Calculating trends in nutrient data

Detecting trends in a water quality data series is not as simple as drawing a 'line of best fit' and measuring the slope. There are likely to be multiple factors contributing to variation in water quality over time - many of which can hide or exaggerate trend components in the data. The most likely sources of variation include: flow variation, seasonal variation, trend and random components. Changes in water quality brought about by human activity will usually be superimposed on natural sources of variation. Therefore, the influence of flow and seasonal variation needs to be examined prior to analysing for trending periods in a water quality data series. Although the primary objective is to detect trends over time, sources of natural variation must be known and adjusted for prior to analysis. This will provide management with an improved perception of changes in water quality that are (more than likely) linked to human intervention in the catchment.

Assumptions of the trend tests

Non-parametric significance tests were used to identify statistically significant trending periods in a water quality data series. Non-parametric tests were used because they are not affected when the distribution of data is not normal, insensitive to outliers and are not affected by missing or censured data (Loftis *et al*., 1991).

An assumption of trend tests is that trends are consistently increasing or decreasing, otherwise known as monotonic changes (Helshel and Hirsch, 1992). If concentrations vary non-monotonically over the period being analysed the results of linear tests for trend may be misleading (Robson and Neal, 1996). For this analysis, the assumption of monotonic change was verified by a visual examination of a LOWESS (Locally Weighted Scatterplot Smooth) line fitted to the data over the period of interest (Helshel and Hersh 1992, Aulenbach *et al.*, 1996). If the water quality data series was non-monotonic over the whole monitoring period, only the most recent period of monotonic change was examined for trend.

Another assumption of the trend tests is that samples in a data series must be independent. If the data series are not independent (that is, exhibits auto-correlation) the risk of falsely detecting a trend is increased (Esterby 1996, Ward *et al*., 1990). A correlated data series contains surplus data and ultimately results in the little or no nett information gain. As a rule, the level of serial correlation in a data series increases as the frequency of sampling increases. The maximum sampling frequency possible without encountering serial correlation can be thought of as the point of information saturation (Ward *et al.*, 1990).

Five years of data is required to test for trends in this assessment. If five consecutive years of data was not available then trend analysis could not be undertaken for that site.

Testing for statistically significant changes

The Mann Kendall test was used to determine the statistical significance of the trending periods (Gilbert, 1987). It is an example of a non-parametric test and was only used when the data series exhibited independence (ie. no correlation in the data series).

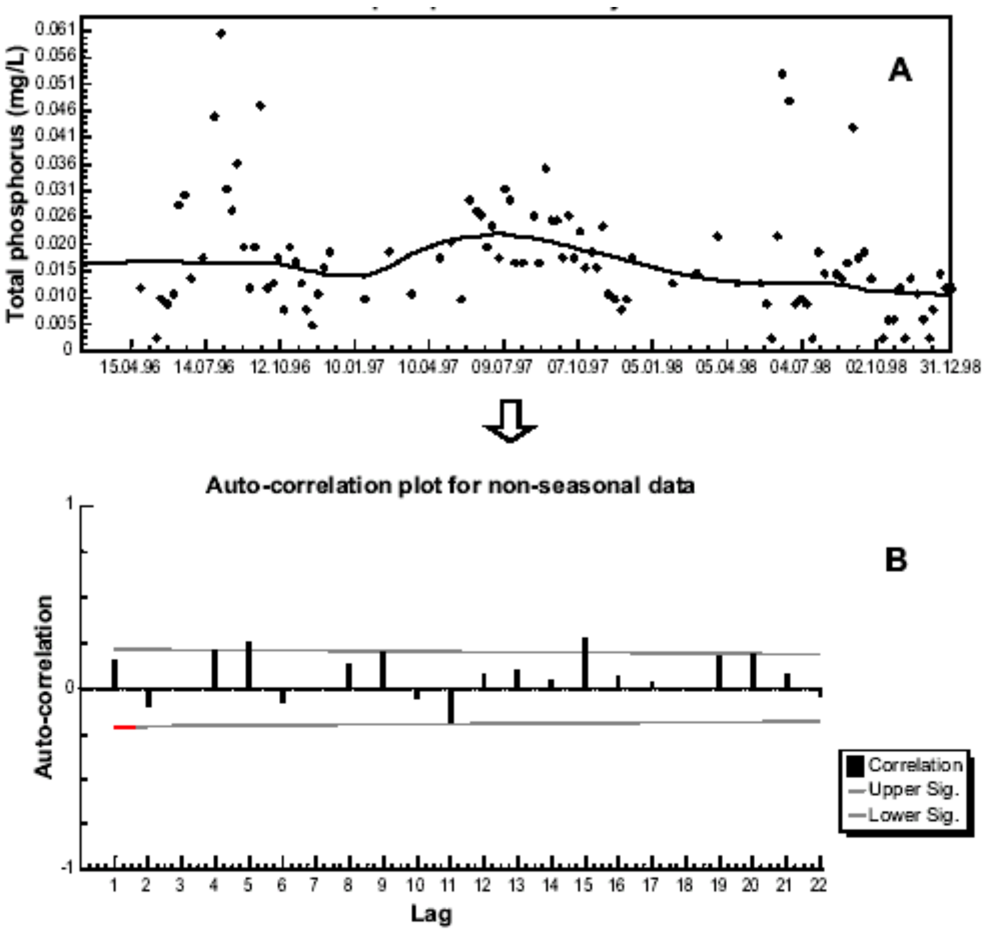


Figure A above shows an example of a time series for TP with little evidence of seasonal variation (LOWESS smooth line). Figure B above shows an autocorrelation plot which indicates that the data points in the time series are mostly independent of each other.

When seasonal cycles were evident in a data series the Seasonal Kendall test was used to test for trend. The Seasonal Kendall test is a variant of the Mann Kendall test that accounts for the presence of seasonal cycles in the data series (Gilbert, 1987). Seasonal cycles in water quality are common in waterways and can be introduced by natural cycles in rainfall, runoff, tributary hydrology and seasonal variation in groundwater. The presence of seasonal cycles in a data series can introduce correlation to the data series which will complicate the detection of trends. The detection of seasonal variation in the data series was tested for by using an auto-correlation analysis.

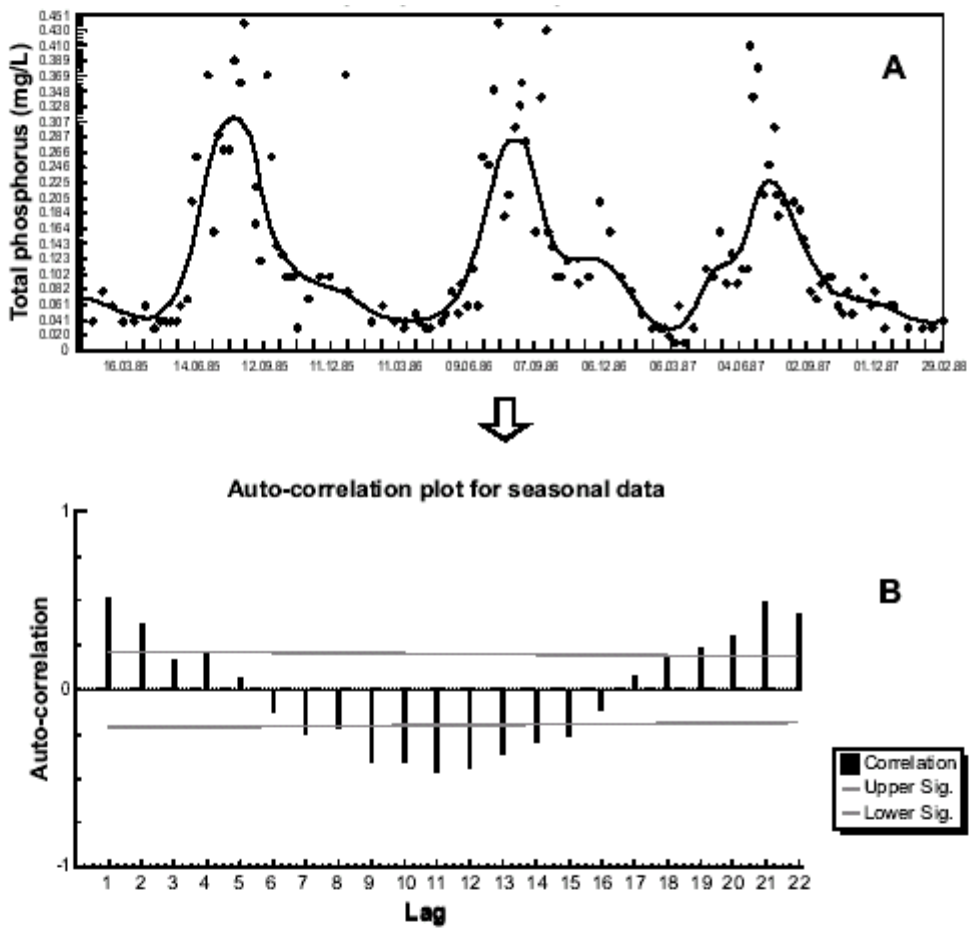


Figure A above shows an example of a time series for TP with seasonal variation (LOWESS smooth line). Figure B above shows an autocorrelation plot which indicates that the data points in the time series are dependent on each other.

A trend will be found to be statistically significant when the magnitude of the change is large relative to the variation of the data around the trend line. Unfortunately, when analysing long periods with large sample sizes any trend no matter how small will be statistically significant (Loftis, 1996; McBride *et al*., 1993; Loftis *et al*., 1991). The identification of a statistically significant trend should be seen as filter that removes small drifts in concentration from further consideration. Further analysis using sample size estimates are required to determine whether a sufficient number of ‘independent’ samples were collected to detect a trend.

Removing variation due to flow

Water quality in waterways can also be affected by changes in discharge that may create or hide trends in a fixed-interval data series. For this reason, trend analysis was also carried out on the data after it was adjusted for the effects of variation due to flow. The relationship between nutrient concentration and flow was modelled using a LOWESS fit on the flow / concentration response (Esterby, 1996, Robson and Neil, 1996, Lettenmaier *et al* 1991). The difference or ‘residuals’ between the observed concentration and the LOWESS modelled concentration is known as a flow-adjusted concentration (Hipel and McLeod, 1994). Subsequently, the flow-adjusted concentrations were reordered in time and then analysed for trend (Gilbert, 1987, Helshel and Hersh, 1992, Harned *et al* 1981, Hipel and McLeod 1994, Lettenmaier *et al* 1991). The flow-adjustment process often helped to remove seasonal variation, although some evidence of seasonal variation often remained in the flow-adjusted data series.

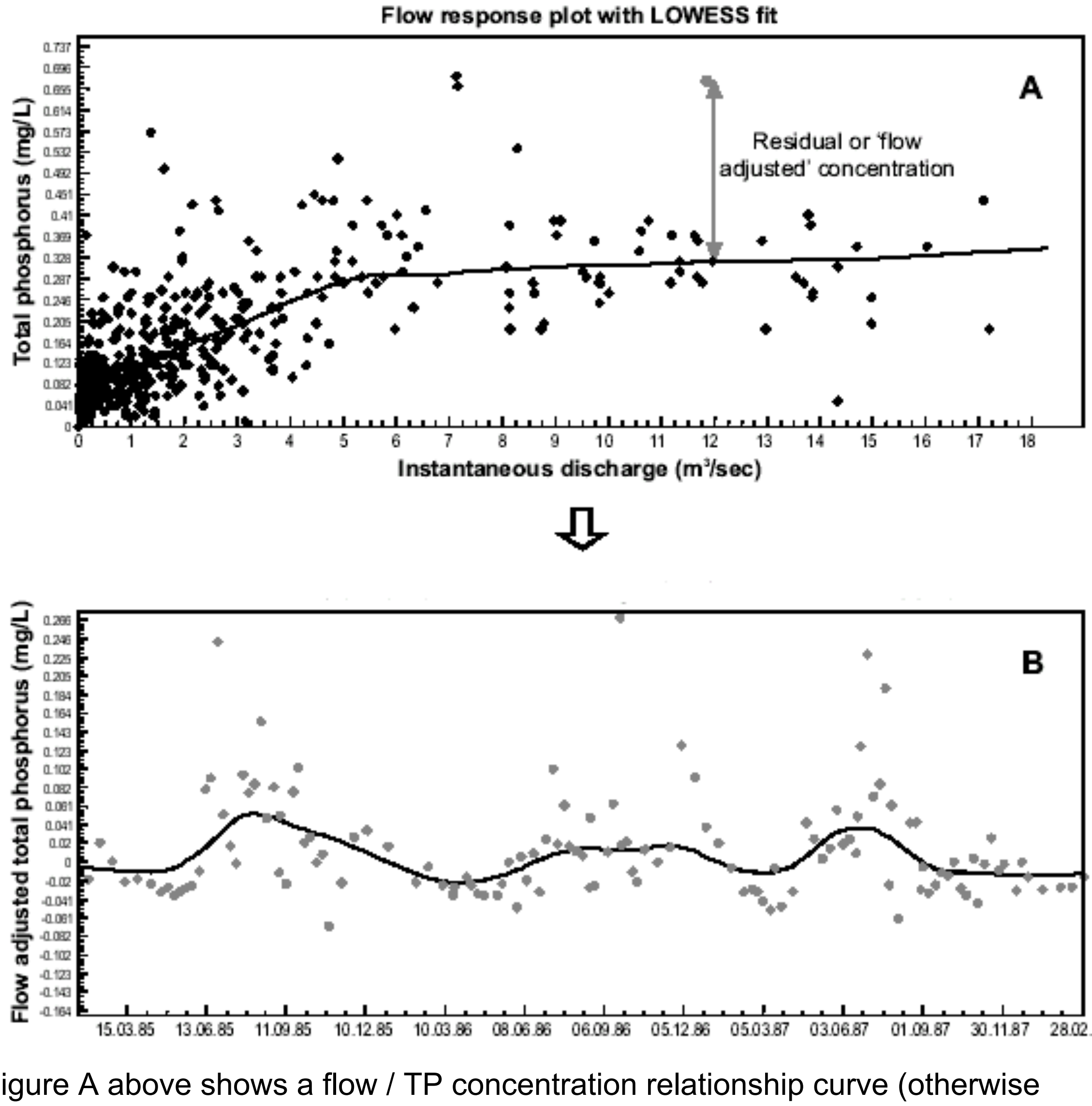
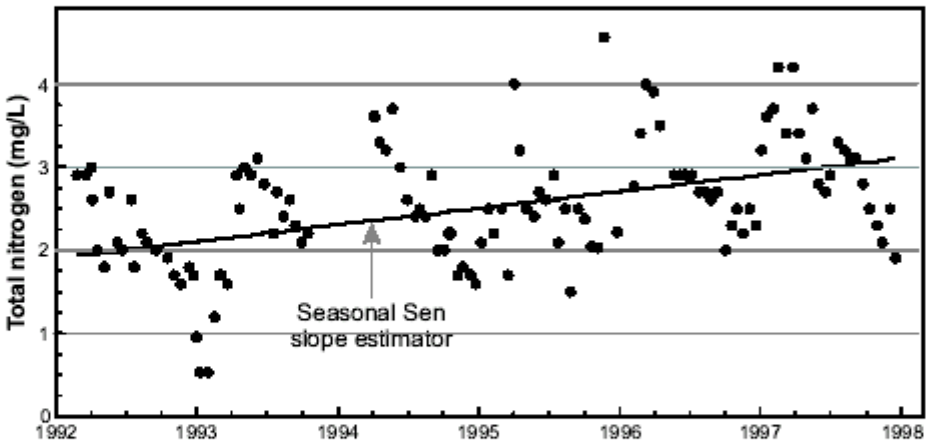


Figure A above shows a flow / TP concentration relationship curve (otherwise known as a flow response) with a LOWESS smooth line. Modelled concentrations are derived for every flow level and compared to the observed data. The difference between the modelled and observed data are known as residuals. Figure B above shows the residuals reordered in time with a LOWESS smooth line and are considered to have flow effects removed from the data.

The Sen slope estimator was used to estimate the slope of the trend line (Gilbert, 1987). The Sen estimate is the median slope of all slopes calculated using all inter-annual pairs of observations. In the presence of seasonal cycles the Seasonal-Kendall slope estimator was used (Gilbert, 1987), which is the median slope of all slopes calculated using pairs of observations collected at the same time each year.



An example of the Seasonal Sen slope estimator being applied to TN monitoring data. This line is used to estimate the slope of the trend in the data series.

Sample size estimates

A period of change being analysed was found to be statistically significant when the Kendall Test had a p-value less than or equal to 0.05. This was not enough evidence to conclude a trend was present. '*A-posteriori*' calculations were subsequently carried out to assess whether enough independent samples had been collected and used in the trend test to meet the criteria specified by the nominated statistical error risks (a = 0.05 and b = 0.10). This was achieved by comparing the effective information content in the collected data series with the number of independent samples required to detect a trend.

The effective information content in the data series, that is the effective number of independent values, was estimated for each of the data series analysed for trend using the formula provided by Bayly and Hammersley (1946) (*op cit* Lettenmaier, 1976, Lachance, 1992, Close, 1989, Zhou, 1996):

$$n^* = \left[1/n + 2/n^2 \sum_{j=1}^{n-1} (n - j)\, \rho\, (jt)\right]^{-1}$$

where:

n^* = effective number of independent observations

n = number of samples

j = lag number

t = sampling interval

ρ = coefficient of correlation

Where seasonal cycles were found the data series was de-trended and de-seasonalised (using seasonal medians) prior to calculating the number of independent samples (n*).

The estimated number of independent samples needed to detect a linear trend (in a variable distributed normally about the trend line) was estimated using the function (Lettermaier, 1976; Ward *et al.,* 1990):

$$n^{\#} = 12\, \sigma^2 \left[\, t_{\alpha/2,(n-2)} + t_{\beta\,(n-2)} \,\right]^2/\Delta^2$$

where:

$n^{\#}$ = estimated number of samples needed
to detect a trend

σ = the standard deviation of the de-trended series

Δ = the magnitude of the trend

t = the critical values of the t-distribution,
using $\alpha = 0.05$ and $\beta = 0.1$

This function relies on probabilities predicted by the t-distribution and is therefore from the parametric family of statistical procedures. Data requirements for parametric and the equivalent non-parametric tests are similar, so this equation will approximate the sample size needed for non-parametric tests of significance (Ward *et al.,* 1990).

Detecting the trend

A trend in the data series was considered to be detected only when two criteria were met. Firstly, the Kendall test for trend on the data series must be statistically significant (ie. $p<0.05$). Secondly, the number of independent samples collected (n*) had to approximately equal or exceed the ‘estimated’ number of independent samples (n#) required to detect a trend. The direction of a detected trend either increases (representing a deterioration of water quality) or decreases (representing an improvement in water quality). If any of the above two criteria were breached then the result was 'no trend'. If $p<0.05$

and the number of independent samples collected was less than the 'estimated' number of independent samples required to detect a trend, the trend was described as "emerging" (either increasing or decreasing). Sites with a 'no trend' result may be a consequence of poor monitoring program design and implementation over time and, if it is widely believed there should have been a detected trend over the monitoring period, then the monitoring program needs to be re-evaluated.

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