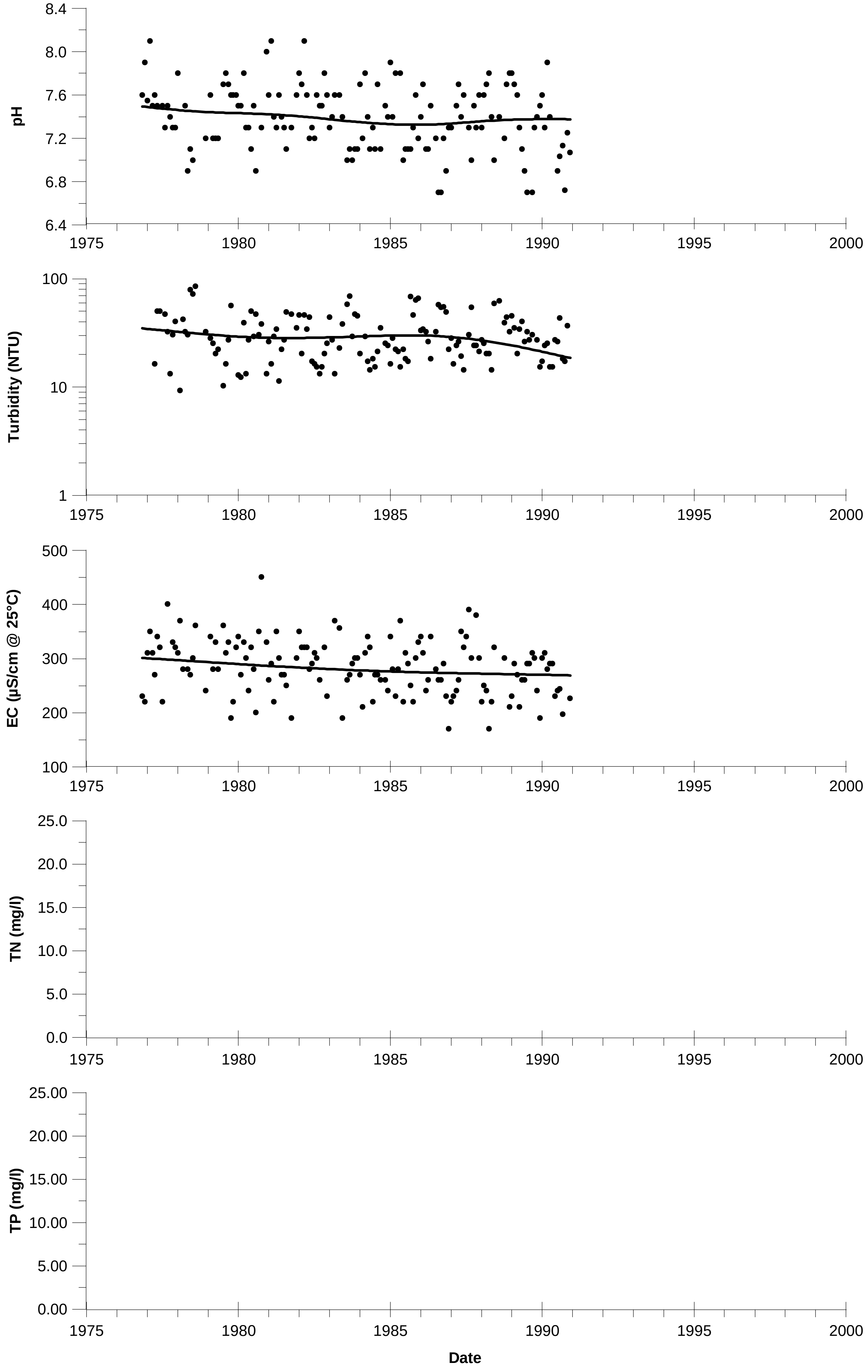
Murray River @ Piangil (Station 409213)



Murray River @ Boundary Bend (Station 414201)



Murray River @ Red Cliffs (Station 414204)



Murray River @ Colignan (Station 414207)